



CASSY[®] Lab

Manual (524 202)

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Introduction

This manual is intended to provide an overview of the many exciting possibilities of the CASSY Lab software. The text is identical to the help texts that can be accessed using the mouse for all program functions.

The help texts in the program provide the following additional support:

- You can jump directly to cross-referenced information using the mouse.
- You can load experiment examples and settings by clicking on them.
- The help system permits both indexed and full-text search modes.

Installation

CASSY Lab can be installed either

- automatically after inserting the CD-ROM or
- manually by executing the file **autorun.exe**

and following the instructions that appear on the screen.

Important information after installing CASSY Lab

Using the software with CASSY-S (Sensor-CASSY, Power-CASSY, Profi-CASSY, CASSY-Display, Pocket-CASSY and Mobile-CASSY)

The first time you start CASSY Lab, you should enter your activation code, which you can find in your bill of delivery and your invoice on a separate sheet under the number 524 200. The software then supports CASSY-S without restrictions (CASSY-S support without the activation code is limited to 20 sessions).

Using the software with serial measuring instruments

CASSY Lab supports other serial measuring instruments, the Joule and wattmeter and the Universal measuring instrument physics without requiring an activation code.

Manual

CASSY Lab is supplied with a comprehensive manual. In order to exploit the full potential of CASSY Lab, you need to read and understand this manual completely. You can do this in several ways:

- Open the manual from CD-ROM (start **autorun.exe**).
- Order the printed manual (524 202).
- Download the manual from the Internet (in Adobe PDF format).
- Use the software help function (text identical to the printed manual, context-sensitive and with numerous jump links and enhanced search capabilities).

Getting started

- Displays the introduction
- Displays experiment examples

You can also read the supplied experiment examples and use these for further evaluations without CASSY. You can use the program settings from the examples to run new measurements, and match these to your experiment conditions.

Support

If there should be any questions left despite the comprehensive help with its numerous experiment examples, please mail to cassy@ld-didactic.de.

Updates

We have an ongoing commitment to expanding and enhancing CASSY Lab – particularly in response to the comments and experiences of our users.

- Download update from the Internet.



User programs for CASSY-S

You can also program CASSY-S yourself. To assist you in this, we have placed a description of the protocol of the interface as well as a Delphi/Lazarus component (with source code) on the Web for free downloading.

- Download developer information from the Internet.

Delphi (Windows) and Lazarus (Linux)

Support of CASSY with your own Delphi or Lazarus programs is easy because this only requires inclusion of the component described above.

C/C++/Visual Basic

Other programming languages can access CASSY via CASSYAPI.DLL (Windows) or libcassypi.so (Linux). For this CASSYAPI.DLL or libcassypi.so has to be included and called. The necessary declarations for C/C++ are contained in CASSYAPI.H. All three files are also contained in our free Developer Information from the Internet.

LabVIEW (Windows and Linux)

Our LabVIEW driver for CASSY is also free available on the Internet. In addition to the VIs (Virtual Instruments) for driving CASSY, the driver also contains application examples.

LabVIEW is a registered trademark of National Instruments.

CASSY Lab

Introduction

CASSY Lab supports one or more CASSY-S modules (Sensor-CASSY, Power-CASSY, Profi-CASSY, CASSY-Display, Pocket-CASSY and Mobile-CASSY) at the USB port (Windows 98/2000 or higher version) or at the serial interface (Windows 95/NT or higher version) of the computer. The software also supports a variety of other serial measuring instruments, the Joule and wattmeter and the Universal measuring instrument physics. The first time you use CASSY or another device, CASSY Lab prompts you to define the serial interface (COM1 to COM4). This must be specified and saved as the program default. For CASSY modules at the USB port (Windows 98/2000 or higher version), no serial interface needs to be specified - the modules will be found automatically. When CASSY is used, the software prompts you to enter the activation code.

Activation code

When using CASSY Lab together with CASSY, you need to enter a 24-digit activation code. The first time you start CASSY Lab, you should enter your activation code, which you can find in your bill of delivery and your invoice on a separate sheet under the number 524 200; you must enter this number once, together with the name that appears on the invoice. This activates the software for CASSY. Please observe our copyright.

If you only intend to use CASSY Lab with other serial devices, with the Joule and wattmeter or with the Universal measuring instrument physics, **no** activation code is necessary.

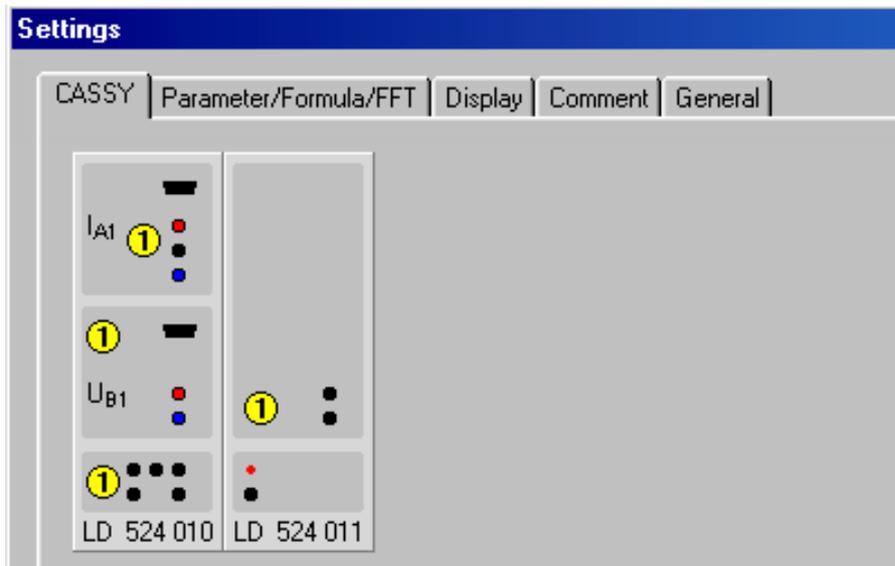
If you did not receive an activation code, please fax your invoice for CASSY Lab (524 200) to +49-2233-604607. We will fax you the activation code as soon as possible. CASSY Lab can also be used with CASSY without the activation code for a limited time (up to 20 sessions).

Future versions, such as updates available for downloading on the Internet, will also use this activation code. This means that there are no restrictions on the use of updates.

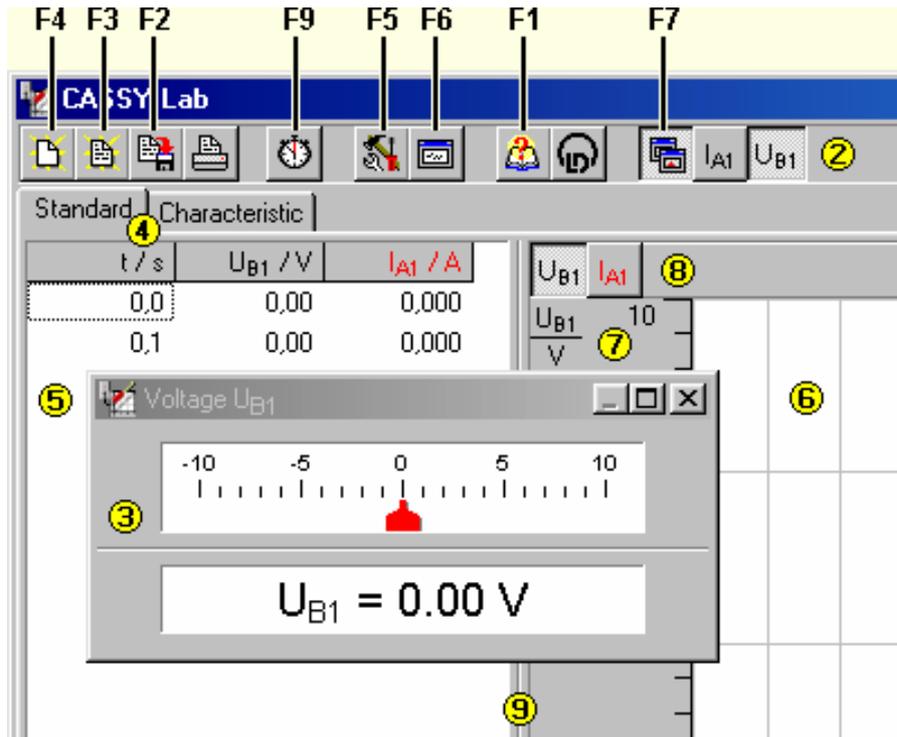
- Download update from the Internet.

First measurements

When the software detects one or more CASSY devices, the CASSY tab of the setup dialog (**F5**) displays the current configuration (including any attached sensor boxes). To conduct a measurement, just click on the corresponding input or output **1**.



An active input or output (channel) is then marked in color and placed among the speed buttons **2** at the top right of the main window (here IA1 and UB1). These buttons are the fastest way to display or close a display instrument **3** for that channel (left mouse button) or to change a setting (right mouse button). In addition, the channel initially appears automatically in the table **5** and in the diagram **6**.



You can access the basic functions quickly using the speed buttons **2** in the top bar. The most important speed buttons are also mapped to function keys.

Below this bar, you can toggle between table **5** and diagram **6** display by clicking on one of the display tabs **4** when different display modes have been defined (here **Standard** and **Characteristic**). The table and diagram can be enlarged or reduced with respect to each other by moving the boundary **9** with the mouse.

At many points, **both** mouse buttons (left and right) can be used to execute different functions:

Control element	Left mouse button	Right mouse button
1 CASSY setup	Activate and modify a channel	Activate and modify a channel.
2 Channel button	Open and close a display instrument, drag and drop in 2 and 5 through 8	Set up a channel
3 Display instrument	Move boundary between analog and digital display, drag and drop values in 5	Set up a channel
4 Name of display	Toggle to another defined display	
5 Table	Edit measured values, drag and drop values within the table or the channels to 2	Set display attributes of table, e.g. text size, delete rows and measurement series
6 Diagram	Mark evaluation ranges	Settings and evaluations in diagram
7 Scale	Move scale	Set minimum, maximum and conversion of scale
8 Axis symbols	Toggle y-scale, drag and drop into 2	Set up a channel
9 Boundary	Move boundary between channel and diagram	

The hot-key assignments of the speed buttons  can often enable you to use the software more efficiently.

**F4**

Clears either the current measurement while retaining the settings or, when no measurement is displayed, the current settings.

Pressing this key twice clears the current measurement with all settings.

**F3**

Opens a measurement series with its settings and its evaluations.

It is also possible to append a measurement series to an existing series (without having to load its settings and evaluations as well). This is possible when the same measurement quantities are used for all series. Alternatively, a further measurement series can be measured and appended subsequently.

The software is also equipped with an ASCII import filter (file type ***.txt**).

**F2**

Saves the current measurement series with its settings and its evaluations.

You can also save just the settings (without measurement data) to make it easier to repeat an experiment at a later date.

The software is additionally equipped with an ASCII export filter (file type ***.txt**). However, you can also open the CASSY Lab files (file type ***.lab**) using any text editor.



Prints out the currently active table or diagram.

**F9**

Starts and stops a new measurement.

Alternatively, you can stop measurements by setting a measuring time.

**F5**

Changes the current settings (e.g. CASSY, Parameter/Formula/FFT, Display, Comment, Serial Interface). This function must be activated **twice** for the measuring parameters.

**F6**

Toggles large display of the status-line information on and off.

**F1**

Opens this help file.



Displays the current version number of the software and enables entry of the activation code.

**F7**

Closes all open display instruments or reopens them.



ASCII export and import

You can import and export ASCII files quickly and easily by selecting the file type ***.txt** in the file selection dialog.

The data format begins with a header, in which all lines begin with a keyword. This specifies the measuring ranges, (MIN, MAX), the SCALE, the number of decimal places (DEC) and the actual definition of the measurement quantities (DEF). All lines except DEF are optional. The table of measured values follows the header.

You can view the exact syntax e.g. in the file that is created using the data export function.

Status line

Evaluation results always appear in the status line at the bottom of the window. You can toggle display of this information in a larger window on and off by pressing  or **F6**.

Drag & drop functionality

Using the mouse, you can drag the evaluation results from the status line and drop them in the table. This enables you to generate diagrams that depend on the evaluation results.

Measurement



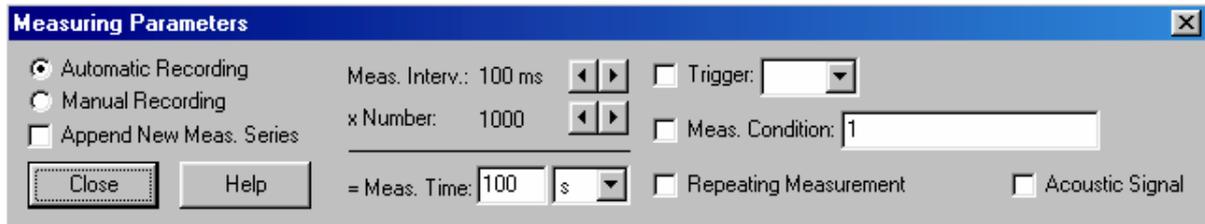
F9

Starts and stops a new measurement. You can use the right mouse button to open the table display menu in the table and the evaluation menu in the diagram.



F5

Allows you to change the settings and (when activated **twice**) the measuring parameters which control the actual measurement.



The defaults that appear in this dialog depend on the currently connected sensor boxes. This simplifies matching to a particular measuring task, as the typical sensor box configuration is already finished. For measurements with the **MCA box** this window looks different.

Automatic recording

The software determines the exact time for the recording of a measured value. After a measurement is started (e.g. with **F9**), the software first waits for any **trigger** that may have been set, and then records one measured-value row each time the predefined time interval elapses. The **interval**, the **number** of measuring points per measurement as well as the total **measuring time** can be matched to the individual requirements before starting the experiment. You can select continuous display by setting a **repeating measurement**.

At time intervals above 100 ms, the software evaluates a **measuring condition** in addition to the trigger, and can also emit an **acoustic signal** when a measured value is recorded. The measuring condition is a formula. A formula result not equal to 0 means ON="Measured-value recording possible", while a formula result equal to 0 means OFF="Measured-value recording inhibited". The measurement then runs for as long as the measurement is started **and** the formula returns the result ON. For example, if you want to run a measurement on 21 April 1999 between 1:00 p.m. and 2:00 p.m. (13:00 and 14:00 hours), you can use the formula: `date = 21.4.1999 and time >= 13:00 and time <= 14:00`.

For some measurement quantities (e.g. rate, frequency, transit time, obscuration time, path when using the GM box or the timer box), the software does not evaluate the specified time interval. In this case the measurement is controlled by the gate time or the measurement pulses themselves.

Manual recording

The user determines the exact time for the recording of a measured value. At each start (e.g. with **F9**), the software records precisely **one** measured-value row, i.e. the current display values of the instruments are entered in the table and the diagram. Thus, manual recording must be executed repeatedly in order to capture a complete measurement series.

Append new measurement series

The Append function enables sequential recording of multiple measurement series. All measurement series are displayed in the table and the diagram together. A different color is used to display each additional measurement series.

Alternatively, the individual measurement series can first be recorded one after another and saved individually. When loading multiple comparable measurement series (with identical quantities), measured series can also be appended "retroactively".

**Changing and deleting measured values / entering parameters**

You can edit all measured values (except time and formulas) in the table. To do this, click on the corresponding table row and edit the numerical value using the keyboard. This is also the only way to enter a parameter in the table.

You can delete measured values in several ways: In the pop-up menu of the table (right mouse button), you can delete either the respective last table row or entire (appended) measurement series. In the pop-up menu of the diagram (right mouse button), you can delete entire ranges of measured values.

Measurement (MCA box)



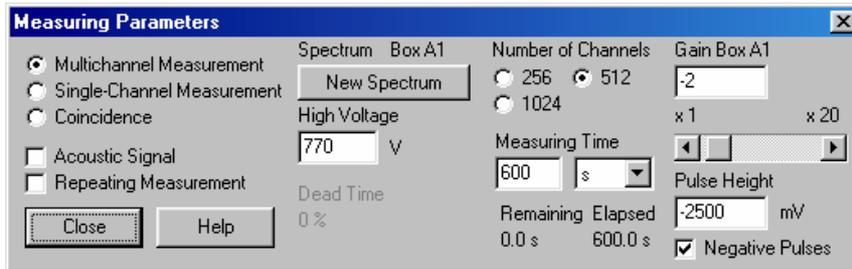
F9

Starts and stops a new measurement. You can use the right mouse button to open the table display menu in the table and the evaluation menu in the diagram.



F5

Allows you to change the settings and (when activated **twice**) the measuring parameters which control the actual measurement.



This is the central control unit for a measurement with the MCA box. General settings such as the measuring time are chosen in the left part of the window. Depending on the mode of measurement (multichannel, single channel, coincidence), different options can be set in the right part of the window.

Multichannel measurement (MCA)

The number of channels, the measuring time and the amplification of the box are set in the right part of the window. The best result is achieved if the amplification is set to 1, 2, 5 or 10, or somewhat more. Red characters indicate that an inappropriate choice has been made.

Single-channel measurement

The number of channels is replaced with the number of measuring points which are measured one after another.

The duration of the measurement and the measuring time per data point influence each other through the number of measuring points.

For each individual measurement, the width of the measuring window can either be given as a percentage of the entire measuring range or as the distance between two measuring points.

The gain is adjusted in the multichannel mode.

Coincidence measurement

Here two MCA boxes are used in conjunction with one CASSY. One of them records a multichannel spectrum, but only if at the same time pulses are registered in the coincidence window of the other box (coincidence) or if no pulses are registered (anticoincidence), respectively.

Basically the mode of measurement is the same as in a multichannel measurement, the settings for the number of channels and the gain in the centre of the window applying for the box that records the spectrum.

The parameters specific to coincidence are set on the right. The minimum and maximum pulse height of the window are given as a percentage of the measuring range. After pressing the button **Show**, a range of the spectrum measured previously with this (!) box can be marked and taken as a window.



Change table display

You can change the table display by clicking on the right mouse button when the pointer is over the table. You can alter individual measured values after activating keyboard input in the respective cells with the left mouse button or transfer them to other cells (drag & drop).

- Change Column Header
- Select Character Size
- Delete Last Table Row
- Delete Last Measurement Series
- Copy Table/Window

Change Column Header

Activates the Display tab. This lets you change the assignment of the x-column and up to 8 y-columns in the table. Mathematical conversion of columns is also possible.

Alternatively, you can move columns back and forth between channel buttons and the table using drag and drop.

Select Character Size

You can change the character size in the table. The software allows you to select small, medium-sized and large characters.

You can save the current setting as the default for subsequent program starts in the tab General.

Delete Last Table Row

Deletes the last row of the table. This also deletes the hidden values of other channels which were recorded at the same time. Alternatively, you can delete entire measurement series.

This is intended for deleting incorrect measurements recorded in manual mode.

Shortcut

Keyboard: Alt + L

Delete Last Measurement Series

Deletes the last measurement series of the table. This also deletes the hidden values of other channels which were recorded at the same time. Alternatively, you can delete the last table row.

This is intended for deleting incorrect measurements recorded in automatic mode.

Clipboard

The functions **Copy Table** and **Copy Window** let you copy the table in text format, and the main window as a bitmap to the Windows clipboard. Once there, they are available for further processing in other Windows programs.

Graphical Evaluations

You can access a wide variety of powerful graphical evaluation functions in the diagram by clicking the right mouse button.

- Change Axis Assignment
- Display Coordinates
- Select Line Width
- Select Value Display
- Select Rulers
- Show Grid
- Zoom
- Zoom Off
- Set Marker
- Text
- Vertical Line
- Horizontal Line
- Measure Difference
- Draw Mean
- Fit Function
- Calculate Integral
- Calculate Poisson Distribution
- Calculate Gaussian Distribution
- Calculate Peak Center
- Calculate Form Factor
- Calculate Ripple
- Fit Gaussian curves
- Find Equivalence Point
- Find Systole and Diastole
- Delete Last Evaluation
- Delete All Evaluations
- Delete Range (only Measured Values)
- Copy Diagram/Window

Marking a curve section

In some cases, you may wish to mark a particular curve section for which the evaluation function is to perform a calculation.

To mark a curve section, hold down the left mouse button and drag the pointer to the end of the curve section. Alternatively, you can also click on the starting and end points.

During marking, the marked curve section is displayed in green.

Change Axis Assignment

Activates the Display tab. This lets you change the assignment of the x-axis and up to 8 y-axes. Mathematical conversion of axes is also possible.

Alternatively, you can move the axis assignments back and forth between the channel buttons and the diagram using drag and drop.

Display Coordinates

When you activate this function, the status line shows the current coordinates of the mouse pointer, as long as it is over a diagram. The coordinate display remains active until you deactivate this menu point by selecting it again, or one of the evaluations Set Marker, Draw Mean Value, Fit Function, Calculate Integral or one of the Other Evaluations shows a result in the status line.

You can also insert the current coordinates in the diagram. However, make sure that you access the evaluation function Text via the keyboard with Alt+T without changing the coordinates of the mouse pointer, as otherwise the wrong coordinates would be adopted.

You can save the current setting as the default for subsequent program starts in General.



Shortcut

Keyboard: Alt + C

Select Line Width

You can modify the line width for display of the diagrams and the evaluations which you carry out in them. You can choose between thin, medium and thick lines.

You can save the current setting as the default for subsequent program starts in General.

Select Value Display

CASSY Lab provides six functions for customizing the display of measured values.

Show Values	Display as squares, triangles, circles, pound characters, ...
Show Connecting Lines	Connecting lines between measurement points
Akima Interpolation	Values between the measuring points interpolated according to Akima's method
sinc Interpolation	Values between the measuring points interpolated with $\text{sinc}(x)=\sin(\pi x)/\pi x$
Show Bars	Values shown by bars
Show Axes	Zero lines of x and y axis

You can save the current setting as the default for subsequent program starts in General.

The Akima and sinc interpolations are neither calculated over gaps in the domain of definition nor during a measurement. During the measurement, the points are only connected by straight lines. Only after the measurement does the interpolation calculate the curve sections between the measuring points. The sinc interpolation is ideal for signals that do not contain any frequency components higher than half the sampling frequency. In this case it leads to 10-fold oversampling.

Select Rulers

This function sets display of rulers at top and left, at bottom and left or off.

You can save the current setting as the default for subsequent program starts in General.

Show Grid

Allows you to toggle a grid on and off in each diagram.

You can save the current setting as the default for subsequent program starts in General.

Zoom

After activating this menu point, define the range which you wish to magnify. Use the left mouse button to do this.

A previously zoomed display can be zoomed further. To reset a zoom, select Zoom Off.

Shortcut

Keyboard: Alt + Z

Zoom Off

Restores the currently selected section of the diagram to its original size.

Shortcut

Keyboard: Alt + O

Energy calibration (MCA box)

Recorded spectra are divided into channels first. If one or two channels are assigned to a particular energy, a spectrum can be displayed in terms of energy. After the energy calibration has been called, a mark can be set with the mouse, and the corresponding channel is entered into the dialog box. Alternatively the channels can be entered by hand after clicking the dialog window. As a third possibility, a Gaussian curve can be fitted. The result is then dragged from the status line into the dialog box using

drag and drop. The two boxes for choosing the energies already contain default values for the customary radioactive preparations.

If the option **global energy calibration** has been chosen, the entered values are valid for all spectra recorded so far and also for all following spectra of this measurement series. If this option has not been chosen, the calibration is valid for the current spectrum and all following spectra of the measurement series. The calibration is deleted when the program is stopped, when the MCA box is exchanged or when the amplification of the box is changed. If there are already calibrated spectra, their calibration can be taken over.

Shortcut

Keyboard: Alt + E

Set Marker

This software provides four different mark-up functions. You can edit the markers, move them or delete them from the diagram by double-clicking on them with the left mouse button.

Alt+T: Text

This text function lets you label all parts of the diagram using any text you wish to enter. Once you have entered your text, just move it to the desired position and anchor it with the left mouse button.

After all evaluations which return a numerical value in the status line, these numerical values are suggested as a text insertion which you can accept, edit or reject.

Alt+V: Vertical Line

This function lets you draw vertical lines in any positions in the diagram. The respective position is given in the status line. If the status line contains a coordinate display this is switched off.

Alt+H: Horizontal Line

This function lets you draw horizontal lines in any positions in the diagram. The respective position is given in the status line. If the status line contains a coordinate display this is switched off.

Alt+D: Measure Difference

After clicking on a reference point, you can draw a line to any point in the diagram. The coordinate difference between the starting and end points of that line are given in the status line. If the status line contains a coordinate display this is switched off.

Draw Mean Value

After choosing mean value calculation, just select the curve section for which you wish to find the mean value with the left mouse button. The mean value appears in the status line along with its statistical error. If the status line contains a coordinate display this is switched off.

You can also insert the mean value in the diagram as Text. The mean-value line can be deleted from the diagram again by double-clicking on it.

Fit Function

The software offers a choice of eight best-fit operations:

Best-fit straight line	$y = Ax + B$	
Line through origin	$y = Ax$	
Normal parabola	$y = Ax^2$	
Parabola	$y = Ax^2 + Bx + C$	
Hyperbola 1/x	$y = A/x + B$	
Hyperbola 1/x²	$y = A/x^2 + B$	
Exponential function	$y = A \cdot \exp(-x/B)$	
Envelope of an oscillation	$y = \pm A \cdot \exp(-x/B) + C$	(attenuation through air friction)
Free fit	$y = f(x, A, B, C, D)$	



After choosing the corresponding operation, select the curve section you wish to apply it to using the left mouse button.

To define a free fit, you need to specify the function $f(x,A,B,C,D)$, meaningful starting values and the maximum permissible execution time before marking the range. The standard rules apply for entering the function. Choose starting values that are as realistic as possible to increase the chances of obtaining a successful fit. If it is not possible to fit the function, try repeating this process with different starting values and/or longer computation times. In addition, individual parameters A, B, C or D can be maintained constant during the fit.

The free fit also enables a new channel to be created automatically via **Display result automatically as a new channel (parameter)**. Different fits are then displayed in different colours and can afterwards be further evaluated via Formulas.

During the fit, the current parameters of the operation (A, B, C and D) appear in the status line. If the status line contains a coordinate display this is switched off. You can subsequently insert these values in the diagram as Text. The operation can be deleted from the diagram again by double-clicking on it.

Calculate Integral

The value of the integral is determined from the area bounded by the curve section you select with the left mouse button and the x-axis, respectively from the peak area. The value of the integral appears in the status line. If the status line contains a coordinate display this is switched off.

You can also insert the current value of the integral in the diagram as Text.

Other Evaluations → Calculate Poisson Distribution

(only suitable for frequency distributions)

The total number n of events, the mean value μ and the standard deviation σ are calculated in the marked range of the histogram and displayed in the status line and the Poisson distribution calculated on the basis of these appears in the diagram: $y=n \cdot \mu^x / x! \cdot \exp(-\mu)$.

Other Evaluations → Calculate Gaussian Distribution

(only suitable for frequency distributions)

The total number n of events, the mean value μ and the standard deviation σ are calculated in the marked range of the histogram and displayed in the status line and the Gaussian distribution calculated on the basis of these appears in the diagram: $y=n/\sigma \cdot \text{Sqrt}(2\pi) \cdot \exp(-(x-\mu)^2 / 2\sigma^2)$.

Other Evaluations → Calculate Peak Center

This function calculates the center of the marked peak and inserts this in the status line. The peak-center line can be deleted from the diagram again by double-clicking on it.

Other Evaluations → Calculate Form Factor

(only suitable for periodic curves)

For the marked range $[t_1, t_2]$ of a periodic signal (e. g. $U(t)$) the following values are calculated and displayed in the status line:

- Rectified mean value (mean of the absolute value)

$$U_{\text{ABS MEAN}} = \int_{t_1}^{t_2} |U(t)| \cdot dt / (t_2 - t_1)$$

- Root-mean-square value

$$U_{\text{RMS}} = \sqrt{\int_{t_1}^{t_2} U^2(t) \cdot dt / (t_2 - t_1)}$$

- Form factor

$$f = U_{\text{RMS}} / U_{\text{ABS MEAN}}$$

For these calculations, always an integer number of periods should be marked.

Other Evaluations → Calculate Ripple

(only suitable for periodic curves)

For the marked range $[t_1, t_2]$ of a periodic signal (e. g. $U(t)$) the following values are calculated and displayed in the status line:

- Mean value

$$U_{\text{MEAN}} = \int_{t_1}^{t_2} U(t) \cdot dt / (t_2 - t_1)$$

- Root-mean-square value

$$U_{\text{RMS}} = \sqrt{\int_{t_1}^{t_2} U^2(t) \cdot dt / (t_2 - t_1)}$$

- Ripple

$$r = \sqrt{U_{\text{RMS}}^2 - U_{\text{MEAN}}^2} / U_{\text{MEAN}}$$

For these calculations, always an integer number of periods should be marked.

Other Evaluations → Fit Gaussian Curves (MCA box)

Other Evaluations → Gaussians of equal width (MCA box)

Other Evaluations → Gaussians of equal relative width (MCA box)

Other Evaluations → Gaussians of specified energy (MCA box)

With these menu items Gaussian curves or sums of Gaussian curves can be fitted to the spectrum in different ways.

The result of a Gauss fit is a sum of several terms of the form

$$A \cdot e^{-(x-\mu)^2 / 2\sigma^2}$$

where the parameters A , μ and σ are determined by the fit.

In the simplest case exactly one Gaussian curve is fitted in the selected area. If a sum of several Gaussian curves is to be fitted the number and approximate position of the individual maxima (peaks) must be specified. This is done by means of markers set in advance (peak centers, vertical lines or selected x-ray energies).

In the general form of "Fit Gaussian curves" all parameters are free. For each Gaussian curve the amplitude A_i , position μ_i and width σ_i as well as a common offset are fitted.

With other menu items the quality of the fit can be improved by restricting the degrees of freedom. For "Gaussians of equal width" there is only one width $\sigma = \sigma_i$. For "Gaussians of equal relative width" is $\sigma_i = \sigma_0 \cdot \mu_i$, so the width of the curves increases with their energy.

For "Gaussians of specified energy" the specified locations of the individual maxima are not changed, therefore $\mu_i = \text{constant}$. All A_i and a $\sigma = \sigma_i$ are fitted and there is no offset. This is particularly suitable for marked x-ray energies.

Other Evaluations → Find Equivalence Point

(only useful for titration curves of pH over volume)

The equivalence point and the pK value are determined for the marked range of the titration curve and displayed in the status line. In the case of strong acids or bases (with $\text{pK} < 1$), it is recommendable to mark only the area immediately before and after the equivalence point in order to avoid the output of an incorrect pK value. The equivalence point can be deleted from the diagram again by double-clicking on it.

Other Evaluations → Find Systole and Diastole

(only suitable for blood-pressure curves)

The systole and diastole are determined for the marked range of the blood pressure curve and displayed in the status line. The systole and diastole can be deleted from the diagram again by double-clicking on it.



Delete Last Evaluation

Undoes the most recent evaluation operation. This is possible for the following evaluation functions:

- Set Marker
- Draw Mean Value
- Fit Function
- Calculate Integral
- Other Evaluations

Shortcut

Keyboard: Alt + Backspace

Delete All Evaluations

Undoes all evaluation operations. This is possible for the following evaluations:

- Set Marker
- Draw Mean Value
- Fit Function
- Calculate Integral
- Other Evaluations

Delete Range (only Measured Values)

The measured values of the marked curve section are deleted. This only applies to measured values that are displayed on the y-axis. Values that have already been evaluated (e.g. calculated by means of a formula) or values on the x-axis cannot be deleted.

Clipboard

The functions **Copy Diagram** and **Copy Window** let you copy the diagram and the main window as a bitmap to the Windows clipboard. Once there, they are available for further processing in other Windows programs.

Addition / Subtraction of spectra (MCA box)

Spectra are added / subtracted in the display tab by simply dragging one spectrum over the other. Alternatively the symbol of a spectrum can be dragged from the symbol line into a diagram. The arithmetic operation and the desired result can then be chosen in the associated box.

Gaussian curves and counting rates (MCA box)

When total counting rates under a peak are calculated, some details have to be taken into account which are relevant in connection with Gaussian curves.

In a measured spectrum, the total counting rate can be determined as an integral over a certain range, e.g. under a peak. The result of a MCA measurement, however, is not a real integral over the x-axis (energy or channels), but simply the sum over the channels the unit being "events".

The total counting rate of a line can also be determined by fitting a Gaussian curve. The result of a Gauss fit is a sum of several terms of the form

$$A \cdot e^{-(x-\mu)^2/2\sigma^2}$$

where the parameters A , μ and σ are determined by the fit.

The area under a Gaussian curve can be calculated. It is

$$\int_{-\infty}^{\infty} A \cdot e^{-(x-\mu)^2/2\sigma^2} dx = A \cdot \sigma \sqrt{2\pi}$$

However, the unit of this real integral over the Gaussian curve is "events * energy", because the width σ has the unit "energy".

This result of the fit is converted into the counting rate, that is, the sum over all channels, by dividing it by the energy width of a single channel. The width of an energy channel is read from the energy difference ΔE between two channels in the table, or it is taken from the properties of a measured spectrum (click on the symbol of a spectrum with the right mouse key).

The total counting rate of a Gaussian curve thus is

$$\frac{A \cdot \sigma \sqrt{2\pi}}{\Delta E}$$

The parameters A and σ are displayed as result of the fit to a Gaussian curve, and the width of an energy channel ΔE can be read from the energy difference between two channels in the table.

The mathematically clean solution to this problem would be to quote the amplitude generally in units of "counting rate per energy interval", but this is unusual in practice.

Settings



F5

This dialog window lets you change all settings except for the measuring parameters. The settings are arranged in six groups (tabs):

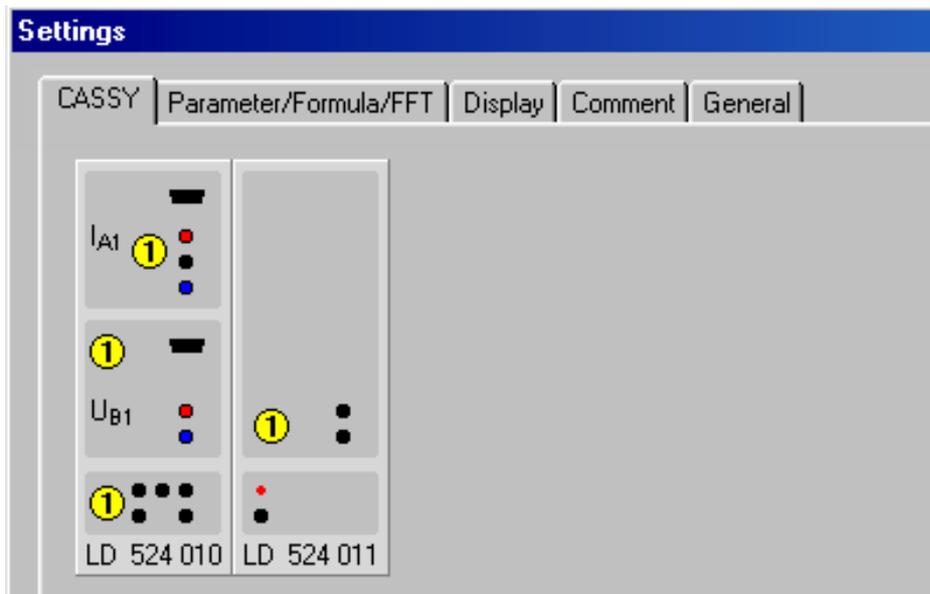
- CASSY (definition of CASSY inputs and outputs)
- Parameter/Formula/FFT (definition of additional quantities as parameters, using a formula, FFT)
- Display (changes the column assignments of the table and axis assignments in the diagram)
- Modelling (Definition of models by means of differential equations)
- Comment (space for entering your own text)
- General (selection of serial device, serial interface and saving of defaults)

Settings – CASSY



F5

This displays the current arrangement of the CASSY modules and sensor boxes. When this arrangement is altered (e.g. by adding a new module or sensor box) this change also appears in the display.



You can activate and configure this by clicking on a channel **1**. The available quantities depend on the CASSY module and the attached sensor box. During measurement, the software includes measured values in the table and the diagram for each active channel. You can also decide how these are to be displayed (column and axis assignment).

When channels are already active, the software no longer displays the current arrangement. Instead, the active channels are compared with the current arrangement and the deviations are displayed. Thus, for example, after loading a measurement file, it is easy to recreate the arrangement of CASSY modules and sensor modules which were used to capture that data.

If this tab does not display the current arrangement, you can update the display by clicking on **Update Setup**. The active channels are lost.

If channels are already active, you can open the Measuring Parameters dialog using **Display Measuring Parameters**.

- Related Help topics

Settings – Parameter/Formula/FFT



F5

Some quantities cannot be measured directly using CASSY, and are thus not available as a CASSY channel. If you need to include these quantities in a table or diagram, you must define these quantities here.

New Quantity generates a new (data) record which begins with the name of the quantity. The new quantity must contain a symbol with which it can be addressed. This symbol should consist of as few (meaningful) letters as possible and may also consist of the & character followed by a letter. The software displays these as the corresponding Greek letter (otherwise only Latin letters). You will also need to match the default values for the measuring range and the axis scale (important for analog and graphical display) as well as the number of decimal places (important for digital and table representation) to your individual measuring task.

There are eight different types of new quantities:

Constant

A constant is a quantity whose value can be accessed in formulas and models via the dedicated symbol of this constant. The great advantage of constants is the simple way of changing their value by dragging the pointer of their display instrument. This provides an easy possibility of varying formulas (see below) or models, for example so that the result of the calculation agrees as accurately as possible with the measurement. In order that parameters and constants can be easily distinguished from other channels, their pointers are magenta.

By setting the range to 0-1 and the number of decimal positions to 0, binary constants (switches) can be defined as well, which can be changed over by clicking on the display instrument.

Parameter

A table column is reserved for a parameter. All numerical values that are to appear in this column must be entered via the keyboard there. You can enter these either before or after measuring the other values by activating keyboard input for that cell with the mouse. It is a good idea to enter the parameter **before** measuring, so that the right measurement points appear in the diagram immediately in manual mode and the old parameter value does not have to be used again.

Alternatively, you can specify the parameter value in the parameter tab of the settings or vary this in the display instrument using the left mouse button. In order that parameters and constants can be easily distinguished from other channels, their pointers are magenta.

Formula

It is possible to define a new measurement quantity using a mathematical formula, regardless of known quantities. The known quantities are addressed via their symbols, which appear in the list the program displays. When entering the formula itself, be sure to observe the correct formula notation (see also the examples). In order that converted quantities can be easily distinguished from other channels, their pointers are violet.

If old formulas are to depend on a new quantity, first the order of the quantities has to be changed within the speed buttons in the upper line by means of drag & drop. All variables of a formula have to be found on the left of the respective formula.

Derivation, Integral, Mean Value, FFT (Fourier transform), Histogram

For time derivation, integral of time and FFT (Fourier transform), simply click on the channel you wish to transform. To calculate the mean value, you additionally need to specify the time interval over which values are to be averaged. Meaningful mean values can only be generated when the interval over which the mean is taken is greater than the measuring interval. For the histogram, the channel width has to be specified in addition. For FFT, the software automatically generates the **frequency spectrum**, and for the histogram the software automatically generates the **frequency distribution** as a further display mode; this can be activated using the display tabs. In order that converted quantities can be easily distinguished from other channels, their pointers are violet.



Notes

A derivation impairs the resolution for shorter time intervals Δt . For example, if the resolution of a path measurement is $\Delta s = 1$ mm and the measurement uses a time interval of $\Delta t = 100$ ms, the first derivation $v(i) = (s(i+1)-s(i-1))/2\Delta t$ has a resolution of $\Delta v = 0.005$ m/s and the second a resolution of $\Delta a = 0.025$ m/s². At a time interval of $\Delta t = 50$ ms these errors increase to $\Delta v = 0.01$ m/s and $\Delta a = 0.1$ m/s². Thus, Δt should be set as high as possible (e.g. 200 ms for motions on a track or 50 ms for oscillating springs).

The maximum frequency of an FFT is half the scanning rate. Thus, if a time interval $\Delta t = 10$ μ s ($f = 100$ kHz) is used for measuring, the frequency range of FFT extends to 50 kHz. The resolution in this frequency range, on the other hand, depends on the number of measured values. The more original measurement points are recorded, the better is the frequency resolution in the frequency spectrum.

Settings – Display



F5

A display consists of a table and a diagram with one x-axis and up to 8 y-axes. You can assign each measurement quantity to any one of these axes, and convert them where necessary (x^2 , $1/x$, $1/x^2$, $\log x$). Three additional quantities are pre-defined for the x-axis: n (table row), t (time), f (frequency for FFT).

If more than one y-axis is to be displayed, the visible y-axis scaling in the diagram can be toggled using the corresponding button. This also effects the coordinate display, but not the other evaluations.

If one display is not enough, you can generate additional displays using the **New Display** function; the name you give the new display appears on the new tab in the main window beneath the speed buttons. This lets you navigate easily between the individual displays using the mouse.

In each display a choice can be made between Cartesian and polar coordinates. In Cartesian diagrams there is an option of representing values as a bar diagram (histogram) for each y-axis. In polar diagrams an angle (range 0° to 360°) has to be chosen as x-coordinate. Then every y-coordinate is interpreted as the magnitude of a complex number, which is displayed with the corresponding angle. Here the origin need not be at $r = 0$ but can be negative as well (e. g. for the representation of polar diagrams of antennas in dB).

Remarks

Alternatively, the displayed channels can also be dragged back and forth from the channel buttons to the table and the diagram (drag and drop).

When the mouse pointer is over the rulers, you can mathematically convert the axes (x^2 , $1/x$, $1/x^2$, $\log x$) and change the scale maximum and minimum via the right mouse button. You can also move the rulers by grabbing them with the left mouse button.

Settings – Modelling


F5

The modelling tool enables values measured on real objects to be compared with a mathematical model. In particular, suitable constants can be chosen and varied such that the model agrees with reality as accurately as possible. In contrast to a fit (e. g. free fit), where the equation that defines the function has to be known from the beginning, modelling just requires one or two first order differential equations as an input.

To achieve this, **New Model** creates a new data set beginning with the name of the model. The model is described in terms of one or two model quantities, each of which has to be assigned a symbol, under which it can be addressed (default x and y). For a symbol as few as possible expressive letters should be chosen. It is also possible to use an &-character followed by a letter. In this case, the corresponding Greek letter will be displayed (otherwise the Latin letter will be displayed). Apart from that, the values proposed for the measuring range and the scaling of the axes (important for analogue and graphical representations) and the number of significant decimal positions (important for digital and tabulated representations) have to be adapted to individual requirements. In order that model quantities can be easily distinguished from other channels, their pointers are blue.

For the mathematical definition of the model, the initial values of the two defined model quantities at the time t and the two differential equations are specified. These five numerical values or formulas have to be entered, whereby the correct formula notation has to be observed. Each of the five formulas may depend on constants, whose values can be varied afterwards by dragging the pointer of the display instrument. In addition, the two differential equations may depend on the measuring time t, on the two defined model quantities and on formulas, which, in turn, may only depend on constants or on the measuring time t. All allowed dependencies of the differential equations are listed in front of their entry field.

Usually one or two first order differential equations are defined in the modelling process. **2nd Order** makes it easier to enter a second order differential equation: the first differential equation automatically relates the two model quantities x and y according to $x' = y$, and the second differential equation has the form $y' = x'' = f(t, x', x'')$. Taking the equation of motion as an example, we have $s = x$ and $v = y = x'$. Then only the differential equation $s'' = v'$ ($= a = F/m$) has to be entered.

The selectable **Accuracy** gives the truncation criterion, which determines when the numerical integration of the differential equation is terminated. A lower accuracy leads to a shorter computation time, but also to a greater error of the result. The accuracy is also enhanced by choosing a smaller range for the first model quantity.

The selectable **Computation Time** determines the maximum time available for the numerical integration of the differential equation. If the computation time selected is too short with regard to the specified accuracy, the calculated values start at the selected starting time, but stop too early.

Examples

The best-known example of a second order differential equation is certainly Newton's equation of motion $F = m \cdot a$ or $s'' = F(s, v, t)/m$. In this case, the two model quantities are the path s and the velocity v, and the first differential equation is $s' = v$. The accelerating force F from the second differential equation $s'' = v' = (F_1 + F_2 + F_3)/m$ depends on the particular experiment and is, e.g.:

$$F_1 = -m \cdot g \quad \text{for free-fall experiments}$$

$$F_1 = -D \cdot s \quad \text{for oscillations of a spring}$$

In addition, several types of friction may occur, which cause additional forces:

$$F_2 = -c \cdot \text{sgn}(v) \quad \text{for Coulomb friction (e. g. solid friction)}$$

$$F_2 = -c \cdot \text{sgn}(v) \cdot |v| \quad \text{for Stokes friction (e. g. laminar fluid friction)}$$

$$F_2 = -c \cdot \text{sgn}(v) \cdot |v|^2 \quad \text{for Newton friction (e. g. aerodynamic drag, turbulent fluid friction)}$$

In forced oscillations (resonance), an exciting force is added, e. g.:

$$F_3 = A \cdot \sin(360 \cdot f \cdot t) \quad \text{sin calculates the sine of the argument in degrees}$$

$$F_3 = A \cdot r \sin(\omega \cdot t) \quad \text{rsin calculates the sine of the argument in radian measure}$$

If various forces are combined, an appreciable number of experiments can be designed, which can easily be investigated in the framework of modelling.

Further examples that suggest themselves are charging and discharging of a capacitor, high-pass and low-pass filters, all of which can be described by a first order differential equation $Q' = (U_0 - Q/C)/R$ for the charge Q of the capacitor.

In the experiment examples, modelling is applied in several cases:

- Free fall with g-ladder (with modelling)
- Oscillations of a spring pendulum (with modelling)
- Oscillations of a spring pendulum with solid friction (with modelling)
- Oscillations of a spring pendulum with lubricant friction (with modelling)
- Oscillations of a spring pendulum with laminar liquid friction (with modelling)
- Oscillations of a spring pendulum with turbulent liquid friction/air friction (with modelling)
- Charging and discharging of a capacitor (with modelling)
- Damped oscillator (with modelling)
- Forced oscillations (resonance, with modelling)
- Low-pass filter (with modelling)
- High-pass filter (with modelling)

Settings – Comment



F5

This function lets you enter a text to better document your own experiments; this text is saved and loaded every time, together with the experiment file. You can also paste text from the clipboard using Ctrl+V.

General settings



F5

The **General** tab lets you change the serial interface of the computer to which CASSY and/or the other serial measuring instruments are connected. For CASSY modules at the USB port (Windows 98/2000 or higher version), no serial interface needs to be specified - the modules will be found automatically. You can also change the language of the software here.

If you want to save your changes so that you can have them already set the next time you use the software, you additionally need to select **Save New Defaults**. This simultaneously saves your settings for:

- Select Character Size
- Display Coordinates
- Select Line Width
- Select Value Display
- Select Rulers
- Show Grid

The CASSY modules described here identify the detected devices and the version information of the CASSY modules. If the version of the software implemented in the CASSY modules is newer or older than this software, a message is generated. Selecting **Update CASSY Modules** causes this software version to overwrite the software implemented in the CASSY modules (regardless of whether it is newer or older).

Hint

If this software is older than the CASSY modules or you wish to update your software, you can download the latest version from our website: <http://www.id-didactic.de>.

Formula notation

Formula variables **f(time,date,n,t,...,old)**

The formula $f(\dots)$ can depend on all channels listed below. To realize this, use the name of the channel as the variable name. For example, the result of the formula **UA1 > 5** is 1 when the voltage is greater than 5 V, otherwise 0.

Formula for	can depend on
Measuring condition	all channels
Formula	inputs, constants, serial measuring instruments and previously defined formulas
Relay/voltage source	inputs, constants, serial measuring instruments, formulas
Analog output	inputs, constants, serial measuring instruments, formulas
Digital output	inputs, constants, serial measuring instruments, formulas
Model	Model quantities, constants and formulas that depend only on the time t

In addition, formulas can also depend on the **time** in seconds, the **date**, the measuring time **t** in seconds, the number of recorded measured values **n** and the last value of the **old** formula. You can add a comment at the end of the formula by separating it with a semicolon.

Symbols can consist of a & character followed by a letter. The software displays these as the corresponding Greek letter (otherwise only Latin letters). You need to enter the & character in the formula.

Functions of a formula

Within a formula, you can use the following functions. The function arguments must be put in brackets when they are compounded, e.g. in **square(t/10)**.

ramp	Ramp (sawtooth between 0 and 1, $\text{ramp}(x) = \text{frac}(x)$)
square	Square-wave function (between 0 and 1, $\text{square}(x) = \text{ramp}(x) < 0.5$)
saw	Triangle (between 0 and 1)
shift	Single ramp (is 0 if argument < 0, 1 if argument > 1, otherwise equal to argument)
sin	Sinus in degrees (period 360°)
cos	Cosine in degrees (period 360°)
tan	Tangent in degrees (period 360°)
arcsin	ArcSine in degrees
arccos	ArcCosine in degrees
arctan	ArcTangent in degrees
rsin	Sine of the argument in radian measure (period 2π)
rcos	Cosine of the argument in radian measure (period 2π)
rtan	Tangent of the argument in radian measure (period 2π)
rarcsin	Arc sine in radian measure
rarccos	Arc cosine in radian measure
rarctan	Arc tangent in radian measure
last	Argument for time of last recorded measured value (last table row)
delta	Change with respect to last recorded measured value ($\text{delta}(x) = x - \text{last}(x)$)
next	Argument for time of next recorded measured value (next table row)
new	Is 1 if the argument has changed, otherwise 0
random	Random number ($0 \leq \text{random}(x) < x$)
sqr	Square root
exp	Exponential function
ln	Natural logarithm
log	Decadic logarithm
int	Integer function (next lowest whole number)
frac	Decimal-place function (difference to next lowest whole number)
abs	Absolute value
sgn	Signum (is 1 if argument > 0, -1 if argument < 0, 0 if argument = 0)
odd	is 1 if argument is odd, 0 if argument is even
even	is 1 if argument is even, 0 if argument is odd
not	Logical inversion (is 1 if argument equals 0, otherwise 0)
defined	is 1 if argument is defined, 0 if argument is not defined



sec	Rounds off the time to the nearest full second ($\text{sec}(x) = \text{int}(x)$)
min	Rounds off the time to the nearest full minute ($\text{min}(x) = 60 * \text{int}(x/60)$)
day	Returns the day of the week (1 = Monday,...)

Linking variables and functions

All variables (or entered numerical values) can be linked using the usual mathematical operations.

The operators have different priorities. The higher an operation stands in the following list, the higher is its priority in evaluating the formula ("dots before dashes"). To force a different evaluation order, place the respective expressions in brackets.

- 1) **^** Powers
 - 2) ***** Multiplication
 - /** Division
 - 3) **+** Addition
 - Subtraction
 - 4) **=** Test for equality
 - <>** Test for inequality
 - >** Test for greater than
 - >=** Test for greater than or equal to
 - <** Test for less than
 - <=** Test for less than or equal to
 - 5) **and** Logical AND operation
 - 6) **or** Logical OR operation
- Related Help topics

Examples for using the variables time, date, n, t and old

t <= 100

has the value of 1 during the first 100 s of the measurement, then 0. You can use this formula e.g. for the time window to stop the measurement after 100 s.

time >= 12:30:35

has the value 1 starting at the time 12:30:35, and 0 prior to that. It must be used with the operator \geq , as exact equality is only valid for 1/100 s, and is thus practically unattainable.

min(time) = 11:45 and date = 18.3.1997

is only true during the single minute on 18 March 1997 at 11:45 hours (value 1), and otherwise false (value 0).

(T < 25) or (T < 27 and old)

realizes a two-position controller. If the temperature T is less than 25 °C, the function result is 1 (here e.g. heating on). If the temperature is less than 27 °C **and** the heating was already switched on, then it remains on. When the temperature exceeds 27 °C, the heating is switched off and remains off until the temperature drops below 25 °C.

0.5 * (n - 1)

calculates e.g. a volume from the number of the present measurement. In this case, a measured value is recorded every 0.5 ml, so that the volume is calculated from n. In the first table line n has the value 1.

Examples for generating frequencies

ramp(t/10)

generates a ramp with a period of 10 seconds (t is the measuring time in seconds and starts at 0 when the measurement is started). The ramp starts at 0 and ends at 1. If other amplitudes are required, you must additionally multiply this by the desired amplitude.

saw(t/5)

generates a triangular ("sawtooth") wave form with a period of 5 seconds.

square(t/5)

generates a square wave form with a period of 5 seconds, similar to the previous example. It switches from 0 to 1 and back every 2.5 seconds.

10*(ramp(t/10) < 0.4)

also generates a square wave form. However, here the amplitude is 10 and the duty factor is 40%. 40% of the time, the expression in brackets is 1 (true); the remaining 60% of the time it is 0 (false).

shift((time-12:30)/100)

generates a single ramp starting at the time 12.30 hours with a period of 100 seconds. In this period, the value of the formula rises continuously to 1.

sin(360*t/7)

generates a sinusoidal oscillation with a period of 7 seconds and an amplitude of 1.

Examples for the priority of arithmetic expressions

x+y^z*2

contains the operator order ^, * and +. As a result, y^z is evaluated first, the result multiplied by two, and then x is added. To suppress the given operator order, place the respective expressions in brackets.

(x+y)^(z*2)

Unlike the previous example, here the addition x+y and the multiplication z*2 are performed first. The first result is not raised to the power of the second until the final step.

Examples for the evaluation of Boolean expressions

x < 5

can have either the value 0 (false, for x >= 5) or 1 (true, for x < 5).

x1 < 5 and x2 > 0

has the value 1 (true when x1 < 5 and x2 > 0 simultaneously), otherwise 0. You do not need to use any brackets, as the operator **and** has a lower priority than < and >.

5*(T < 20)

has only the values 0 (false) and 1 (true) in the brackets. However, these values are multiplied by 5. A formula of this type is thus only useful for analog outputs. In this case the analog output would output a voltage of 5 V when T is less than 20 (e.g. a temperature).

time >= 12:30

has the value 1 as of 12:30 hours and 0 prior to that. It must be used with the operator >=, as exact equality is only valid for 1/100 s, and is thus practically unattainable.

sec(time) = 11:45:07 and date = 18.3.1997

is only true during the single second on 18 March 1997 at 11:45:07 AM hours (value 1), and otherwise false (0).

day(date) = 1

is true every Monday (value 1) and otherwise false (value 0).



Formula examples

Simple controller: $\vartheta A11 < 25$

(ϑ entered as &J) is 1 when the temperature is less than 25 °C and otherwise 0 (e.g. for controlling a heater).

Two-position controller: $\vartheta A11 < 25$ or ($\vartheta A11 < 27$ and old)

(ϑ entered as &J) is 1 when the temperature is less than 25 °C or – for the case that the value was already 1 – 27 °C, and otherwise 0 (e.g. for two-position control of a heater). The controller thus switches on below 25 °C and off again above 27 °C.

Ramp: $8 * \text{ramp}(t/10)$

generates a ramp from 0 to 8 with a period of 10 s (0.1 Hz).

Square wave with user-defined duty factor: $\text{ramp}(t/10) < 0.8$

generates a square wave from with a period of 10 s (0.1 Hz). The square wave is 1 for 80% of the period and otherwise 0.

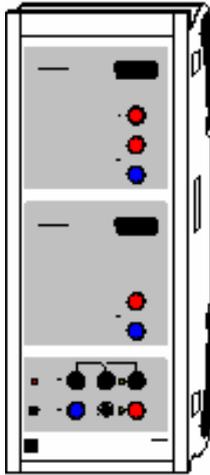
Temperature compensation pH: $7 + (\text{pHA}1 - 7) * (25 + 273) / (\vartheta B1 + 273)$

(ϑ entered as &J) corrects the pH value pHA1 calibrated at 25 °C for the new temperature $\vartheta B1$.

Temperature compensation conductivity: $CA1 / (1 + (\vartheta B1 - 25) / 45)$

(ϑ entered as &J) corrects the conductivity value CA1 calibrated at 25 °C for the new temperature $\vartheta B1$.

Sensor-CASSY



Introduction

Sensor-CASSY (USB or serial respectively) is a cascable interface device for recording measurement data:

- For connection to the USB port of a computer (Windows 98/2000 or higher version) or to the RS-232 serial interface respectively, another CASSY module or the CASSY display.
- 4-fold electrical isolation (inputs A and B, relay R, voltage source S).
- Cascading of up to 8 CASSY modules possible (to expand the inputs and outputs)
- Up to 8 analog inputs per Sensor-CASSY retrofittable using sensor boxes
- Automatic sensor box detection by CASSY Lab (plug and play)
- Microprocessor-controlled with CASSY operating system (easily updatable via software for function enhancements).
- For use as a benchtop, console or demonstration unit (also in CPS/TPS panel frames)
- Voltage supply 12 V AC/DC via cannon plug or adjacent CASSY module.
- Developer information available for downloading to help you develop your own software.

Safety notes

- For your own protection, do not connect Sensor-CASSY to voltages over 100 V.
- Transport multiple cascaded CASSY modules only in the panel frame or individually (the mechanical stability of the connections without panel frame is sufficient for experimenting only, and not for transport).
- Use only the enclosed plug-in supply unit (12 V / 1.6 A) to power the CASSY modules.
- A Sensor-CASSY can also supply an adjacent module with a voltage as long as the total current consumption does not exceed 1.6 A (sufficient for up to 2 modules; overload trips automatic cutout). If using additional Sensor-CASSYs, supply these separately.

- Related Help topics



Technical data

- 5 Analog inputs (any two inputs A and B usable simultaneously)
 - 2 Analog voltage inputs A and B on 4-mm safety sockets
 - Resolution: 12 bits
 - Measuring ranges: $\pm 0.3/1/3/10/30/100$ V
 - Measurement error: ± 1 % plus 0.5 % of range end value
 - Input resistance: 1 M Ω
 - Scanning rate: max. 200,000 values/s (= 100,000 values/s per input)
 - No. of meas. values: virtually unlimited (PC dependent) up to 100 values/s, at a higher measurement rate max. 32,000 values (= 16,000 values per input)
 - 1 Analog current input A on 4-mm safety sockets
 - Measuring ranges: $\pm 0.1/0.3/1/3$ A
 - Measurement error: voltage error plus 1 %
 - Input resistance: < 0.5 Ω (except under overload)
 - See voltage inputs for further data
 - 2 Analog inputs at sensor box connector sites A and B.
(All CASSY sensor boxes and sensors can be connected)
 - Measuring ranges: $\pm 0.003/0.01/0.03/0.1/0.3/1$ V
 - Input resistance: 10 k Ω
 - See voltage inputs for further data
 - The technical data will change depending on a connected sensor box.
 - In this case CASSY Lab automatically detects the possible measurement quantities and ranges when a sensor box is attached.
 - 4 Timer inputs with 32-bit counters at sensor box sites A and B.
(e.g. for BMW box, GM box or timer box)
 - Counter frequency: max. 100 kHz
 - Time resolution: 0.25 μ s
 - Measuring time between two events at same input: min. 100 μ s
 - Measuring time between two events at different inputs: min. 0.25 μ s
 - Memory: max. 10,000 time points (= 2,500 values per input)
 - 1 Changeover relay (switching indication via LED)
 - Range max. 100 V/2 A
 - 1 Analog output (PWM-output) (pulse-width modulated, switchable voltage source, LED switching state indicator, e.g. for holding magnet or supplying experiment)
 - Variable voltage range: max. 16 V / 200 mA (load \geq 80 Ω)
 - PWM range: 0 % (off), 5-95 % (1 % resolution), 100 % (on)
 - PWM frequency: 100 Hz
 - 12 Digital inputs (TTL) on sensor box sites A and B
(at present only used for automatic sensor box detection)
 - 6 Digital outputs (TTL) on sensor box sites A and B
(at present only used for automatic switching of a sensor box measuring range)
 - 1 USB port (USB version), respectively serial interface RS232 (subD-9) for connection to a computer
 - 1 CASSY bus for connecting additional CASSY modules or the CASSY display.
- Dimensions (WxHxD): 115 mm x 295 mm x 45 mm
Weight: 1.0 kg

Scope of supply

- 1 Sensor-CASSY
- 1 CASSY Lab software, without activation code, for Windows 95/98/NT or higher version with comprehensive help function (20 full-functionality sessions free, then usable as demo version)
- 1 Installation guide
- 1 USB cable or serial cable (subD-9)
- 1 Plug-in supply unit 12 V / 1.6 A

Sensor input settings

Sensor-CASSY is equipped with two electrically isolated sensor inputs A and B, which can be used to capture voltage values (resp. current as well at input A) as well as other measurement quantities – as determined by the attached sensor box. CASSY Lab detects the sensor box and thus the measuring options **automatically**, i.e. the visual image of the CASSY arrangement shows the inputs with any sensor boxes that are connected. In this display they can also be configured for measuring by clicking on them.

The available measurement quantities and the measuring ranges thus depend on whether a sensor box is connected, and which one. You will need different sensor boxes for different measuring requirements (see also our product catalog).

The selected quantity can be measured as an instantaneous value, averaged over several values or output as the corresponding RMS value. Normally, measurement of **instantaneous values** without averaging will be sufficient. However, if the input signal shows noise or hum, you need to measure **averaged values**. AC voltages are usually measured as **RMS values** (a two-channel RMS measurement automatically generates the suitable $\cos \varphi$ channel). If the time interval is less than 10 ms, the measured values recorded in the table and the diagram will deviate from that shown in the display instruments in the latter two cases. This means that it is possible to display the curve form and the RMS values simultaneously.

As a standard the averaged values and RMS values are calculated during a time interval of 100 ms. This time interval can be changed globally for all channels. If Power-CASSY or Profi-CASSY is used, this time interval is changed on every change in frequency of the output signal so that always an integer number of periods is evaluated.

If the accuracy of the measured values is not sufficient, you can increase this by executing a correction. This can be necessary e.g. when matching a special pH electrode to the software.

Special buttons (often hidden)

- Box-LED** LED on the sensor box on/off,
e.g. SMOOTH (bridge box) or
COMPENSATION (prerequisite for tare compensation of B box)
- 0 ←** Zero-point adjustment (takes current value as zero point),
e.g. for path, force, pressure, events, collision)
- s ↔ -s** Sign inversion for path
(motion sensing element with the BMW box)

There are also special input fields which make it much easier to use the BMW box, GM box and timer box (e.g. gate time, width of interrupter flag) and which are only visible when the corresponding box is attached.

When using the reaction test box, the reaction signal must first be requested by pressing a switch (hand or foot switch). The reaction itself must then occur after the pointer appears on the display instrument in accordance with the color of the pointer (red, green or yellow).

■ Related Help topics

Measurement quantities of sensor input

The recordable measurement quantities of a sensor input depend greatly on the sensor box that is connected to the sensor input. The table below defines the correlation between sensor box, measurement quantity and sensor:

Cat. No.	Sensor box	Quantity	Sensor	Remark
	none	Voltage Current		Only input A and only for currents less than 3 A
524 031	Current supply box	Resistance Path	Displacement transducer (529 031)	Potentiometer for measuring displacement
524 032	BMW box	Path ($\Delta s = \pm 1$ mm) Angle ($\Delta s = \pm 1$ mm) Path ($\Delta s = \pm 1$ cm) Angle ($\Delta s = \pm 1$ cm)	Motion sensing element (337 631*) ditto Pair of recording pulleys (337 16*) ditto	Top socket on BMW box with direction of motion ditto Enter radius also Bottom socket on BMW box Use only first pulley ditto Enter radius also
524 033	GM box	Events Rate	End-window counter (e.g. 559 01) ditto	Enter gate time with frequency distribution as alternative display
524 0331	GM counter tube S	Events Rate	integrated integrated	Enter gate time with frequency distribution as alternative display
524 034	Timer box	Level Events Frequency Rate Period Transit time Obscuration Obscuration time Path ($\Delta s = 1$ cm) Angle ($\Delta s = 1$ cm) Linear collision (v) Torsion collision (ω)	 Forked light barrier (337 46*) ditto Spoked wheel (e.g. 337 461) or g-ladder (529 034) with forked light barrier (337 46*) ditto 2 forked light barriers (337 46*) ditto	Enter gate time with frequency distribution as alternative display of event at E to F Number of obscuration Duration of obscuration Enter radius Enter flag width Enter flag width and radius
524 035	pH box	pH Voltage	pH electrode (e.g. 667 424) ditto	Correct with two buffer solutions Temperature compensation possible using formula Special evaluation for equivalence point
524 036	KTY box	Temperature Resistance	KTY-sensor (529 036) ditto	
524 037	Conductivity box	Conductivity	Conductivity measuring cell (667 426)	Correct with factor k printed on measuring cell Temperature compensation possible using formula
524 038	B box	Magnetic flux density Relative pressure (2000 hPa) Relative pressure (70 hPa) Absolute pressure	Tangential B-probe (516 60*) Axial B-probe (516 61*) Pressure sensor (529 038*) Pressure sensor 70 hPa (529 040*) Absolute pressure sensor (529 042*)	Switch on box with Box-LED for offset calibration with $\rightarrow 0 \leftarrow$
524 0381	Combination B probe S	Magnetic flux density (tangential or axial)	integrated	Offset calibration with $\rightarrow 0 \leftarrow$
524 0382	Axial B probe S	Magnetic flux density (axial)	integrated	Offset calibration with $\rightarrow 0 \leftarrow$

524 039	dU box	Voltage		No longer necessary thanks to electrical isolation
524 040	μ V box	Voltage		Highly sensitive input (resolution to 0.5 μ V)
524 041	Bridge box	Force	Force sensor (314 261*)	Box-LED toggles between SMOOTHed and unsmoothed; replaced by Force sensor S, ± 1 N.
524 042	Force sensor S, ± 50 N	Force Acceleration	integrated	For greater forces up to 50 N
524 043	30-A box	Current		Use only for currents greater than (otherwise without box at A)
524 044	Temperature sensor S (NTC)	Temperature	integrated	
524 045	Temperature box	Temperature Temperature difference	Temperature sensor NTC (666 212) or NiCr-Ni (666 193) 2 NiCr-Ni (666 193)	
524 046	Reaction test box	Reaction time	Push button 8662 148) or foot switch (662 149)	To start press key first – and again for reaction depending on the color of the pointer
524 0461	Reaction test adapter S	Reaction time	Push button 8662 148) or foot switch (662 149)	To start press key first – and again for reaction depending on the color of the pointer
524 047	Pulse box	Pulse Voltage	integrated	Wait at least 10 s for box to stabilize Circulation curve
524 0471	Pulse sensor S	Pulse Voltage	integrated	Wait at least 10 s for sensor to stabilize Circulation curve
524 048	Skin resistance box	Skin resistance	integrated	Match measuring range individually (move axis with mouse or click on it with right mouse button)
524 0481	Skin resistance sensor S	Skin resistance	integrated	Match measuring range individually (move axis with mouse or click on it with right mouse button)
524 049	ECG/EMG box	3 ECG leads EMG	integrated	
524 050	Blood pressure box	Blood pressure Pulse	integrated	Special evaluation for systole and diastole blood pressure variations only
524 0501	Blood pressure sensor S	Blood pressure Pulse	integrated	Special evaluation for systole and diastole blood pressure variations only
524 051	Lux box	Illuminance	Lux sensor (666 243) IR sensor (666 247) UV-A sensor (666 244) UV-B sensor (666 245) UV-C sensor (666 246)	Correct with factor F printed on sensor
524 0511	Lux adapter S	Illuminance	Lux sensor (666 243) IR sensor (666 247) UV-A sensor (666 244) UV-B sensor (666 245) UV-C sensor (666 246)	Correct with factor F printed on sensor
524 052	Oxygen box	O ₂ saturation O ₂ concentration Temperature	Oxygen electrode (667 458)	Correct to 100% in O ₂ gas Correct with same factor as for saturation
524 0521	Oxygen adapter S	O ₂ saturation O ₂ concentration Temperature	Oxygen electrode (667 458)	Correct to 100% in O ₂ gas Correct with same factor as for saturation
524 054	Electrometer box	Voltage		Extremely high-ohm input, e.g. for electrostatics
524 055	Amplifier box	Voltage		Replaced by μ V Box
524 056	Spirometer box	Volume flux	integrated	

524 057	Climate box	Rel. humidity Temperature Temperature Barometric pressure Illuminance	Humidity sensor (529 057) Humidity sensor (529 057) Temperature sensor NTC (666 212) Integrated Lux sensor (666 243)	Calibrate with values C1 to C4 printed on sensor. Correct with factor F printed on sensor
524 0572	Humidity sensor S	Rel. humidity Temperature	integrated integrated	
524 058	MCA Box	Pulse height distribution	Scintillation counter (559 901) with Detector output stage (559 912) or Semiconductor detector (559 92) with Discriminator pre-Amplifier(559 93*)	α -, β -, γ - Spectroscopy
524 059	Microphone S	Voltage Frequency Transit time Level	integrated	External microphone connectable
524 060	Force sensor S, ± 1 N	Force	integrated	For forces up to 1 N
524 062	UI sensor S	Voltage Current	integrated 1 Ω shunt	for Pocket-CASSY and Mo- bile-CASSY
524 0621	UIP sensor S	Voltage Current	integrated integrated	for Pocket-CASSY and Mo- bile-CASSY
524 064	Pressure sen- sor S, 2000 hPa	Relative pressure	integrated	
524 065	Absolu- te-pressure sensor S	Absolute pressure	integrated	
524 066	Pressure sen- sor S, 70 hPa	Relative pressure	integrated	
524 067	Chemistry box	pH value Conductivity Temperature Temperature Temperature difference Potential	pH-sensor (667 4172) Conductivity sensor (529 670) Conductivity sensor (529 670) Temperature sensor (529 676) 2 temperature sensors (529 676)	
524 0671	Conductivity adapter S	Conductivity Temperature	Conductivity sensor (529 670) Conductivity sensor (529 670)	
524 0672	pH adapter S	pH value Potential	pH-sensor (667 4172)	
524 0673	NiCr-Ni adapter S	Temperature Temperature difference	Temperature sensor (529 676) 2 temperature sensors (529 676)	
524 068	Centrifugal force apparatus S	Centrifugal force	integrated	
524 069	Immersion photometer S	Transmission Extinction Concentration	integrated	
524 070	Ultrasonic motion sensor S	Path Temperature	integrated integrated	
524 071	Ethanol sensor S	Concentration Temperature	integrated integrated	
524 073	Laser motion sensor S	Path	integrated	

524 074	Timer S	Level		
		Events		
		Frequency		Enter gate time
		Rate		ditto with frequency distribution as alternative display of event at E to F
		Period		
		Transit time		
		Obscurations	Forked light barrier (337 46*)	Number of obscuration
		Obscuration time	ditto	Duration of obscuration
		Path ($\Delta s=1$ cm)	Spoked wheel (e.g. 337 461) or g-ladder (529 034) with forked light barrier (337 46*)	
			ditto	
	Angle ($\Delta s=1$ cm)		Enter radius	
	Linear collision (v)	2 forked light barriers (337 46*)	Enter flag width	
	Torsion collision (ω)	ditto	Enter flag width and radius	
	Path ($\Delta s=\pm 1$ mm)	Combination light barrier (337 462*) with combination spoked wheel (337 464)	Connect to left socket	
		ditto		
			Enter radius also	
524 076	Car box i	Rotational speed	Stand workshop TDC generator (738 989)	
		Ignition angle		
		Level	Inductive-type pulse pick-up (738 986)	
		Frequency		
		On/off ratio		
		Shut-off time		
		Operating time		
		Injection time		
524 077	Car box Z	Primary voltage	Capacitive-type pick-up (738 987)	
		Secondary voltage		
		Contact closed interval		
		Rotational speed		
524 078	CAN bus box	CAN bus message	integrated	
		CAN bus data		
524 081	LIN bus box	LIN bus voltage	integrated	
		LIN bus message		
		LIN bus data		
524 082	Rotary motion sensor S	Angle	integrated	
		Path		
		Amplitude		
		Period		
		Frequency		

Sensors indicated with * require a 6-pole connecting cable (501 16) for connection to the sensor box.

■ Related Help topics



Correcting a sensor input

You can correct measured values in a variety of ways, all of them easily accessible via Windows dialogs.

You can enter an offset value and/or a factor to the left of the equal sign; the software then uses these values to calculate the displayed values to the right of the equals sign (target values) from the measured values displayed on the left of the equal sign (actual values). To calculate the correction, click on the appropriate button, **Correct Offset** or **Correct Factor**.

Alternatively, you can also define both target values, or one target value and one calculation value. **Correction Off** cancels the correction.

Saving

A correction is saved with the other program settings. To ensure that the correction corresponds to the real situation when the program is loaded subsequently, be sure to use the same electrodes and sensor boxes on the same Sensor-CASSY (you may want to mark the electrodes, sensor boxes and CASSY devices).

Examples

Two buffer solutions with pH 3 and pH 9 are to be used for correction. The two target values are then 3 and 9 (enter these on the right side). When the pH electrode is immersed in the pH 3 solution, activate the button next to the target value (e.g. **Correct Offset**), and activate the other button (e.g. **Correct Factor**) for the pH 9 solution.

A conductivity electrode with the K-factor 1.07 must be matched to the software. To do this, simply enter the factor 1.07 in the second line as a factor and select **Correct Factor**.

Special configuration information for climate box (524 057)

When using the climate box, you need to calibrate the humidity sensor (529 057) before the first measurement. The four values C1 to C4 printed on the sensor are provided for this purpose. You only need to enter these values once; they are then stored and retained in Sensor-CASSY. These values do not need to be entered again, as they remain available for subsequent measurements with CASSY-Display.

■ Related Help topics

Relay/voltage source settings

Sensor-CASSY is equipped with a relay R and a voltage source S which can be adjusted using the knob. Both can be switched by the software. They must first be activated by clicking on them in the CASSY arrangement.

The easiest way to do this is to synchronize the relay with the start of a measurement (e.g. for a holding magnet at voltage source S). Simply activate **Changeover During Automatic Recording**.

However, you can also define the switching state using a formula. A formula can depend on any and all quantities that appear in the displayed list, and must be entered using the correct formula notation (see also the examples). A formula result not equal to 0 means ON="switched on", while a result equal to 0 means OFF="switched off". This formula is not evaluated during the measurement when **Changeover During Automatic Recording** is switched on.

PWM analog output

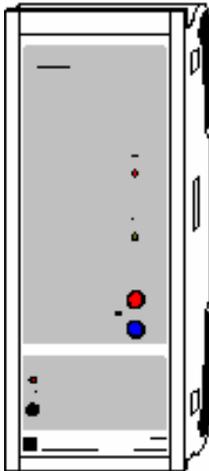
The voltage source S is actually a pulse width-modulated analog output. You can set the maximum voltage using the knob. The formula then controls not only OFF (=0) or ON (=1), but also allows intermediate values (e.g. 0.41 = alternately ON 41 % of the time and OFF 59 % of the time over a period of 10 ms). The function **Changeover During Automatic Recording** has no effect for these intermediate values.

Thus, this analog output lets you control modules for which only the average or the RMS value of the output voltage is relevant (e.g. the formula **saw(time/10)** would cause a small light bulb to become brighter for 5 s and then darker for 5 s).

Power-CASSY and Profi-CASSY are equipped with a more universal analog output.

■ Related Help topics

Power-CASSY



Introduction

Power-CASSY (USB or serial respectively) is a cascable interface device which can be used as a programmable voltage or current supply (power function generator) with integrated current or voltage measurement.

- For connection to the USB port of a computer (Windows 98/2000 or higher version) or to the RS-232 serial interface respectively, another CASSY module or the CASSY display.
- Electrically isolated.
- Cascading of up to 8 CASSY module possible (to expand the inputs and outputs).
- Microprocessor-controlled with CASSY operating system (easily updatable via software for function enhancements).
- For use as a benchtop, console or demonstration unit (also in CPS/TPS panel frames).
- Voltage supply 12 V (AC only) via cannon plug.
- Developer information available for downloading to help you develop your own software.

Safety notes

- Transport multiple cascaded CASSY modules only in the panel frame or individually (the mechanical stability of the connections without panel frame is sufficient for experimenting only, and not for transport).
- Use only the enclosed plug-in supply unit (12 V / 1.6 A) to power the CASSY modules.
- Related Help topics

Technical data

- 1 Programmable voltage source with simultaneous current measurement (e.g. for recording characteristics)
 - Resolution: 12 bits
 - Control range: ± 10 V
 - Measuring range: $\pm 0.1/0.3/1$ A
 - Voltage error: ± 1 % plus 0.5 % of range end value
 - Current error: voltage error plus ± 1 %
 - Scanning rate: 200,000 values/s
(= 100,000 values/s each for voltage and current)
 - No. of meas. values: virtually unlimited (PC dependent) up to 100 values/s,
at a higher measuring rate max. 32,000 values
(= 16,000 values/s each for voltage and current)
 - 1 Programmable current source with simultaneous voltage measurement (as alternative to voltage source)
 - Control range: ± 1 A
 - Measuring range: $\pm 1/3/10$ V
 - For further data see voltage source
 - 1 USB port (USB version), respectively serial interface RS232 (subD-9) for connection to a computer
 - 1 CASSY bus for connecting additional CASSY modules or the CASSY display.
- Dimensions (WxHxD): 115 mm x 295 mm x 45 mm
Weight: 1.0 kg

Scope of supply

- 1 Power-CASSY
- 1 CASSY Lab software, without activation code, for Windows 95/98/NT or higher version with comprehensive help function (20 full-functionality sessions free, then usable as demo version)
- 1 Installation guide
- 1 USB cable or serial cable (subD-9)
- 1 Plug-in supply unit 12 V / 1.6 A

Notes on the power limit

Due to the rating of the supplied plug-in power supply unit, Power-CASSY can not always guarantee a DC current of 1 A at 10 V. In such marginal cases, Power-CASSY only has sufficient power reserves when a second plug-in unit (not included) is used.

The scanning frequency of 100 kHz for the output channel limits the output frequency to a maximum value of 10 kHz. Here, the signal form is resolved with 10 μ s, and thus consists of at least 10 points per period, each 10 μ s apart. If it is not possible to achieve the set frequency or duty factor exactly by this means, the system attempts to achieve both set values as exactly as possible by averaging over a longer period.

When Power-CASSY is used as a current source, the maximum frequency is additionally reduced by a virtual output capacitance of up to 10 μ F. For an ohmic load of $R = 100 \Omega$, the output capacitance results in a time constant of $R \cdot C = 1$ ms, and thus a cut-off frequency of around 1000 Hz. For inductive loads, the cut-off frequency is much lower (a resistor connected in series with the inductance can help). For capacitive loads the effective capacitance is up to 10 μ F higher.

■ Related Help topics



Function generator settings

Power-CASSY is a computer-controlled power function generator. The manipulated variable of the function generator is either the voltage U (voltage source) or the current I (current source). The device simultaneously measures the current I when used as a voltage source and the applied voltage U when used as a current source. The control and measuring ranges are user-definable.

The output of the function generator can be actively limited to the actual measuring time **while a measurement is active (single shot)**. The function generator is then inactive between two measurements, so that no determination of mean or RMS values is possible then either.

The output curve form, frequency f (in Hz or kHz), amplitude A (in Vp or Ap), DC voltage offset O (in $V=$ or $A=$) and duty factor (in %) can be set in specific ranges:

Curve form	Frequency f	Amplitude A	Offset O	Duty factor
DC	-	-	-10 V .. 10 V / -1 A .. 1 A	-
Sine	0.01 Hz - 10 kHz	-10 V .. 10 V / -1 A .. 1 A	-10 V .. 10 V / -1 A .. 1 A	0 % .. 100 %
Square	0.01 Hz - 10 kHz	-10 V .. 10 V / -1 A .. 1 A	-10 V .. 10 V / -1 A .. 1 A	0 % .. 100 %
Triangle	0.01 Hz - 10 kHz	-10 V .. 10 V / -1 A .. 1 A	-10 V .. 10 V / -1 A .. 1 A	0 % .. 100 %
Formula	0.01 Hz - 10 kHz	-10 V .. 10 V / -1 A .. 1 A	-10 V .. 10 V / -1 A .. 1 A	-

Square and triangular waves can be generated in two variations. The symmetrical curve form is between $-A$ and $+A$. The asymmetrical curve form is between 0 and $+A$.

Negative amplitudes of A are allowed and mirror the signal through 0. The duty factor determines the ratio between the rising and falling curve sections. Thus, e.g. it is easy to convert a triangular signal (50 %) into a sawtooth signal (100 %).

In addition to the usual curve forms, Power-CASSY also offers a user-programmable curve form. To generate this, you need to enter a formula $f(x)$ that describes that curve form. To determine the curve form, this function is evaluated in the variable x in the interval $[0,1]$ and output with the specified frequency f , amplitude A and offset O . Formula entry is governed by the standard rules. In addition, the function **synth(a:b:c:...)** permits definition of a harmonic synthesis according to **$a*\sin(360*x)+b*\sin(2*360*x)+c*\sin(3*360*x)+...$** . The signal is also output with the specified frequency f , amplitude A and offset O (see also the example sonic synthesis).

The formula input box is relatively small. You can use any standard text editor to generate longer formulas and then cut and paste these into the input box (right mouse button).

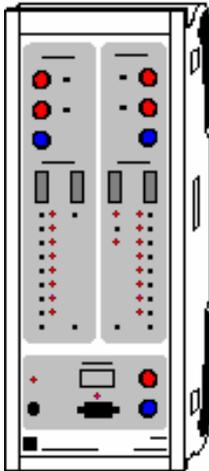
The voltage U and the current I can be displayed as instantaneous values, averaged over multiple measured values or calculated as the RMS value. Normally, display of **instantaneous values** without averaging will be sufficient. When Power-CASSY is active continuously (and not just during a measurement), it is also possible to display **averaged values** or **RMS values** (the corresponding φ channel for the phase angle between the voltage and the current is generated automatically). If the time interval is less than 10 ms, the measured values recorded in the table and the diagram will deviate from those shown in the display instruments in the latter two cases. This means that it is possible to display the curve form and the RMS values simultaneously.

Hint

Instead of fixed numerical values, you can specify previously defined channels for frequency, amplitude, offset and duty factor. Thus, for example, the frequency of a sinusoidal oscillation or the output voltage can be controlled flexibly (e.g. by specifying a formula when recording resonance curves or operating control systems). However, the initialization of the output of a new frequency (or amplitude, offset or duty factor) in Power-CASSY may take a few 100 ms. The parameters can thus only be increased in steps, and not continuously.

■ Related Help topics

Profi-CASSY



Introduction

Profi-CASSY is an intelligent interface for all fields of electrical engineering

- For connection to the USB port of a computer (Windows 98/2000 or higher version).
- Electrically isolated from the computer.
- Cascadable with Sensor-CASSY or Power-CASSY (to expand the inputs and outputs).
- Microprocessor-controlled with CASSY operating system (easily updatable via software for function enhancements).
- For use as a benchtop, console or demonstration unit (also in CPS/TPS panel frames).
- Voltage supply 12 V (AC only) via cannon plug.
- Developer information available for downloading to help you develop your own software.

Safety notes

- Transport multiple cascaded CASSY modules only in the panel frame or individually (the mechanical stability of the connections without panel frame is sufficient for experimenting only, and not for transport).
- Use only the enclosed plug-in supply unit (12 V / 1.6 A) to power the CASSY modules.
- A Profi-CASSY can also supply an adjacent module with a voltage as long as the total current consumption does not exceed 1.6 A (sufficient for up to 2 modules; overload trips automatic cutout). If using additional CASSYs, supply these separately.

- Related Help topics



Technical data

- 2 Analog voltage inputs A and B on 4-mm safety sockets
 Resolution: 12 bits
 Measuring range: ± 10 V
 Measurement error: ± 1 % plus 0,5 % of range end value
 Input resistance: 1 M Ω
 Scanning rate: 20,000 values/s (= 10,000 values/s per input)
 No. of meas. values: virtually unlimited (PC dependent) up to 100 values/s, at a higher measurement rate max. 16,000 values (= 8,000 values per input)
- 2 Analog voltage outputs X and Y on 4-mm safety sockets
 Resolution: 12 bits
 Control range: ± 10 V
 Error: ± 1 % plus 0.5 % of range end value
 Output current: max. 100 mA per output
 Scanning rate: 10,000 values/s for output X,
 max. 100 values/s for output Y (PC dependent)
 No. of meas. values: virtually unlimited (PC dependent) up to 100 values/s, at a higher measuring rate max. 8,000 values (output X only)
- 16 Digital inputs I0 to I15
 Logic: 5 V or 24 V
 Scanning rate: max. 100 values/s (PC dependent)

The digital inputs are each equipped with two 10-pole plug-in connectors for direct connection to automation devices. In addition, eight of them are equipped with 2-mm sockets and status LEDs.

- 16 Digital outputs Q0 to Q15
 Logic: 5 V or 24 V
 Output current: 10 mA for internal supply with 5 V
 500 mA for external power supply with up to 30 V
 Total current: 2 A
 Scanning rate: max. 100 values/s (PC dependent)

The digital outputs are each equipped with two 10-pole plug-in connectors for direct connection to automation devices. In addition, eight of them are equipped with 2-mm sockets and status LEDs.

- 1 PROFIBUS connection with 9-pole subD socket
 passive station (slave) at the PROFIBUS-DP fieldbus with 16 digital inputs and outputs and a bit rate of up to max. 3 Mbit/s
 address can be set via CASSY Lab
- 1 USB port for connection to a computer
- 1 CASSY bus for connecting Sensor-CASSYs or Power-CASSYs.

Dimensions (WxHxD): 115 mm x 295 mm x 45 mm
 Weight: 1.0 kg

Scope of supply

- 1 Profi-CASSY
 1 CASSY Lab software, without activation code, for Windows 95/98/NT or higher version with comprehensive help function (20 full-functionality sessions free, then usable as demo version)
 1 Installation guide
 1 USB cable
 1 Plug-in supply unit 12 V / 1.6 A
 1 GSD file LD066F.GSD for easy parametrization of the PROFIBUS on the CASSY Lab-CD

Applications

- CBS9 plant simulator for PLC, COM3LAB, digital technology and MFA
- CASSY[®] Lab for recording and evaluating measuring data
- WinFACT[®] for applications in control engineering

Analog input settings

Profi-CASSY is equipped with two analog inputs A and B. The voltage U_A or U_B can be measured as an instantaneous value, averaged over several values or output as the corresponding RMS value. Normally, measurement of **instantaneous values** without averaging will be sufficient. However, if the input signal shows noise or hum, you need to measure **averaged values**. AC voltages are usually measured as **RMS values** (a two-channel RMS measurement automatically generates the suitable $\cos \varphi$ channel). If the time interval is less than 10 ms, the measured values recorded in the table and the diagram will deviate from that shown in the display instruments in the latter two cases. This means that it is possible to display the curve form and the RMS values simultaneously.

As a standard the averaged values and RMS values are calculated during a time interval of 100 ms. This time interval can be changed globally for all channels. If Power-CASSY or Profi-CASSY is used, this time interval is changed on every change in frequency of the output signal so that always an integer number of periods is evaluated.

If the accuracy of the measured values is not sufficient, you can increase this by executing a correction.

■ Related Help topics



Analog output X settings (Function generator)

The Profi-CASSY also is a computer-controlled function generator at output X. The output of the function generator can be actively limited to the actual measuring time **while a measurement is active (single shot)**. The function generator is then inactive between two measurements, so that no determination of mean or RMS values is possible then either.

The output curve form, frequency f (in Hz or kHz), amplitude A (in V_p or A_p), DC voltage offset O (in $V=$ or $A=$) and duty factor (in %) can be set in specific ranges:

Curve form	Frequency f	Amplitude A	Offset O	Duty factor
DC	-	-	-10 V .. 10 V	-
Sine	0,01 Hz - 1000 Hz	-10 V .. 10 V	-10 V .. 10 V	0 % .. 100 %
Square	0,01 Hz - 1000 Hz	-10 V .. 10 V	-10 V .. 10 V	0 % .. 100 %
Triangle	0,01 Hz - 1000 Hz	-10 V .. 10 V	-10 V .. 10 V	0 % .. 100 %
Formula	0,01 Hz - 1000 Hz	-10 V .. 10 V	-10 V .. 10 V	-

Square and triangular waves can be generated in two variations. The symmetrical curve form is between $-A$ and $+A$. The asymmetrical curve form is between 0 and $+A$.

Negative amplitudes of A are allowed and mirror the signal through 0. The duty factor determines the ratio between the rising and falling curve sections. Thus, e.g. it is easy to convert a triangular signal (50 %) into a sawtooth signal (100 %).

In addition to the usual curve forms, Profi-CASSY also offers a user-programmable curve form. To generate this, you need to enter a formula $f(x)$ that describes that curve form. To determine the curve form, this function is evaluated in the variable x in the interval $[0,1]$ and output with the specified frequency f , amplitude A and offset O . Formula entry is governed by the standard rules. In addition, the function **synth(a:b:c:...)** permits definition of a harmonic synthesis according to **$a*\sin(360*x)+b*\sin(2*360*x)+c*\sin(3*360*x)+....$** . The signal is also output with the specified frequency f , amplitude A and offset O (see also the example sonic synthesis).

The formula input box is relatively small. You can use any standard text editor to generate longer formulas and then cut and paste these into the input box (right mouse button).

The voltage U_x can be displayed as instantaneous values, averaged over multiple measured values or calculated as the RMS value. Normally, display of **instantaneous values** without averaging will be sufficient. When Profi-CASSY is active continuously (and not just during a measurement), it is also possible to display **averaged values** or **RMS values** (the corresponding φ channel for the phase angle between the output X and the input A is generated automatically). If the time interval is less than 10 ms, the measured values recorded in the table and the diagram will deviate from those shown in the display instruments in the latter two cases. This means that it is possible to display the curve form and the RMS values simultaneously.

Hint

Instead of fixed numerical values, you can specify previously defined channels for frequency, amplitude, offset and duty factor. Thus, for example, the frequency of a sinusoidal oscillation or the output voltage can be controlled flexibly (e.g. by specifying a formula when recording resonance curves or operating control systems). However, the initialization of the output of a new frequency (or amplitude, offset or duty factor) in Profi-CASSY may take a few 100 ms. The parameters can thus only be increased in steps, and not continuously.

■ Related Help topics

Analog output Y settings

Apart from the analog output X, which can be used as a function generator, the Profi-CASSY provides another analog output Y, whose output level can be controlled via a program if a formula is assigned to it.

■ Related Help topics

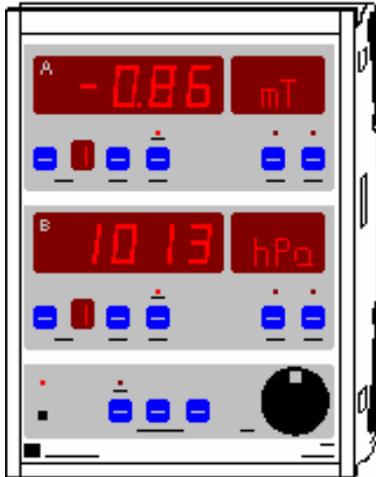
Digital input/output settings

The Profi-CASSY has 16 digital input and 16 digital outputs, which can be activated in groups of 8 inputs or outputs.

The inputs I0 to I15 render the current input levels. To the outputs Q0 to Q15 formulas can be assigned, whereby the output levels are controlled via a program.

■ Related Help topics

CASSY-Display



Introduction

CASSY-Display (USB or serial respectively) is a two-channel instrument for displaying measured values without a computer.

- Microprocessor-controlled with CASSY operating system (easily updatable via software for function enhancements).
- For use as a benchtop, console or demonstration unit (also in CPS/TPS panel frames).
- Supports up to 8 Sensor-CASSY units (for 16 measuring channels)
- Values are measured using Sensor-CASSY or a sensor box connected there (see Sensor-CASSY for measurement quantities and ranges).
- Measured values can be toggled and calibrated individually. Measurement quantity and unit change automatically when a sensor box is added or moved.
- With integrated real-time clock and data logger.
Data storage for up to 32,000 measured values is retained when the device is switched off, enabling these to be read out by a computer via the USB port (Windows 98/2000 or higher version) or via the serial interface respectively.
- Voltage supply 12 V AC/DC via cannon plug.

Safety notes

- Transport multiple cascaded CASSY modules only in the panel frame or individually (the mechanical stability of the connections without panel frame is sufficient for experimenting only, and not for transport).
- Use only the plug-in supply unit (12 V / 1.6 A) to power the CASSY modules.

■ Related Help topics

Data logger

CASSY-Display is equipped with an integrated memory function for storing measurement data. This data can be read out by CASSY-Lab at a later date. When CASSY-Display is connected to a computer, the current arrangement of CASSY modules is shown on the CASSY tab of the Settings dialog. To read out the data, simply click on **Read Out Data**.

During this process the real-time clock of CASSY-Display is synchronized with the system clock of the computer. Therefore, make sure the computer's system clock shows the correct time.

Please refer to the CASSY Instruction Sheet for more information on using the device.

■ Related Help topics

Pocket-CASSY



Introduction

Pocket-CASSY is an interface device for recording measurement data:

- For connection to the USB port of a computer (Windows 98/2000 or higher version) or to an active hub.
- Compatible with USB 1.x and 2.0 (Full speed)
- Up to 8 analog inputs per Pocket-CASSY available using sensor boxes
- Up to 8 Pocket-CASSYs can be used at different USB ports (to expand the inputs even more)
- Automatic sensor box detection by CASSY Lab (plug and play)
- Power supply via USB port (500 mA).
- Developer information available for downloading to help you develop your own software.

Safety notes

- For your own protection, do not connect sensors and sensor boxes to voltages over 30 V.
- Mind possible ground connections between the sensors and the computer.
- Related Help topics



Technical data

- 1 Analog input at sensor connector site
(All CASSY sensor boxes and sensors can be connected)
Resolution: 12 Bit
Measuring ranges: $\pm 0.003/0.01/0.03/0.1/0.3/1$ V
Measuring error: ± 1 % plus 0.5 % of range limit value
Input resistance: 10 k Ω
Scanning rate: max. 7,800 values/s
No. of meas. values: virtually unlimited (PC dependent) up to 100 values/s,
at a higher measurement rate max. 16,000 values

The technical data will change depending on a connected sensor box.

In this case CASSY Lab automatically detects the possible measurement quantities and ranges when a sensor box is attached.

- 2 Timer inputs at sensor connector site
(e.g. for BMW box, GM box or timer box)
Counter frequency: max. 10 kHz
Time resolution: 1 μ s
Measuring time
between two events: min. 100 μ s
Memory: max. 5,000 time points (= 2,500 values per input)
- 6 Digital inputs (TTL) at sensor connector site
(at present only used for automatic sensor box detection)
- 3 Digital outputs (TTL) at sensor connector site
(at present only used for automatic switching of a sensor box measuring range)
- 1 USB port for connection to a computer and for power supply

Dimensions (WxHxD): 50 mm x 25 mm x 60 mm

Weight: 0.1 kg

Scope of supply

- 1 Pocket-CASSY
 - 1 CASSY Lab software, without activation code, for Windows 95/98/NT or higher version with comprehensive help function (20 full-functionality sessions free, then usable as demo version)
 - 1 Installation guide
 - 1 USB cable
- Related Help topics

Use of Pocket-CASSY

Pocket-CASSY is an interface designed as a low-cost device for students' practice. Therefore some features of the Sensor-CASSY have been renounced. However, most of the experiments described can also be carried out using Pocket-CASSY. These experiments are labelled with the Pocket-CASSY logo. The subsequent description and equipment list nevertheless refer to the use of Sensor-CASSY.

Carrying out an experiment intended for Sensor-CASSY using the Pocket-CASSY

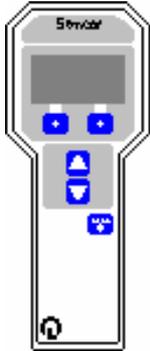
- For voltage and current measurements the UI sensor S (524 062) or the UIP sensor S (524 0621) is required if the Pocket-CASSY is used.
- If both analog inputs A and B of the Sensor-CASSY are used, two Pocket-CASSYs have to be employed instead (maybe in conjunction with two UI sensors S). In the case of a combined voltage and current measurement, a single Pocket-CASSY with a UIP sensor S is sufficient.
- The symbols of the measurement quantities have one index less than those given in the experiment descriptions as, in the case of the Pocket-CASSY, no distinction has to be made between input A and input B. For example, you have U_1 and U_2 (two Pocket-CASSYs) instead of U_{A1} and U_{B1} (one Sensor-CASSY).

Limitations of Pocket-CASSY as compared with Sensor-CASSY

- There is only one sensor input. If there are enough USB ports available, several sensor inputs can be realised by using several Pocket-CASSYs. As there is no direct signal transmission between several Pocket-CASSYs, trigger time errors of up to 5 ms may arise.
- There are no voltage and current inputs on 4-mm sockets. These can be made available by means of the UI sensor S or the UIP sensor S. However, the UI sensor S has only 7 instead of 10 measuring ranges. It lacks the ranges ± 100 V, ± 3 A, ± 0.1 A. Moreover, it cannot be used to record U and I simultaneously. The UIP sensor S only lacks the range ± 100 V.
- Time resolutions $\Delta t < 100$ μ s cannot be selected. Internally Pocket-CASSY scans at $\Delta t \geq 128$ μ s so that an interpolation has already to be made for $\Delta t = 100$ μ s.
- There is no relay R and no voltage source S.
- The timer inputs only have 1 μ s resolution - a variable latency of up to 10 μ s may arise in addition. The maximum measurable frequency is approx. 10 kHz.
- Pocket-CASSY is not isolated. Depending on the sensor connected, a continuous ground connection may exist between the sensor and the computer. If two Pocket-CASSYs are used simultaneously at the same computer, even an electrical connection between two sensors may occur. In order to compensate this disadvantage, the UI sensor S (524 062) and the UIP sensor S (524 0621), which are often employed, have been designed as difference amplifiers. Their input sockets are only connected to the ground via high resistances.

■ Related Help topics

Mobile-CASSY



Introduction

Mobile-CASSY is a universal hand-held measuring instrument:

- For almost all CASSY sensors and sensor boxes
- Automatic sensor box detection (plug and play)
- Up to 8 analog inputs per Mobile-CASSY available using sensor boxes
- Power supply via 4 mignon cells (AA, batteries or accumulators) or plug-in power supply 12 V AC/DC
- With integrated data logger for up to 16,000 measured values
- Can be connected to the USB port of a computer (Windows 98/2000 or higher version) for reading the data logger or for displaying the measured values on a large screen
- Compatible with USB 1.x and 2.0
- Up to 8 Mobile-CASSYs can be used at different USB ports
- Isolated from the computer
- Developer information available for downloading to help you develop your own software.

Safety notes

- For your own protection, do not connect sensors and sensor boxes to voltages over 30 V.
- Related Help topics.

Technical data

- 1 Analog input at sensor connector site
(Almost all CASSY sensor boxes and sensors can be connected)
Resolution: 12 Bit
Measuring ranges: $\pm 0.003/0.01/0.03/0.1/0.3/1$ V
Measuring error: ± 1 % plus 0.5 % of range limit value
Input resistance: 10 k Ω
Scanning rate: max. 5 values/s
No. of meas. values: 16,000 in the integrated data logger or virtually unlimited
(depending on the PC) if the measurements are made with a PC
The technical data will change depending on a connected sensor box.
When a sensor box is attached, the possible measurement quantities and ranges are detected automatically.
 - 1 Display for simultaneously displaying up to four values in various character sizes
 - 1 USB port for connection to a computer
- Dimensions (BxHxT): 87 mm x 215 mm x 30 mm
Weight: 0.25 kg

Scope of supply

- 1 Mobile-CASSY
 - 1 CASSY Lab software, without activation code, for Windows 95/98/NT or higher version with comprehensive help function (20 full-functionality sessions free, then usable as demo version)
 - 1 Instruction sheet
 - 1 USB cable
- Siehe auch.



Use of Mobile-CASSY

Mobile-CASSY is an interface designed for mobile use. Therefore many features of the Sensor-CASSY have been renounced, and a data logger has been integrated instead. However, some of the experiments described can also be carried out using the Mobile-CASSY. These experiments are labelled with the Mobile-CASSY logo. The subsequent description and equipment list nevertheless refer to the use of Sensor-CASSY.

Carrying out an experiment intended for Sensor-CASSY using the Mobile-CASSY

- For voltage and current measurements the UI sensor S (524 062) or the UIP sensor S (524 0621) is required if the Mobile-CASSY is used.
- If both analog inputs A and B of the Sensor-CASSY are used, two Mobile-CASSYs have to be employed instead (maybe in conjunction with two UI sensors S). In the case of a combined voltage and current measurement, a single Mobile-CASSY with a UIP sensor S is sufficient.
- The symbols of the measurement quantities have one index less than those given in the experiment descriptions as, in the case of the Mobile-CASSY, no distinction has to be made between input A and input B. For example, you have U_1 and U_2 (two Mobile-CASSYs) instead of U_{A1} and U_{B1} (one Sensor-CASSY).

Limitations of Mobile-CASSY as compared with Sensor-CASSY

- There is only one sensor input. If there are enough USB ports available, several sensor inputs can be realised by using several Mobile-CASSYs.
- There are no voltage and current inputs on 4-mm sockets. These can be made available by means of the UI sensor S or the UIP sensor S. However, the UI sensor S has only 7 instead of 10 measuring ranges. It lacks the ranges ± 100 V, ± 3 A, ± 0.1 A. Moreover, it cannot be used to record U and I simultaneously. The UIP sensor S only lacks the range ± 100 V.
- Time resolutions $\Delta t < 200$ ms cannot be selected.
- There is no relay R and no voltage source S.
- Support of the timer inputs is very limited.

Data logger

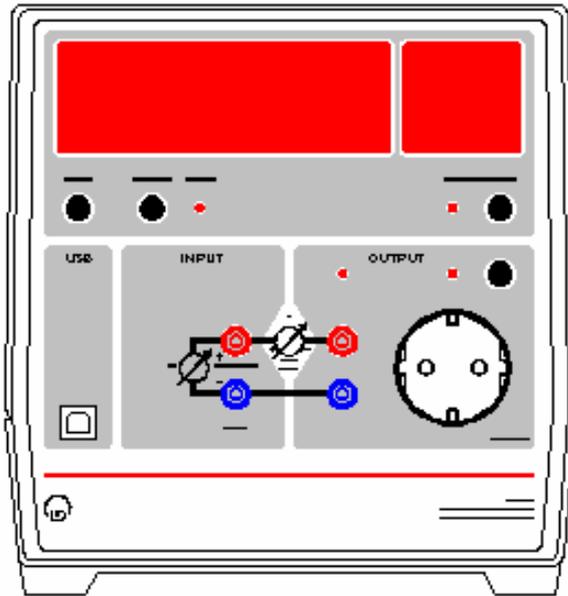
The Mobile-CASSY is equipped with an integrated data memory, where measurement data can be stored. This data is retained when the power supply is switched off and can later be read from the memory by CASSY Lab. When the Mobile-CASSY is connected to a computer, it is displayed in the current arrangement of CASSY modules on the CASSY tab of the Settings dialog. To read out the data, simply click on **Read Out Data**.

During this process the real-time clock of the Mobile-CASSY is synchronized with the system clock of the computer. Therefore, make sure the computer's system clock shows the correct time.

Please refer to the Mobile-CASSY Instruction Sheet for more information on using the device.

- Related Help topics.

Joule and wattmeter



Introduction

The Joule and wattmeter is a universal multimeter with a wattmeter

- for measuring and displaying effective voltages U and effective currents I for voltages and currents of any shape
- for displaying the nonreactive power P determined from U and I and the time integrals $\int P(t) dt$ (work), $\int U(t) dt$ (surge) and $\int I(t) dt$ (charge)
- with large power range from nW to kW (12 decades)
- with large display, which can be read from great distances
- with connection of the load optionally via 4 mm safety sockets or grounded socket (front panel)
- with possibility of connecting to the USB port of a computer (Windows 98/2000 or higher version) for reading the time-resolved curve shapes $U(t)$, $I(t)$ and $P(t)$ and their effective values
- compatible with USB 1.x and 2.0 (full speed)
- isolated from the computer
- Developer information for your own software development available on the Internet

Safety notes

The device complies with the safety requirements for electrical measuring, control and laboratory equipment in accordance with DIN EN 61010 part 1. It is intended for use in dry rooms, which are suitable for electrical equipment and devices.

If the device is used as prescribed, its safe operation is guaranteed. However, safety is not guaranteed if the device is improperly used or carelessly handled. If it has to be assumed that safe operation is no longer possible (e. g. in the case of visible damage), shut the device down immediately.

When putting the device into operation for the first time:

- Check whether the value for the mains voltage indicated on the rating plate agrees with the local value.
- Look for the instruction sheet of the device on the enclosed CD "Instruction Sheets" with the aid of the catalogue number, and read it.

Before putting the device into operation:

- Examine the housing for damage. In case of malfunction or visible damage, shut the device down and make sure that it is not used inadvertently.

On every operation:

- Connect the device only to sockets with grounded neutral wire.
- Never apply voltages over 250 V and currents over 10 A.



- Examine connecting leads, test leads and probes for defective insulation and bare wires.
 - When carrying out experiments with hazardous-contact voltages, use only 4 mm safety connecting leads.
 - The socket on the front panel may be alive even if the output is not active.
 - Replace a defective fuse only with a fuse that corresponds to the original value (T 10 A / 250 V).
 - Never short the fuse or the fuse holder.
 - Always keep the ventilation slots of the housing free in order to ensure sufficient air circulation for cooling the internal components.
 - Keep metallic objects, foreign matter and water away from the ventilation slots.
 - Do not put the device into operation if objects of that kind have got into the interior of the device.
 - Allow only skilled persons to open the device.
 - The device must not be subjected to strong shocks.
- Related Help topics.

Technical data

- 1 Analog voltage input on 4 mm sockets
 - Resolution: 12 bit
 - Measuring ranges: $\pm 5^{**}/\pm 50^{**}/\pm 500$ mV / $\pm 5/\pm 50/\pm 250$ V
 - Measuring accuracy*: 1 %
 - Input resistance: ≥ 1 M Ω
 - Scanning rate: max. 10,000 values/s
 - No. of meas. values: virtually unlimited (PC dependent) up to 100 values/s, at a higher measurement rate max. 16,000 values
 - 1 Analog voltage input for grounded socket (can be used alternatively)
 - Resolution: 12 Bit
 - Measuring range: 250 V
 - Measuring accuracy*: 1 %
 - Input resistance: 2 M Ω
 - Scanning rate: max. 10,000 values/s
 - No. of meas. values: virtually unlimited (PC dependent) up to 100 values/s, at a higher measurement rate max. 16,000 values
 - 1 Analog current input for 4 mm safety sockets and grounded socket
 - Resolution: 12 bit
 - Measuring ranges: $\pm 0,2/\pm 2/\pm 20$ mA / $\pm 0,2/\pm 2/\pm 10$ A
 - Measuring accuracy*: 1 %
 - Input resistance: 10 Ω / approx. 0.01 Ω
 - Scanning rate: max. 10,000 values/s
 - No. of meas. values: virtually unlimited (PC dependent) up to 100 values/s, at a higher measurement rate max. 16,000 values
- Connection of load: optionally via 4 mm safety sockets or grounded socket (front panel)
- Display: 5 digit 7 segment display for numerical value and 7x15 matrix for unit
- Height of digits: 25 mm
- USB-Port: USB 1.x and 2.0 (full speed), isolated
- Supply: 230 V, 50/60 Hz
- Dimensions (BxHxT): 20 cm x 21 cm x 23 cm
- Weight: 2 kg

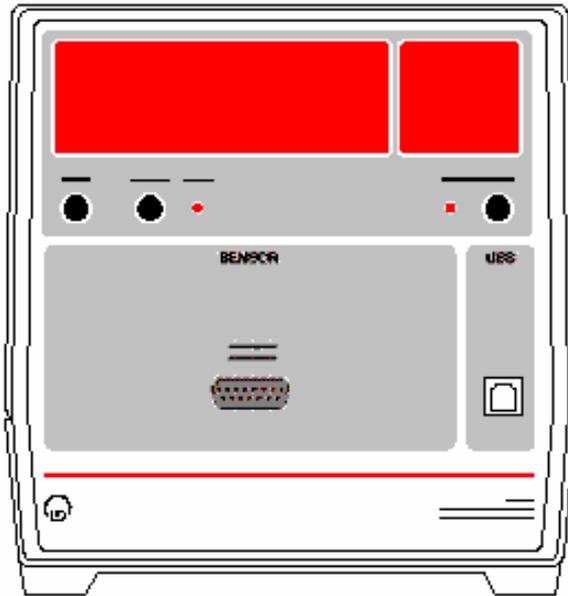
* The specified accuracy is valid at the upper limit of range for DC and for AC with a frequency of 50 to 60 Hz and a crest factor = maximum value : effective value ≤ 2 .

** This range is only suited for DC (not for AC).

Scope of supply

- 1 Joule and wattmeter
 - 1 CASSY Lab software without activation code for 95/98/NT or higher version with comprehensive help (can be used for the Joule and wattmeter without limitations)
 - 1 Instruction sheet
 - 1 USB cable
- Related Help topics.

Universal measuring instrument physics



Introduction

The universal measuring instrument physics is a universal multimeter

- for measuring and displaying many physical quantities
- with large display, which can be read from great distances
- with possibility of connecting to the USB port of a computer (Windows 98/2000 or higher version) for reading the time-resolved curve shapes
- compatible with USB 1.x and 2.0 (full speed)
- isolated from the computer
- Developer information for your own software development available on the Internet

Safety notes

The device complies with the safety requirements for electrical measuring, control and laboratory equipment in accordance with DIN EN 61010 part 1. It is intended for use in dry rooms, which are suitable for electrical equipment and devices.

If the device is used as prescribed, its safe operation is guaranteed. However, safety is not guaranteed if the device is improperly used or carelessly handled. If it has to be assumed that safe operation is no longer possible (e. g. in the case of visible damage), shut the device down immediately.

When putting the device into operation for the first time:

- Check whether the value for the mains voltage indicated on the rating plate agrees with the local value.
- Look for the instruction sheet of the device on the enclosed CD "Instruction Sheets" with the aid of the catalogue number, and read it.

Before putting the device into operation:

- Examine the housing for damage. In case of malfunction or visible damage, shut the device down and make sure that it is not used inadvertently.

On every operation:

- Connect the device only to sockets with grounded neutral wire.
- Always keep the ventilation slots of the housing free in order to ensure sufficient air circulation for cooling the internal components.
- Keep metallic objects, foreign matter and water away from the ventilation slots.
- Do not put the device into operation if objects of that kind have got into the interior of the device.
- Allow only skilled persons to open the device.
- The device must not be subjected to strong shocks.

Technical data

- 1 Analog sensor input at sensor connector site for many sensors S
 - Resolution: 12 Bit
 - Measuring ranges: depending on sensor
 - Measuring error: ± 1 % plus sensor error
 - Input resistance: 10 k Ω
 - Scanning rate: max. 10,000 values/s
 - No. of meas. values: virtually unlimited (PC dependent) up to 100 values/s,
at a higher measurement rate max. 16,000 values
- Display: 5 digit 7 segment display for numerical value and 7x15 matrix for unit
- Height of digits: 25 mm
- USB-Port: USB 1.x and 2.0 (full speed), isolated
- Supply: 230 V, 50/60 Hz
- Dimensions (BxHxT): 20 cm x 21 cm x 23 cm
- Weight: 2 kg

Scope of supply

- 1 Universal measuring instrument physics
 - 1 CASSY Lab software without activation code for 95/98/NT or higher version with comprehensive help
(can be used for the Universal measuring instrument physics without limitations)
 - 1 Instruction sheet
 - 1 USB cable
- Siehe auch.



Other serial devices

In addition to CASSY, CASSY Lab also supports other serial devices. You can use them on any other free interface simultaneously with CASSY. These devices include:

- ASCII (configurable)
- Balance (various manufacturers)
- VideoCom (337 47)
- IRPD (332 11)
- Multifunction instrument MFA 2001 (727 230)
- MetraHit (531 28 - 531 30)
- Thermometer (666 209 / 666 454)
- Digital spectrophotometer (667 3491)
- Data logger (666 252)
- pH meter (666 221)
- Conductivity meter (666 222)
- Lux meter (666 223 / 666 230)
- O₂ meter (666 224)
- Photometer (666 225)
- Sound level meter (666 231)
- CO₂-CO-CH₄ meter (666 232)
- Optical power meter (736 435)
- Rotating antenna platform (737 405)

ASCII, balance, VideoCom, IRPD, MFA 2001

In addition to balances, VideoCom (337 47), the IR position detector (332 11) and the Multifunction instrument MFA 2001 (727 230), CASSY Lab supports all devices at the serial interface as long as they transmit ASCII data (plain text, number and unit, mode 8N1 = 8 data bits, no parity, 1 stop bit or mode 7E1 = 7 data bits, even parity, 1 stop bit). The software then only compares the defined unit with the transmitted unit. If these agree at least in the beginning, the transmitted numerical value is displayed as a measured value. If no unit is specified, all transmitted numerical values are displayed.

The transmission rate of VideoCom and IRPD is fixed. As balances and other devices can work with different transmission rates, this can be set.

Troubleshooting

If no measured values are displayed, this may be due to one of several reasons:

- Serial interface not correctly defined
- Incorrect interface parameters: make sure that the device is using the same transmission rate and the same mode (8N1 = 8 data bits, no parity, 1 stop bit or 7E1 = 7 data bits, even parity, 1 stop bit). VideoCom and IRPD always fulfill this condition.
- Wrong connecting cable: depending on the device, you may need either an uncrossed (1:1) cable or a crossed (null modem) cable. VideoCom, IRPD and MFA 2001 require a 1:1 cable, balances usually need a null modem cable.
- Wrong unit: the unit can be deleted for test purposes. The software then displays all numerical values. VideoCom, IRPD and MFA 2001 always return the correct unit.
- Device not transmitting: check this using a terminal program such as HyperTerminal (supplied as a Windows accessory; however, you may need to install this program retroactively in the Control Panel).

VideoCom restrictions

VideoCom also uses the specified display range to calibrate the path, and this should thus correspond to the width of VideoCom's field of view.

The position of the first detected reflection only is displayed. The VideoCom software can still be used for multiple positions.

The measurement is not processed in synchronized form. Although VideoCom transmits 80 positions

per second, the software does not synchronize measured-value recording with this rate. Therefore, you should measure with a time interval of at least 100 ms. This is sufficient for the typical VideoCom application together with CASSY (position control).

■ Related Help topics

MetraHit

CASSY Lab supports MetraHit devices 14S to 18S (531 28 - 531 30) when these are equipped with an interface adapter (531 31).

The measurement quantity must be selected so as to correspond with the setting of the MetraHit meter. You can change the set measuring range at any time; this has nothing to do with the actual measuring range of the MetraHit unit. When the measuring range of the MetraHit is changed, the display range in the software is retained until it too is explicitly changed.

The various MetraHit devices measure to different numbers of decimal places. The software can **suppress a decimal place** to ensure identical display.

Troubleshooting

If no measured values are displayed, this may be due to one of several reasons:

- Serial interface not correctly defined.
- Wrong connecting cable: use the uncrossed (1:1) cable supplied with the interface device (531 31).
- Wrong measurement quantity: set the correct quantity on the device and in the software.
- LED on interface adapter not flashing: activate data transmission on the MetraHit device (press **DATA** and **ON** simultaneously).

■ Related Help topics

Thermometer

CASSY Lab supports the thermometer (666 209 or 666 454). Each of the four temperatures receives its own display instrument, and these are arrayed in the speed buttons of the main window.

You can change the set measuring range at any time; this has nothing to do with the actual measuring range of the thermometer.

The thermometer is equipped with a measurement storage function which can be read out. Simply activate **Read Out Memory**.

Troubleshooting

If no measured values are displayed, this may be due to one of several reasons:

- Serial interface not correctly defined.
- Wrong connecting cable: use an uncrossed (1:1) cable.
- Wrong device selected: compare the catalog number of the device with that shown in the dialog. Older versions of the thermometer can be operated as **ASCII (configurable)**.
- No temperature sensor attached.

■ Related Help topics

Digital spectrophotometer

The Digital spectrophotometer (667 3491) is supported. A display instrument is assigned to both the current wavelength λ and the currently measured transmission T and placed near the speed buttons in the main window.

If in addition the values of the absorption (100-T) or the extinction ($-\log(T/100)$) are to be displayed, these values can be calculated with Formulae or the settings of the corresponding Experiment example can be loaded.

Troubleshooting

If no measured values are displayed, this may be due to one of several reasons:

- Serial interface not correctly defined
- Wrong connecting cable: use only the cable delivered together with the device.
- Wrong device selected: compare the catalog number of the device with that shown in the dialog.

■ See also.

Hand-held measuring instruments and data logger

CASSY Lab supports all devices of the LD Didactic hand-held measuring instrument series and the corresponding data logger:

- Data logger (666 252)
- pH meter (666 221)
- Conductivity meter (666 222)
- Lux meter (666 223 / 666 230)
- O₂ meter (666 224)
- Photometer (666 225)
- Sound level meter (666 231)
- CO₂-CO-CH₄ meter (666 232)
- Optical power meter (736 435)

However, each hand-held instrument can only be connected once. If a hand-held instrument type is to be used for multiple measurements simultaneously (e.g. two pH meters), you need to connect them via the data logger.

You can change the set measuring range at any time; this has nothing to do with the actual measuring range of the hand-held measuring instrument. When the measuring range of the instrument is changed, the display range in the software is retained until it is explicitly changed.

Each measurement quantity receives its own display instrument, and these are placed in the speed buttons of the main window.

The data logger and the sound level meter are equipped with a measurement storage function that can be read out. To do this, click on **Read Out Memory** and start transmission on the device.

Troubleshooting

If no measured values are displayed, this may be due to one of several reasons:

- Serial interface not correctly defined.
- Wrong connecting cable: use only the special computer connecting cable (666 251).
- Wrong device selected: compare the catalog number of the device with that shown in the dialog.
- Wrong measurement quantity: set the device to the correct measurement quantity.

■ Related Help topics

Rotating antenna platform

The rotating antenna platform (737 405) is supported. Apart from numerous predefined experiment examples, the following parameters can be changed manually for optimum use:

- **Range from**
Starting angle for the measurement given in degrees, e. g. –180
- **Range to**
Target angle given in degrees, e. g. 180
- **Angular Increment**
In this menu for the angular resolution, one of the following intervals of rotation can be selected: 0.5° / 1° / 2°.
- **Bias Current**
Can be switched on / off. The Schottky detector diode used in the dipole antenna (737 411) requires a small DC bias current of the order of magnitude of 15 µA. Without this bias current, the sensitivity of the detector is considerably diminished.
- **Gunn Modulation**
Superimposes a square-wave voltage of approx. 1 kHz, 1 Vpp on the DC supply for the Gunn oscillator. Should only be switched on if no PIN modulator (737 05) is available.
- **Detector Characteristic**
The test antennas always have to be connected to a detector (e. g. coax detector 737 03), or they have a built-in detector diode. The original antenna signal A before the detector cannot be measured directly. Only the voltage drop generated by the detector current at the measuring amplifier is measurable. In general, A is not proportional to U. There are the following choices:
 - Quadratic detector: $A \propto U^{1/2}$ (good approximation for small received voltages $U < 5$ mV)
 - Linear detector: $A \propto U$ (approximation for high received voltages $U > 5$ mV)
 - Free: $A \propto U^{(1/m)}$ (here the detector characteristic has to be entered, e.g. after a gauging measurement with a calibrated attenuator 737 09).
- **Far-Field Computer**
The input is DT (greatest lateral dimension of the test antenna in mm). The extension of the of the transmitting antenna DQ (e. g. large horn antenna 737 21: DQ = 100 mm) and the wavelength $\lambda_0 = 32$ mm being taken into account, the minimum distance r_0 between the transmitting and the receiving antenna is calculated at which the far-field condition

$$r_0 \geq \frac{2(D_Q + D_T)^2}{\lambda_0}$$
 is fulfilled.
- **Normalize Level**
Forms the ratio $A = U/U_{\max}$, which is 1 in the maximum. The logarithmic damping factor is $a = 0$ dB in the maximum.
- **Rotate Maximum to 0°**
Sets the maximum of the measured curve to 0°. The measured curve can be rotated and shifted manually with the two screenshot keys. Important note regarding cursor operation: the measuring instruments (e. g. level A or angle ϑ) display the current measured value and not the position of the cursor in the diagram or the table.
- **Approach Reference Point**
Interrupts the current measurement and returns the rotating platform to the starting position +/-180°. This is necessary, e. g., after free movement of the rotating platform has been hindered so that errors occur in recording the position.
- **Stop Rotating Platform**
Stops the rotating platform. Static measurements are possible, e. g. for determining the antenna gain. The rotating platform may be controlled step by step via the screenshot keys.

Troubleshooting

If no measured values are displayed, this may be due to one of several reasons:

- Serial interface not correctly defined
- Wrong connecting cable: use only the cable delivered together with the device (1:1).
- Wrong device selected: compare the catalog number of the device with that shown in the dialog.



STM (Science Teaching Modules)

The experiment examples help you in using CASSY. The measurement data or settings can be loaded into CASSY Lab directly. Simply click the  symbols in the descriptions. New examples are labelled with a red •.

Teacher's versions

The teacher's versions are able to load the examples with measurement data and also contain the answers to questions asked in the text. The STM help has to be installed separately. If you have not yet installed it, please do it now using the CASSY Lab CD-ROM. Afterwards you can download future versions of the STM help from the Internet.

Texts which are written in red in the teacher's versions are not found in the student's versions.

Mechanics

- P1.3.1.3 Uniformly accelerated motion - path-time diagram (Teacher's version)
- Uniform motion between two light barriers (Teacher's version)
- Uniformly accelerated motion between a holding magnet and a light barrier (Teacher's version)
- Relation between acceleration and mass ($F=\text{constant}$) (Teacher's version)
- Relation between acceleration and force ($m=\text{constant}$) (Teacher's version)

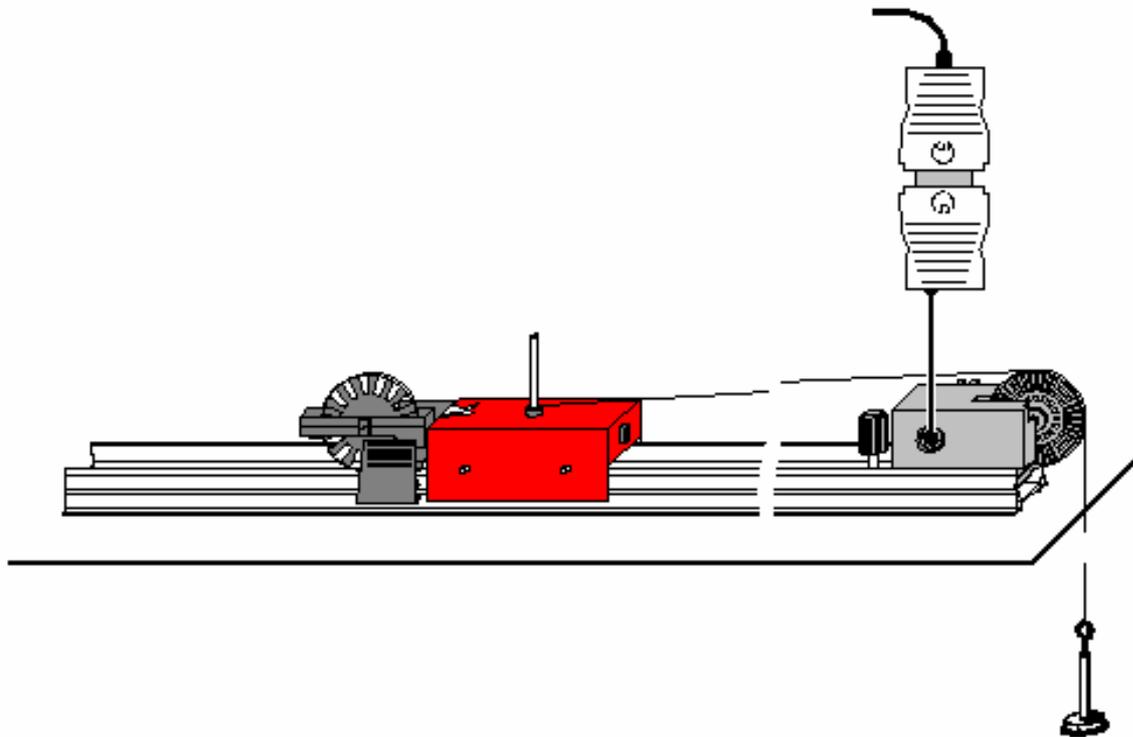
Electricity

- Ohm's law (Teacher's version)
- P3.2.3.1a Series connection of resistors (Teacher's version)
- P3.2.3.1b Parallel connection of resistors (Teacher's version)
- P3.2.3.2 Adjusting a voltage by means of a potentiometer (Teacher's version)
- P3.2.3.3 Principle of Wheatstone's bridge (Teacher's version)

Atomic and Nuclear physics

- The effect of the distance between the radiation source and the end-window counter on the pulse rate (Teacher's version)

Uniformly accelerated motion - path-time diagram



Task

Investigate the motion of a trolley driven by a weight which is suspended from a piece of cord that runs over a pulley.

Equipment list

1 Pocket-CASSY	524 006
1 CASSY Lab	524 200
1 Timer S	524 074
1 Combination light barrier	337 462
1 Combination spoked wheel	337 464
1 Adapter combination light barrier for student's track	337 465
1 Multi-core cable, 6-pole, 1.5 m	501 16
1 Precision metal rail, 1 m	460 81
1 Trolley, 85 g	337 00
1 Set of driving weights	337 04
1 Cord	200 70 322
1 Single pulley on clamp rider	337 14
alternatively: 1 clamp rider	460 95
1 PC with Windows 98/2000 or higher version	

Experiment setup (see drawing)

- Cut an approx. 80 cm long piece of cord, and tie loops at the ends. The length of the cord should be chosen so that the suspended weight is just over the bottom when the trolley stands at the end of the track.
- Move the trolley on the track until the suspended weight is just before the pulley without touching it. Now attach the single pulley on clamp rider (or a clamp rider) to the precision metal rail as the starting point for the trolley.
- At the beginning, only suspend the hanger (5.2 g) from the cord.



Carrying out the experiment

■ Load settings

- Move the trolley to its starting point, keep it there, and define the zero in the window Settings Path s1 with $\rightarrow 0 \leftarrow$. Start the measurement with **F9** or by clicking the  button and release the trolley.
- Lay additional weights on the hanger (each time 5 g), and repeat the experiment.

Evaluation

- What was measured in the experiment (see table or diagram)?

- What is displayed in the diagram?

- How do the path differences covered in equal time intervals behave?

- What kind of curve is described by the measured values? Suggestion:

- Confirm the suggestion by fitting to a corresponding curve with Fit Function.
- What is your conclusion regarding the relation between the path s and the time t ?

- Display the axes correspondingly in the **Check** sheet by clicking with the right mouse button. Then determine the factor of proportionality by Line through origin. The results for the three motions are:

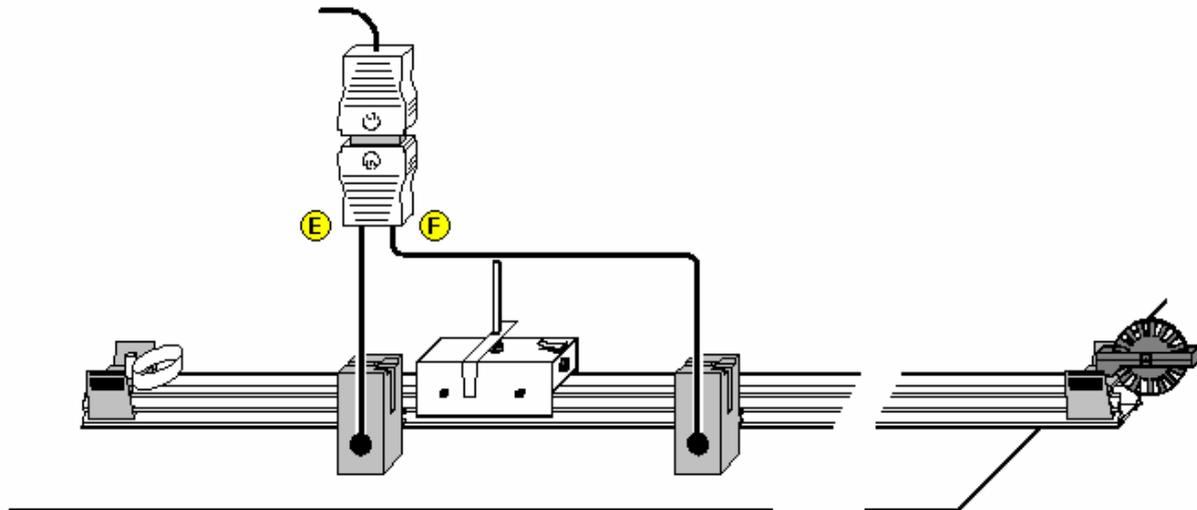
1.)

2.)

3.)

- What is your conclusion regarding the general mathematical description of the motion (equation of motion)?

Uniform motion between two light barriers



Task

Investigate the relations between the path s and the time t and between the velocity v and the time t for the uniform motion of a trolley between two light barriers.

Equipment list

1 Pocket-CASSY	524 006
1 CASSY Lab	524 200
1 Timer S	524 074
1 Precision metal rail, 1 m	460 81
1 Trolley 1	337 00
1 Single pulley on clamp rider	337 14
1 Spring and buffer	337 03
1 Clamp rider	460 95
1 Extension pin	309 00 441
1 Accessories for electronic time measurement	337 466
2 Combination light barriers	337 462
2 Multi-core cables, 6-pole, 1.5 m	501 16
1 PC with Windows 98/2000 or higher version	

Experiment setup (see drawing)

- Set up the light barrier 1 at a distance of 40 cm from the beginning of the metal rail, and connect it to the input E of the timer S. Connect the light barrier 2 to the input F.
- Put the trolley with spring and interruptor flag onto the metal rail.
- Mount the clamp rider and the extension pin as a start device at the beginning of the metal rail and the single pulley as a stop device at the end of the metal rail.

Carrying out the experiment

■ Load settings

- Set up the light barrier 2 at a distance of 10 cm from the light barrier 1. Use the mouse to drag the pointer in the display window Path s to 10 cm.
- To start the motion press the trolley with the spring against the holding pin. The spring should be compressed by approximately 2 cm.
- Release the trolley. Take the measured values into the table with the **F9** key.
- Repeat the measurement increasing the path in steps of 5 cm.



When the trolley is slid back to the zero position, the light barrier 1 is interrupted and the time measurement is started. In order to stop it, the light barrier 2 has to be interrupted as well. However, it is simpler to take the trolley off the rail and to put it back before the light barrier 1.

Evaluation

- Draw a straight line through the origin and the measuring points in the $s(t)$ diagram. What relation between s and Δt_1 can be derived?

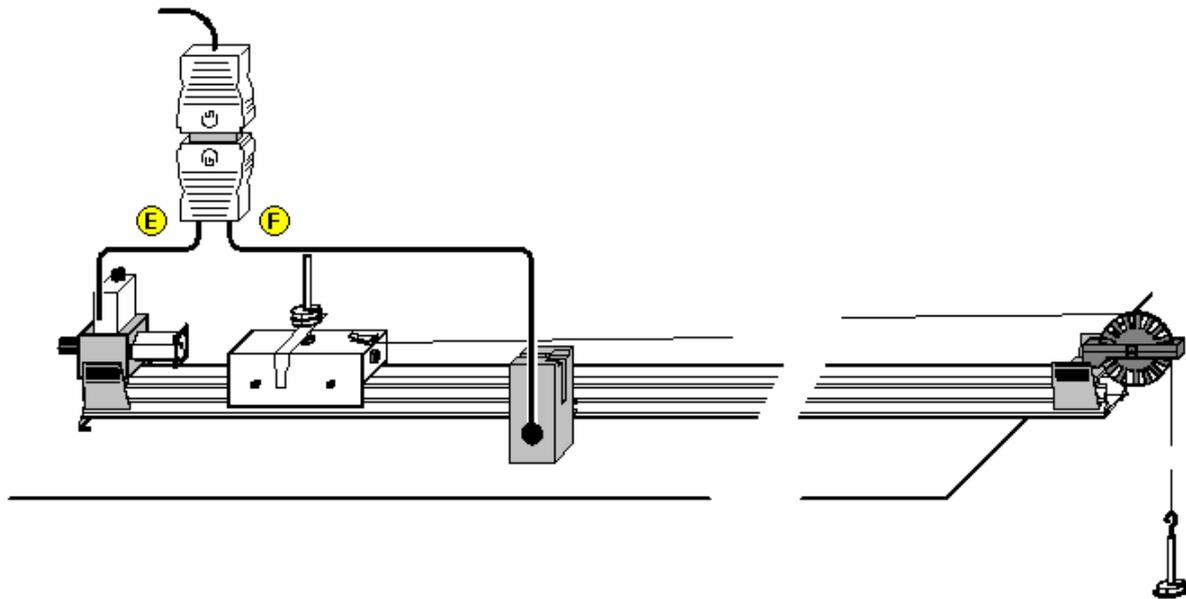
- Read the slope A of the straight line.

- Determine the mean value v_m of the measuring points in the $v(t)$ diagram.

- Compare the slope A of the straight line in the $s(t)$ diagram with the mean value v_m of the velocity.

- What equation of motion can be derived for the uniform motion?

Uniformly accelerated motion between a holding magnet and a light barrier



Task

Investigate the relations between the path s and the time t and between the mean velocity v_m and the time t for the uniformly accelerated motion of a trolley between a holding magnet and a light barrier.

Equipment list

1	Pocket-CASSY	524 006
1	CASSY Lab	524 200
1	Timer S	524 074
1	Precision metal rail, 1 m	460 81
1	Trolley 1	337 00
1	Set of driving weights	337 04
1	Fishing line	309 48
1	Single pulley on clamp rider	337 14
1	Holding magnet for track	683 41
1	Holding magnet adapter with a release mechanism	336 25
1	Accessories for electronic time measurement	337 466
1	Combination light barrier	337 462
1	Multi-core cable, 6-pole, 1.5 m	501 16
1	PC with Windows 98/2000 or higher version	

Experiment setup (see drawing)

- Put the holding magnet with the holding magnet adapter onto the metal rail and connect it to the input E of the timer S.
- Set up the light barrier at a distance of 20 cm from the beginning of the metal rail and connect it to the input F.
- Put the trolley with the holding pin onto the metal track.
- Fix a piece of fishing line to the trolley, and suspend the hanger and a slotted weight from it.
- Adjust the screw of the holding magnet so that the trolley is just kept from rolling.
- Displace the trolley together with the holding magnet so that the interruptor flag of the trolley all but interrupts the light barrier (zero).



Carrying out the experiment

■ Load settings

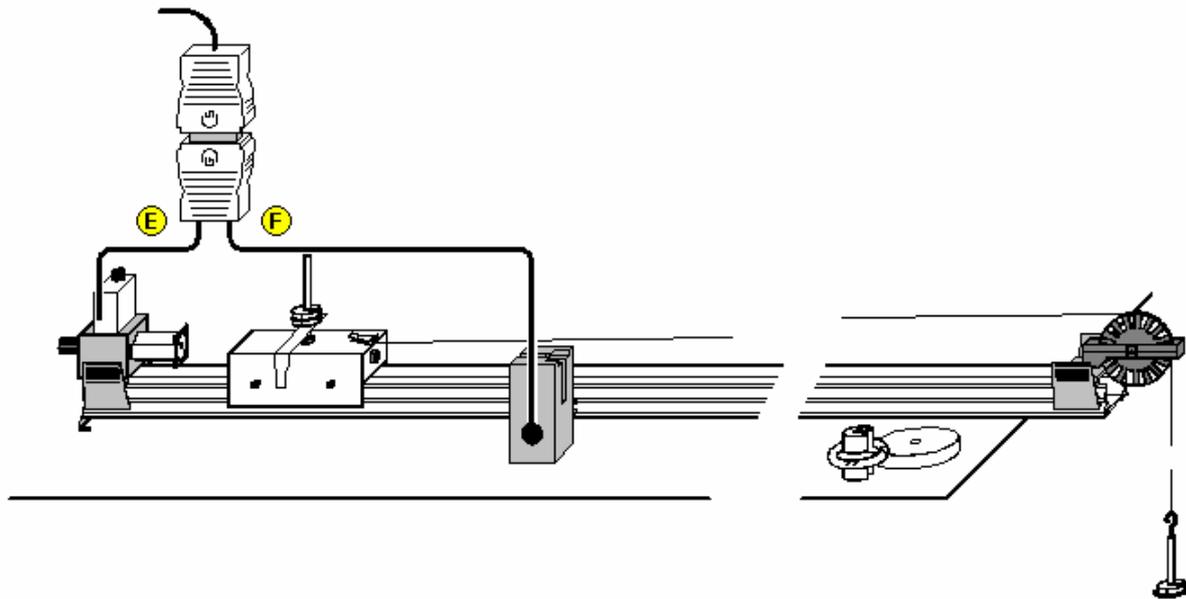
- Position the light barrier at a distance s of 10 cm behind the zero just defined.
- Use the mouse to drag the pointer in the display window Path s to 10 cm.
- Start the measurement by pressing the pushbutton of the holding magnet adapter.
- Take the path s and the travel time Δt_1 into the table with **F9**.
- Increase the distance s of the light barrier in steps of 5 cm each time repeating the measurement.

Evaluation

- Draw a normal parabola through the measuring points of the $s(t)$ diagram. What relation between s and Δt_1 can be derived?

- Draw a straight line through the origin and the measuring points in the $v_m(t)$ diagram. What relation between the mean velocity v_m and the travel time Δt_1 can be derived?

Relation between acceleration and mass ($F=\text{constant}$)



Task

Investigate the relation between the acceleration a and the mass m for the uniformly accelerated motion of a trolley between a holding magnet and a light barrier.

Equipment list

1	Pocket-CASSY	524 006
1	CASSY Lab	524 200
1	Timer S	524 074
1	Precision metal rail, 1 m	460 81
1	Trolley 1	337 00
1	Set of driving weights	337 04
1	Additional weight 1	337 05
1	Weight, 50 g	from 340 85
1	Fishing line	309 48
1	Single pulley on clamp rider	337 14
1	Holding magnet for track	683 41
1	Holding magnet adapter with a release mechanism	336 25
1	Accessories for electronic time measurement	337 466
1	Combination light barrier	337 462
1	Multi-core cable, 6-pole, 1.5 m	501 16
1	Electronic balance CS 2000	667 794
1	PC with Windows 98/2000 or higher version	

Experiment setup (see drawing)

- Put the holding magnet with the holding magnet adapter onto the metal rail and connect it to the input E of the timer S.
- Set up the light barrier at a distance of 20 cm from the beginning of the metal rail and connect it to the input F.
- Put the trolley with the holding pin onto the metal track.
- Fix a piece of fishing line to the trolley, and suspend the hanger and a slotted weight ($F = 0.10 \text{ N}$) from it.



- Put the other slotted weights on the plug-in holder of the trolley.
- Adjust the screw of the holding magnet so that the trolley is just kept from rolling.
- Displace the trolley together with the holding magnet so that the interruptor flag of the trolley all but interrupts the light barrier (zero).

Carrying out the experiment

■ Load settings

- Determine the mass m of the trolley (including the hanger and the slotted weights).
- Position the light barrier at the distance $s = 30$ cm from the zero.
- Start the measurement by pressing the pushbutton of the holding magnet adapter.
- Read the travel time Δt_1 in the display window and accept it with **F9** for calculating the acceleration.
- Increase the mass of the trolley in steps of 50 g and repeat the measurement.
- Before recording a new measurement series, use the mouse to select **Append New Meas. Series** in the Measuring Parameters window (press **F5** twice).
- Next increase the accelerating force by putting one and two slotted weights, respectively, on the hanger, and repeat the measurements.

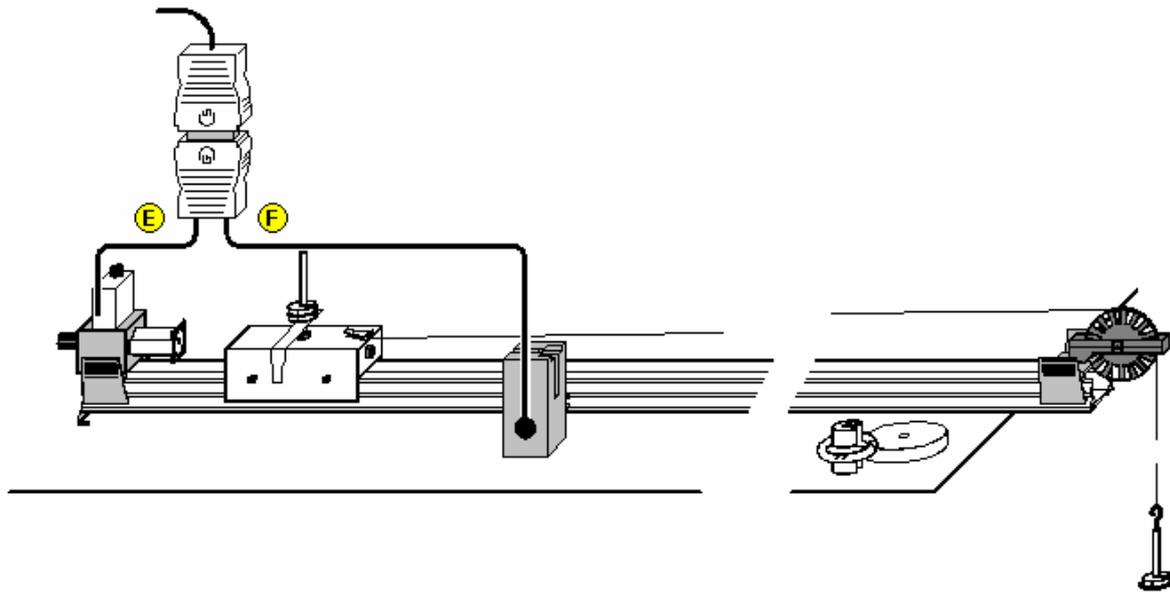
Evaluation

- How can the acceleration a of the trolley be calculated from the path s and the travel time Δt_1 ?

- Enter the respective masses m (trolley, additional weights, hanger weight and slotted weights) in the table. Draw hyperbolas ($1/x$) through the measuring points in the $a(m)$ diagram.
- What relation between the acceleration a and the mass m can be derived?

- On which physical quantity does the acceleration a of the trolley depend if the mass is constant?

Relation between acceleration and force ($m=\text{constant}$)



Task

Investigate the relation between the acceleration and the force for the uniformly accelerated motion of a trolley between a holding magnet and a light barrier.

Equipment list

1	Pocket-CASSY	524 006
1	CASSY Lab	524 200
1	Timer S	524 074
1	Precision metal rail, 1 m	460 81
1	Trolley 1	337 00
1	Set of driving weights	337 04
1	Additional weight 1	337 05
1	Weight, 50 g	from 340 85
1	Fishing line	309 48
1	Single pulley on clamp rider	337 14
1	Holding magnet for track	683 41
1	Holding magnet adapter with a release mechanism	336 25
1	Accessories for electronic time measurement	337 466
1	Combination light barrier	337 462
1	Multi-core cable, 6-pole, 1.5 m	501 16
1	Electronic balance CS 2000	667 794
1	PC with Windows 98/2000 or higher version	

Experiment setup (see drawing)

- Put the holding magnet with the holding magnet adapter onto the metal rail and connect it to the input E of the timer S.
- Set up the light barrier at a distance of 20 cm from the beginning of the metal rail and connect it to the input F.
- Put the trolley with the holding pin onto the metal track.
- Fix a piece of fishing line to the trolley, and suspend the hanger and all three slotted weights from it.
- Adjust the screw of the holding magnet so that the trolley is just kept from rolling.
- Displace the trolley together with the holding magnet so that the interruptor flag of the trolley all but interrupts the light barrier (zero).



Carrying out the experiment

■ Load settings

- Determine the mass m of the trolley (including the hanger and the slotted weights).
- Position the light barrier at the distance $s = 30$ cm from the zero.
- Take all three slotted weights from the hanger and put them on the plug-in holder of the trolley.
- Start the measurement by pressing the pushbutton of the holding magnet adapter.
- Read the travel time Δt_1 in the display window and accept it with **F9** for calculating the acceleration.
- One after another take a slotted weight from the plug-in holder, put it on the hanger, and repeat the measurement.
- Before recording a new measurement series, use the mouse to select **Append New Meas. Series** in the Measuring Parameters window (press **F5** twice).
- Next increase the mass of the trolley by 0.05 kg and 0,10 kg, respectively, and repeat the measurements.

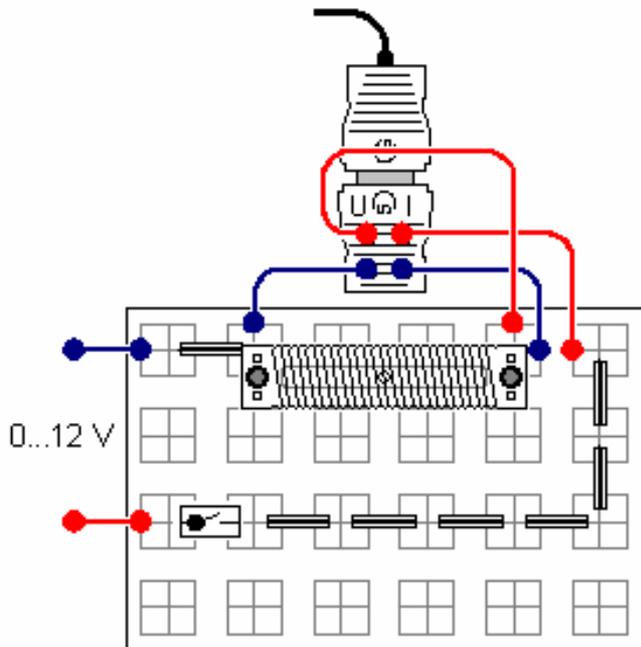
Evaluation

- How can the acceleration of the trolley be calculated from the path s and the travel time Δt_1 ?

- Enter the force F acting on the trolley in each case in the table. Draw a straight line through the origin and the measuring points in the $a(F)$ diagram.
- What relation between a and F can be derived from the graphical representation?

- On which physical quantity does the acceleration a of the trolley depend if the force acting on the trolley is constant?

Ohm's law



Task

Determine the relation between the voltage U applied to a conductor and the current I flowing through the conductor.

Equipment list

1	Pocket-CASSY		524 006
1	CASSY Lab		524 200
1	UIP sensor S		524 0621
1	Plug-in board A4		576 74
1	Set of 10 bridging plugs		501 48
1	Wrapping plate for wires		567 18
1	Toggle switch, single pole STE 2/19		579 13
1	Chrome-nickel wire, 0.25 mm, approx. 200 cm long	from	550 46
1	Resistor 100 Ω STE2/19		577 32
3	Connecting leads, red, 25 cm		500 411
3	Connecting leads, blue, 25 cm		500 412
1	Voltage source, 0...12 V, adjustable	e.g.	521 230
1	PC with Windows 98/2000 or higher version		

Experiment setup (see drawing)

- Wind the chrome-nickel wire on the wrapping plate for wires, and establish electric contact with the plugs via the screws. In the beginning, the switch is open.
- For measuring the voltage and the current, connect the connecting leads to the UIP sensor as shown in the drawing.



Carrying out the experiment

■ Load settings

- Close the circuit with the switch. Store the first measured value at $U = 0 \text{ V}$ with **F9** or by clicking the  button.
- Adjust various voltages (3 V, 6 V, 9 V, and 12 V) at the power supply, each time storing the measured values.

Remark: Allow the current to flow for a short time only during each measurement to avoid warming of the wire because this would lead to an increase in resistance so that the measuring result would be distorted.

- Replace the wrapping plate for wires in the circuit with the STE resistor 100Ω and two bridging plugs.
- Tick **Append New Measurement Series** in the Measuring Parameters window (e.g. by pressing the **F5** key).
- Repeat the experiment with the STE resistor 100Ω .

Evaluation

- We have the following relation: The greater the voltage U , the

- How does the current I flowing through a wire change if the voltage U is doubled?

- Perform a fit to a Best-fit straight line in the diagram for both measurement series. How are the measured values distributed?

- What is your conclusion regarding the relation between the voltage U and the current I in the two experiments?

- The electric resistance R is defined as the quotient of U and I :

$$R = \frac{U}{I}$$

The unit of the electric resistance is Ω (Ohm):

$$[R] = \Omega = \frac{\text{V}}{\text{A}}$$

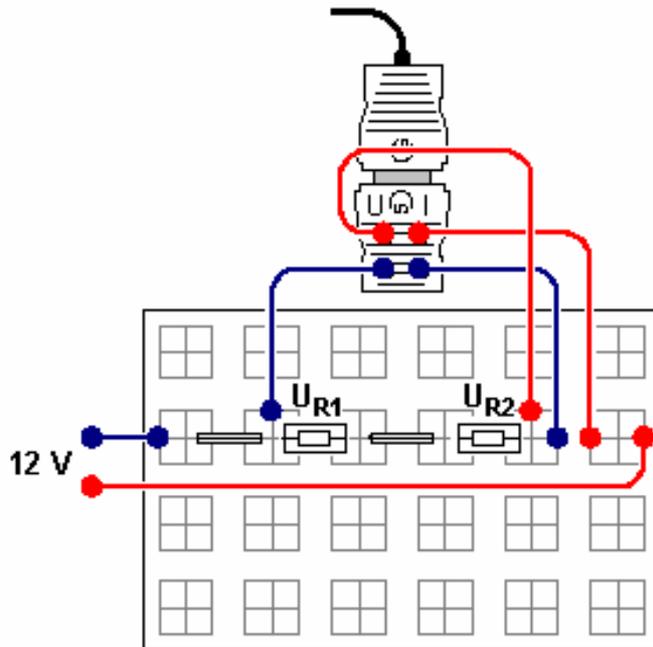
What can you say about the two resistors used in the experiment?

- What is the magnitude of the chrome-nickel wire and of the STE resistor used in the experiment?

Chrome-nickel wire: _____

STE resistor: _____

Series connection of resistors



Task

Measure the voltages U_0 , U_{R1} , U_{R2} and the current I_0 at two series-connected resistors R_1 and R_2 , and establish the relation between R_1 , R_2 and the total resistance R_0 .

Equipment list

1	Pocket-CASSY	524 006
1	CASSY Lab	524 200
1	UIP sensor S	524 0621
1	Plug-in board A4	576 74
1	Set of 10 bridging plugs	501 48
1	Resistor 220 Ω STE 2/19	577 36
1	Resistor 330 Ω STE 2/19	577 38
1	Resistor 470 Ω STE 2/19	577 40
1	Resistor 1 k Ω STE 2/19	577 44
3	Connecting leads, 25 cm, red	500 411
3	Connecting leads, 25 cm, blue	500 412
1	Voltage source, 0...12 V, adjustable	e.g. 521 230
1	PC with Windows 98/2000 or higher version	

Experiment setup (see drawing)

- Set up the circuit for a combination of resistors, e.g. 220 Ω /330 Ω , as shown in the drawing.
- For measuring the voltage U_0 and the current I_0 , connect the connecting leads to the UIP sensor S as shown in the drawing.

Carrying out the experiment

■ Load settings

- Set a voltage of approx. 12 V at the power supply.
- Measure the voltage U_0 and the current I_0 . Using the mouse, transfer the measured values from the display instruments U and I into the prepared table (drag & drop).



- Connect the connecting leads for the voltage measurement of U_{R1} (see drawing), and measure the voltage U_{R1} . Using the mouse, transfer the measured value from the display instrument U into the prepared table, and enter the value of the resistance R_1 manually.
- Connect the connecting leads for the voltage measurement of U_{R2} (see drawing), and measure the voltage U_{R2} . Using the mouse, transfer the measured value from the display instrument U into the prepared table, and enter the value of the resistance R_2 manually.
- Repeat the experiment with other combinations of resistors.

Evaluation

For evaluating the experiment, the prepared table **Evaluation** is provided, from which the relations between the voltages U_0 , U_{R1} , U_{R2} and the resistances R_0 , R_1 , R_2 become obvious.

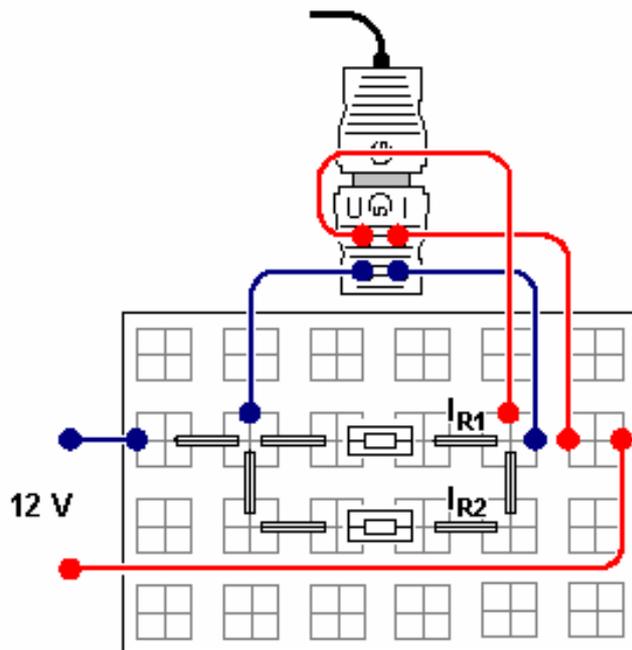
- The current which flows through the series-connected resistors R_1 and R_2 is

- What is the relation between the voltages U_{R1} and U_{R2} and the total voltage U_0 ?

- What is the relation between the ratio of the resistances R_1 and R_2 and the ratio of the voltages U_{R1} and U_{R2} ?

- What is the relation between the total resistance $R_0 = U_0/I_0$ and the resistances R_1 and R_2 ?

Parallel connection of resistors



Task

Measure the voltage U_0 and the currents I_0 , I_{R1} , I_{R2} at two parallel connected resistors R_1 and R_2 , and establish the relation between R_1 and R_2 and the total resistance R_0 .

Equipment list

1	Pocket-CASSY	524 006
1	CASSY Lab	524 200
1	UIP sensor S	524 0621
1	Plug-in board A4	576 74
1	Set of 10 bridging plugs	501 48
1	Resistor 220 Ω STE 2/19	577 36
1	Resistor 330 Ω STE 2/19	577 38
1	Resistor 470 Ω STE 2/19	577 40
1	Resistor 1 k Ω STE 2/19	577 44
3	Connecting leads, 25 cm, red	500 411
3	Connecting leads, 25 cm, blue	500 412
1	Voltage source, 0...12 V, adjustable	e.g. 521 230
1	PC with Windows 98/2000 or higher version	

Experiment setup (see drawing)

- Set up the circuit for a combination of resistors, e.g. 220 Ω /330 Ω , as shown in the drawing.
- For measuring the voltage U_0 and the current I_0 , connect the connecting leads to the UIP sensor S as shown in the drawing.

Carrying out the experiment

■ Load settings

- Set a voltage of approx. 12 V at the power supply.
- Measure the voltage U_0 and the current I_0 . Using the mouse, transfer the measured values from the display instruments U and I into the prepared table (drag & drop).



- Connect the connecting leads for the current measurement of I_{R1} (see drawing, plug the bridging plugs appropriately), and measure the current I_{R1} . Using the mouse, transfer the measured value from the display instrument I into the prepared table, and enter the value of the resistance R_1 manually.
- Connect the connecting leads for the current measurement of I_{R2} (see drawing, plug the bridging plugs appropriately), and measure the current I_{R2} . Using the mouse, transfer the measured value from the display instrument I into the prepared table, and enter the value of the resistance R_2 manually.
- Repeat the experiment with other combinations of resistors.

Evaluation

For evaluating the experiment, the prepared table **Evaluation** is provided, from which the relations between the currents I_0 , I_{R1} , I_{R2} and the resistances R_0 , R_1 , R_2 become obvious.

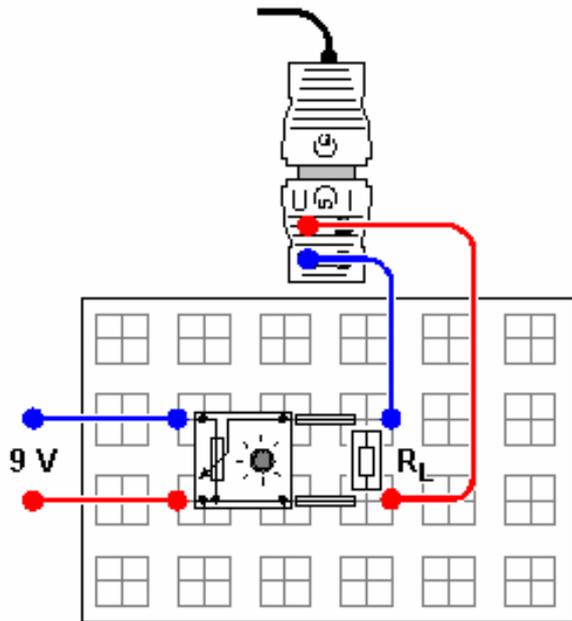
- The voltages U_{R1} and U_{R2} at the resistors R_1 and R_2 are equal to

- What is the relation between the currents I_{R1} and I_{R2} and the total current I_0 ?

- What is the relation between the ratio of the resistances R_1 and R_2 and the ratio between the currents I_{R1} and I_{R2} ?

- What is the relation between the total resistance $R_0 = U_0/I_0$ and the resistances R_1 and R_2 ?

Adjusting a voltage by means of a potentiometer



Task

Measure the partial voltage U_1 at the potentiometer in the currentless, unloaded state for different potentiometer positions.

Measure the partial voltage U_1 at the potentiometer as a function of the potentiometer position for different loads R_L , and compare the results with the measurement in the unloaded state (R_L remains constant within a measurement series).

Equipment list

1	Pocket-CASSY	524 006
1	CASSY Lab	524 200
1	UIP sensor S	524 0621
1	Plug-in board A4	576 74
1	Set of 10 bridging plugs	501 48
1	Resistor 47 Ω STE 2/19	577 28
2	Resistor 100 Ω STE 2/19	577 32
1	Resistor 150 Ω STE 2/19	577 34
1	Resistor 470 Ω STE 2/19	577 40
1	Potentiometer 220 Ω , 3 W, STE 4/50	577 90
2	Connecting leads, 25 cm, red	500 411
2	Connecting leads, 25 cm, blue	500 412
1	Voltage source, 0...15 V, adjustable	e.g. 521 45
1	PC with Windows 98/2000 or higher version	

Experiment setup (see drawing)

Set up the circuit as shown in the drawing, and connect the UIP sensor for the voltage measurement. At first do not use the load R_L .



Carrying out the experiment

■ Load settings

- Apply a total voltage of approx. 9 V.
- The potentiometer being unloaded ($R_L = \infty$), enter the voltage U_1 in the prepared table for different potentiometer positions by pressing **F9** or by clicking , and enter the number corresponding to the switch position in the column PN.
- Before recording a measurement series with another load, each time put a tick at **Append New Measurement Series** in the window Measuring Parameters (e.g. by pressing **F5**).
- Insert the STE resistor $R_L = 470 \Omega$ in the circuit, and record a new measurement series for a loaded potentiometer.
- Repeat the experiment with other loads $R_L = 100 \Omega$, 47Ω .

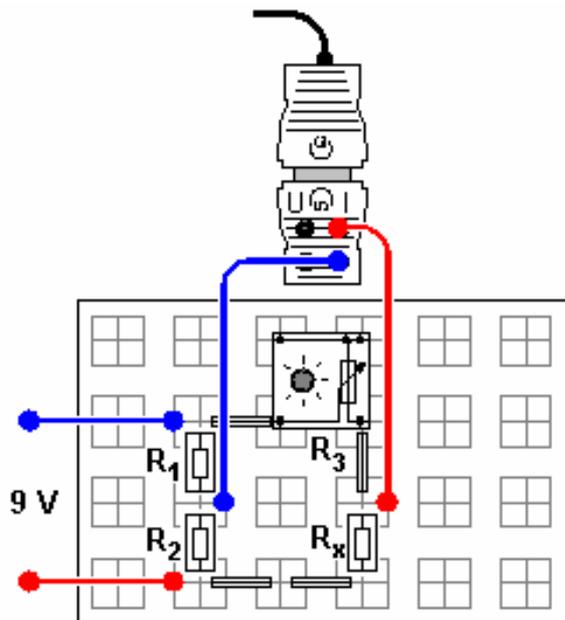
Evaluation

- What is the relation between the partial voltage U_1 and the resistance R_1 at an unloaded potentiometer?

- What is the effect of loading the potentiometer with a resistance R_L ?

- Where do you expect the curve of the measurement series to be located if the potentiometer is loaded with a resistance $R_L < 47 \Omega$?

Principle of Wheatstone's bridge



Task

In order to measure an "unknown" resistance R_x , vary the variable resistance R_3 (potentiometer) in the bridge circuit until no current flows between the two arms of the bridge.

Equipment list

1	Pocket-CASSY	524 006
1	CASSY Lab	524 200
1	UIP sensor S	524 0621
1	Plug-in board A4	576 74
1	Set of 10 bridging plugs	501 48
1	Resistor 220 Ω STE 2/19	577 36
2	Resistor 330 Ω STE 2/19	577 38
1	Resistor 470 Ω STE 2/19	577 40
1	Resistor 1 k Ω STE 2/19	577 44
1	Potentiometer 1 k Ω , 1 W STE 4/50	577 92
	or 10-turn potentiometer 1 k Ω , 2 W	577 93
2	Connecting leads, 25 cm, red	500 411
2	Connecting leads, 25 cm, blue	500 412
1	Voltage source, 0...15 V, adjustable	e.g. 521 45
1	PC with Windows 98/2000	
	or higher version	

Experiment setup (see drawing)

Set up the circuit with the combination of resistors $R_1 = 1\text{k}\Omega$ / $R_2 = 470\ \Omega$ as shown in the drawing, and connect the UIP sensor for the current measurement.

Carrying out the experiment

■ Load settings

- If necessary, set the display of the current to $\rightarrow 0 \leftarrow$ in Settings I_1 .
- Apply a voltage of approx. 9 V.
- Adjust the potentiometer for a selected resistance R_x (e. g. 330 Ω) so that no current I_1 flows between the arms of the bridge circuit.



- Read the value R_3 of the adjusted resistance, and write it in the prepared table. The value of the resistance R_3 can be estimated from the position of the rotary knob if the STE potentiometer $1\text{ k}\Omega$ is used: the left stop corresponds to approx. $1\text{ k}\Omega$
- Repeat the measurement for other resistances R_x .

Evaluation

- What is the relation between the ratios of the resistances in the two arms of the bridge circuit if no current flows between the two arms ($I_1 = 0$)?

- How is R_x determined if the resistances R_1 , R_2 and R_3 are known?

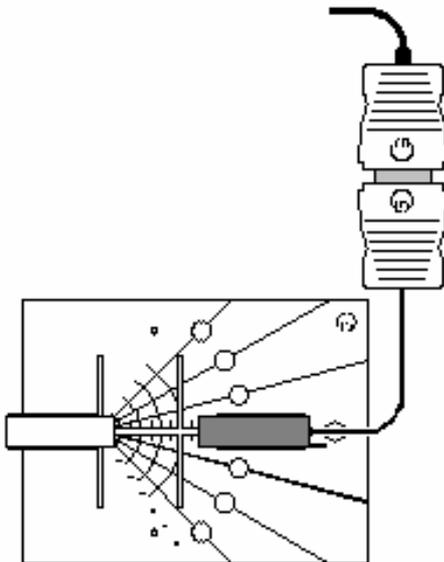
- What is the relation between the voltage drops U_1 and U_3 or U_2 and U_x , respectively, at the 4 resistances R_1 and R_3 or R_2 and R_x , respectively, if the bridge is balanced ($I_1 = 0$)?

- What is the effect of the applied voltage U on the determination of the resistance R_x if the bridge is balanced ($I_1 = 0$)?

Remark

The resistance R_x could, of course, also be determined by measuring the voltage drop U while a current I is flowing, i.e. using the relation $R_x = U/I$. However, this presupposes that the internal resistances of the measuring instruments can be neglected, which is usually the case. If the bridge circuit is used, the internal resistance of the ammeter does not play a role at all because no current flows. Therefore the bridge circuit provides an opportunity of an accurate measurement of the fourth resistance if the other three resistances are known precisely.

The effect of the distance between the radiation source and the end-window counter on the pulse rate



Task

Increase the distance d between the radiation source and the end-window counter step by step, each time measuring the pulse rate R .

Equipment list

1	Pocket-CASSY	524 006
1	CASSY Lab	524 200
1	Geiger counter S	524 0331
1	RAD experiment board	309 00 372
1	Set of 2 holders for counter tube and preparation	308 01 356
1	Ra226 preparation 30.3 kBq	559 430
1	PC with Windows 98/2000 or higher version	

Experiment setup (see drawing)

- When handling the radioactive preparation, observe the safety notes, i.e. in particular, take the preparation out of the protective container only as long as is required for carrying out the experiment, do not allow the aperture for the emission of the radiation to get close to your eyes, and do not touch it.
- Mount the counter tube and the Ra226 preparation on the RAD experiment board so that they are placed opposite each other at a distance of 2 cm.
- Remove the protective cap from the counter tube.
Remark: Under no circumstances touch the end-window with your finger or with the preparation as it is very thin and therefore easily destroyed.

Carrying out the experiment

- Load settings
- Enter the distance 2 in the column d/cm of the table. Start the measurement with the **F9** key or with the  button. As soon as the measurement has been finished, the pulse rate R is entered in the table automatically.



- Repeat the experiment with the distance between the counter and the preparation being increased step by step. Each time increase the distance by 1 cm up to 10 cm.
- Put the Ra226 preparation back into the protective container.
- Click **Append New Measurement Series** in the window Measuring parameters.
- Repeat the experiment without preparation to obtain the zero rate from the background radiation.
- After carrying out the experiment, put the protective cap carefully onto the counter tube without keeping the cap closed for the pressure compensation.

Evaluation

- What is the difference between N_1 and the pulse rate R ?

- How does the pulse rate R change with respect to the distance d between the preparation and the counter tube?

- What curve is described by the measured values? Suggestion:

- Confirm your suggestion by fitting a corresponding curve with Fit Function.
- What is your conclusion regarding the relation between the pulse rate R and the distance d ?

- What protective measure derives from this relation for handling radioactive materials?

- What is the magnitude of the zero rate R_0 ?

- At what distance does the preparation used in this experiment lead to an additional irradiation which is of the order of magnitude of the background radiation? To determine this distance, activate Zoom in order that the value can be read.

Experiment examples physics

These experiment examples support you in using CASSY Lab. Where applicable, the corresponding experiment number from the General Catalog of Physics Experiments is also given. The measurement data or settings for the examples can be loaded directly into CASSY Lab. Simply click the  buttons in the descriptions. New examples are labelled with a red •.

Mechanics

- Uniform motions between two light barriers
- Accelerated motions between holding magnet and light barrier
- P1.3.2.3a Motions with spoked wheel (newton definition)
- P1.3.3.4-6 Motions on the linear air track (Newton's equation of motion)
- P1.3.4.1-2ab Conservation of momentum and energy (collision)
- Conservation of linear momentum by measuring the motion of the centre of mass (collision)
- Confirming the relation action=reaction by measuring accelerations (collision)
- P1.3.5.3 Free fall with g-ladder
- Free fall with g-ladder (with modelling)
- P1.4.1.2 Rotational motions (Newton's equation of motion)
- P1.4.2.1-2 Conservation of angular momentum and energy (torsion collision)
- Centrifugal force (rotatable centrifugal force arm)
- P1.4.3.3 Centrifugal force (centrifugal force apparatus)
- Oscillations of a rod pendulum
- Oscillations of a rod pendulum (with added mass)
- Oscillations of a rod pendulum (with modelling)
- Dependency of the period of the oscillation on the amplitude
- Determination of the acceleration due to gravity on earth by means of a reversible pendulum
- Pendulum with changeable acceleration due to gravity (variable g-pendulum)
- P1.5.2.1 Harmonic oscillations of a spring pendulum
- Oscillations of a spring pendulum (with modelling)
- Oscillations of a spring pendulum with solid friction (with modelling)
- Oscillations of a spring pendulum with lubricant friction (with modelling)
- Oscillations of a spring pendulum with laminar liquid friction (with modelling)
- Oscillations of a spring pendulum with turbulent liquid friction/air friction (with modelling)
- P1.5.2.2 Dependence of the period of oscillation of a spring pendulum on the mass
- P1.5.4.4 Coupled pendulum with two tachogenerators
- Coupled pendulums with two rotary motion sensors
- P1.7.1.3 Acoustic beats
- P1.7.2.1 String vibrations
- P1.7.3.3 Velocity of sound in the air
- Determining the velocity of sound in air with 2 microphones
- P1.7.3.4 Velocity of sound in gases
- P1.7.3.5 Velocity of sound in solid bodies
- P1.7.7.1 Fourier analysis of simulated signals
- P1.7.7.2 Fourier analysis of signals of a function generator
- P1.7.7.4 Sound analysis
- Sonic synthesis

Heat

- P2.3.3.2 Conversion of mechanical energy into thermal energy
- P2.3.4.3 Conversion of electrical energy into thermal energy
- P2.6.2.4 pV diagram of a hot-air engine



Electricity

- P3.1.2.3 Coulomb's law
- P3.3.3.3 Force in the magnetic field of an air coil
- P3.3.3.2 Force in the magnetic field of an electromagnet
- P3.3.3.4 Force between two current-carrying conductors (ampere definition)
- P3.4.1.1 Impulse of voltage (Faraday's law of induction)
- P3.4.3.1-2 Induction in a variable magnetic field
- P3.4.5.3 Voltage and current curves of a transformer as a function of time
- P3.4.5.4 Power transfer of a transformer
- Power of arbitrary loads operated with mains AC voltage
- Charging and discharging of a capacitor
- Charging and discharging of a capacitor (with modelling)
- Charging and discharging of a small capacitor (cable capacitances)
- Damped oscillator
- Damped oscillator (with modelling)
- P1.7.7.3 Coupled oscillators
- Forced oscillations (resonance)
- Forced oscillations (resonance, with modelling)
- RLC filter (low pass, high pass, band pass)
- Low-pass filter (with modelling)
- High-pass filter (with modelling)

Electronics

- P4.1.2.1 Characteristic of an incandescent lamp
- Characteristic of a diode
- Characteristic of a transistor
- D3.4.7.7a Power characteristic of a solar cell
- Temperature control
- Brightness control
- Voltage control

Optics

- P5.3.1.4 Diffraction at a single slit
- P5.3.1.5 Diffraction at multiple slits
- P5.5.1.2a Inverse square law for light
- Velocity of light on air
- Velocity of light in various materials

Atomic and Nuclear Physics

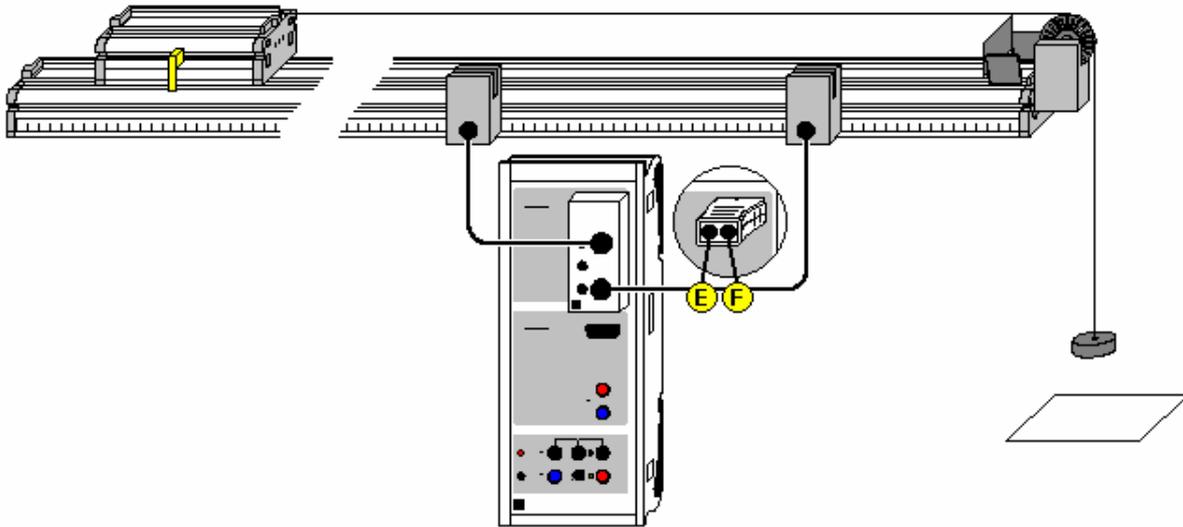
- P6.1.2.3-4 Millikan's experiment
- P6.2.4.2 Franck-Hertz experiment with mercury
- P6.2.4.4 Franck-Hertz experiment with neon
- P6.3.5.4 Moseley's law (K-line x-ray fluorescence)
- P6.3.5.5 Moseley's law (L-line x-ray fluorescence)
- P6.3.5.6 Energy dispersive Bragg reflection into different orders of diffraction
- P6.3.7.2 Compton effect on X-rays
- P6.4.2.1 Poisson distribution
- P6.4.3.2 Half-life of radon
- P6.5.4.1 α spectroscopy of radioactive samples (Am-241)
- P6.5.4.2 Determining the energy loss of α radiation in air
- P6.5.4.3 Determining the energy loss of α radiation in aluminium and in gold
- P6.5.4.4 Determining the age of a Ra-226 sample
- P6.5.5.1 Detecting γ radiation with a scintillation counter (Cs-137)
- P6.5.5.2 Recording and calibrating a γ spectrum
- P6.5.5.3 Absorption of γ radiation

- P6.5.5.4 Identifying and determining the activity of weakly radioactive samples
- P6.5.5.5 Recording a β spectrum using a scintillation counter
- P6.5.6.1 Quantitative observation of the Compton effect
- Recording the complex γ spectrum of Ra-226 and its decay products
- Recording the complex γ spectrum of an incandescent gas hood
- P6.5.5.6 Coincidence and γ - γ angular correlation in positron decay
- Measurements with the single-channel analyzer

Solid State Physics

- P7.2.2.1-2 Electrical conductivity of solids
- P7.3.2.1 Hysteresis of a transformer core
- P7.5.1.1 Non-destructive analysis of the chemical composition (x-ray fluorescence)
- P7.5.1.2 Determination of the chemical composition of a brass sample (x-ray fluorescence)

Uniform motions between two light barriers



can also be carried out with Pocket-CASSY

■ Load example

Experiment description

This experiment measures the times t that a trolley requires to travel different distances (paths) s between two light barriers with a constant velocity v . The path s is read directly from a scale on the track and the $s(t)$ diagram is generated by the software.

Additionally, the software calculates the average velocities $v_m = s/t$ and shows these in a $v_m(t)$ diagram.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Timer box or Timer S	524 034 or 524 074
1	Track	337 130
1	Trolley for track	337 110
1	Slotted mass hanger	315 410
4	Slotted weights	315 418
2	Combi-light barriers	337 462
1	Holder for combi-light barrier	337 463
1	Combi-spoked wheel	337 464
1	Cord, 10 m	309 48
2	Multicore cable, 6-pole	501 16
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Set up the two light barriers on the track so that the interrupter flag of the trolley breaks both beams. Connect the light barriers to inputs E and F of the timer box at input A of Sensor-CASSY. The direction of motion must always be from the light barrier at E to the one at F.

To achieve a constant velocity between the two light barriers, compensate the friction by inclining the track slightly.

Before each measurement the trolley must be accelerated to a constant, reproducible velocity. To this end, it is accelerated from a fixed position by a drive weight which is trapped at the end of a defined

acceleration path (e.g. comes to rest on a supporting surface). The trolley continues to roll with a constant velocity.

Carrying out the experiment

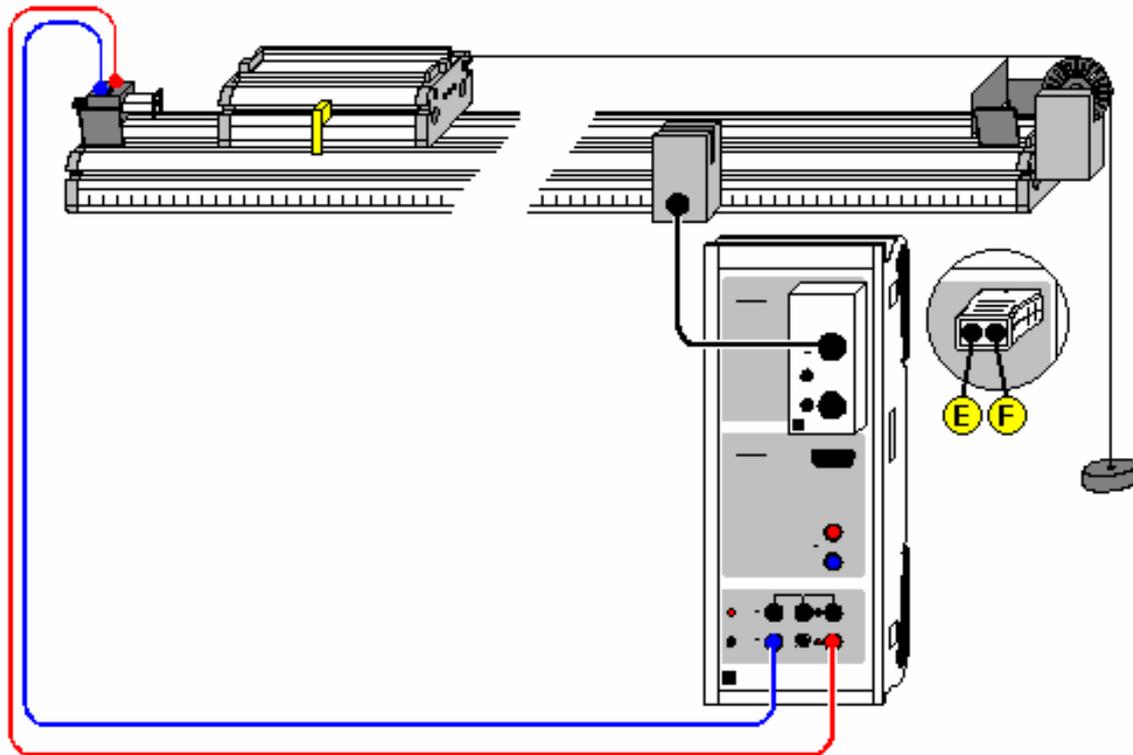
■ Load settings

- Accelerate the trolley to a constant speed as described above and allow it to pass through both light barriers.
- Save your measured values with **F9**.
- Read off path s between the two light barriers and enter this in the table (activate keyboard input in the correct table cell using the mouse).
- Repeat the measurement for other paths s ; again, accelerate the trolley to the same velocity, let it pass both light barriers and save the measured value with **F9**.

Evaluation

The $s(t)$ diagram of a uniform motion is a straight line. The slope of the straight line corresponds to the velocity v and can be determined e.g. by fitting a straight line. If you click on the display **Average Velocity**, you can also read off the respective quotients $v_m = s/t$ directly.

Accelerated motions between holding magnet and light barrier



■ Load example

Experiment description

This experiment measures the times t that a uniformly accelerated trolley requires to travel different distances (paths) s between a holding magnet and a light barrier. The path s is read directly from a scale on the track and the $s(t)$ diagram is generated.

Additionally, the software calculates the average velocities $v_m = s/t$ and shows these in a $v_m(t)$ diagram.

The obscuration times Δt of the light barrier, which are caused by a flag having the width Δs , are also determined. This permits determination of the instantaneous velocities $v = \Delta s / \Delta t$ at the site of the light barrier within close approximation and their display in a $v(t)$ diagram. The difference between the average velocity and instantaneous velocity becomes easily recognizable.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Timer box or Timer S	524 034 or 524 074
1	Track	337 130
1	Trolley for track	337 110
1	Slotted mass hanger	315 410
4	Slotted weights	315 418
1	Holding magnet	683 41
1	Combi-light barrier	337 462
1	Holder for combi-light barrier	337 463
1	Combi-spoked wheel	337 464
1	Cord, 10 m	309 48
1	Multicore cable, 6-pole	501 16
1	Pair of cables, 1 m, red and blue	501 46
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Set up the light barrier on the track so that the interrupter flag of the trolley breaks the beam. Connect the light barrier to input E of the timer box at input A of Sensor-CASSY. The holding magnet receives its voltage supply from voltage output S of Sensor-CASSY. Sensor-CASSY de-energizes this output simultaneously with the start of time measurement.

To achieve good measuring results, compensate the friction by inclining the track slightly.

Accelerate the trolley over the spoked wheel using a constant mass. Adjust the holding-magnet voltage so that it just holds the trolley.

Carrying out the experiment

■ Load settings

- You may need to adjust the maximum measuring time in the Measuring Parameters dialog (current setting: 2 s).
- Hold the trolley in place with the holding magnet.
- Start the measurement with **F9** (trolley starts to move).
- Read off path s between the holding magnet and the light barrier and enter this in the table (activate keyboard input in the correct table cell using the mouse).
- Repeat the measurement for other paths s ; fix the trolley in place using the holding magnet and start the measurement with **F9**.

Evaluation

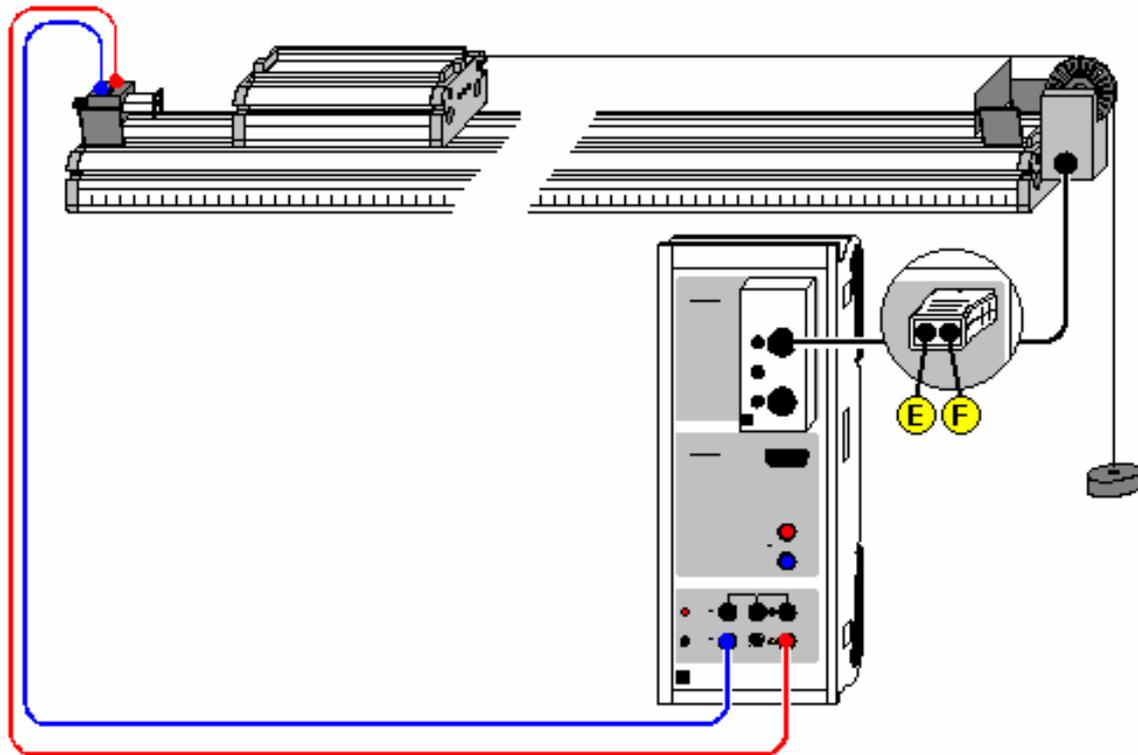
The $s(t)$ diagram of a uniformly accelerated motion is a parabola. You can confirm this e.g. by fitting a parabola.

Click on the display **Average Velocity** to see the rise in the average velocities $v_m = s/t$. However, for an accelerated motion these do **not** correspond with the instantaneous velocities at the same times t .

The instantaneous velocities v can be determined to within a close approximation from the obscuration times Δt of the light barrier interrupted by the flag with the width Δs . Both the curves of the obscuration times and the instantaneous velocities over time can be read directly from the corresponding displays, simply by clicking on the appropriate tab.

It is apparent that the $v(t)$ diagram of a uniformly accelerated motion is a straight line. The slope of the straight line corresponds to the acceleration a and can be determined e.g. by fitting a straight line.

Motions with spoked wheel (newton definition)



■ Load example

Experiment description

This experiment investigates motion sequences that are transmitted to a spoked wheel by means of a thin cord. The spoked wheel serves as an easy-running deflection pulley, and at the same time enables path measurement. The signals generated by the spoked wheel in the light barrier are recorded and converted into a path-time diagram. As this diagram is generated in real time while the experiment is running, the relationship between the motion and the diagram is extremely clear.

The same experiment sequence can also be used to demonstrate the effect of acceleration of a mass $m = 1 \text{ kg}$ with a force $F = 1 \text{ N}$. The resulting acceleration a is then determined to be $a = 1 \text{ m/s}^2$ (newton definition) as theory predicts.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Timer box or Timer S	524 034 or 524 074
1	Track	337 130
1	Trolley for track	337 110
1	Newton weights	337 115
1	Holding magnet	683 41
1	Combi-light barrier	337 462
1	Combi-spoked wheel	337 464
1	Cord, 10 m	309 48
1	Multicore cable, 6-pole	501 16
1	Pair of cables, 1 m, red and blue	501 46
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The combi-spoked wheel serves simultaneously as the deflection pulley and the signal generator. Here, the combi-light barrier, which is connected to input E of the timer box at input A of Sensor-CASSY, holds the spoked wheel. Each spoke interrupts the light barrier, so that a signal is sent to Sensor-CASSY for every centimeter. The holding magnet receives its voltage supply from voltage output S of Sensor-CASSY. Sensor-CASSY de-energizes this output simultaneously with the start of time measurement.

To obtain an accelerating force of $F = 1 \text{ N}$, you need to use a driving mass of 102 g. The trolley (including the equivalent roller mass) must be augmented to a total mass of 898 g so that the total accelerated mass $m = 1 \text{ kg}$. This is possible using the additional weights for newton definition.

To achieve good measuring results, compensate the friction by inclining the track slightly.

Adjust the holding-magnet voltage so that it just holds the trolley.

Carrying out the experiment

■ Load settings

- You may want to modify the automatic measuring stop parameter in Settings SA1 (current setting 70 edges for 0.7 m).
- You may need to adjust the maximum measuring time in the Measuring Parameters dialog (current setting: 2 s).
- Hold the magnet in place with the holding magnet.
- Define the path zero point ($\rightarrow 0 \leftarrow$ in Settings SA1)
- Start the measurement with **F9** (trolley starts to move).
- The measurement stops automatically after the predefined number of edges.
- If desired, repeat the measurement for other forces F ; fix the trolley in place using the holding magnet, define the path zero point and start the measurement with **F9**.

Evaluation

The $s(t)$ diagram of a uniformly accelerated motion is a parabola. You can confirm this e.g. by fitting a parabola.

Clicking on the **Velocity** display shows the calculated velocities $v(t)$. It is apparent that the $v(t)$ diagram of a uniformly accelerated motion is a straight line. The slope of the straight line is the constant acceleration a and can be determined e.g. by fitting a straight line.

In this example the accelerating force used is $F = 1 \text{ N}$ and the accelerating mass $m = 1 \text{ kg}$ (newton definition). In this case the $v(t)$ diagram gives us of velocity v of 1 m/s after $t = 1 \text{ s}$. Also, the straight line in the $f(t)$ diagram has the slope $a = 1 \text{ m/s}^2$.

Remark

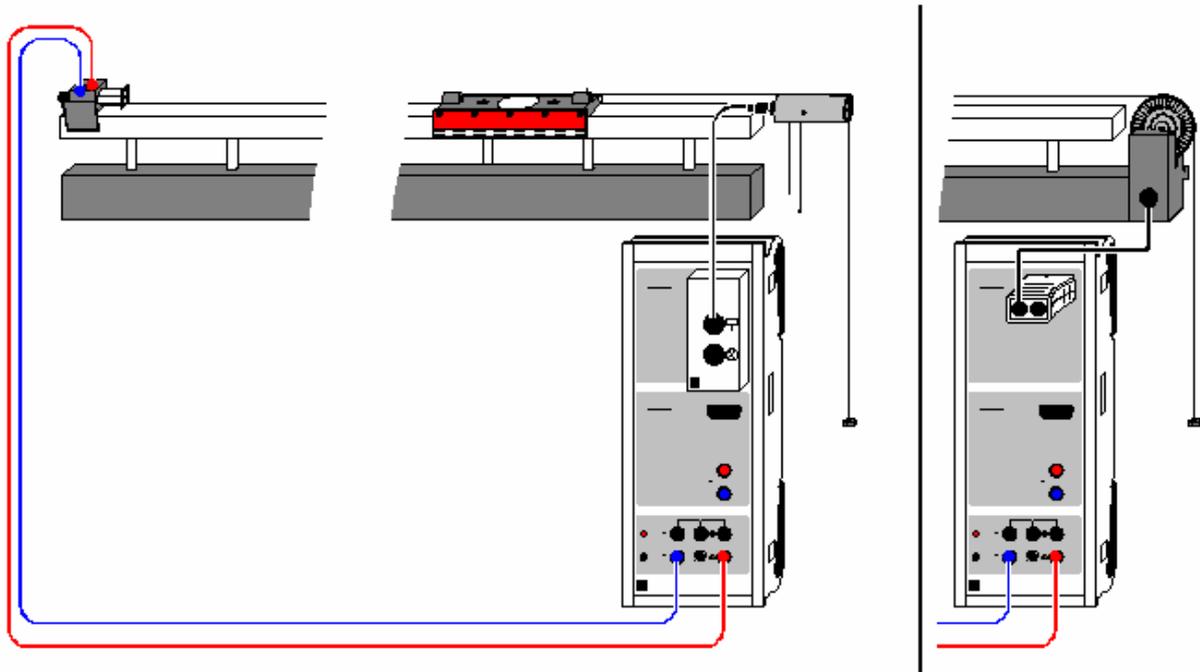
The individual velocity values $v(i)$ are calculated as

$$v(i) = (s(i+1) - s(i-1)) / (t(i+1) - t(i-1))$$

This is the average velocity in the interval $[t(i-1), t(i+1)]$ and is an initial approximation of the instantaneous velocity at the time $(t(i-1) + t(i+1)) / 2$, and thus not at time $t(i)$.

However, this was already taken into consideration in the $v(t)$ display by means of suitable conversion of the time axis.

Motions on the linear air track (Newton's equation of motion)



- Load example ($m = \text{constant}$)
- Load example ($F = \text{constant}$)

Experiment description

A trolley with a constant mass m is accelerated with different forces F . When the accelerations a determined in the experiment are plotted as a function of the accelerating forces F , F is found to be proportional to a (with m as the proportionality factor), thus confirming Newton's equation of motion $F=m \cdot a$. Alternatively, the accelerating force can also be kept constant and the mass m can be varied. The result here is m proportional to $1/a$ (with F as the proportionality factor).

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	BMW box	524 032
1	Motion sensing element	337 631
	or	
1	Timer S	524 074
1	Combi-light barrier	337 462
1	Combi-spoked wheel	337 464
1	Linear air track	337 501
1	Air supply	337 53
1	Power controller	667 823
1	Multicore cable, 6-pole	501 16
1	Pair of cables, 1 m, red and blue	501 46
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

First put the linear air track into operation; adjust the holding-magnet voltage so that it just holds the trolley. The trolley is accelerated by means of weights suspended from the transmission cord. The transmission cord passes around the motion sensing element, which is connected to the top socket of the BMW box on Sensor-CASSY.

The small weights are also accelerated, and thus are considered part of the accelerated mass m . If the mass is to be kept constant, then the weights not suspended from the cord must be placed on the trolley.

Carrying out the experiment

- Load settings ($m = \text{constant}$) or
- Load settings ($F = \text{constant}$)
- Enter the maximum travel path s_{A1} as the measuring condition in the Measuring Parameters dialog (open this with **F5**); current setting: $s_{A1} < 0.8$ for 0.8 m
- You may want to modify the time interval (currently 200 ms) in the Measuring Parameters dialog (open this with **F5**); a longer interval means fewer measured values and less scattering in $a(t)$.
- You may need to invert the sign of path measurement (select $s \leftrightarrow -s$ in Settings s_{A1}).
- Hold the magnet in place with the holding magnet.
- Define the path zero point ($\rightarrow 0 \leftarrow$ in Settings s_{A1})
- Start the measurement with **F9** and stop it with **F9** when the experiment is finished. You can delete a faulty measurement series from the table with **Delete Last Measurement Series** (click right mouse button over table).
- Repeat the measurement with different parameters (different accelerating force or accelerated mass). Be sure to redefine the path zero point.

Evaluation

In addition to the $s(t)$ diagrams, the software also calculates the $v(t)$ and $a(t)$ diagrams. You can see these simply by clicking on the tabs of the other displays. Suitable evaluation functions include parabola and line fits and calculation of mean value.

To confirm Newton's equation of motion, you need to fill out a further table, which has already been prepared on the Newton display tab. After determining an acceleration value as the mean of an $a(t)$ diagram or the slope of a $v(t)$ diagram, you can use the mouse to drag this value from the status line and drop it into the table (drag & drop). Enter the parameter force F or mass m directly via the keyboard. The desired diagram is generated as you enter the values. You can easily convert or rescale the axes by clicking on them (e.g. $a \rightarrow 1/a$).

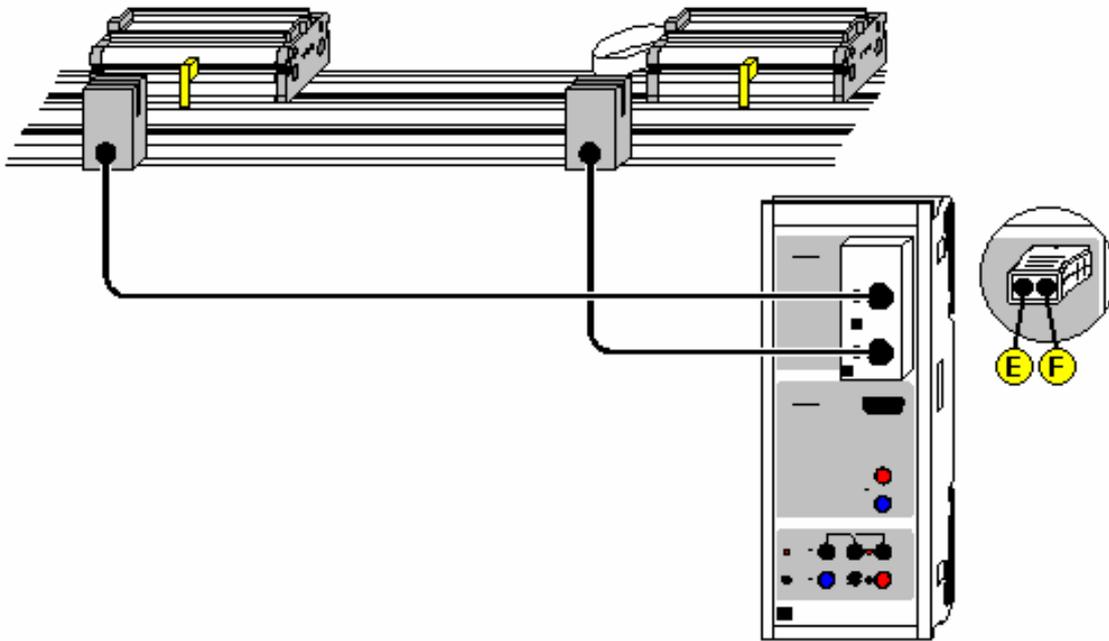
As a further evaluation, you can e.g. compare the kinetic energy with the work performed using formulas. The kinetic energy is

$$E = 0.5 \cdot m \cdot v^2 \text{ (type in the numerical value for } m\text{)}$$

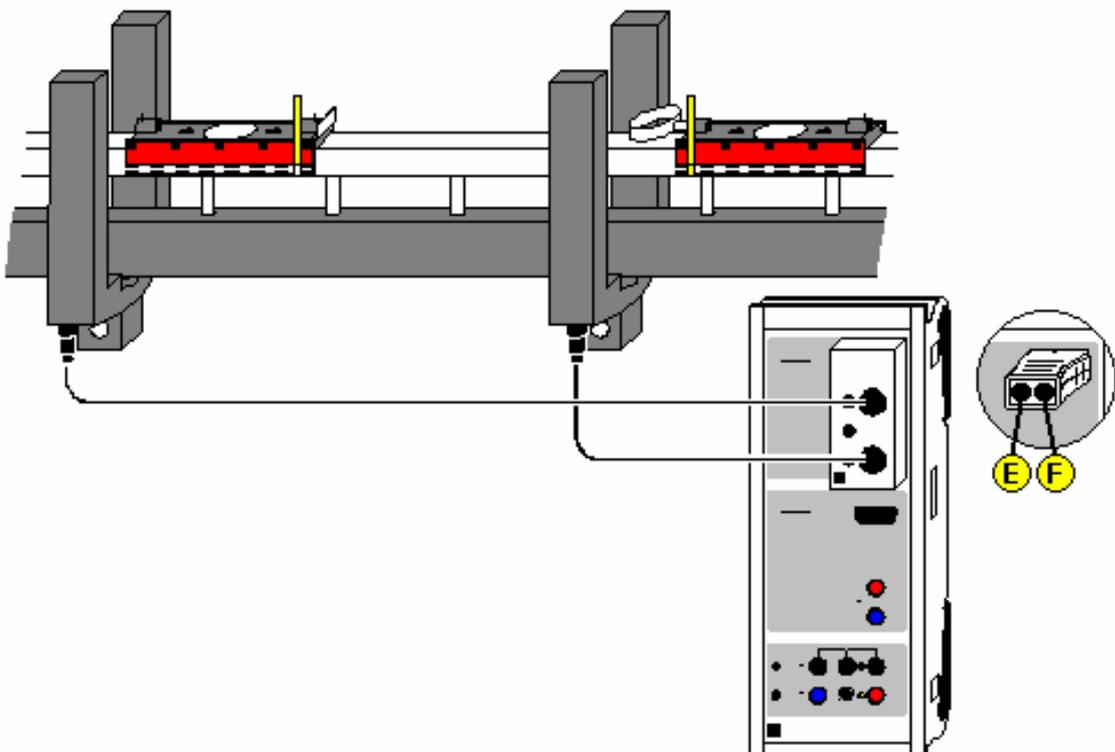
and the work performed is

$$W = F \cdot s_{A1} \text{ (type in the numerical value for } F\text{)}.$$

Conservation of momentum and energy (collision)



Alternatively (with linear air track):



can also be carried out with Pocket-CASSY

■ Load example

Experiment description

On a track, the velocities v of two trolleys before and after their collisions can be measured from the obscuration times of two light barriers. By this means, it is possible to verify the law of conservation of momentum for elastic and inelastic collision, as well as that of conservation of energy for elastic collision.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Timer box or Timer S	524 034 or 524 074
1	Track	337 130
2	Trolleys	337 110
1	Additional weights	337 114
1	Impact spring for trolley	337 112
2	Combination light barriers	337 462
2	Multicore cables, 6-pole	501 16
1	PC with Windows 95/98/NT or higher version	

Alternatively (with linear air track)

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Timer box or Timer S	524 034 or 524 074
1	Linear air track	337 501
1	Track support	337 45
1	Air supply	337 53
1	Power controller	667 823
2	Forked light barriers	337 46
2	Multicore cables, 6-pole	501 16
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

First put the track into operation and position the two light barriers (at inputs E and F of the timer box) so that the trolleys collide **between** the light barriers. The flags of the two trolleys must interrupt the light barriers when they pass through.

Carrying out the experiment

- Load settings
 - Enter masses m_1 and m_2 in the table (activate keyboard input in the cells beneath m_1 and m_2 with the mouse).
 - Enter the trolley arrangement before collision in relation to light barriers E and F (Settings v_1 , v_2 , v_1' or v_2'). There are four different arrangements:
 - Both trolleys outside of light barriers.
 - Left trolley between light barriers, right trolley outside.
 - Right trolley between light barriers, left trolley outside.
 - Both trolleys inside (explosion).
 - Enter the flag width (also in Settings v_1 , v_2 , v_1' or v_2').
 - Initiate the collision (if velocities are displayed before the collision, you can clear these with $\rightarrow 0 \leftarrow$) and watch to make sure that the light barriers do not register any extra pulses (e.g. due to reflection of a trolley at the end of the track).
 - Terminate the measurement with **End of Collision** (the measurement is terminated automatically after four measured velocities).
 - Transfer the measured values to the table for evaluation with **F9** or initialize the next measurement with $\rightarrow 0 \leftarrow$.



Evaluation

Tables have been pre-defined for momentum before and after collision, total momentum, energy, total energy and energy loss; you can transfer measured values to these tables with **F9**. Click on the table tabs to display these. If these quantities are to be visible immediately after collision, open the corresponding display instruments.

You can also define additional formulas to compare your results with theory. For elastic collision, we say that

$$v1' = (2 \cdot m2 \cdot v2 + (m1 - m2) \cdot v1) / (m1 + m2)$$

$$v2' = (2 \cdot m1 \cdot v1 + (m2 - m1) \cdot v2) / (m1 + m2)$$

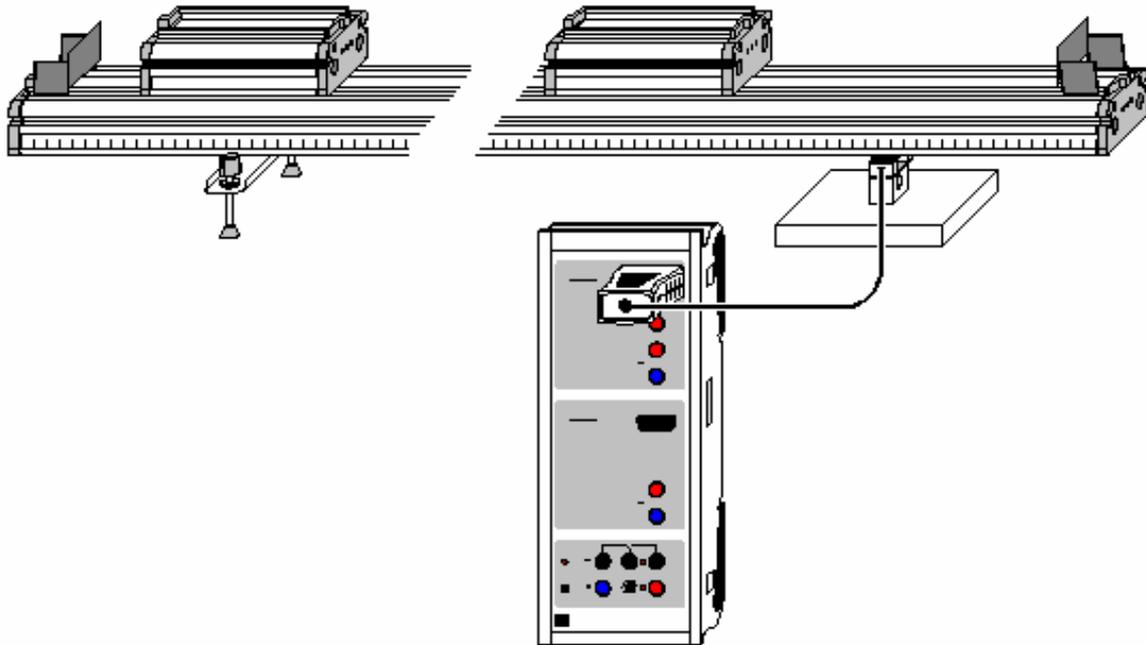
For inelastic collision, the following applies:

$$v1' = v2' = (m1 \cdot v1 + m2 \cdot v2) / (m1 + m2).$$

Table for converting specified units to SI units

Quantity	SI unit =	Factor	· specified unit
Mass m	kg	1	kg
Velocity v	m/s	1	m/s
Momentum p	N·s = kg·m/s	1000	mN·s
Energy E	J = kg·m ² /s ²	1000	mJ

Conservation of linear momentum by measuring the motion of the centre of mass (collision)



can also be carried out with Pocket-CASSY

■ Load example

Experiment description

The motion of the centre of mass is observed during elastic and inelastic collision of two trolleys. As a result, it is shown for both cases that the velocity of the centre of mass is constant during the whole collision process. Conservation of linear momentum during the whole collision process is an immediate consequence of this experiment.

Principle of measurement

On a track the motion of the centre of mass s of two colliding trolleys with masses m_1 and m_2 is easily determined by the supporting force F on a force sensor.

For, if the sum of torques M around the left supporting point is considered, this sum has to be 0 - as the track is at rest -, i.e.

$$m_1 \cdot g \cdot s_1 + m_2 \cdot g \cdot s_2 + F \cdot d = 0,$$

where d is the distance between the two supporting points. The centre of mass s is given by

$$s = (m_1 \cdot s_1 + m_2 \cdot s_2) / (m_1 + m_2).$$

From this

$$s \cdot g / (m_1 + m_2) + F \cdot d = 0$$

or

$$s = -F \cdot d / (m_1 + m_2) / g$$

is obtained.



Thus measurement of the supporting force F is sufficient, to determine the motion of the centre of mass during a collision. If $s(t)$ is a straight line, this means that the centre of mass moves at a constant velocity v , i.e.

$$v = (m_1 \cdot v_1 + m_2 \cdot v_2) / (m_1 + m_2) = p / (m_1 + m_2) = \text{constant.}$$

It follows that the total linear momentum p is conserved.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Force sensor S, ± 50 N	524 042
1	Track	337 130
2	Trolley	337 110
1	Pair of additional weights	337 114
1	Impact spring	337 112
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The force sensor S is laid under the track instead of the right support so that the track is still aligned horizontally or, if desired, so that compensation of friction is ensured. As the force sensor is somewhat shorter than the support, the force sensor has to be bedded.

Carrying out the experiment

■ Load settings

- Enter the masses m_1 and m_2 and the distance d between the two support points into the display instruments (click with the right mouse button and enter them as parameters). The total mass of a trolley is the sum of the mass of the trolley (0.5 kg) and, if present, the spring (0.01 kg) and an additional weight (0.5 kg).
- Set the force to $\rightarrow 0 \leftarrow$ in Settings FA1; thereby the centre of mass s is set to 0 as well.
- Start the measurement with **F9**.
- Make an elastic or inelastic collision; the measurement is stopped automatically after 5 s.

Evaluation

The display **Standard** shows the $F(t)$ diagram, and the display **Centre of mass** shows the associated $s(t)$ diagram (see Principle of measurement).

Both diagrams exhibit a linear course, also while the collision occurs. From the $s(t)$ diagram the velocity v of the centre of mass and thus the constant total linear momentum $p(t) = (m_1 + m_2) \cdot v$ is obtained by a linear fit.

On the other hand, it follows from conservation of linear momentum that

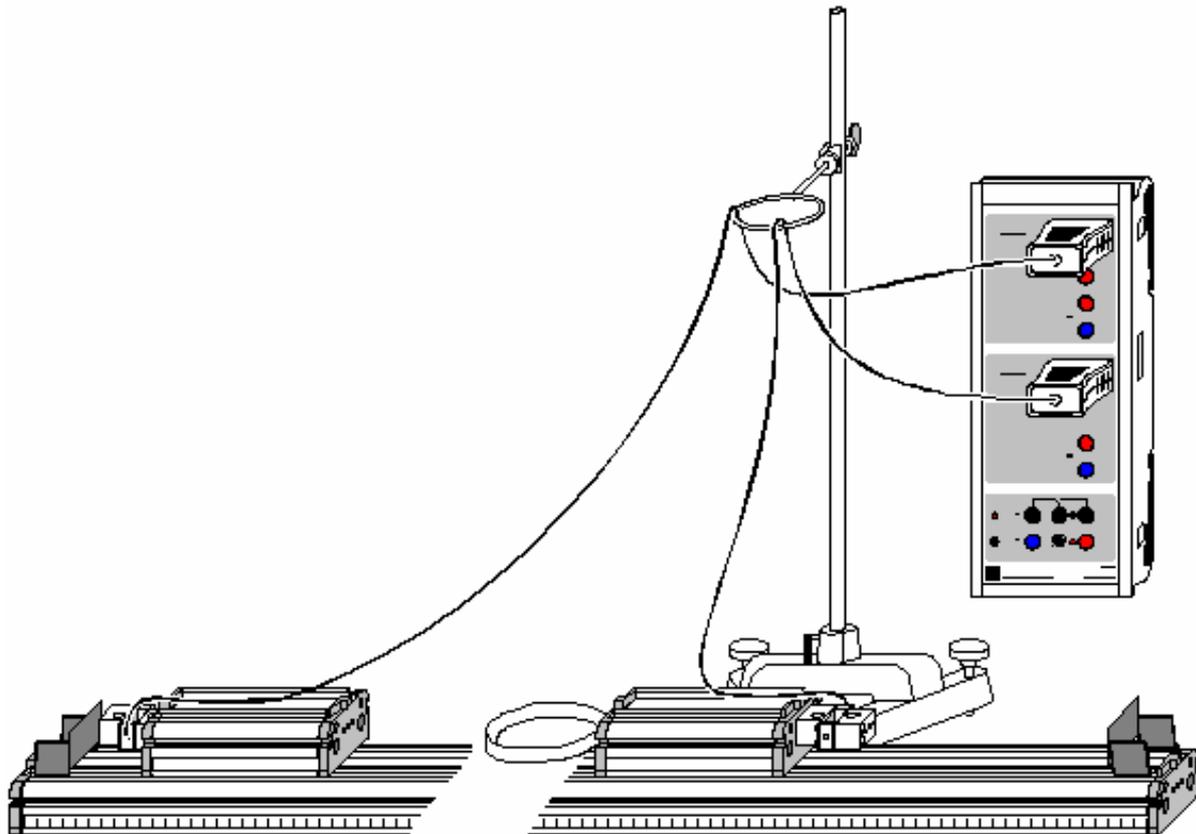
$$0 = d/dt (p_1(t) + p_2(t)) = m_1 \cdot a_1(t) + m_2 \cdot a_2(t) = F_1(t) + F_2(t),$$

i.e.

$$F_1(t) = -F_2(t) \quad (\text{"action = reaction"}).$$

The conclusion relies on the fact that $p(t)$ is a constant, particularly during the collision process. The mere fact that the total linear momentum before and after the collision is the same (e. g. by measurement with light barriers) does not justify the conclusion.

Confirming the relation action=reaction by measuring accelerations (collision)



can also be carried out with Pocket-CASSY

■ Load example

Experiment description

During an elastic collision the accelerations $a_1(t)$ and $a_2(t)$ of the two trolleys are measured. If the measured accelerations are multiplied by the masses m_1 and m_2 , the forces $F_1(t)$ and $F_2(t)$ are obtained. The relation $F_1(t) = -F_2(t)$ is confirmed for the time interval during which the collision takes place.

Principle of measurement

If a force sensor with mass m is attached to a trolley so that that half of the sensor to which the lead is fixed is firmly mounted to the trolley, the other half of mass $m/2$ hangs in the air and is movable. If the trolley then is accelerated, this mass exerts the force of inertia $F = m \cdot a/2$. This force is measured by the force sensor and automatically converted into the acceleration a .

After the two accelerated masses (trolley + force sensor + spring) have been entered, the software computes the two forces $F_1(t) = m_1 \cdot a_1(t)$ and $F_2(t) = m_2 \cdot a_2(t)$.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
2	Force sensors S, ± 50 N	524 042
4	Coupling plugs	340 89
1	Track	337 130
2	Trolleys	337 110



1	Pair of additional weights	337 114
1	Large impact spring	337 473
1	Stand base, V-shape, 20 cm	300 02
1	Stand rod, 1 m	300 44
1	Clamp with ring	301 10
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Attach the two force sensors to the outside of the trolleys with 2 coupling plugs each so that the leads are fixed relative to the trolleys and not to the movable halves of the force sensors. Lock the leads so that they do not move within the force sensors during the collision (e. g. stick them to the trolleys with adhesive tape). In addition, guide the leads so that they do not hinder the trolleys during the collision.

The collision is intercepted by the large impact spring, which is attached to the inside of one of the trolleys. The large impact spring has been proposed deliberately because it leads to a longer collision time so that more measured values can be recorded. However, the spring is relatively soft and should not be overloaded in the collision process.

Carrying out the experiment

■ Load settings

- Enter the masses m_1 and m_2 into the display instruments (click with the right mouse button and enter them as parameters). The total mass of a trolley is the sum of the mass of the trolley (0.5 kg), of the force sensor (0.1 kg) and, if present, the mass of the spring (0.01 kg) and an additional mass (0.5 kg).
- Set the acceleration to $\rightarrow 0 \leftarrow$ in Settings aA1 and aB1.
- Start the measurement with **F9**.
- Perform an elastic collision; the measurement is stopped automatically after 5 s.

Evaluation

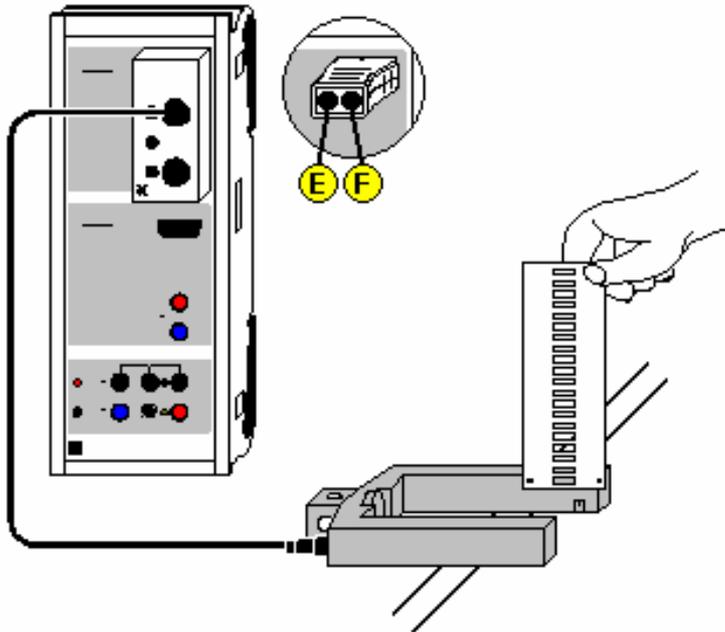
The display **Standard** shows the two $a(t)$ diagrams and the display **Force** the associated $F(t)$ diagrams (see principle of measurement).

In the $F(t)$ diagrams it is easy to see that

$$F_1(t) = -F_2(t) \quad (\text{"Action = Reaction"}).$$

From this conservation of linear momentum can be inferred immediately as the integrals over both curves (momentum transfers) between arbitrary times t_1 and t_2 always have the same magnitude and opposite signs.

Free fall with g-ladder



can also be carried out with Pocket-CASSY

■ Load example

Experiment description

When a ladder falls through a light barrier, the software registers the times of the obscurations of the light barrier caused by the rungs of the ladder. The known rung spacing together with the time information gives us the $s(t)$ diagram of the fall. This is then used to calculate the $v(t)$ and the $a(t)$ diagram. Each of the three diagrams can be used to determine the gravitational acceleration g .

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Timer box or Timer S	524 034 or 524 074
1	g-ladder	529 034
1	Forked light barrier	337 46
1	Multicore cable, 6-pole	501 16
1	Set of weights, 50 g, optional	342 61
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Suspend or hold the g-ladder above the light barrier so that its rungs interrupt the light beam when falling. The light barrier is connected to Sensor-CASSY via input E of the timer box. The independence of gravitational acceleration from mass can be verified by suspending weights from the ladder. Moreover, the aerodynamic drag of the g-ladder can be increased or decreased by sticking small wings or transparent plastic sheets to it.



Carrying out the experiment

■ Load settings

- Start the measurement with **F9**.
- Allow the ladder to fall through the light barrier so that all 21 rungs pass the beam.
- The measurement stops automatically 0.2 seconds after detection of the first rung, or after 21 rungs. You can delete a faulty measurement series from the table with **Delete Last Measurement Series** (click right mouse button over table).
- You can repeat the measurement with different masses or falling heights. Simply restart it with **F9**.

Evaluation

This example contains prepared display tabs for path $s(t)$, velocity $v(t)$ and acceleration $a(t)$ which can be accessed by clicking on them. The gravitational acceleration g can be determined in the $s(t)$ diagram by fitting a parabola, in the $v(t)$ diagram by fitting a straight line and in the $a(t)$ diagram by finding the mean value. You can enlarge display of the numerical values of the evaluation shown in the status line with **F6**.

As the ladder had an initial velocity when the light barrier was interrupted by the first rung, the peak of the $s(t)$ parabola is not visible, and the $v(t)$ straight line does not pass through the origin. However, to better illustrate the matter, you can move e.g. the t and s axes with the mouse so that after fitting a parabola its peak is also visible.

Remark

The individual velocity values $v(i)$ are calculated as

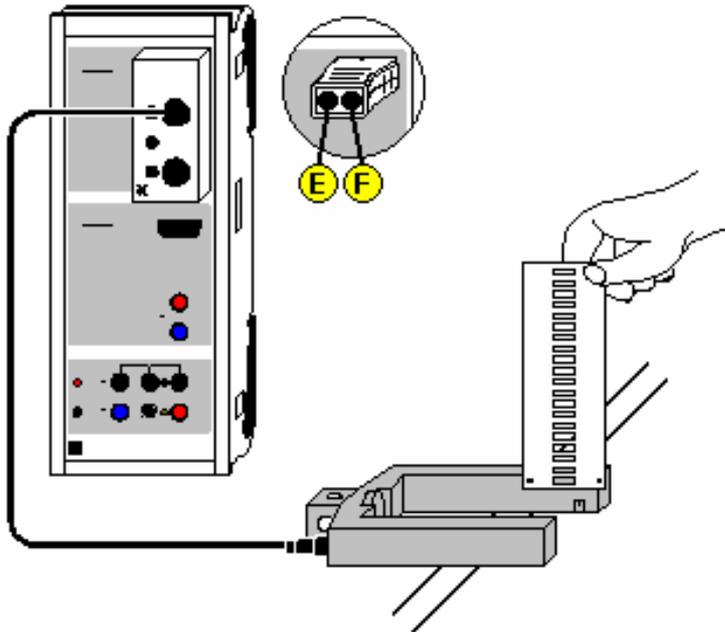
$$v(i) = (s(i+1) - s(i-1)) / (t(i+1) - t(i-1))$$

This is the average velocity in the interval $[t(i-1), t(i+1)]$ and an initial approximation of the instantaneous velocity at the time $(t(i-1) + t(i+1)) / 2$, i.e. not at time $t(i)$. The same is true for the acceleration values:

$$a(i) = (v(i+1) - v(i-1)) / ((t(i+2) - t(i-2)) / 2).$$

However, this has already been taken into consideration in the $v(t)$ and $a(t)$ displays by means of suitable conversion of the time axis.

Free fall with g-ladder (with modelling)



can also be carried out with Pocket-CASSY

■ Load example

Experiment description

During a free fall of a ladder through a light barrier, the software registers the times of the obscurations of the light barrier caused by the rungs of the ladder. The known rung spacing together with the time information gives us the $s(t)$ diagram of the fall.

As a supplement to the previous experiment, the measured motion is now compared with the motion described by the equation

$$s'' = a = g.$$

Experiment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Timer box or Timer S	524 034 or 524 074
1	g-ladder	529 034
1	Forked light barrier	337 46
1	Multicore cable, 6-pole	501 16
1	Set of weights, 50 g, optional	342 61
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Suspend or hold the g-ladder above the light barrier so that its rungs interrupt the light beam when falling. The light barrier is connected to Sensor-CASSY via input E of the timer box.



Carrying out the experiment

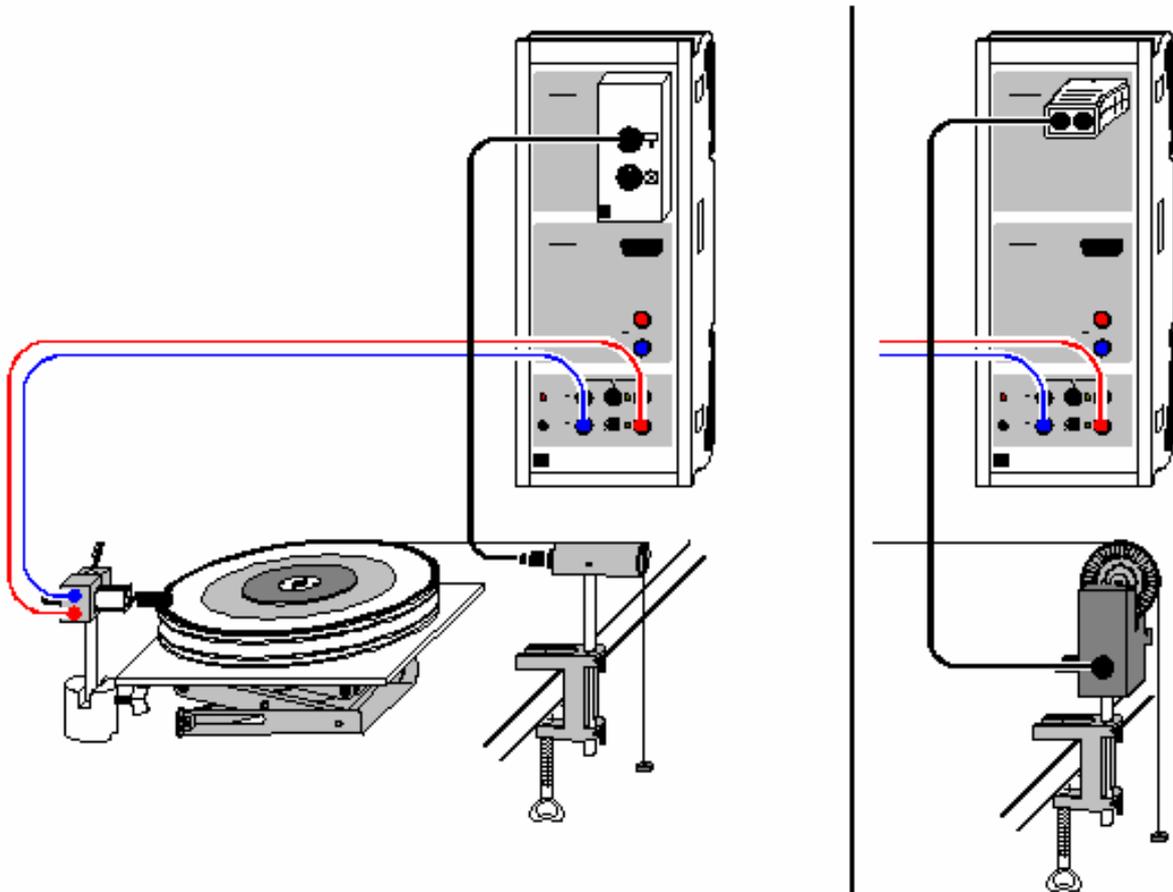
■ Load settings

- Start the measurement with **F9**.
- Allow the ladder to fall through the light barrier so that all 21 rungs pass the beam.
- The measurement stops automatically 0.2 seconds after detection of the first rung or after 21 rungs. You can delete a faulty measurement series from the table with **Delete Last Measurement Series** (click right mouse button over table).
- You can repeat the measurement with different masses or falling heights. Simply restart it with **F9**.

Modelling

In the present example, the two initial conditions $s(t=0)=0$ and $v(t=0)=v_0$ and the acceleration $g=9.81$ m/s² were chosen, whereby g and v_0 can be altered by dragging the pointer of the corresponding display instrument (or by clicking to the left or to the right of the pointer) until the model agrees with the measurement.

Rotational motions (Newton's equation of motion)



- Load example ($J = \text{constant}$)
- Load example ($M = \text{constant}$)

Experiment description

A rotating body with a constant moment of inertia J is accelerated with different torque values. When the angular accelerations α determined are plotted as a function of the accelerating torques M , M is found to be proportional to α (with J as the proportionality factor), thus confirming Newton's equation of motion $M = J \cdot \alpha$.

Alternatively, you can keep the accelerating torque M constant and vary the moment of inertia J . The result here is J proportional to $1/\alpha$ (with M as the proportionality factor).

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	BMW box	524 032
1	Motion sensing element	337 631
	or	
1	Timer S	524 074
1	Combi-light barrier	337 462
1	Combi-spoked wheel	337 464
1	Rotation model	347 23
1	Multicore cable, 6-pole	501 16
1	Holding magnet	336 21
1	Stand rod, 25 cm	300 41
1	Base	300 11



1	Bench clamp, simple	301 07
1	Laboratory stand II	300 76
1	Pair of cables, 1 m, red and blue	501 46
1	Paper clip	
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Tie the transmission thread to the flag of the rotation model ($r = 10$ cm) or to one of the pins of the extra disk ($r = 5$ cm, 2.5 cm) and run it over the motion sensing element, which is connected to Sensor-CASSY via the top socket of the BMW box. The holding magnet prevents the start of rotation when it is placed close to the paper clip attached to the flag of the rotation model.

The accelerating force is generated e.g. by 3 small suspended weights of 1 g each ($F = 0.0294$ N). The different torques at a constant moment of inertia are realized using the different pulley radii ($M = r \cdot F = 2.94$ mNm, 1.47 mNm, 0.73 mNm). Alternatively, you can realize different moments of inertia for a constant torque using extra disks.

Carrying out the experiment

- Load settings ($J = \text{constant}$) or
- Load settings ($M = \text{constant}$)
- Modify the maximum rolling angle β_{A1} in the measuring condition of the Measuring Parameters dialog (accessible via **F5**); current setting: **&bA1 < 6** for 6 radii, &b stands for β)
- You may want to modify the time interval (currently 500 ms) in the Measuring Parameters dialog (accessible with **F5**); a longer interval means fewer measured values and less scattering in $\alpha(t)$.
- You may need to invert the sign of angular measurement (**s** \leftrightarrow **-s** in Settings β_{A1}).
- Allow the rotating disk to fall from the holding magnet.
- Define the current rolling radius and the path zero point (both in Settings β_{A1})
- Start the measurement with **F9** and stop it with **F9** when the experiment is finished. You can delete a faulty measurement series from the table with **Delete Last Measurement Series** (click right mouse button over table).
- Repeat the measurement with different parameters (different accelerating torque or accelerated moment of inertia). Be sure to redefine the rolling radius and path zero point.

Evaluation

In addition to the $\beta(t)$ diagrams, the software also calculates the $\omega(t)$ and $\alpha(t)$ diagrams. You can see these simply by clicking on the tabs of the other displays. Suitable evaluation functions are parabola and line fits and calculation of mean value.

To confirm Newton's equation of motion, you need to fill out a further table, which has already been prepared on the Newton display tab. After determining an angular acceleration value as the mean of an $\alpha(t)$ diagram or the slope of an $\omega(t)$ diagram, you can use the mouse to drag this value from the status line and drop it into the table (drag & drop). As the parameter, enter the parameter angular momentum M or moment of inertia directly via the keyboard. The desired diagram is generated as you enter the values. You can easily convert or rescale the axes by clicking on them with the right mouse button (e.g. $\alpha \rightarrow 1/\alpha$).

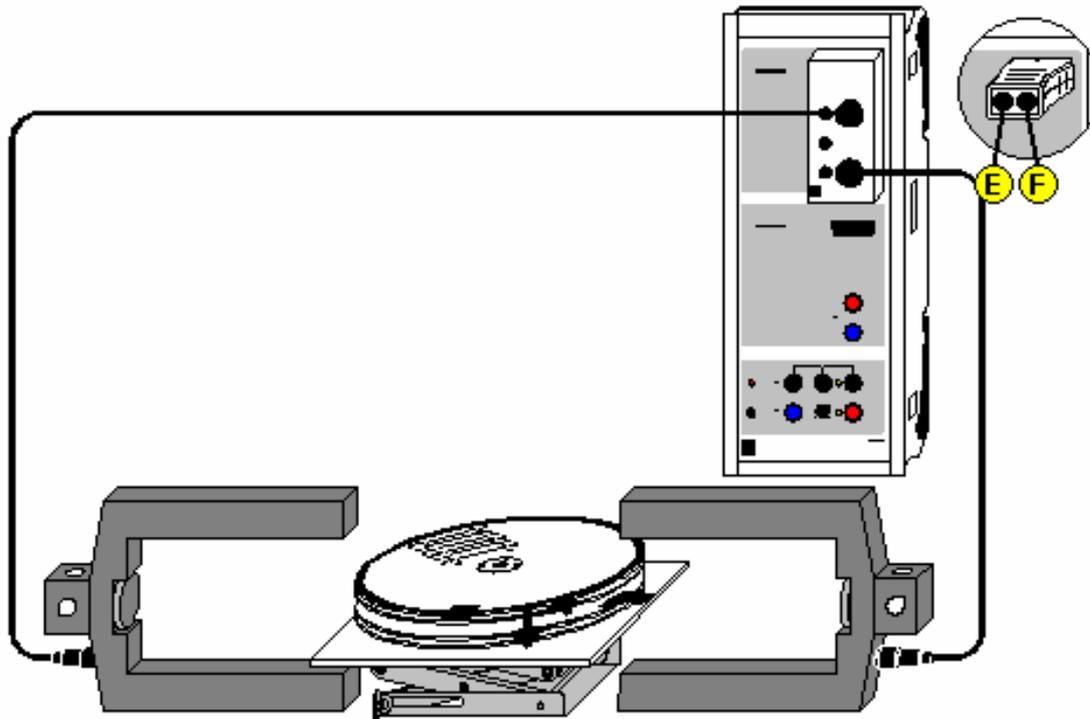
As a further evaluation, you can e.g. compare the rotational energy with the work performed using formulas. The rotational energy is

$$E = 0.5 \cdot J \cdot \omega^2 \text{ (enter the numerical value for } J, \text{ \&w stands for } \omega)$$

and the work performed is

$$W = M \cdot \beta_{A1} \text{ (enter the numerical value for } M, \text{ \&b stands for } \beta)$$

Conservation of angular momentum and energy (torsion collision)



can also be carried out with Pocket-CASSY

■ Load example

Experiment description

With the rotation model, the angular velocities ω of two bodies before and after their collisions can be measured from the obscuration times of two light barriers. By this means, it is possible to verify the law of conservation of angular momentum for elastic and inelastic torsion collision, as well as that of conservation of energy for elastic torsion collision.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Timer box or Timer S	524 034 or 524 074
1	Rotation model	347 23
2	Forked light barriers	337 46
2	Multicore cables, 6-pole	501 16
1	Laboratory stand II	300 76
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

First position the rotation model and the two light barriers (connected to inputs E and F of the timer box) so that the flags of the rotating bodies are **between** the light barriers when torsion collision occurs. The flags of the two bodies must interrupt the light barriers when they pass through.



Carrying out the experiment

■ Load settings

- Enter the moments of inertia J_1 and J_2 in the table (activate keyboard input in the cells beneath J_1 and J_2 with the mouse).
- Enter the arrangement of the flags before collision in relation to light barriers E and F (Settings ω_1 , ω_2 , ω_1' or ω_2'). There are four different arrangements:
Both flags outside of light barriers.
Left flag between the light barriers, right flag outside.
Left flag outside the light barriers, right flag between them.
Both flags inside (explosion).
- Enter the flag width and radius (also in Settings ω_1 , ω_2 , ω_1' or ω_2').
- Initiate the collision (if angular velocities are displayed before the collision, you can clear these with $\rightarrow 0 \leftarrow$) and watch to make sure that the light barriers do not register any extra pulses (e.g. due to reflection of a rotating body).
- Terminate the measurement with **End of Collision** (the measurement is terminated automatically after four measured angular velocities).
- Transfer the measured values to the table for evaluation with **F9** or initialize the next measurement with $\rightarrow 0 \leftarrow$.

Evaluation

Tables have been pre-defined for angular momentum before and after collision, overall angular momentum, energy, total energy and energy loss; you can transfer measured values to these with **F9**. Click on the table tabs to display these. If you want these quantities to be visible immediately after collision, open the corresponding display instruments.

You can also define additional formulas to compare your results with theory. For elastic torsion collision, we say that

$$\omega_1' = (2 \cdot J_2 \cdot \omega_2 + (J_1 - J_2) \cdot \omega_1) / (J_1 + J_2)$$

$$\omega_2' = (2 \cdot J_1 \cdot \omega_1 + (J_2 - J_1) \cdot \omega_2) / (J_1 + J_2)$$

For inelastic torsion collision, the following applies:

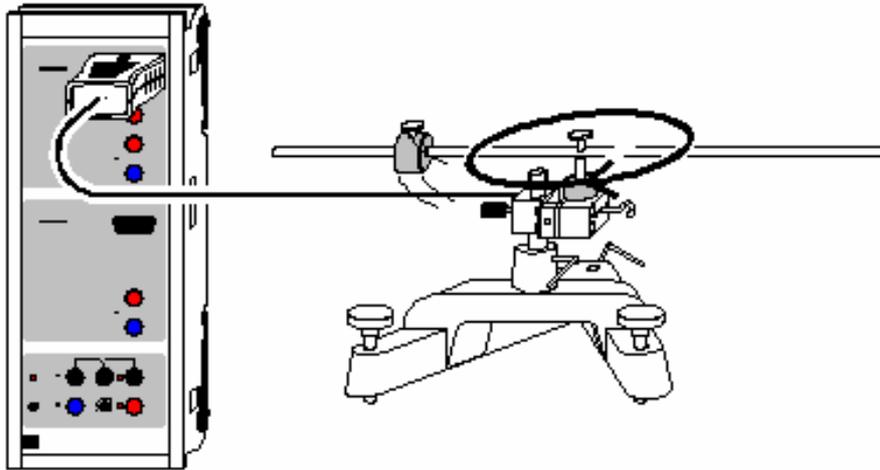
$$\omega_1' = \omega_2' = (J_1 \cdot \omega_1 + J_2 \cdot \omega_2) / (J_1 + J_2).$$

In all formulas, the character combination ω plus w is used to represent (and generate) the Greek ω .

Table for converting specified units to SI units

Quantity	SI unit =	Factor	· specified unit
Moment of inertia J	$\text{kg} \cdot \text{m}^2$	1000	$\text{g} \cdot \text{m}^2$
Angular velocity ω	rad/s	1	rad/s
Angular momentum L	$\text{N} \cdot \text{s} \cdot \text{m} = \text{kg} \cdot \text{m}^2 / \text{s}$	1000	mJ·s
Energy E	$\text{J} = \text{kg} \cdot \text{m}^2 / \text{s}^2$	1000	mJ

Centrifugal force (rotable centrifugal force arm)



can also be carried out with Pocket-CASSY

- Load example (single measurement)
- Load example ($r = 190 \text{ mm}$, m and ω variable)
- Load example ($m = 200 \text{ g}$, r and ω variable)

Experiment description

The centrifugal force F acting on a rotating mass m is described by $F = m \cdot \omega^2 \cdot r$ (ω : angular velocity, r : distance of the centre of mass from the axis of rotation). This law is confirmed by varying the three parameters m , ω and r .

The centrifugal force F can be measured by means of the force sensor S , $\pm 50 \text{ N}$. As the sensor almost exclusively measures forces in one direction, the measurement results in a sinusoidal shape of the force, the minima and maxima corresponding to the radial centrifugal force.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Force sensor S , $\pm 50 \text{ N}$	524 042
1	Rotable centrifugal force arm	347 211
1	Stand base, V-shape, 28 cm	300 01
1	Stand rod, 10 cm	300 40
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Use the stand rod to mount the force sensor horizontally as close as possible to the stand base. Tighten all screws firmly! Then align the stand base horizontally with the levelling screws so that the rotatable centrifugal force arm swings as little as possible and rotates at a constant velocity even if the angular frequency is low.

Carrying out the experiment

- Load settings
 - Screw the weights at a certain distance (r is determined between the axis of rotation and the centre of the weight) onto the rotatable arm.
 - Set the force sensor to $\rightarrow 0 \leftarrow$ in Settings Force FA1.



- Make the rotatable arm rotate by tapping it with your finger near the axis of rotation. When the force has reached about 5 N, start data recording with **F9**. Repeat the measurement every 5 to 10 s until the measured force has reached about 1 N. A set of sine curves is obtained with decreasing amplitudes and increasing periods. In the example the trigger is set so that all curves start in the coordinate origin.

Evaluation

Determine the period T and the minimum and maximum force F_{\min} and F_{\max} of the first period for each sine curve by clicking with the mouse and reading the table values. Transfer these values into the display **Input** (mouse click). If there are inaccuracies in the setup or the zero adjustment of the force sensor, these are compensated by taking into account F_{\min} and F_{\max} .

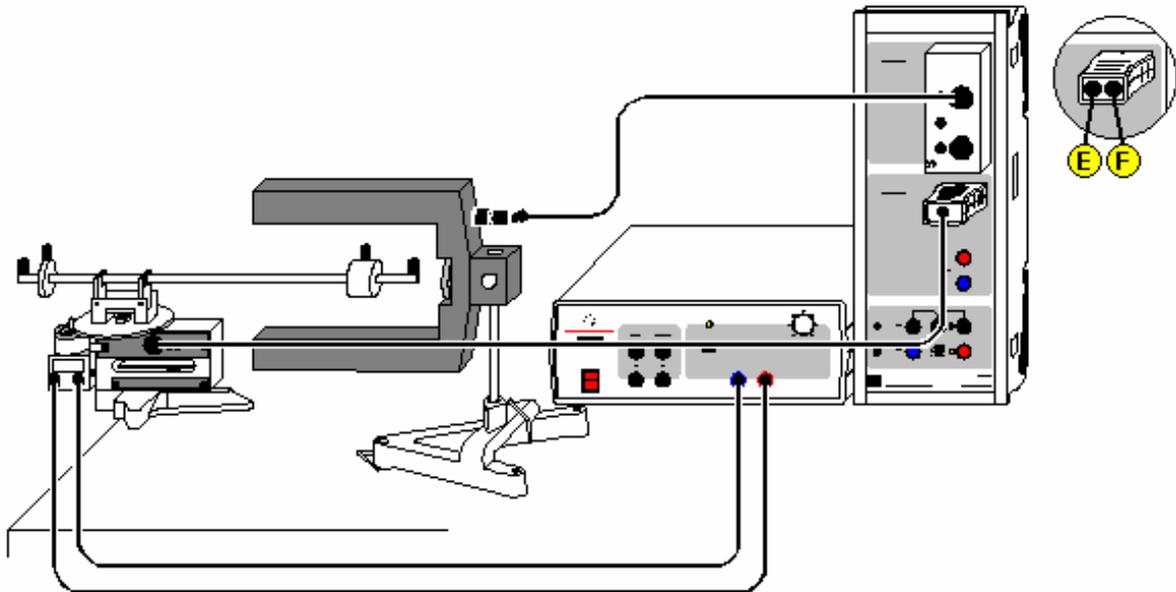
In the display **Centrifugal Force**, the result of this evaluation is plotted automatically. The centrifugal force $F = (F_{\max} - F_{\min})/2$ shown in the diagram and the angular velocity $\omega = 2\pi/T$ are calculated from the input values. The proportionality $F \sim \omega^2$ is clearly seen.

For confirming the proportionalities $F \sim m$ and $F \sim r$, the measurements have to be repeated with other weights and radii and then evaluated all together. It is recommendable to evaluate each measurement individually and to store it in a separate file because several measurements are confusing for an evaluation in a graphic representation. Afterwards several evaluated measurements can be loaded into a common display.

Hint

As the experiment has to be repeated with other masses m and radii r for a complete evaluation, manual evaluation is very tedious. However, the period T and the two forces F_{\min} and F_{\max} can also be determined automatically. For this the display instruments T , F_{\min} , and F_{\max} in the upper line have to be opened. Immediately after an individual measurement, the values calculated there can be shifted into the display **Input** with the mouse (drag & drop). As long as the rotatable arm is still rotating and the measured force is greater than 1 N, this procedure is repeated for decreasing angular velocities ω in short intervals.

Centrifugal force (centrifugal force apparatus)



can also be carried out with Pocket-CASSY

- Load example ($r = 0.25$ m, m and ω variable)
- Load example ($m = 0.1$ kg, r and ω variable)

Experiment description

The centrifugal force apparatus enables experimental investigation of the centrifugal force F as a function of the rotating mass m , the distance r of the mass from the centre of rotation and the angular velocity ω , thus making it possible to confirm the relation $F = m \cdot \omega^2 \cdot r$ for the centrifugal force.

In the centrifugal force apparatus, the force F acting on a rotating mass m is transmitted via a lever with ball-and-socket joint and a push pin in the axis of rotation to a leaf spring, whose deflection is measured electrically by means of a bridge-connected strain gauge. In the measuring range relevant for the experiment, the deformation of the leaf spring is elastic and thus proportional to the force F .

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Timer box or Timer S	524 034 or 524 074
1	Centrifugal force apparatus S	524 068
1	Power supply	521 49
1	Forked light barrier	337 46
1	Multi-core cable, 6-pole	501 16
1	Bench clamp	301 06
1	Stand base, V-shape, 20 cm	300 02
1	Stand rod, 10 cm	300 40
1	Pair of cables, 50 cm, red and blue	501 45
1	PC with Windows 95/98/NT or higher version	

If there are centrifugal force apparatus (347 21) available, they can be upgraded by means of the centrifugal force adapter (524 0681). Handling and measuring results of this combination do not differ from those of the centrifugal force apparatus S (524 068). Before the centrifugal force apparatus (347 21) is used with the centrifugal force adapter (524 0681) for the first time, the zero and the gain at the cen-



trifugal force apparatus should once be readjusted according to the instruction sheet of the centrifugal force adapter.

Experiment setup (see drawing)

Use the bench clamp to fix the centrifugal force apparatus to the table. The light barrier is set up by means of the stand rod and the stand base so that the rotating arm can freely rotate between the legs of the light barrier; the light beam should not be interrupted by the weight. The centrifugal force apparatus is connected to Input B and the light barrier via the 6-pole cable to the timer box at Input A of the Sensor-CASSY. The power supply is connected to the driving motor of the centrifugal force apparatus via two connecting leads. The maximum voltage for driving the motor should be selected so that the force measuring range does not exceed 15 N.

Carrying out the experiment

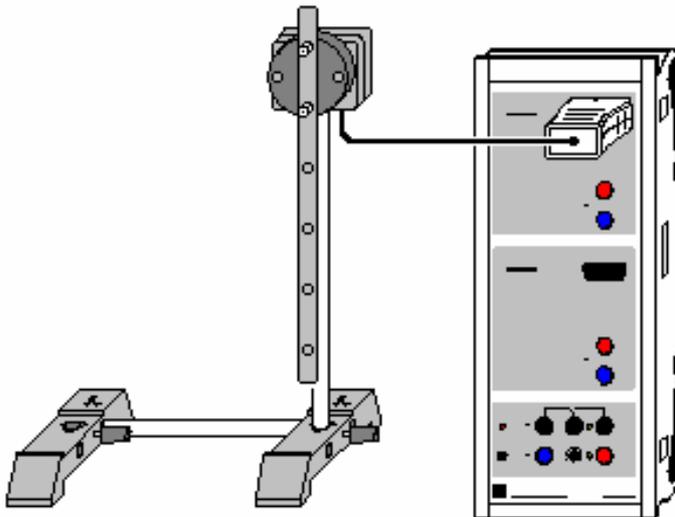
- Load settings ($r = \text{constant}$) or
- Load settings ($m = \text{constant}$)
- Set the force display to 0 while the rotating arm is at rest. For this set the centrifugal force apparatus to $\rightarrow 0 \leftarrow$ in Settings Force FB1 (right mouse button).
- Adjust the compensating weight on the short arm of the apparatus so that no force F is measured when the measurement is made without additional weight m but with the safety screw.
- Starting with low angular velocities ω , store the measured force manually with **F9** in the table.
- Repeat the measurement with higher angular velocities ω .
- After finishing a measurement series, repeat the measurements with other masses m ($r = \text{constant}$) or radii r ($m = \text{constant}$). For this select **Append new measurement series** in **Measuring Parameters (F5)** and restart at low angular velocities.

Evaluation

Each individual measurement series immediately confirms the proportionality between the force F and ω^2 by a fit to a straight line. If you want to confirm the two other proportionalities between F and m (ω, r constant) and between F and r (ω, m constant), the forces F have to be determined for constant angular velocities ω . To do this, draw a vertical line at a value of ω^2 in the diagram and read the coordinates of the intersections with the $F(\omega^2)$ line (switch the coordinate display on). Enter these coordinates manually into the prepared second display $F(m)$ or $F(r)$ (click the field in the table with the mouse). There the desired proportionality eventually shows up.

$F = m \cdot \omega^2 \cdot r$ is confirmed by determining the proportionality factors.

Oscillations of a rod pendulum



can also be carried out with Pocket-CASSY

■ Load example

Experiment description

The equation of motion for a physical pendulum with moment of inertia J , mass m and distance s between fulcrum and centre of gravity

$$M = J \cdot \alpha'' = -m \cdot g \cdot s \cdot \sin \alpha$$

describes for small deflections ($\sin \alpha \approx \alpha$) an harmonic oscillation with period of oscillation

$$T = 2\pi \cdot \sqrt{J/mgs}.$$

For a better understanding, the reduced pendulum length $l_r = J/ms$ is introduced. Then the period of oscillation is

$$T = 2\pi \cdot \sqrt{l_r/g}.$$

For mathematical pendulums, the entire pendulum mass is concentrated at a single point. It has therefore the moment of inertia $J = ms^2$ and the reduced pendulum length is $l_r = J/ms = s$, which is equivalent to the distance between the pendulum mass (centre of gravity) and fulcrum.

A physical pendulum with the reduced pendulum length l_r corresponds to a mathematical pendulum of this length.

In this experiment the reduced pendulum length is determined from the measured period of oscillation and compared with the reduced pendulum length.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Rotary motion sensor S	524 082
1	Physical pendulum	346 20
1	Stand rod, 25 cm, d = 10 mm	301 26
2	Stand bases MF	301 21
1	PC with Windows 95/98/NT or higher version	



Experiment setup (see diagram)

The pendulum is attached using coupling plugs to the wheel on the rotary motion sensor.

Carrying out the experiment

■ Load settings

- Define the zero point in the equilibrium position of the pendulum ($\rightarrow 0 \leftarrow$ in settings $\alpha A1$)
- Deflect the pendulum by approx. 5° only and release
- Start measurement by pressing **F9**. The measurement will stop automatically after 10 s
- Repeat the measurement without the mass or using a further mass

Evaluation

After several oscillations, the duration of these oscillations can be determined by means of a vertical line and from this the period of oscillation. In the example, the result is $T = 0.840$ s. With $g = 9.81$ m/s² this results in a reduced pendulum length of $l_r = g \cdot T^2 / 4\pi^2 = 17.5$ cm.

This corresponds well to the calculated (using an approximation) pendulum length l_r of the rod. The moment of inertia of the rod for rotation through the centre of gravity is $J_S = 1/12 \cdot m l^2$. The axis of rotation of this pendulum is, however, $s = 1/3 \cdot l$ displaced from the centre of gravity. According to Steiner's theorem this gives $J = J_S + m s^2 = 7/36 m l^2$ and $l_r = 7/36 \cdot m l^2 / m s = 7/12 \cdot l = 17.5$ cm (for $l = 30$ cm).

Conversely, from the calculated reduced pendulum length and the measured period of oscillation the earth's acceleration due to gravity can also be calculated $g = l_r \cdot 4\pi^2 / T^2$.

Experimental determination of the reduced pendulum length

If mass m_2 is shifted on the pendulum rod until the period of oscillation T compared to the rod without added mass is unchanged, then the reduced pendulum length l_r will also be unchanged. The position x when the (point) mass is now found increases the moment of inertia of the pendulum by $J_2 = m_2 \cdot x^2$. Because the reduced pendulum length l_r has not been changed, the following applies

$$l_r = J/ms = (J + J_2)/(m + m_2)/s'$$

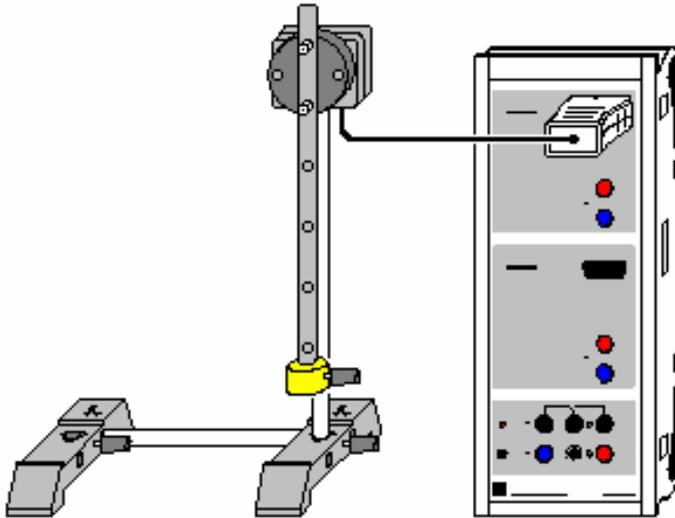
with s' being the distance between the new centre of gravity and the fulcrum, therefore $s' = (m \cdot s + m_2 \cdot x)/(m + m_2)$. From this you get

$$J/ms = (J + m_2 \cdot x^2)/(m \cdot s + m_2 \cdot x) = J/ms \cdot (1 + m_2 \cdot x^2/J)/(1 + m_2 \cdot x/ms) \quad \text{or} \quad m_2 \cdot x^2/J = m_2 \cdot x/ms, \quad \text{therefore}$$

$$x = J/ms = l_r.$$

The (point) mass is then exactly located at the reduced pendulum length. But, because in reality it has a finite size, this is only an approximation.

Oscillations of a rod pendulum (with added mass)



can also be carried out with Pocket-CASSY

■ Load example

Experiment description

The oscillations of a physical rod pendulum are recorded as a function of time t . For the evaluation, the angle α , velocity ω and acceleration a are compared to one another. There is a choice of displaying them as a function of time t or in the form of a phase diagram.

In addition, the reduced pendulum length $l_r = J/ms$ is determined from the measured oscillation period $T = 2\pi \cdot \sqrt{l_r/g}$.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Rotary motion sensor S	524 082
1	Physical pendulum	346 20
1	Stand rod, 25 cm, $d = 10$ mm	301 26
2	Stand bases MF	301 21
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The pendulum is attached with coupling plugs to the wheel of the rotary motion sensor and the weight is attached to the lower end of the pendulum.

Carrying out the experiment

■ Load settings

- Define the zero point in the equilibrium position of the pendulum ($\rightarrow 0 \leftarrow$ in settings $\alpha A1$)
- Deflect the pendulum by approximately 20° and release
- Start the measurement by pressing **F9**. The measurement will stop 10 s later
- Repeat the measurement without the mass or with a further mass added



Evaluation

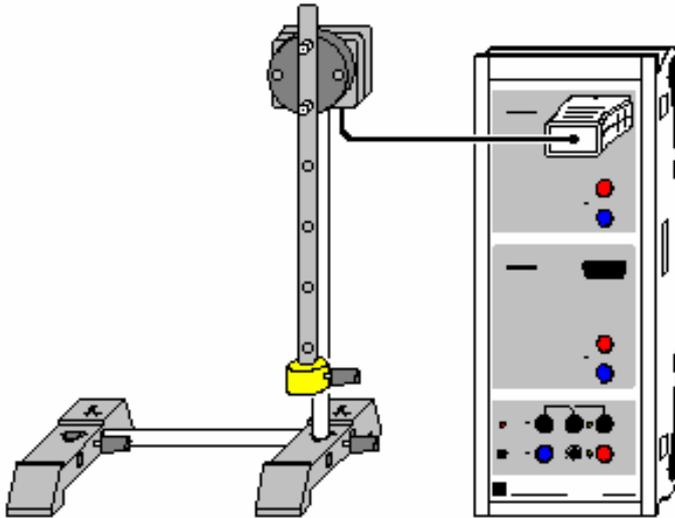
In addition to the angular diagram, an overview diagram with $\alpha(t)$, $\omega(t)$ and $a(t)$ and a phase diagram $\omega(\alpha)$ have already been prepared. The various diagrams can be selected by clicking on them.

After several oscillations the duration of these oscillations can be determined by means of a vertical line and from this the period of oscillation. In the example the result is $T = 0.96$ s. With $g = 9.81$ m/s², this results in the reduced pendulum length $l_r = g \cdot T^2 / 4\pi^2 = 22.9$ cm. This is a somewhat less than the distance between the weight and the fulcrum (25 cm).

Comment

The curves drawn strongly depend on the selected Time interval. The time interval can only be a compromise between rapid measuring sequence, clearly marked $\alpha(t)$ minima and maxima (short time interval) and low errors in the $\omega(t)$ and $a(t)$ diagram (longer time interval).

Oscillations of a rod pendulum (with modelling)



can also be carried out with Pocket-CASSY

■ Load example

Experiment description

A rod pendulum is excited and the free oscillation is recorded. In addition to an investigation of the oscillations of a rod pendulum purely based on measurements, the measured oscillation is compared to the oscillation $\alpha(t)$ which results from the equation of motion

$$M = J \cdot \alpha'' = -m \cdot g \cdot s \cdot \sin \alpha$$

with moment of inertia J , mass m and the distance s between the fulcrum and the centre of gravity. The required modelling equation is

$$\alpha'' = a = -m \cdot g \cdot s \cdot \sin \alpha / J = g/l_r \cdot \sin \alpha$$

with the reduced pendulum length $l_r = J/ms$.

For small angles α , $\sin \alpha$ is usually approximated by α and then the equation can be solved analytically. In this example, this approximation is not required, because the solution is found numerically.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Rotary motion sensor S	524 082
1	Physical pendulum	346 20
1	Stand rod, 25 cm, d = 10 mm	301 26
2	Stand bases MF	301 21
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The pendulum is attached with coupling plugs to the wheel of the rotary motion sensor and the weight is attached to the lower end of the pendulum.

Carrying out the experiment

■ Load settings

- Define the zero point in the equilibrium position of the pendulum ($\rightarrow 0 \leftarrow$ in settings $\alpha A1$)



- Deflect the pendulum by approximately 20° (this corresponds to an angle of approximately 0.35 rad) and release
- Start the measurement by pressing **F9**. The measurement will stop 10 s later.

Modelling

In the present example, the two starting conditions are selected $\alpha(t=0)=0$ and $\omega(t=0)=\omega_0$ because the oscillation was triggered at the origin. The starting speed ω_0 and reduced pendulum length l_r can be modified by pulling the pointer of the corresponding display instrument (or by clicking on the left-hand button or after clicking on the right-hand button) until Model corresponds to the measurement.

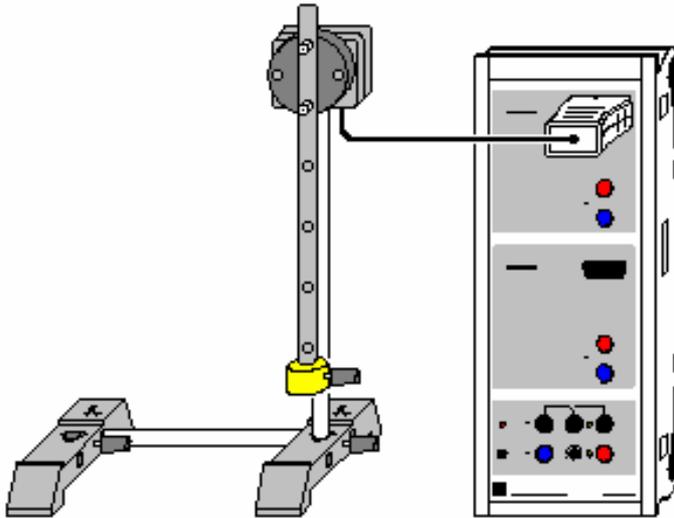
For confirmation of the model, the weight can be moved to a different position and the experiment be repeated. The new measured oscillation will again correspond to the mathematical model.

Influence of the approximation $\sin \alpha \approx \alpha$

It is very impressive to observe the influence of the otherwise commonly used approximation for small deflections ($\sin \alpha \approx \alpha$). For this the model equation can be reduced from $-9.81/l_r \cdot r \sin \alpha$ to $-9.81/l_r \cdot \alpha$. The change to the period through the influence of the approximation is already clearly apparent for a deflection of 20° .

In the following Example this influence is investigated in more detail.

Dependency of the period of the oscillation on the amplitude



can also be carried out with Pocket-CASSY

■ Load example

Experiment description

The period T depending on the amplitude of the oscillation is recorded. For this the pendulum is activated once at the beginning and the amplitude and period are continuously recorded. Because of the low degree of friction, the amplitude reduces slowly. This in turn results in a small reduction in the oscillation period.

The equation of motion for a physical pendulum with a moment of inertia J , mass m and distance s between the fulcrum and the centre of gravity.

$$M = J \cdot \alpha'' = -m \cdot g \cdot s \cdot \sin \alpha$$

describes for small deflections ($\sin \alpha \approx \alpha$) an harmonic oscillation with the period

$$T = 2\pi \cdot \sqrt{I_r / g},$$

with the reduced pendulum length being $I_r = J / ms$. Without this approximation, in general the following applies

$$T = 2\pi \cdot \sqrt{I_r / g} \cdot (1 + (1/2)^2 \cdot (\sin(\alpha/2))^2 + (3/4)^2 \cdot (\sin(\alpha/2))^4 + (5/6)^2 \cdot (\sin(\alpha/2))^6 + \dots)$$

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Rotary motion sensor S	524 082
1	Physical pendulum	346 20
1	Stand rod, 25 cm, d = 10 mm	301 26
2	Stand bases MF	301 21
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The pendulum is attached with coupling plugs to the wheel of the rotary motion sensor and the weight is attached to the lower end of the pendulum.



Carrying out the experiment

■ Load settings

- Deflect the pendulum by approximately 30° and release
- Once the displayed value for the oscillation period TA1 has settled to a constant value, start the measurement by pressing **F9**
- If after a while no measuring points appear, click on the y-axis with the right mouse button and select **Find Minimum and Maximum**.
- Stop the measurement by clicking **F9** as soon as the amplitude falls below 5°. Below this the determined oscillation period will become unreliable.

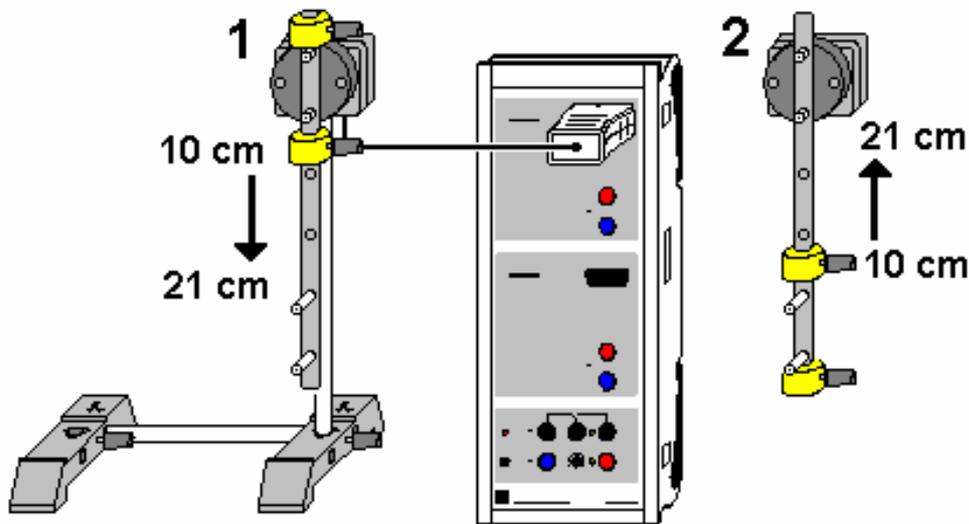
Evaluation

During the measurement, the amplitude decreases slowly. This causes a minor reduction in oscillation period. The theoretical connection between amplitude and period is

$$T = T_0 \cdot (1 + (1/2)^2 \cdot (\sin(\alpha/2))^2 + (3/4)^2 \cdot (\sin(\alpha/2))^4 + (5/6)^2 \cdot (\sin(\alpha/2))^6 + \dots))$$

and can be easily confirmed by carrying out a free fit.

Determination of the acceleration due to gravity on earth by means of a reversible pendulum



can also be carried out with Pocket-CASSY

■ Load example

Experiment description

For a physical pendulum with small deflections, the oscillation period is given by

$$T = 2\pi \cdot \sqrt{I_r/g}$$

with the reduced pendulum length $I_r = J/ms$. If the reduced pendulum length I_r and the oscillation period T are known, this can be used for calculating the acceleration due to gravity $g = I_r \cdot 4\pi^2/T^2$.

Often the reduced pendulum length cannot be determined with the desired precision if the precise determination of the moment of inertia or of the centre of gravity are difficult. With the reversible pendulum, the mass distribution is modified in such a way that the oscillation period is identical for both rotational axes. From this it can be concluded that the reduced pendulum length I_r corresponds to the distance between the two axes and therefore is known to a high degree of precision.

According to Steiner's theorem, $J = J_S + ms^2$ with J_S being the moment of inertia of the pendulum with respect to the axis through the centre of gravity and s being the distance between the centre of gravity and rotational axes. The reduced pendulum length is therefore

$$I_r = J/ms = J_S/ms + s.$$

The second rotational axis is now located on the other side of the centre of gravity and, with the same oscillation period and the same reduced pendulum length, is at a distance x from the centre of gravity. In this case

$$I_r = J_S/mx + x.$$

If the equation is rearranged to give the value for x , $x = I_r - s$. The distance between the two rotational axes $s+x$ therefore precisely corresponds to the reduced pendulum length I_r .

Because the oscillation period T can be determined precisely, the reversible pendulum is very suitable for the determination of the value of the earth's acceleration g .

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Rotary motion sensor S	524 082



1	Physical pendulum	346 20
1	Stand rod, 25 cm, d = 10 mm	301 26
2	Stand bases MF	301 21
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The pendulum is attached with coupling plugs to the wheel of the rotary motion sensor and the mass is attached to the pendulum as shown in (1). Already at this stage two coupling plugs are inserted at the lower end pointing outwards for minimising the error and easier reversal of the pendulum.

The rod of the pendulum is marked starting from the top in 1 cm steps using a pencil. A range from 10 cm to approximately 21 cm is adequate for this.

Carrying out the experiment

■ Load settings

- Attach the variable pendulum mass at the position $x = 10$ cm and deflect by approximately 10° .
- Once the value displayed for the oscillation period TA_1 has settled to a constant value and the amplitude αA_1 has fallen to approximately 5° , record the measuring value by pressing **F9** and enter the position in column x (click at the cell in the table with the mouse)
- Push the pendulum mass 1 cm down and measure again. Repeat until $x = 21$ cm is reached.
- Move the mass back to $x = 10$ cm and change the suspension point of the pendulum as shown in (2); reverse the pendulum
- In the measuring parameter window select **Append new measurement series**
- Again deflect the pendulum by approximately 10° and wait until the value displayed for the oscillation period TA_1 has settled to a constant and the amplitude TA_1 has fallen to approximately 5° , record the measuring value by pressing **F9** and enter the position in column x (click on the cell in the table with the mouse)
- Push the pendulum mass 1 cm **upwards** and measure again. Repeat until $x = 21$ cm is reached.

Evaluation

In the graphic display, two intersections of the oscillation period curves can be seen. In both intersection the period of oscillation and therefore the reduced pendulum length are equal. It corresponds to the displacement of the two axes of rotation, that is $l_r = 0.20$ m.

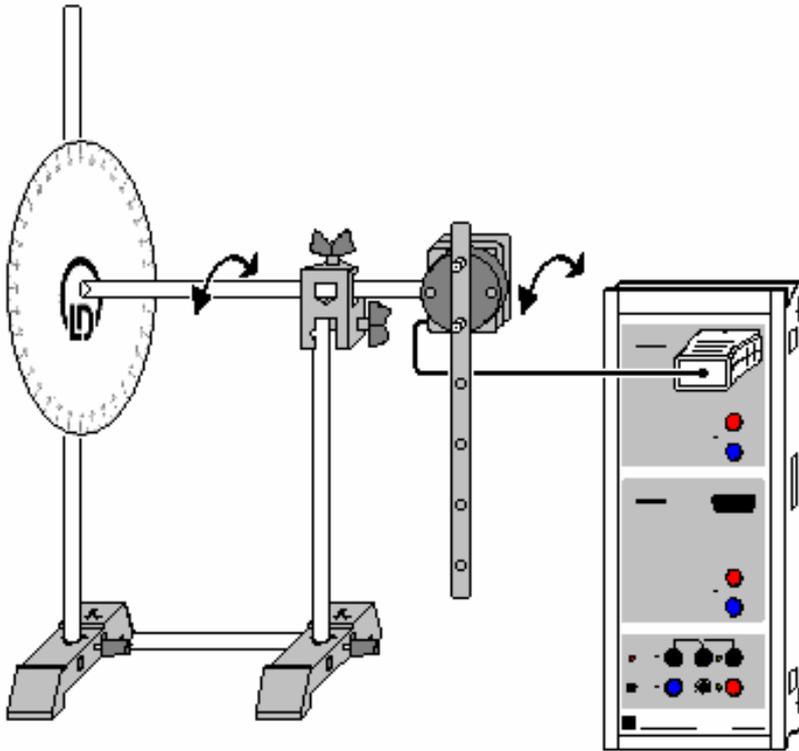
By means of a horizontal mark the corresponding period can be determined. In this example it is $T = 0.898$ s. This results in an earth's acceleration due to gravity of $g = l_r \cdot 4\pi^2 / T^2 = 7.896 \text{ m/s}^2 = 9.79 \text{ m/s}^2$.

Alternatively, the earth's acceleration due to gravity can be found with somewhat higher resolution in diagram **g**.

Comments about the measuring error

In addition to the manufacturing error in the rod, which will appear as an error in the reduced pendulum length l_r (approximately $\Delta l_r = \pm 0.1$ mm, that is $\Delta g = \pm 0.005 \text{ m/s}^2$), an error in the oscillation period T is to be considered. Besides the simple measuring fault (in this case approximately $\Delta T = \pm 0.001 \cdot T$, corresponding to $\Delta g = \pm 0.02 \text{ m/s}^2$) there is also a systematic fault. As already demonstrated in the experiment Dependency of the period of the oscillation on the amplitude, the oscillation period shows a weak dependency on the amplitude. For the 5° amplitude this systematic error is $\Delta T = +0.0005 \cdot T$, corresponding to $\Delta g = -0.01 \text{ m/s}^2$. With even smaller amplitudes the determination of the oscillation period by means of the rotary motion sensor will become unreliable. For greater amplitudes, this systematic fault will soon exceed the normal measuring fault (for 10° amplitude it is $\Delta T = +0.002 \cdot T$, corresponding to $\Delta g = -0.04 \text{ m/s}^2$)

Pendulum with changeable acceleration due to gravity (variable g-pendulum)



can also be carried out with Pocket-CASSY

■ Load example

Experiment description

With a variable g-pendulum (pendulum after Mach) only the component $g \cdot \cos \vartheta$ of the earth's gravitational acceleration affects the pendulum. Depending on the inclination ϑ , different oscillation periods result:

$$T = 2\pi \cdot \sqrt{l_r / g \cdot \cos \vartheta}$$

with the reduced pendulum length $l_r = J/ms$.

In the experiment, the oscillation period is investigated depending on the angle of inclination. Alternatively, the acceleration due to gravity of a number of simulated celestial bodies can be determined. The reduced pendulum length $l_r = 17.5 \text{ cm}$ was calculated in the experiment Oscillations of a rod pendulum and confirmed experimentally. The effective part of the acceleration due to gravity is therefore $a = g \cdot \cos \vartheta = l_r \cdot 4\pi^2 / T^2 = 6.91 \text{ m}/T^2$.

On the printable angle scale the settings for

Celestial body	ϑ	$g \cdot \cos \vartheta$
Earth (reference location)	0°	9.81 m/s^2
Venus	25.3°	8.87 m/s^2
Mars	67.8°	3.71 m/s^2
Mercury	67.8°	3.70 m/s^2
Moon	80.5°	1.62 m/s^2
Pluto	86.6°	0.58 m/s^2

are already entered.



Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Rotary motion sensor S	524 082
1	Physical pendulum	346 20
1	Angle scale with the entered celestial body	print out
1	Leybold clamp	301 01
2	Stand rods, 25 cm, d = 10 mm	301 26
1	Stand rod, 50 cm, d = 10 mm	301 27
2	Stand bases MF	301 21
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The pendulum is connected by means of the coupling plugs to the wheel of the rotary motion sensor. The scale is pushed onto the stand rod of the rotary motion sensor. To do this cut the scale as indicated by means of a sharp knife.

Carrying out the experiment

■ Load settings

- Set up pendulum vertically ($\vartheta = 0^\circ$), align the experiment setup and deflect the pendulum by approximately 10°
- Once the displayed value for the oscillation period T_{A1} has settled to a constant value, start the measurement by pressing **F9** and enter the angle in column ϑ (click with the mouse onto the table cell)
- Increase the angle repeatedly by 10° and repeat measurement until $\vartheta = 80^\circ$ is reached.

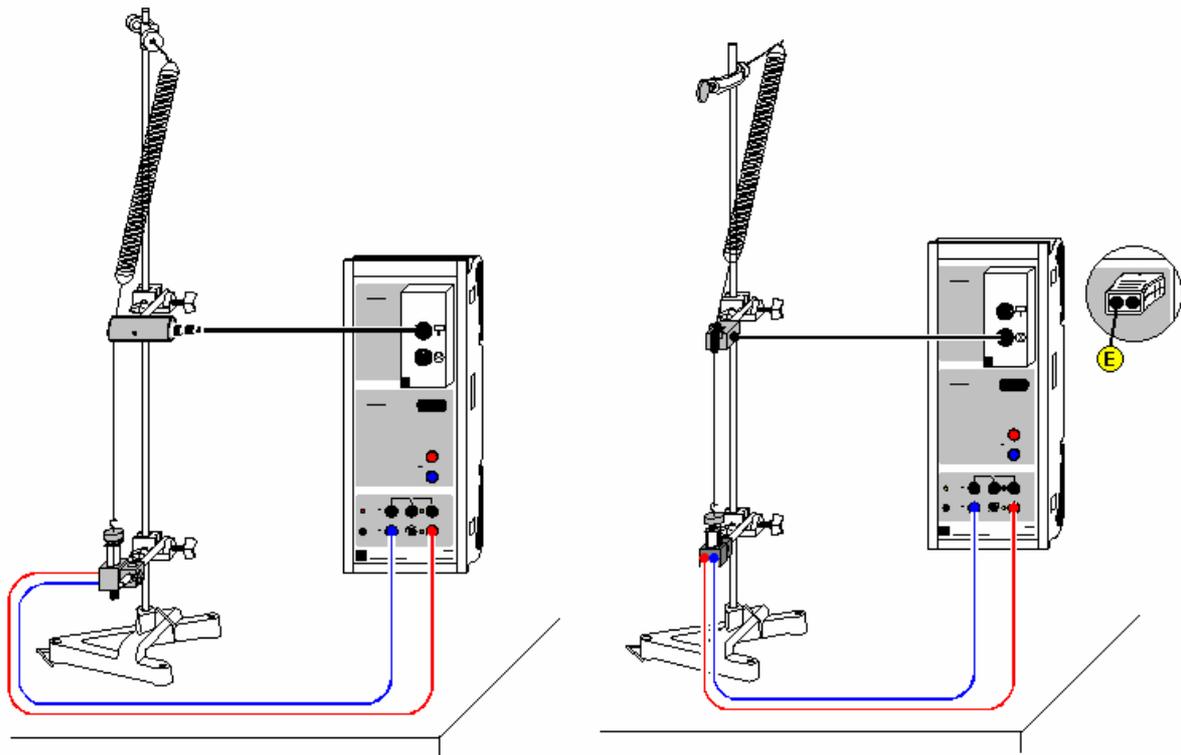
Evaluation

During the measurement, the effective part of the acceleration due to gravity $a = l \cdot 4\pi^2/T^2$ with $l = 17.5$ cm is entered into the diagram.

With a free fit the relationship $a = g \cdot \cos \vartheta$ can easily be confirmed.

Alternatively, a range of celestial bodies can be simulated and their acceleration due to gravity determined. To do this align the pendulum with the red markers on the angle scale.

Harmonic oscillations of a spring pendulum



■ Load example

Experiment description

This experiment records the harmonic oscillations of a spring pendulum as a function of the time t . The evaluation compares the path s , velocity v and acceleration a . These can be displayed either as a function of the time t or as a phase diagram.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	BMW box	524 032
1	Motion sensing element	337 631
	or	
1	Timer S	524 074
1	Combi-light barrier	337 462
1	Combi-spoked wheel	337 464
1	Multicore cable, 6-pole	501 16
1	Helical spring, 3 N/m	352 10
1	Set of weights, 50 g	342 61
1	Holding magnet	336 21
1	Stand base, V-shape, 28 cm	300 01
1	Stand rod, 25 cm	300 41
1	Stand rod, 150 cm	300 46
2	Leybold multiclamps	301 01
1	Clamp with hook	301 08
1	Cord, 10 m	309 48
1	Pair of cables, 1 m, red and blue	501 46
1	PC with Windows 95/98/NT or higher version	



Experiment setup (see drawing)

Lay the string of the spring pendulum over the deflection pulley of the motion sensing element so that the oscillation of the pendulum is transmitted to the sensor without slip; connect the sensor to the top socket of the BMW box. The holding magnet enables a defined measurement start by holding the pendulum weight in the bottom reversing point of the oscillation before the start of measurement recording.

This experiment can be expanded to investigate air friction (e.g. with a piece of cardboard on the weight) or the effect of a change in the pendulum mass.

Carrying out the experiment

■ Load settings

- If necessary, change the time interval in the measuring parameter window accessed with **F5** (a shorter interval enables more measured values and smoother $s(t)$ and $v(s)$ diagram, while a longer interval generates fewer measured values and less scattering in $a(t)$).
- You may need to invert the sign of path measurement ($s \leftrightarrow -s$ in Settings SA1).
- Define the zero point in the equilibrium position of the pendulum ($\rightarrow 0 \leftarrow$ in Settings SA1)
- Deflect the pendulum approx. 10 cm and hold it there with the holding magnet.
- Start the measurement with **F9** and stop it with **F9** when the experiment is finished.
- Always check that the path zero point is at the equilibrium position before repeating the experiment.

Evaluation

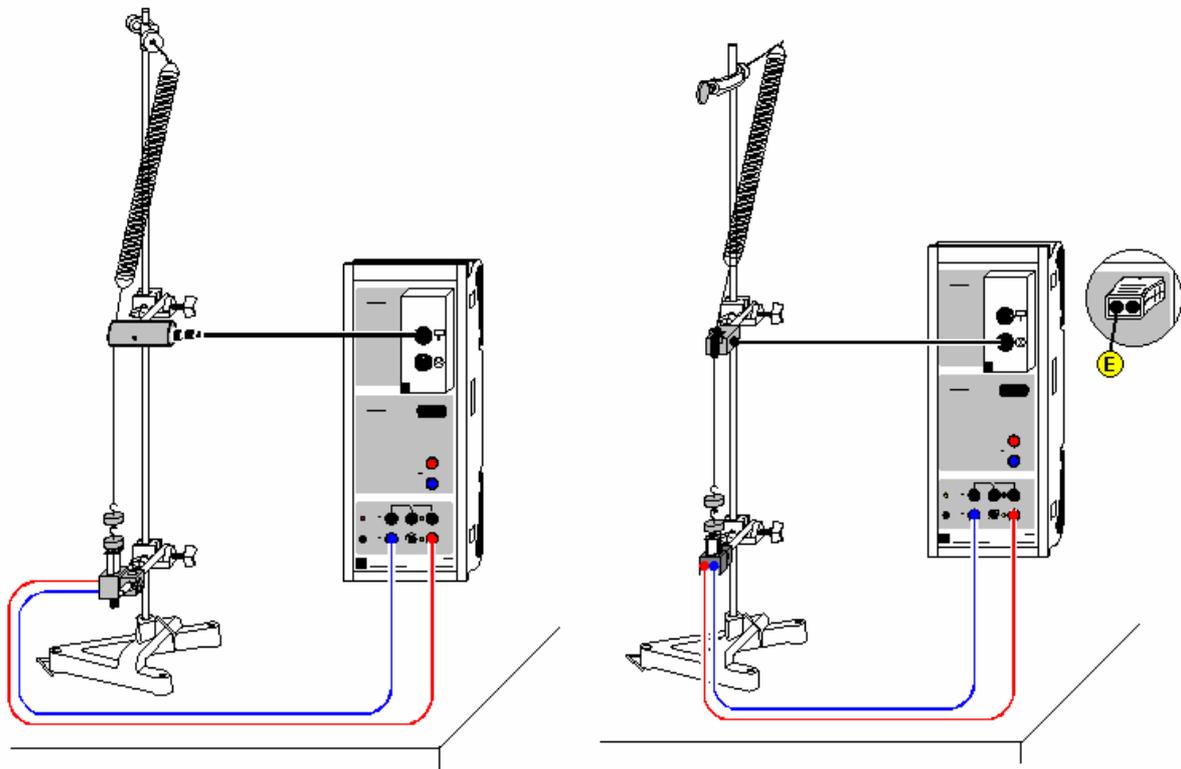
In addition to the path display, this example also contains an overview display with $s(t)$, $v(t)$ and $a(t)$ and a phase diagram $v(s)$. Click on the respective displays to view them.

The phase relations and the damping are easy to see.

Remark

The recorded curve forms depend greatly on the selected time interval. The time interval is necessarily a compromise between a rich sequence of measured values, clearly apparent $s(t)$ minima (shorter interval) and low inaccuracy in the $v(t)$ and $a(t)$ diagram (longer interval).

Dependence of the period of oscillation of a spring pendulum on the mass



■ Load example

Experiment description

The harmonic oscillations of a spring pendulum as a function of the time t are recorded for various suspended masses. From the path-time diagram $s(t)$, the period of oscillation T is determined. A plot of T^2 as a function of the suspended mass m confirms the relation $T^2 = (2\pi)^2 \cdot m/D$ (D = spring constant).

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	BMW box	524 032
1	Motion sensing element	337 631
	or	
1	Timer S	524 074
1	Combi-light barrier	337 462
1	Combi-spoked wheel	337 464
1	Multicore cable, 6-pole,	501 16
1	Helical spring, 3 N/m	352 10
1	Set of weights, each 50 g	342 61
1	Holding magnet	336 21
1	Stand base, V-shape, 28 cm	300 01
1	Stand rod, 25 cm	300 41
1	Stand rod, 150 cm	300 46
2	Leybold multiclamps	301 01
1	Clamp with hook	301 08
1	Fishing line, 10 m	309 48
1	Pair of cables, 100 cm, red and blue	501 46
1	PC with Windows 95/98/NT or higher version	



Experiment setup (see drawing)

- Clamp the stand rod in the stand base, and fasten the clamp with hook to the upper end of the stand rod.
- Suspend the spring from the hook, and elongate it via a piece of fishing line of approx. 45 cm length by means of the desired number of weights.
- Fasten a multiclamp with the motion sensing element close to the middle of the piece of fishing line.
- Lay the piece of fishing line over the deflection pulley of the motion sensing element so that the oscillations of the pendulum are transmitted to the motion sensing element without slip. In order to keep damping of the oscillation low, see to it that the axis of the spring does not deviate too much from the vertical.
- Position the holding magnet at the lower dead point of the oscillation of the spring pendulum.
- Connect the motion sensing element via the upper socket of the BMW box to the input A of the Sensor-CASSY.
- Connect the holding magnet to the output S of the Sensor-CASSY.

Experiment notes

The holding magnet provides a well-defined start of the oscillation by keeping the weights suspended for a particular measurement in the lower dead point of the oscillation. Depending on the number of suspended weights, the motion sensing element and the holding magnet have to be displaced vertically with respect to the position of the hook. The ideal position of the motion sensing element is close to the middle of the fishing line when the pendulum is in its equilibrium position.

Carrying out the experiment

■ Load settings

- Suspend the desired number of weights, and adjust the height of the holding magnet and of the motion sensing element.
- Calibrate the zero of the path SA1 in the equilibrium position of the pendulum – to do this, click the $\rightarrow 0 \leftarrow$ button in Settings SA1.
- If required, invert the sign of the path measurement ($s \leftrightarrow -s$ button in Settings SA1)
- Elongate the pendulum so that the weights are held by the holding magnet.
- Start the measurement with **F9**.
- When repeating a measurement, check the zero of the path in the equilibrium position of the pendulum before recording data.

Evaluation

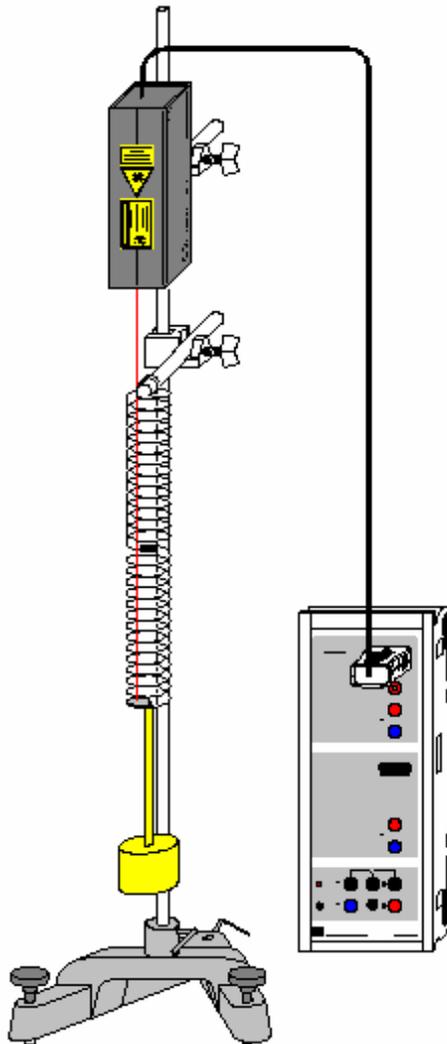
For every path-time diagram, the period of oscillation T is determined by clicking Measure Difference with the right mouse button (or **Alt+D**) and subsequently clicking two corresponding zero passages with the left mouse button. The value of the period of oscillation then displayed in the status line can be transferred into the prepared display **Input** by means of the mouse (drag & drop). In addition, the mass m associated with T has to be entered in the table. By a fit to a straight line in the display **Evaluation**, the proportionality $T^2 \sim m$ is confirmed in a further step.

The spring constant D can be determined from the slope of the straight line. Note that the straight line does not pass the origin. For a description of this experiment result, the mass of the spring has also to be taken into account.

Hint

As a complete evaluation requires the experiment to be repeated for various masses m , the period of oscillation T would have to be determined manually in each case. Alternatively, the period of oscillation T can also be determined automatically. For this you only have to open the display instrument T' in the upper line. After the oscillation has been measured, the value display there can be copied directly into the display **Input** (drag & drop).

Oscillations of a spring pendulum (with modelling)



can also be carried out with Pocket-CASSY

■ Load example

Safety note

Mind the safety notes in the instruction sheet of the laser motion sensor S.

Experiment description

A spring pendulum is excited, and the free oscillation is recorded for various masses m .

As a supplement to the investigation of the oscillations of a spring pendulum merely by way of measurement, the measured oscillation is now additionally compared with the oscillation $s(t)$ which is obtained from the equation

$$s'' = a = -D/m \cdot s.$$

The gravitational force $-m \cdot g$ is not taken into account (see Remark concerning the gravitational force). The constants D and m correspond to the spring constant and the oscillating mass. As a certain portion of the spring oscillates too, the oscillating mass is greater than the mass of the pendulum bob by approximately 20 g (=1/3 of the mass of the spring).



Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Laser motion sensor S	524 073
1	Stand rod with thread	309 00 335
1	Pair of helical springs	352 15
1	Big slotted mass hanger, 500 g	315 452
1	Slotted weight 100 g	315 456
1	Slotted weight 200 g	315 458
1	Stand rod, 1 m	300 44
1	Stand rod, 25 cm	300 41
2	Leybold multiclamps	301 01
1	Stand base, V-shape, 28 cm	300 01
1	with Windows 95/98/NT or higher version	

Alternative

Instead of the laser motion sensor S, the force sensor S, ± 50 N (524 042) can also be used for the path measurement. From the measured force F_{A1} and the spring constant D , the deflection $s_{A1}=F_{A1}/D$ can be calculated using a formula.

Experiment setup (see drawing)

Set up the spring pendulum with the large spring (diameter=3.5 mm). For the path measurement, attach a piece of retroreflecting foil to the lowest turn of the spring so that the laser spot of the motion sensor hits the foil during the entire oscillation (if necessary, attach the foil outside the spring).

Due to the reversal of its helical sense in the middle, this particular spring makes possible a free stable up and down oscillation because no torsional oscillation is excited.

Carrying out the experiment

■ Load settings

- If modelling is not yet desired, switch to the **Standard** display during the measurement.
- Define the pendulum's equilibrium position as the zero point of the path ($\rightarrow 0 \leftarrow$ in Settings s_{A1} ; before doing so, you may allow the laser motion sensor S to warm up for some minutes).
- Deflect the pendulum bob downwards.
- Start the measurement with **F9**.
- Release the pendulum bob. The measurement starts automatically when the equilibrium position at $s=0$ is passed for the first time.
- After carrying out the evaluation, repeat the experiment for various masses (slotted weights), and compare the results with the prediction of the model.

Modelling

In the present example, the two initial conditions $s(t=0)=0$ and $v(t=0)=v_0$ were chosen because the triggering took place in the zero point of the path. The initial velocity v_0 , the spring constant D and the mass m can be altered by dragging the pointer of the corresponding display instrument (or by clicking to the left or to the right of the pointer) until the model agrees with the measurement.

In order to confirm the model, you can increase the mass m and repeat the experiment with this increased mass. The new measured oscillation will again agree with the mathematical model (you may have to adjust the initial velocity).

Solution of the differential equation

The differential equation can also be solved analytically, and, with the initial conditions $s(t=0)=0$ and $v(t=0)=v_0$, we obtain

$$s(t) = v_0/\omega_0 \cdot \sin(\omega_0 \cdot t)$$

with $\omega_0 = \sqrt{D/m}$.

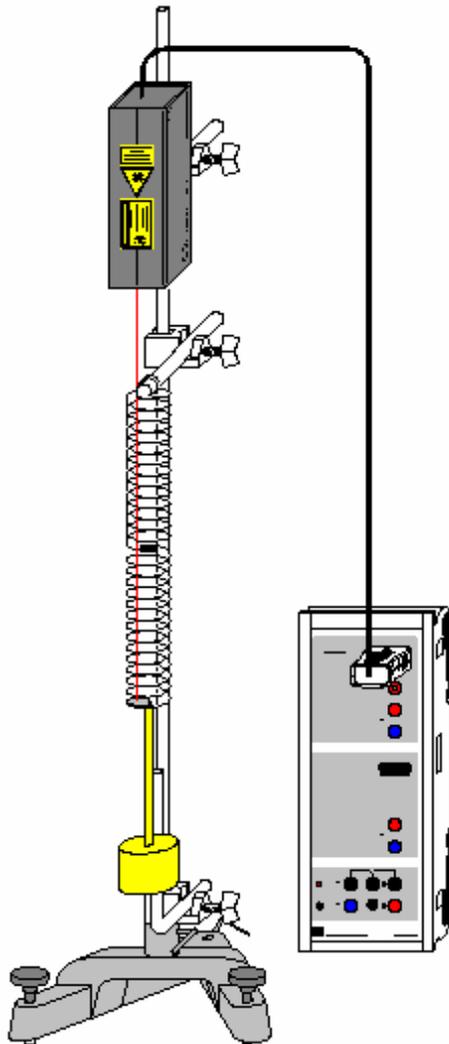
Remark concerning the gravitational force

In the model equation used above, the action of the gravitational force $m \cdot g$ on the pendulum mass m was not taken into account. Strictly speaking, the model equation should read

$$s'' = a = -D/m \cdot s - g = -D/m \cdot (s + m \cdot g/D) = -D/m \cdot (s - s_0)$$

with $s_0 = -m \cdot g/D$. This shift of the zero point of the pendulum is exactly displayed in the display **Modelling with g**, which can be selected with the mouse. As only the zero point is shifted, the gravitational force is usually omitted in the model equation. This is also done in the following examples, where solid friction, lubricant friction, laminar liquid friction and turbulent liquid friction/air friction will be investigated.

Oscillations of a spring pendulum with solid friction (with modelling)



can also be carried out with Pocket-CASSY

■ Load example

Safety note

Mind the safety notes in the instruction sheet of the laser motion sensor S.

Experiment description

As a supplement to the experiment Oscillations of a spring pendulum, the oscillating body is subjected to an additional frictional force F through sliding friction on a metal rod (Coulomb friction). The magnitude of this frictional force is constant and its direction is always opposite to that of the motion. Thus it can be written in the form $F = -F_0 \cdot \text{sgn}(v)$ with a constant F_0 . The model equation then reads

$$s'' = a = -D/m \cdot s - F_0/m \cdot \text{sgn}(v).$$

The gravitational force $-m \cdot g$ is not taken into account (see Remark concerning the gravitational force). The constants D and m correspond to the spring constant and the oscillating mass. As a certain portion of the spring oscillates too, the oscillating mass is greater than the mass of the pendulum bob by approximately 20 g (=1/3 of the mass of the spring).

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Laser motion sensor S	524 073
1	Stand rod with thread	309 00 335
1	Pair of helical springs	352 15
1	Big slotted mass hanger, 500 g	315 452
1	Stand rod, 1 m	300 44
1	Stand rod, 25 cm	300 41
1	Stand rod, bent at right angles	300 51
3	Leybold multiclamps	301 01
1	Stand base, V-shape, 28 cm	300 01
1	with Windows 95/98/NT or higher version	

Alternative

Instead of the laser motion sensor S, the force sensor S, ± 50 N (524 042) can also be used for the path measurement. From the measured force F_{A1} and the spring constant D, the deflection $s_{A1}=F_{A1}/D$ can be calculated using a formula.

Experiment setup (see drawing)

Set up the spring pendulum with the large spring (diameter=3.5 mm). For the path measurement, attach a piece of retroreflecting foil to the lowest turn of the spring so that the laser spot of the motion sensor hits the foil during the entire oscillation (if necessary, attach the foil outside the spring).

Due to the reversal of its helical sense in the middle, this particular spring makes possible a free stable up and down oscillation because no torsional oscillation is excited.

When the pendulum bob is in its equilibrium position, it should be near the middle of the bent stand rod. During the oscillation, the pendulum bob should always slide along the bent stand rod with friction.

Carrying out the experiment
■ Load settings

- If modelling is not yet desired, switch to the **Standard** display during the measurement.
- Define the pendulum's equilibrium position as the zero point of the path ($\rightarrow 0 \leftarrow$ in Settings SA1; before doing so, you may allow the laser motion sensor S to warm up for some minutes).
- Deflect the pendulum bob downwards.
- Start the measurement with **F9**.
- Release the pendulum bob. The measurement starts automatically when the equilibrium position at $s=0$ is passed for the first time.
- After carrying out the evaluation, repeat the experiment for other frictional forces, and compare the results with the prediction of the model. In order to vary the frictional force, clamp the bent stand rod in slightly varied positions.

Modelling

In the present example, the two initial conditions $s(t=0)=0$ and $v(t=0)=v_0$ were chosen because the triggering took place in the zero point of the path. The initial velocity v_0 , the spring constant D, the mass m and the frictional force F_0 can be altered by dragging the pointer of the corresponding display instrument (or by clicking to the left or to the right of the pointer) until the model agrees with the measurement.

The dependence of the model's frictional force on the velocity can be seen in the **Frictional force** display.

In order to confirm the model, you can increase the frictional force F_0 (shift the bent stand rod correspondingly). If the magnitude of the frictional force F_0 in the model is increased correspondingly and, if necessary, the initial velocity v_0 is adjusted, the new measured oscillation will again agree with the mathematical model.



Estimating the frictional force

The order of magnitude of the force of sliding friction can be estimated directly from the experiment setup. In the case of sliding friction, the magnitude of the frictional force is

$$F_0 = \mu \cdot F_N = \mu \cdot m \cdot g \cdot \sin \alpha$$

with the coefficient of sliding friction μ and the normal force $F_N = m \cdot g \cdot \sin \alpha$. In this example, the angle α between the vertical and the axis of friction was approximately 2° and $\mu = 0.12$ (coefficient of sliding friction for steel on steel), and we obtain $F_0 = 20$ mN, which is in agreement with the model.

Envelope

The linear decrease of the amplitude of the oscillation in the case of a frictional force with constant magnitude follows from energy conservation. Between two subsequent reversal points $s_1 > 0$ and $s_2 < 0$, the work performed by the friction is $W = F_0 \cdot s_1 + (-F_0) \cdot s_2$. Since the kinetic energy at the reversal points is 0, only the energy of the spring $1/2 \cdot D \cdot s_1^2$ and $1/2 \cdot D \cdot s_2^2$ is left (see also Remark concerning the gravitational force).

The energy balance thus is

$$1/2 \cdot D \cdot s_1^2 = 1/2 \cdot D \cdot s_2^2 + W \quad \text{or}$$

$$W = 1/2 \cdot D \cdot (s_1^2 - s_2^2) = 1/2 \cdot D \cdot (s_1 + s_2) (s_1 - s_2) = F_0 \cdot (s_1 - s_2).$$

From this it follows that the difference of the magnitudes of the amplitudes is $|s_1| - |s_2| = s_1 + s_2 = 2F_0/D$. Then it follows that the constant decrease of the amplitude for an entire period is $\Delta s = 4F_0/D$.

The initial amplitude s_0 of the envelope also derives from the constants of the model from

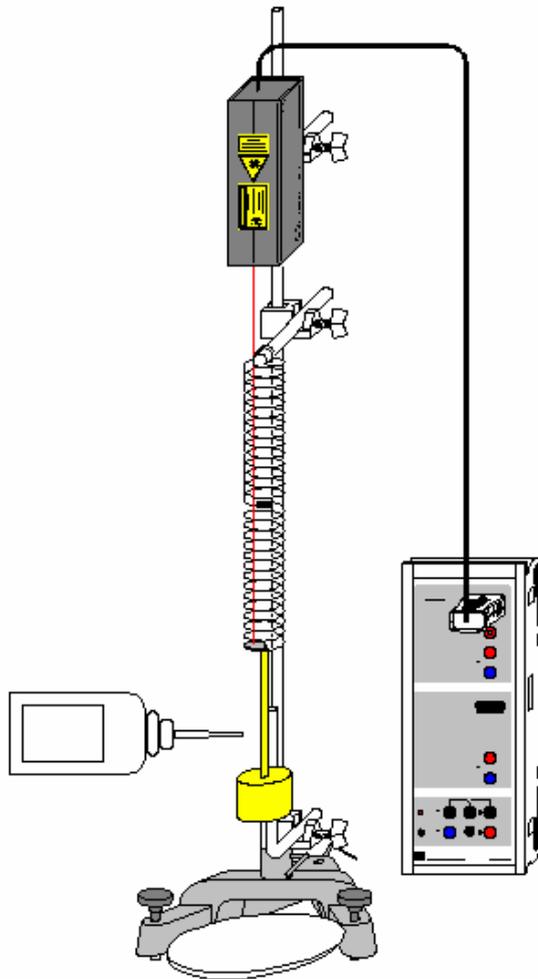
$$1/2 \cdot m \cdot v_0^2 = 1/2 \cdot D \cdot s_0^2.$$

For small frictional forces, the function describing the envelope can be written in the form

$$\pm f(t) = s_0 - 4F_0/D \cdot t/T = |v_0|/\omega_0 - 4F_0/D \cdot t/(2\pi/\omega_0) = |v_0|/\omega_0 \cdot (1 - 2/\pi \cdot F_0/m/|v_0| \cdot t) = s_0 \cdot (1 - 2/\pi \cdot k \cdot t)$$

with $\omega_0 = \sqrt{D/m}$, $s_0 = |v_0|/\omega_0$ und $k = F_0/m/|v_0|$.

Oscillations of a spring pendulum with lubricant friction (with modelling)



can also be carried out with Pocket-CASSY

■ Load example

Safety note

Mind the safety notes in the instruction sheet of the laser motion sensor S.

Experiment description

As a supplement to the experiment Oscillations of a spring pendulum, the oscillating body is subjected to an additional frictional force F through lubricant friction (Reynolds friction). The magnitude of this frictional force is proportional to the square root of the velocity, but its direction is always opposite to that of the motion. Thus it can be written in the form $F = -F_0 \sqrt{|v/v_0|} \cdot \text{sgn}(v)$. F_0 is the magnitude of the frictional force acting on the system at the initial velocity $|v_0|$. The model equation then reads

$$s'' = a = -D/m \cdot s - F_0/m \cdot \sqrt{|v/v_0|} \cdot \text{sgn}(v).$$

The gravitational force $-m \cdot g$ is not taken into account (see Remark concerning the gravitational force). The constants D and m correspond to the spring constant and the oscillating mass. As a certain portion of the spring oscillates too, the oscillating mass is greater than the mass of the pendulum bob by approximately 20 g (=1/3 of the mass of the spring).



Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Laser motion sensor S	524 073
1	Stand rod with thread	309 00 335
1	Pair of helical springs	352 15
1	Big slotted mass hanger, 500 g	315 452
1	Paraffin, viscous, 100 ml	674 0800
1	Petri dish	664 183
1	Stand rod, 1 m	300 44
1	Stand rod, 25 cm	300 41
1	Stand rod, bent at right angles	300 51
3	Leybold multiclamps	301 01
1	Stand base, V-shape, 28 cm	300 01
1	with Windows 95/98/NT or higher version	

Alternative

Instead of the laser motion sensor S, the force sensor S, ± 50 N (524 042) can also be used for the path measurement. From the measured force F_{A1} and the spring constant D , the deflection $s_{A1}=F_{A1}/D$ can be calculated using a formula.

Experiment setup (see drawing)

Set up the spring pendulum with the large spring (diameter=3.5 mm). For the path measurement, attach a piece of retroreflecting foil to the lowest turn of the spring so that the laser spot of the motion sensor hits the foil during the entire oscillation (if necessary, attach the foil outside the spring).

Due to the reversal of its helical sense in the middle, this particular spring makes possible a free stable up and down oscillation because no torsional oscillation is excited.

When the pendulum bob is in its equilibrium position, it should be near the middle of the bent stand rod. During the oscillation the viscous paraffin should always form a film between the pendulum bob and the bent stand rod. Other suitable lubricants are liquid soaps or vaseline (675 3100) mixed with oil.

Carrying out the experiment

■ Load settings

- If modelling is not yet desired, switch to the **Standard** display during the measurement.
- Apply a good deal of viscous paraffin to the bent stand rod in order that there is always a film between the pendulum bob and the stand rod during the measurement.
- Define the pendulum's equilibrium position as the zero point of the path ($\rightarrow 0 \leftarrow$ in Settings s_{A1} ; before doing so, you may allow the laser motion sensor S to warm up for some minutes).
- Deflect the pendulum bob downwards.
- Start the measurement with **F9**.
- Release the pendulum bob. The measurement starts automatically when the equilibrium position at $s=0$ is passed for the first time.

Modelling

In the present example, the two initial conditions $s(t=0)=0$ and $v(t=0)=v_0$ were chosen because the triggering took place in the zero point of the path. The initial velocity v_0 , the spring constant D , the mass m and the friction constant F_0 can be altered by dragging the pointer of the corresponding display instrument (or by clicking to the left or to the right of the pointer) until the model agrees with the measurement.

The dependence of the model's frictional force on the velocity can be seen in the **Frictional force** display.

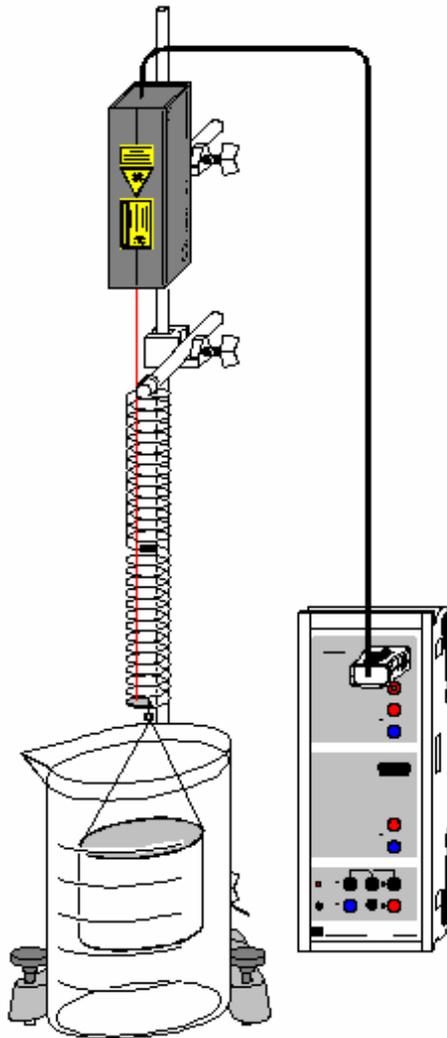
Envelope

For small frictional forces proportional to the square root of the velocity, the function describing the envelope is given by

$$\pm f(t) = |v_0|/\omega_0 \cdot (1 - 0.2782 \cdot F_0/m/|v_0| \cdot t)^2 = s_0 \cdot (1 - 0.2782 \cdot k \cdot t)^2$$

with $\omega_0 = \sqrt{D/m}$, $s_0 = |v_0|/\omega_0$ and $k = F_0/m/|v_0|$.

Oscillations of a spring pendulum with laminar liquid friction (with modelling)



can also be carried out with Pocket-CASSY

■ Load example

Safety note

Mind the safety notes in the instruction sheet of the laser motion sensor S.

Experiment description

As a supplement to the experiment Oscillations of a spring pendulum, the oscillating body is subjected to an additional frictional force F through laminar liquid friction (Stokes friction) in water. The magnitude of this frictional force is proportional to the velocity, but its direction is always opposite to that of the motion. Thus it can be written in the form $F = -F_0 \cdot v / |v_0|$. F_0 is the magnitude of the frictional force acting on the system at the initial velocity $|v_0|$. The model equation then reads

$$s'' = a = -D/m \cdot s - F_0/m \cdot v / |v_0|.$$

The gravitational force $-m \cdot g$ is not taken into account (see Remark concerning the gravitational force). The constants D and m correspond to the spring constant and the oscillating mass. As water is moved and a certain portion of the spring oscillates too, the oscillating mass is greater than the mass of the pendulum bob.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Laser motion sensor S	524 073
1	Stand rod with thread	309 00 335
1	Pair of helical springs	352 15
1	Hollow cylinder for liquid friction	342 11
1	Beaker, 3000 ml	664 134
1	Stand rod, 1 m	300 44
1	Stand rod, 25 cm	300 41
2	Leybold multiclamps	301 01
1	Stand base, V-shape, 28 cm	300 01
1	with Windows 95/98/NT or higher version	

Alternative

Instead of the laser motion sensor S, the force sensor S, ± 50 N (524 042) can also be used for the path measurement. From the measured force F_{A1} and the spring constant D , the deflection $s_{A1}=F_{A1}/D$ can be calculated using a formula.

Experiment setup (see drawing)

Set up the spring pendulum with the large spring (diameter=3.5 mm). For the path measurement, attach a piece of retroreflecting foil to the lowest turn of the spring so that the laser spot of the motion sensor hits the foil during the entire oscillation (if necessary, attach the foil outside the spring).

Due to the reversal of its helical sense in the middle, this particular spring makes possible a free stable up and down oscillation because no torsional oscillation is excited.

When the hollow cylinder is in its equilibrium position, it should be near the middle of the water-filled beaker. In order to obtain approximately laminar friction, align the hollow cylinder vertically as precisely as possible.

Carrying out the experiment

■ Load settings

- If modelling is not yet desired, switch to the **Standard** display during the measurement.
- Define the pendulum's equilibrium position as the zero point of the path ($\rightarrow 0 \leftarrow$ in Settings s_{A1} ; before doing so, you may allow the laser motion sensor S to warm up for some minutes).
- Deflect the hollow cylinder downwards.
- start the measurement with **F9**.
- Release the hollow cylinder. The measurement starts automatically when the equilibrium position at $s=0$ is passed for the first time.

Modelling

In the present example, the two initial conditions $s(t=0)=0$ and $v(t=0)=v_0$ were chosen because the triggering took place in the zero point of the path. The initial velocity v_0 , the spring constant D , the mass m and the friction constant F_0 can be altered by dragging the pointer of the corresponding display instrument (or by clicking to the left or to the right of the pointer) until the model agrees with the measurement.

The dependence of the model's frictional force on the velocity can be seen in the **Frictional force** display.

Solution of the differential equation

In contrast to Coulomb friction, Reynolds friction and Newton friction, the differential equation can be solved analytically in the case of Stokes friction. With the initial conditions $s(t=0)=0$ and $v(t=0)=v_0$,

$$s(t) = v_0/\omega \sin(\omega \cdot t) \exp(-1/2 \cdot k \cdot t)$$

is obtained, with $\omega_0=\text{sqr}(D/m)$, $\omega=\text{sqr}(\omega_0^2-k^2/4)$ and $k=F_0/m/|v_0|$.

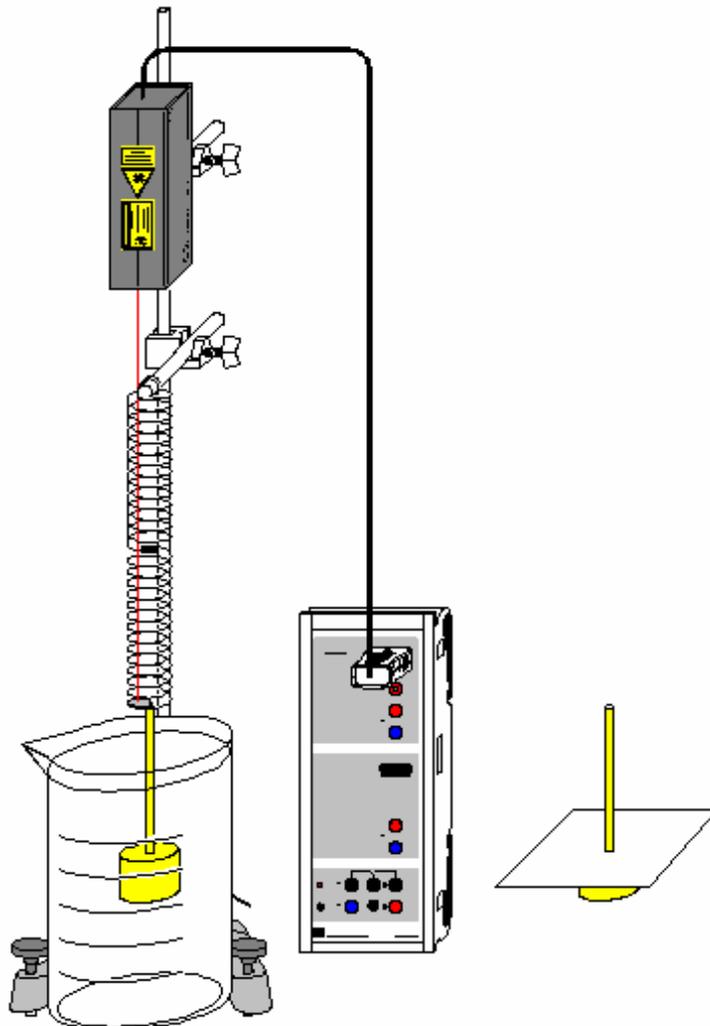
**Envelope**

For frictional forces proportional to the velocity, the function describing the envelope therefore has the form

$$\pm f(t) = s_0 \cdot \exp(-1/2 \cdot k \cdot t)$$

with $s_0 = |v_0|/\omega$.

Oscillations of a spring pendulum with turbulent liquid friction/air friction (with modelling)



can also be carried out with Pocket-CASSY

- Load example (liquid friction)
- Load example (air friction)

Safety note

Mind the safety notes in the instruction sheet of the laser motion sensor S.

Experiment description

As a supplement to the experiment Oscillations of a spring pendulum, the oscillating body is subjected to an additional frictional force F through turbulent liquid friction or turbulent air friction (Newton friction). The magnitude of this frictional force is proportional to the square of the velocity, but its direction is always opposite to that of the motion. Thus it can be written in the form $F = -F_0 \cdot (v/v_0)^2 \cdot \text{sgn}(v)$. F_0 is the magnitude of the frictional force acting on the system at the initial velocity $|v_0|$. The model equation then reads

$$s'' = a = -D/m \cdot s - F_0/m \cdot (v/v_0)^2 \cdot \text{sgn}(v).$$

The gravitational force $-m \cdot g$ is not taken into account (see Remark concerning the gravitational force).



The constants D and m correspond to the spring constant and the oscillating mass. As water is moved and a certain portion of the spring oscillates too, the oscillating mass is greater than the mass of the pendulum bob.

From the friction constant F_0 the drag coefficient (c_w value) for the cylindrical pendulum bob can be estimated.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Laser motion sensor S	524 073
1	Stand rod with thread	309 00 335
1	Pair of helical springs	352 15
1	Big slotted mass hanger, 500 g	315 452
1	Beaker, 3000 ml	664 134
1	Stand rod, 1 m	300 44
1	Stand rod, 25 cm	300 41
2	Leybold multiclamps	301 01
1	Stand base, V-shape, 28 cm	300 01
1	with Windows 95/98/NT or higher version	

Alternatives

Instead of the laser motion sensor S, the force sensor S, ± 50 N (524 042) can also be used for the path measurement. From the measured force F_{A1} and the spring constant D , the deflection $s_{A1} = F_{A1}/D$ can be calculated using a formula.

For investigating air friction, attach a piece of cardboard to the pendulum bob to create air friction.

Experiment setup (see drawing)

Set up the spring pendulum with the large spring (diameter=3.5 mm). For the path measurement, attach a piece of retroreflecting foil to the lowest turn of the spring so that the laser spot of the motion sensor hits the foil during the entire oscillation (if necessary, attach the foil outside the spring).

Due to the reversal of its helical sense in the middle, this particular spring makes possible a free stable up and down oscillation because no torsional oscillation is excited.

When the pendulum bob is in its equilibrium position, it should be near the middle of the water-filled beaker.

Carrying out the experiment

- Load settings (liquid friction)
- Load settings (air friction)
- If modelling is not yet desired, switch to the **Standard** display during the measurement.
- Define the pendulum's equilibrium position as the zero point of the path ($\rightarrow 0 \leftarrow$ in Settings s_{A1} ; before doing so, you may allow the laser motion sensor S to warm up for some minutes).
- Deflect the pendulum bob downwards.
- Start the measurement with **F9**.
- Release the pendulum bob. The measurement starts automatically when the equilibrium position at $s=0$ is passed for the first time.

Modelling

In the present example, the two initial conditions $s(t=0)=0$ and $v(t=0)=v_0$ were chosen because the triggering took place in the zero point of the path. The initial velocity v_0 , the spring constant D , the mass m and the friction constant F_0 can be altered by dragging the pointer of the corresponding display instrument (or by clicking to the left or to the right of the pointer) until the model agrees with the measurement.

The dependence of the model's frictional force on the velocity can be seen in the **Frictional force** display.

The drag force F_L for the pendulum bob around which the liquid flows is given by

$$F_L = c_w \cdot \frac{1}{2} \cdot \rho \cdot v^2 \cdot A = F_0 \cdot (v/v_0)^2$$

with the drag coefficient c_w , the dynamic pressure $p = \frac{1}{2} \cdot \rho \cdot v^2$ and the backwater surface $A = \pi \cdot r^2$. The drag coefficient is the ratio of the measured force and the imagined dynamic force $p \cdot A$. We obtain

$$c_w = 2F_0/v_0^2/(\rho \cdot A).$$

In the present example, we have $r = 2.5 \text{ cm}$ and $\rho = 1 \text{ g/cm}^3$, and therefore $\rho \cdot A = 1.96 \text{ kg/m}$. The modelling process gives $F_0 = 0.1828 \text{ N}$ and $v_0 = 0.325 \text{ m/s}$. Thus we find $c_w = 1.7$.

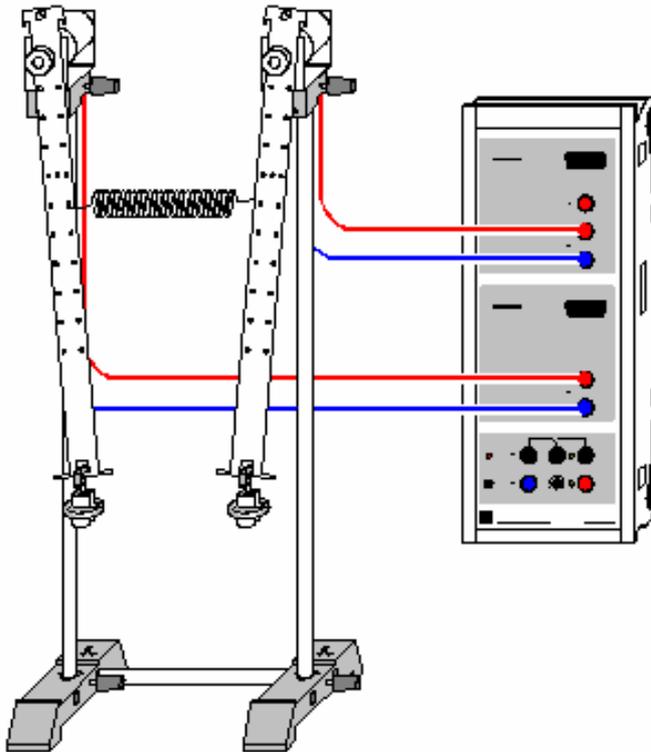
Envelope

For small frictional forces proportional to the square of the velocity, the function describing the envelope is given by

$$\pm f(t) = |v_0| \cdot \sqrt{(m/D)/(1+4/3\pi \cdot F_0/m/|v_0| \cdot t)} = s_0/(1+4/3\pi \cdot k \cdot t)$$

with $\omega_0 = \sqrt{D/m}$, $s_0 = |v_0|/\omega_0$ and $k = F_0/m/|v_0|$.

Coupled pendulums with two tachogenerators



can also be carried out with Pocket-CASSY

■ Load example

Experiment description

Two coupled pendulums swing in phase with a frequency f_1 when they are deflected from the rest position by the same distance. When the second pendulum is deflected in the opposite direction, the two pendulums oscillate in opposing phase with the frequency f_2 . Deflecting only one pendulum generates a coupled oscillation with the frequency

$$f_n = (f_1 + f_2) / 2$$

in which oscillation energy is transferred back and forth between the two pendulums. The first pendulum comes to rest after a certain time, while the second pendulum simultaneously reaches its greatest amplitude. The time from one standstill of a pendulum to the next is called T_s . For the corresponding beat frequency, we can say

$$f_s = |f_1 - f_2|.$$

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Pair of bar pendulums, 40 cm	346 03
1	Set of weights	340 85
2	Support clips, for plugging in	314 04
1	Helical spring, 3 N/m	352 10
2	STE tachogenerators	579 43
2	Clamping blocks MF	301 25
1	Stand rod, 25 cm, d = 10 cm	301 26
2	Stand rods, 50 cm, d = 10 cm	301 27
2	Stand bases MF	301 21

- 2 Pair of cables, 1 m, red and blue 501 46
 1 PC with Windows 95/98/NT
 or higher version

Experiment setup (see drawing)

The motions of the pendulums are transmitted to the tachogenerators. The voltages of the tachogenerators are measured at Sensor-CASSY inputs A and B. You can attach the coupling spring at different heights to vary the coupling.

Carrying out the experiment

- Load settings
 - Start the experiment with **F9** and deflect both pendulums in phase (measurement stops after 30 s).
 - Start the experiment with **F9** and deflect both pendulums in opposing phase (measurement stops after 30 s).
 - Start the experiment with **F9** and deflect only the first pendulum (measurement stops after 30 s).

Evaluation

Click on the **Natural Oscillations** display to view the two natural oscillations

$$U_+ = U_A + U_B$$

$$U_- = U_A - U_B$$

When the pendulums are excited in phase, only U_+ oscillates with a frequency f_1 ; only U_- oscillates for opposing phase oscillation and has the frequency f_2 . Only when the single pendulum alone is deflected does the system oscillate with both natural frequencies, thus generating the typical beat in the **Standard** display.

To determine the beat frequency f_s and the new oscillation frequency f_n , you can mark e.g. the diagram with vertical lines or measure the difference directly (to increase the accuracy you should average the values over several periods when determining the oscillation frequency).

In this example we obtain $f_1 = 0.875$ Hz, $f_2 = 0.986$ Hz, $f_n = 0.93$ Hz, $f_s = 0.11$ Hz, which closely confirms the theory $f_n = (f_1 + f_2) / 2 = 0.93$ Hz and $f_s = |f_1 - f_2| = 0.11$ Hz.

In the **Frequency Spectrum**, you can compare the frequencies and amplitudes U_+ , U_- and U_A . The easiest way to determine the frequency is to find the peak centers.

Theory

When we apply suitable approximations (small deflections, negligible weight of coupling spring and pendulum bar, no damping), the motion equations of the pendulum bodies are as follows:

$$F_1 = ma_1 = -Dx_1 + C(x_2 - x_1)$$

$$F_2 = ma_2 = -Dx_2 - C(x_2 - x_1)$$

$-Dx_i$ (where $D = mg/l$) represents the restoring force of the individual pendulum, and $C(x_2 - x_1)$ describes the force of the coupling between the two pendulums. These resolve to the superposition

$$x(t) = A \cos(\omega_1 \cdot t) + B \cos(\omega_2 \cdot t)$$

with the fundamental frequencies ω_1 and ω_2 . The specific initial conditions provide the values for A and B:

In-phase excitation gives us $A = x_0$, $B = 0$ (harmonic oscillation with ω_1)

Opposing phase excitation gives us $A = 0$, $B = x_0$ (harmonic oscillation with ω_2)

Deflection of one pendulum gives us $A = B = x_0 / 2$.

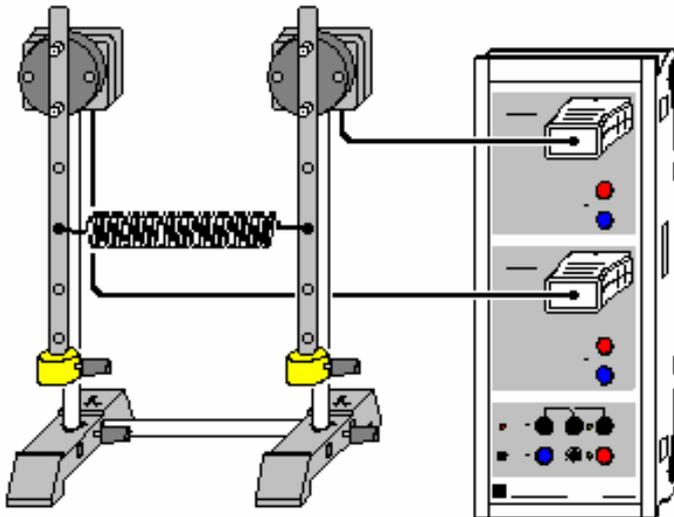
In the latter case we can say:

$$x(t) = 1/2 \cdot x_0 (\cos(\omega_1 \cdot t) + \cos(\omega_2 \cdot t)) = x_0 \cos(1/2 \cdot \omega_s \cdot t) \cos(\omega_n \cdot t)$$

where $\omega_s = | \omega_1 - \omega_2 |$ and $\omega_n = (\omega_1 + \omega_2) / 2$ or $f_s = |f_1 - f_2|$ and $f_n = (f_1 + f_2) / 2$.

When the difference between frequencies f_1 and f_2 is small, this equation describes an oscillation with the frequency f_n which is modulated by the slower frequency f_s – i.e. a beat.

Coupled pendulums with two rotary motion sensors



can also be carried out with Pocket-CASSY

■ Load example

Experiment description

Two coupled pendulums swing in phase with a frequency f_1 when they are deflected from the rest position by the same distance. When the second pendulum is deflected in the opposite direction, the two pendulums oscillate in opposing phase with the frequency f_2 . Deflecting only one pendulum generates a coupled oscillation with the frequency

$$f_n = (f_1 + f_2) / 2$$

in which oscillation energy is transferred back and forth between the two pendulums. The first pendulum comes to rest after a certain time, while the second pendulum simultaneously reaches its greatest amplitude. The time from one standstill of a pendulum to the next is called T_s . For the corresponding beat frequency, we can say

$$f_s = |f_1 - f_2|.$$

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
2	Rotary motion sensors S	524 082
2	Physical pendulums	346 20
1	Helical spring, 3 N/m	352 10
1	Stand rod, 25 cm, d = 10 mm	301 26
2	Stand bases MF	301 21
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The pendulum is attached with coupling plugs to the wheel of the rotary motion sensor and the masses are attached to the lower end of the pendulum. To vary the coupling, the coupling spring can be connected at different heights.

Carrying out the experiment

■ Load settings

- Define the zero points in the equilibrium position of the pendulums ($\rightarrow 0 \leftarrow$ in settings α_{A1} and α_{B1})
- Start the experiment with **F9** and deflect both pendulums in phase (measurement stops after 40 s).
- Start the experiment with **F9** and deflect both pendulums in opposing phase (measurement stops after 40 s).
- Start the experiment with **F9** and deflect only the first pendulum (measurement stops after 40 s).

Evaluation

Click on the **Natural Oscillations** display to view the two natural oscillations

$$\alpha_+ = \alpha_A + \alpha_B$$

$$\alpha_- = \alpha_A - \alpha_B$$

When the pendulums are excited in phase, only α_+ oscillates with a frequency f_1 ; only α_- oscillates for opposing phase oscillation and has the frequency f_2 . Only when the single pendulum alone is deflected does the system oscillate with both natural frequencies, thus generating the typical beat in the **Standard** display.

To determine the beat frequency f_s and the new oscillation frequency f_n , you can mark e.g. the diagram with vertical lines or measure the difference directly (to increase the accuracy you should average the values over several periods when determining the oscillation frequency).

In this example we obtain $f_1 = 1.059$ Hz, $f_2 = 1.151$ Hz, $f_n = 1.097$ Hz, $f_s = 0.092$ Hz, which closely confirms the theory $f_n = (f_1 + f_2) / 2 = 1.105$ Hz and $f_s = |f_1 - f_2| = 0.092$ Hz.

In the **Frequency Spectrum**, you can compare the frequencies and amplitudes α_+ , α_- and α_A . The easiest way to determine the frequency is to find the peak centers.

Theory

When we apply suitable approximations (small deflections, negligible weight of coupling spring and pendulum bar, no damping), the motion equations of the pendulum bodies are as follows:

$$F_1 = ma_1 = -Dx_1 + C(x_2 - x_1)$$

$$F_2 = ma_2 = -Dx_2 - C(x_2 - x_1)$$

$-Dx_i$ (where $D = mg/l$) represents the restoring force of the individual pendulum, and $C(x_2 - x_1)$ describes the force of the coupling between the two pendulums. These resolve to the superposition

$$x(t) = A \cos(\omega_1 \cdot t) + B \cos(\omega_2 \cdot t)$$

with the fundamental frequencies ω_1 and ω_2 . The specific initial conditions provide the values for A and B:

In-phase excitation gives us $A = x_0$, $B = 0$ (harmonic oscillation with ω_1)

Opposing phase excitation gives us $A = 0$, $B = x_0$ (harmonic oscillation with ω_2)

Deflection of one pendulum gives us $A = B = x_0 / 2$.

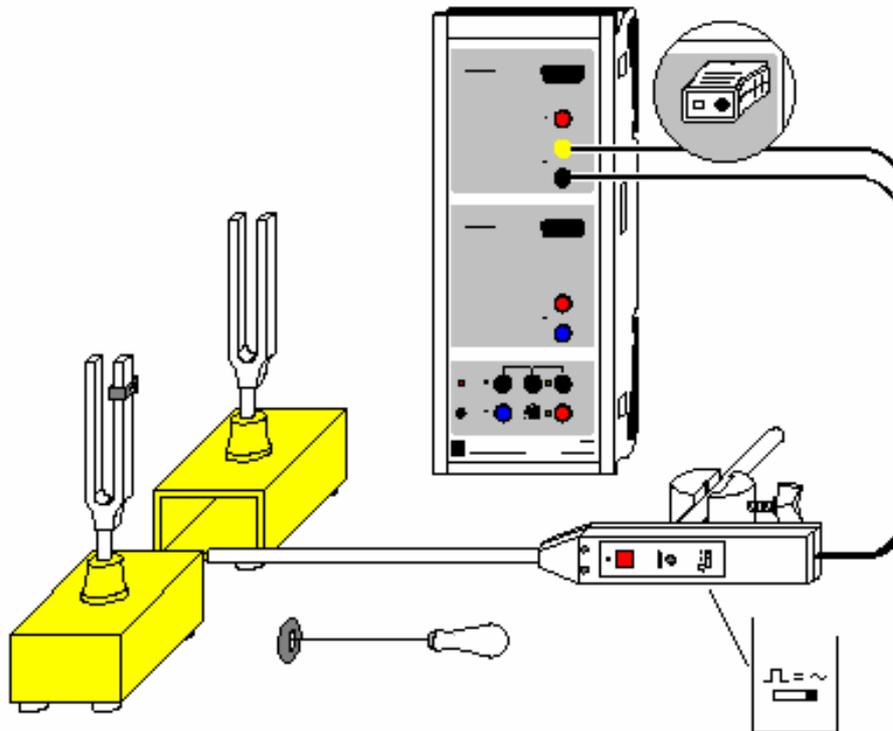
In the latter case we can say:

$$x(t) = 1/2 \cdot x_0 (\cos(\omega_1 \cdot t) + \cos(\omega_2 \cdot t)) = x_0 \cos(1/2 \cdot \omega_s \cdot t) \cos(\omega_n \cdot t)$$

where $\omega_s = | \omega_1 - \omega_2 |$ and $\omega_n = (\omega_1 + \omega_2) / 2$ or $f_s = | f_1 - f_2 |$ and $f_n = (f_1 + f_2) / 2$.

When the difference between frequencies f_1 and f_2 is small, this equation describes an oscillation with the frequency f_n which is modulated by the slower frequency f_s – i.e. a beat.

Acoustic beats



can also be carried out with Pocket-CASSY

- Load example (multi-purpose microphone)
- Load example (microphone S)

Experiment description

This experiment records a beat caused by two tuning forks having slightly different frequencies. The individual frequencies f_1 and f_2 , the new oscillation frequency f_n and the beat frequency f_s are determined and compared with the theoretical values

$$f_n = (f_1 + f_2) / 2 \text{ and } f_s = |f_1 - f_2|.$$

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Pair of resonance tuning forks	414 72
1	Multi-purpose microphone with Base	586 26 300 11
	or	
1	Microphone S	524 059
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Position the two tuning forks and the multipurpose microphone and connect the latter to input A of Sensor-CASSY (don't forget to set the microphone to "Signal" mode and switch it on). "Mistune" one of the tuning forks slightly by attaching an additional weight.

Carrying out the experiment

- Load settings (multi-purpose microphone)
- Load settings (microphone S)
 - Strike the first tuning fork and start the measurement with **F9**.
 - Optimize the signal strength using the control on the microphone.
 - Determine the frequency f_1 (e.g. by marking the **Standard** display with vertical lines or finding the peak center in the **Frequency Spectrum**).
 - Delete the measurement with **F4**.
 - Strike the second tuning fork and start the measurement with **F9**.
 - Find frequency f_2 .
 - Delete the measurement with **F4**.
 - Strike both tuning forks equally hard and start the measurement with **F9**.

Evaluation

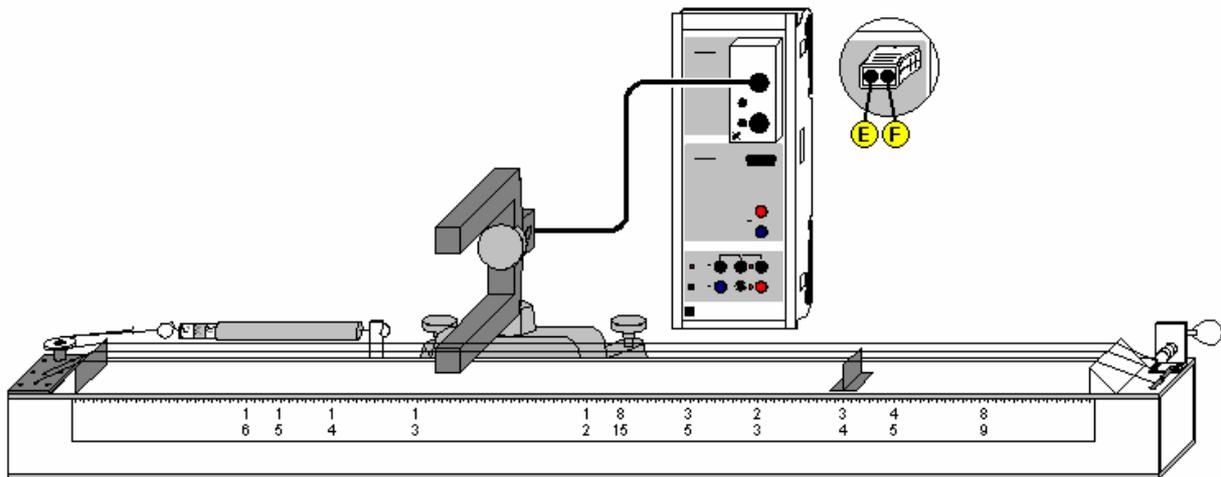
When the amplitudes of the two tuning forks are equal, the nodes and antinodes in the beat become clearly distinguished. The beat frequency f_s is determined from the interval T_s between two nodes as $f_s = 1/T_s$.

To ensure satisfactory accuracy in determining the new oscillation period T_n , you should average the measurements over 10 periods before determining the new oscillation frequency as $f_n = 1/T_n$. To determine the time differences you can e.g. insert vertical lines in the diagram or measure the difference directly.

In this example we obtain $f_1 = 425$ Hz, $f_2 = 440$ Hz, $f_n = 433$ Hz, $f_s = 14.5$ Hz, which closely confirms the theory $f_n = (f_1 + f_2) / 2 = 432.5$ Hz and $f_s = |f_1 - f_2| = 15$ Hz.

Click on the **Frequency Spectrum** to read out the two frequencies f_1 and f_2 of the tuning forks and their amplitudes. The easiest way to determine the frequency is to find the peak centers.

String vibrations



can also be carried out with Pocket-CASSY

- Load example (constant string length $L = 1.2 \text{ m}$)
- Load example (constant tensile force $F = 60 \text{ N}$)

Experiment description

When a string is stretched, the string length L is equal to half the wavelength of the fundamental mode: $L = \lambda/2$. Therefore the frequency f of the fundamental tone of the string is

$$f = c/(2L),$$

where c is the phase velocity of the string. It depends on the tensile force F , the cross-sectional area A , and the density ρ . This dependence is described by the following relation:

$$c^2 = F/(A\rho)$$

In this experiment, the vibrational frequency f and thus the pitch of the string is measured as a function of the string length L and the tensile force F . For this the CASSY is used as a high-resolution stopwatch for measuring the period of vibration T . The relations $f^2 \sim F$ and $f \sim 1/L$ are confirmed.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Timer box or Timer S	524 034 or 524 074
1	Forked light barrier, infrared	337 46
1	Multicore cable, 6-pole, 1.5 m	501 16
1	Monochord	414 01
1	Precision dynamometer, 100 N	314 201
1	Stand base, V-shape, 20 cm	300 02
1	Stand rod, 10 cm	300 40
1	Stand rod, 25 cm	300 41
1	Leybold multiclamp	301 01
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The period of vibration T is measured by means of a forked light barrier, which is positioned between the wooden resonance box of the monochord and the string. The light barrier is connected to the input A of the Sensor-CASSY via the timer box by means of the multicore cable.

Experiment notes

The period of vibration T is determined unambiguously if the passages of the string through its position of rest are determined. For this the string has to be positioned so that the red LED on the side of the forked light barrier does not shine when the string is in its position of rest. The forked light barrier has two small apertures for the infrared beam. The best results are obtained if the string is positioned immediately over the smaller one of the two apertures (if necessary, turn the light barrier correspondingly).

The string is made vibrate by plucking it parallel to the surface of the resonance box.

The tensile force F is measured manually with the precision dynamometer. For this the hook is replaced with the precision dynamometer. The tension of the string on the monochord can be varied by means of a tuning key. In the first experiment, the best results are obtained if a string tension of 100 N is adjusted at first and then the measurement is carried out starting from high tension to lower tensions.

In the measurement with varying string length L , the string length is varied by displacing the bridge. When plucking the string, do not touch the part which does not vibrate with the other hand. For an optimal measurement of the period of vibration T , always position the forked light barrier in the middle of the vibrating part of the string.

Carrying out the experiment

a) Variation of the tensile force

■ Load settings (constant string length L)

- Adjust the desired string tension F by turning the tuning key.
- Write the force F displayed on the dynamometer in the prepared column of the table.
- Position the forked light barrier under the string at rest and check whether the red LED is out; if necessary, position the forked light barrier anew.
- Make the string vibrate by plucking it (while the string vibrates, the LED shines), and immediately transfer the displayed measured value into the table by pressing the **F9** key.

b) Variation of the string length

■ Load settings (constant tensile force F)

- Adjust the desired string length by positioning the bridge.
- Read the string length, and write it in the prepared column.
- Check whether the red LED is out; if necessary, position the forked light barrier anew.
- Make the string vibrate by plucking it (while the string vibrates, the LED shines), and immediately transfer the displayed measured value into the table by pressing the **F9** key.

Evaluation

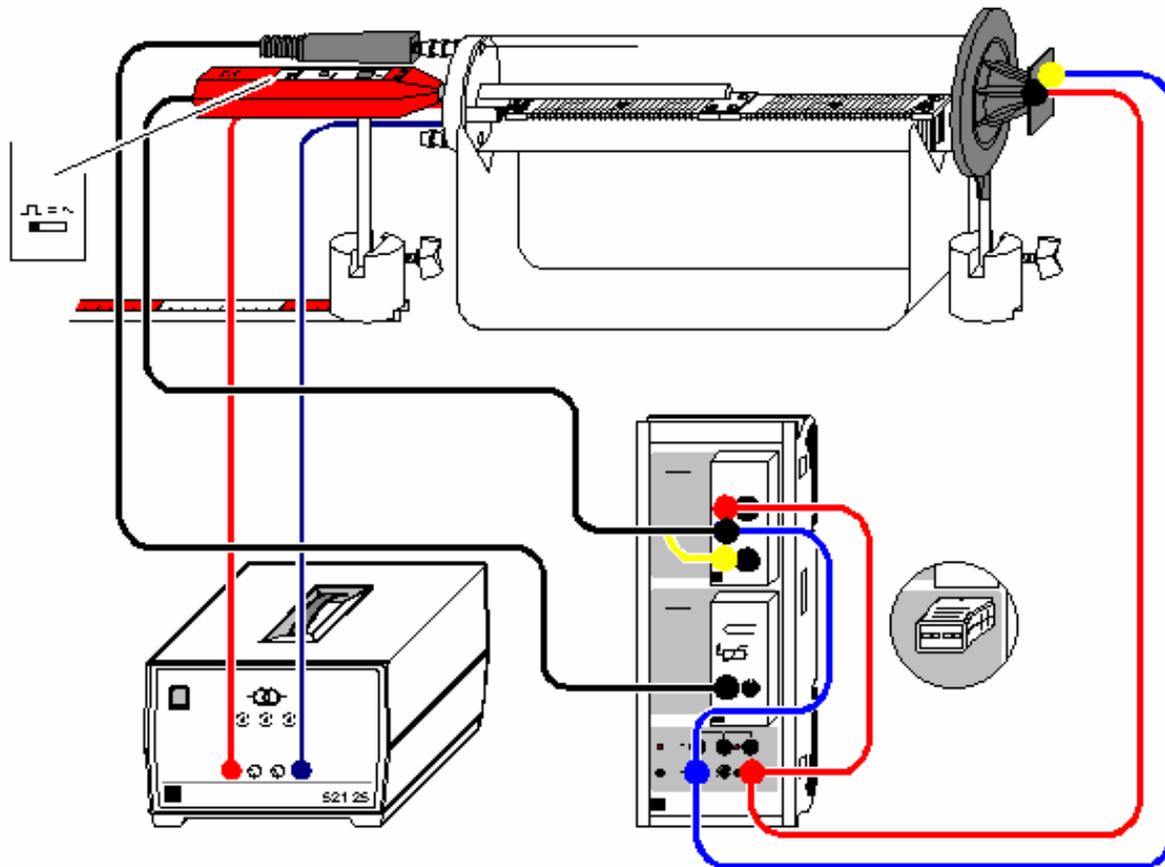
a) Variation of the tensile force

The $T(F)$ and the $f(F)$ diagram already appear while the measurement is running. In the prepared display **Evaluation**, the square of the frequency f is plotted against the tensile force F . The relation $f^2 \sim F$ can be confirmed by fitting a line through the origin (right mouse button). That means, the pitch, and thus the frequency, of a vibrating string increases with increasing string tension. Correspondingly, the pitch of a string can be lowered by decreasing the string tension.

b) Variation string length

The $T(L)$ and the $f(L)$ diagram already appear while the measurement is running. In the prepared display **Evaluation**, the square of the frequency f is plotted against $1/L$. The relation $f \sim 1/L$ can be confirmed by fitting a line through the origin (right mouse button). That means, the pitch, and thus the frequency, of a vibrating string increases with decreasing length.

Velocity of sound in air



■ Load example

Experiment description

This experiment determines the speed of propagation of a sound pulse in air, and thus, since the group and phase velocities coincide, the velocity of sound. The sound pulse is generated by "shaking" the membrane of a loudspeaker with a steep voltage edge; this motion causes the pressure variation in the air. The sound pulse is registered by a microphone at a specified distance from the loudspeaker.

To determine the velocity of sound c , we measure the time t between generation of the pulse at the loudspeaker and registration at the microphone. As the exact point of origin of the sound pulse in the loudspeaker cannot be determined directly, two measurements are conducted, once with the microphone located at point s_1 , and one at s_2 . The velocity of sound is determined from the path difference $\Delta s = s_1 - s_2$ and the corresponding difference in the transit time $\Delta t = t_1 - t_2$ as $c = \Delta s / \Delta t$.

The apparatus for sound and velocity lets you heat the air with a heater; at the same time, this apparatus blocks out ambient effects such as temperature differences and air convection which can interfere with measuring. In this system the pressure p remains constant (actual ambient barometric pressure). As the temperature T rises, the density ρ decreases and the velocity of sound c increases.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Timer box	524 034
1	Temperature box	524 045
1	Temperature sensor NiCr-Ni	666 193
	or	
1	NiCr-Ni adapter S	524 0673
1	Temperature sensor NiCr-Ni, type K	529 676

1	Apparatus for sound and velocity	413 60
1	Stand for coils and tubes	516 249
1	Tweeter	587 07
1	Multi-purpose microphone	586 26
1	Transformer 12 V/3.5 A, e.g.	521 25
1	Scaled metal rail, 500 mm long	460 97
2	Bases	300 11
1	Pair of cables, 25 cm, red and blue	501 44
2	Pairs of cables, 1 m, red and blue	501 46
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

- Attach the heater of the apparatus for sound and velocity in the plastic tube on the plug pins of the cover.
- Place the plastic tube on the stand for tubes and coils and push the tweeter against it so that it seals the plastic tube as tightly as possible.
- Insert the multipurpose microphone approx. 1 cm deep into the middle hole of the cover and align it so that it moves parallel to the plastic tube when displaced. Set the multipurpose microphone to "Trigger" mode; don't forget to turn it on!
- Place the scaled metal rail directly beneath the base.
- Plug in the timer box at input A and the temperature box at input B on Sensor-CASSY and set up the circuit as shown in the drawing; set the maximum output voltage at the voltage source S.

Safety notes

The plastic tube of the apparatus for sound and velocity can be destroyed by excessive temperatures.

- Do not heat it above 80 °C.
- Do not exceed the maximum permissible voltage of 25 V (approx. 5 A) for the heating filament.

Carrying out the experiment

a) Measuring at room temperature

- Load settings (the sound pulses are already recorded and the transit times Δt_{A1} displayed).
- Store multiple single measurements with **F9**.
- Slide the multipurpose microphone all the way into the plastic tube and read off the change in distance Δs from the scaled metal rail.
- Store multiple single measurements with **F9**.
- Determine the velocity of sound using $c = \Delta s / \Delta t$ (determine the mean values of the transit times in the diagram using **Draw Mean Value**).

b) Measuring as a function of temperature

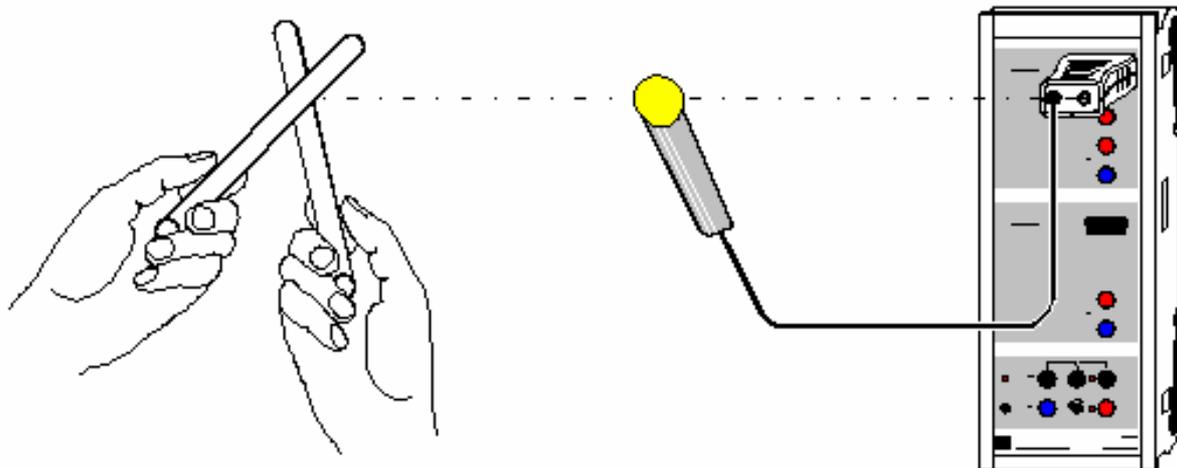
- Load settings (the sound pulses are already recorded and the transit times t_{A1} displayed).
- Pull out the universal microphone.
- At room temperature, determine the transit time Δt_{A1} again and, using the velocity of sound c already determined, calculate the distance $s = c \cdot \Delta t_{A1}$ between the microphone and the speaker and write this value in the table (click on the first row in the s -column).
- Connect the heating filament to the voltage supply (12 V / approx. 3.5 A) via the sockets in the cover of the apparatus.
- Save the current transit times with **F9** (e.g. every 5 °C).

Evaluation

Once you determine the velocity of sound at room temperature in a) and thus the distance s between the microphone and the speaker in b), the software calculates the correct sound velocity c for each transit time Δt_{A1} simultaneously. The sound velocities are plotted in the **Temperature** display as a function of the temperature while the measurement is running. By fitting a straight line you can easily confirm the literature value of

$$c = (331.3 + 0.6 \cdot \vartheta / ^\circ\text{C}) \text{ m/s}$$

Determining the velocity of sound in air with 2 microphones



can also be carried out with Pocket-CASSY. If Pocket-CASSY is used on old computers, the stop pulse may sometimes be recognized too late. In this case, things are put right by reducing the distance between the two microphones or by using a new computer under Windows XP.

■ Load example

Experiment description

In this experiment, the propagation velocity of a sound pulse is determined, and thus - as the group and phase velocity are equal - the velocity of sound. The sound pulse is generated by banging two stand rods together. This causes a pressure fluctuation in the air. The sound pulse is recorded in succession by two microphones which are at a distance Δs from each other.

For determining the velocity of sound c the time interval Δt between the two recordings at the microphones is measured. The velocity of sound is then obtained from the path difference Δs and the associated run time difference Δt . It is $c = \Delta s / \Delta t$.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Microphone S	524 059
1	Wooden ruler	311 03
2	Stand rods, 47 cm	300 42
1	Condenser microphone with 3.5 mm jack e. g. from a computer dealer	
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The external microphone is set up in front of the internal microphone at a distance $\Delta s = 0.50$ m. When sound is generated by means of the stand rods, the source of sound has to be located on the direct extension of the line between the two microphones. Moreover, sound coupling via the table should be as weak as possible because otherwise too high velocities may be measured.

Carrying out the experiment

■ Load settings

- Start the measurement with **F9**.
- Trigger several measurements by banging the stand rods together. Thereby noise from the surroundings, which might affect the measurement, should be avoided.
- Stop the measurement with **F9**.
- Increase the distance Δs between the microphones.
- Repeat the measurement.

Evaluation

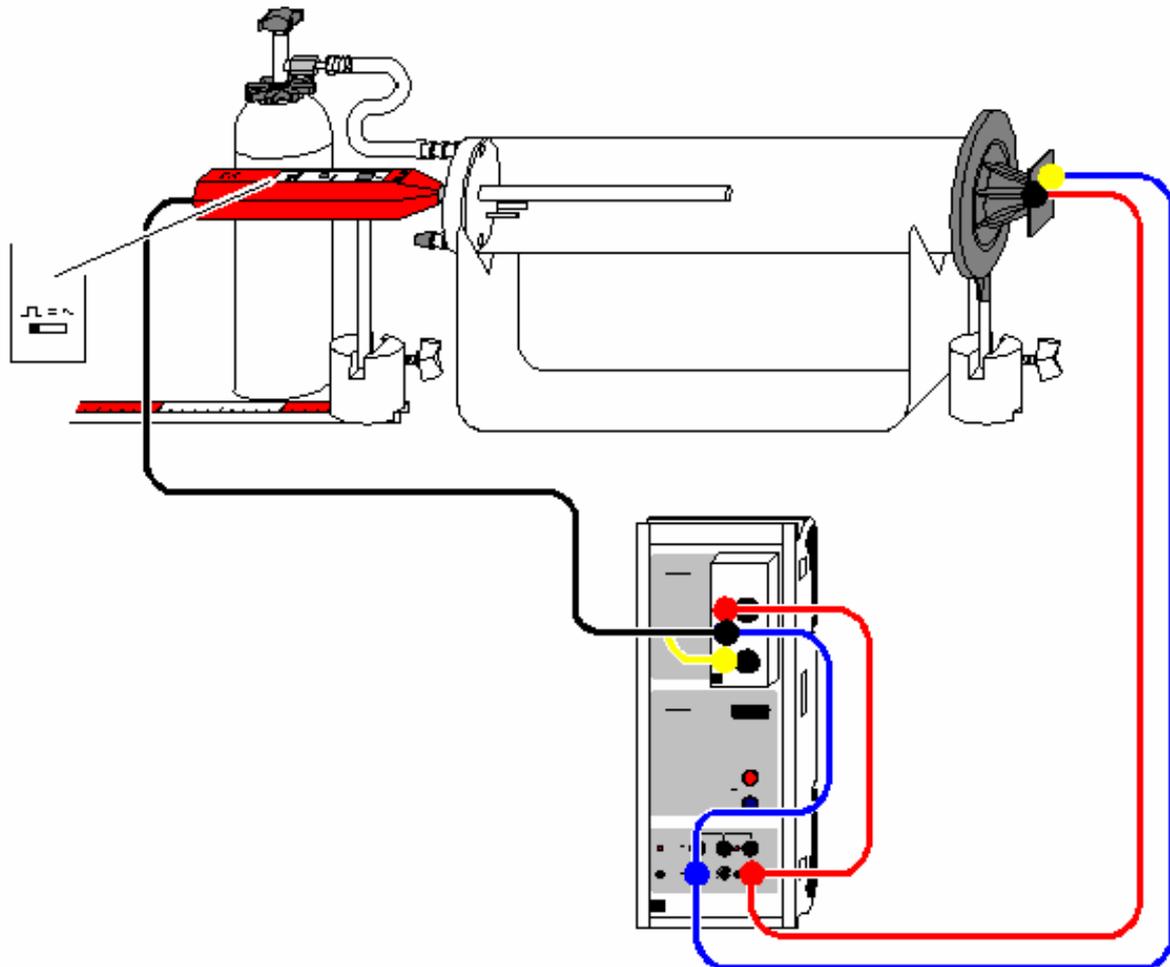
During the measurement, noise from the surroundings may lead to faulty measurements, which can easily be deleted. For this, just click the faulty value and delete it (backspace).

Next determine the mean values of the run times in the diagram using **Draw Mean Value**. There is a comfortable way of taking every mean value into the display **Velocity of sound** (mouse click) immediately after it has been calculated by shifting it from the Status line into the new table (Drag & Drop).

In addition, the associated distance Δs between the two microphones is entered into the corresponding column, whereby a $\Delta s(\Delta t)$ diagram is generated. The slope of the straight line in this diagram is $c = \Delta s / \Delta t$.

The velocity of sound obtained at room temperature is approx. $c = 346$ m/s.

Velocity of sound in gases



■ Load example

Be careful when handling Minican gas cans

The cans are pressurized; use only the fine regulating valve (660 980) to discharge gas.

Protect the cans against sun light or warming over 50 °C.

Do not use force to open the cans.

Only dispose of completely emptied cans.

Never refill the cans.

Experiment description

In this experiment, the velocity of propagation of a sound pulse in carbon dioxide and in the noble gases helium and neon is determined. As sound waves in gases exhibit only little dispersion, – i.e., the group and phase velocity are equal to a good approximation when sound propagates in gases – the velocity of sound c can simply be determined experimentally from the velocity of propagation of a sound pulse:

$$c^2 = \frac{p}{\rho} \kappa / \rho \quad \text{with} \quad \kappa = C_p / C_V$$

κ : adiabatic exponent

ρ : density

p : pressure

C_p, C_V : specific heat capacity

The sound pulse is generated by a steep voltage edge which causes the diaphragm of a tweeter to perform a jerky motion. This motion of the diaphragm leads to a pressure variation in the gas, which can be detected by means of a microphone.

For determining the velocity of sound c in a gaseous medium, the travel time t between the pulse generation at the tweeter and the detection at the microphone is measured. As the sound pulse cannot be located exactly at the tweeter, the effective measuring distance is first determined by determining the velocity c_{air} of sound in air. To do this, two travel time measurements are carried out with the microphone being located at the location s_{A1} in one measurement and at the location s_{A2} in the other measurement. The velocity of sound in air is then obtained from the path difference $\Delta s = s_{A1} - s_{A2}$ and the associated travel time difference $\Delta t = t_1 - t_2$: $c_{\text{air}} = \Delta s / \Delta t$. This enables the effective measuring distance $s_{\text{eff}} = c_{\text{air}} \cdot t_1$ to be calculated for the location s_{A1} , which eventually enables a direct measurement of the velocity of sound in a gas.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Timer box	524 034
1	Apparatus for sound velocity	413 60
1	Stand for tubes and coils	516 249
1	Tweeter	587 07
1	Multipurpose microphone	586 26
1	Scaled metal rail, 0.5 m	460 97
2	Saddle bases	300 11
1	Minican gas can, carbon dioxide	660 999
1	Minican gas can, helium	660 984
1	Minican gas can, neon	660 985
1	Fine regulating valve for Minican gas cans	660 980
1	Silicone tubing, 7 / 1.5 mm, 1 m	667 194
1	Rubber tubing, $d = 4$ mm	604 481
1	Tubing connector	604 510
1	Pair of cables, 25 cm, red and blue	501 44
1	Pair of cables, 100 cm, red and blue	501 46
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

- Lay the plastic tube (without heating coil) on the stand for tubes and coils, and turn it so that the two hose nipples are one above the other.
- Move the tweeter close to the plastic tube so that the plastic tube is closed as tight as possible.
- Insert the multipurpose microphone in the central bore of the cap to a depth of approx. 1 cm, and align it so that it moves parallel to the plastic tube when it is displaced. Set the function switch of the multipurpose microphone to the "Trigger" mode. Do not forget to switch the microphone on.
- Lay the scaled metal rail immediately under the saddle base.
- Plug the timer box on the input A of the Sensor-CASSY, and set up the circuit as shown in the drawing; set the maximum output voltage at the voltage source S.

Experiment notes

To avoid unintended loss of gas, turn the handwheel of the fine regulating valve to the right stop before screwing the fine regulating valve on the gas can.

Any leakage of the measuring apparatus leads to an escape of gas and thus to a distortion of the measuring result; therefore the tweeter has to be placed as close to the plastic tube as possible.

In order to fill the plastic tube with carbon dioxide, put the silicone tubing on the lower hose nipple of the plastic tube. In this way, the gas is almost completely exchanged because the lighter air is pressed out through the upper hose nipple when carbon dioxide enters. Correspondingly, proceed the other way round when filling the plastic tube with the noble gases helium and neon: when helium or neon, respectively, enters through the upper hose nipple, the air, which is heavier, is pressed out through the lower hose nipple.



Concerning the measurements on helium and neon, keep in mind that the measuring apparatus cannot be perfectly sealed so that part of the highly-volatile gas in the plastic tube escapes. This results in a relatively high proportion of air, which distorts the measurements – therefore the measurements should be carried out quickly.

Carrying out the experiment

■ Load settings (the sound pulses are already generated, and the travel times Δt_{A1} are displayed)

First determine the effective measuring distance s_{eff} :

- Insert the multipurpose microphone in the plastic tube by approx. 1 cm, read the position s_{A1} , and write it in the first line of the table. Write the travel time Δt_{A1} in the table with **F9**. Repeat the measurement of the travel time several times to improve the accuracy of measurement.
- Insert the multipurpose microphone entirely in the plastic tube, read the position s_{A2} , and write it in the next line of the table. Write the travel time Δt_{A1} in the table with **F9**. Repeat the measurement of the travel time several times to improve the accuracy of measurement.
- In order to determine the average travel times t_1 and t_2 , select Draw Mean Value, and determine the velocity of sound in air $c_{\text{air}} = \Delta s / \Delta t = (s_{A1} - s_{A2}) / (t_1 - t_2)$.
- Determine the effective measuring distance $s_{\text{eff}} = c_{\text{air}} \cdot t_1$; for this enter the determined travel times t_1 and t_2 in the settings s_{eff} (right mouse button on s_{eff}) in the formula $(s_{A1} - s_{A2}) / (t_1 - t_2) \cdot t_1$.

Now the velocity of sound in carbon dioxide, helium and neon can be measured directly:

- Shift the multipurpose microphone back to the position s_{A1} .
- Let gas in through the hose nipple. Open the fine regulating valve very cautiously until the gas flowing out of the gas can is heard.
- Read the velocity of sound, and write it in the prepared display **Input** in the table or enter it there using drag & drop. In addition, write the density ρ in the table:

Gas	Density ρ	Adiabatic exponent $\kappa = C_p/C_V$
Carbon dioxide	1.98 kg/m ³	1.29
Nitrogen (air)	1.25 kg/m ³	1.40
Neon	0.90 kg/m ³	1.64
Helium	0.18 kg/m ³	1.63

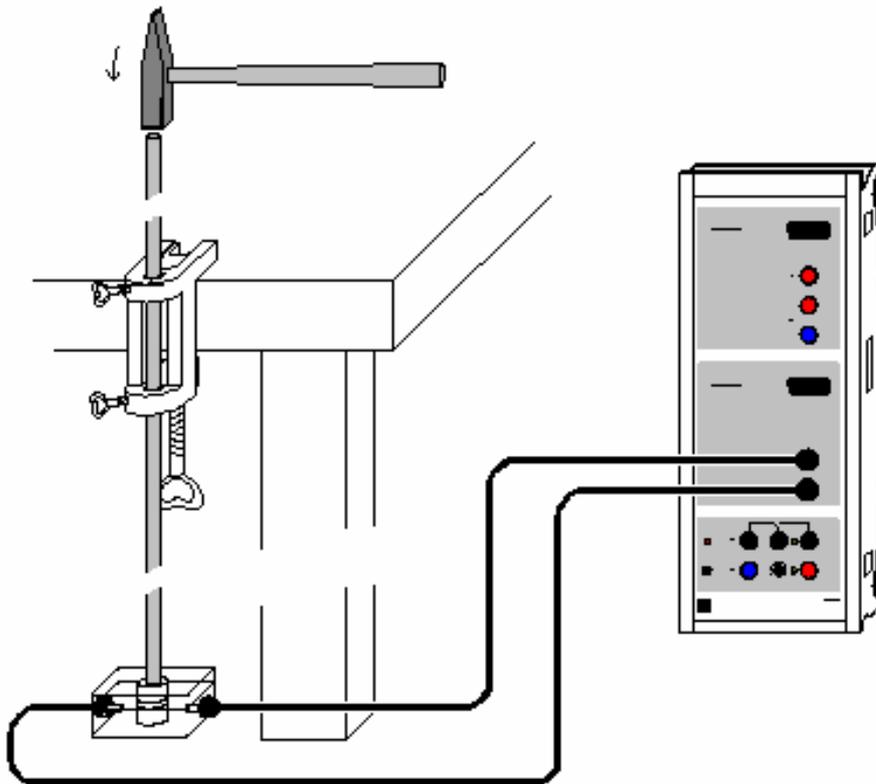
Evaluation

In the prepared display **Evaluation**, the relation between c^2 and $1/\rho$ is shown. There you can, e. g. by entering the formula $101300 \cdot 1.4 \cdot x$ in Free fit, draw the straight line which corresponds to the mean adiabatic coefficient $\kappa=1.4$ at normal air pressure.

Deviations of the measured values from this straight line are normal, particularly in the case of helium, which is highly volatile, because then the actual density of the gas is higher.

The great differences in the velocity of sound are essentially due to the different densities ρ of the gases as the differences in the adiabatic exponents C_p/C_V are relatively small.

Velocity of sound in solid bodies



■ Load example

Experiment description

The object of this experiment is to determine the velocity of sound in aluminum, copper, brass and steel rods. This measurement exploits the multiple reflections of a brief sound pulse at the rod ends. The pulse is initially generated by tapping the top end of the rod with a small hammer, and initially runs downward. The pulse is reflected several times in succession at the two ends of the rod, whereby the pulses arriving at one end are delayed with respect to each other by the time Δt . As Δt is the sum of the transit time out and back, we can calculate the velocity of sound s using the rod length s as

$$c = 2s / \Delta t.$$

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Set of 3 metal rods	413 651
1	Stand rod, 150 cm	300 46
1	Piezoelectric body	587 25
1	Bench clamp, simple	301 07
2	Connecting leads, 2 m, black	501 38
1	Small hammer	
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The metal rods rest on the piezoelectric body, which converts the pressure oscillations of the sound pulses into electrical oscillations. These are recorded at input B of Sensor-CASSY.



Carrying out the experiment

■ Load settings

- Start the measurement with **F9** (software waits for the trigger signal).
- Tap the top end of the first metal rod with the small hammer (to generate the trigger signal).
- Repeat the experiment with a different metal rod, or delete a faulty measurement with **Delete Last Measurement Series** (right mouse button in table).

Evaluation

You can determine the time differences Δt of the minima or maxima e.g. using vertical lines, finding the peak center or by measuring the difference directly. As Δt is the sum of the transit time out and back, we can calculate the velocity of sound c using the rod length s as

$$c = 2s / \Delta t.$$

This example gives us the following sound velocity values:

Metal	Measurement	Literature value
Brass	3530 m/s	3500 m/s
Copper	3900 m/s	3800 m/s
Aluminum	5000 m/s	5110 m/s
Steel	5170 m/s	5100 m/s

Fourier analysis of simulated signals

- Load example (simulated square-wave signal)
- Load example (simulated delta signal)

Experiment description

Harmonic analysis is a common method in many applications where time-variant signals (or measured values) occur. In acoustics, for example, exact knowledge of the overtones of a sound is important for the artificial generation of sounds or language.

In this experiment, the Fourier transform of simple periodic signals is studied as an introduction to the topic of Fourier transformation. In a first step, the Fourier transform of a numerically simulated signal is calculated and the frequencies of the associated amplitudes are determined (Fourier analysis). Based on this harmonic analysis, the time-variant signal is composed in a second step according to Fourier's theorem and compared with the theoretically calculated Fourier series and the numerically simulated original signal (Fourier synthesis).

Equipment list

- | | | |
|---|---|---------|
| 1 | CASSY Lab | 524 200 |
| 1 | PC with Windows 95/98/NT
or higher version | |

Experiment setup

Remark: the experiment is a pure simulation experiment on Fourier analysis with CASSY Lab. For an experiment with electric signals of corresponding shapes see the subsequent experiment. The signals S_1 investigated in this experiment are generated by the following functions:

Delta: $S_1 = 4 \cdot (1 - 2 \cdot \text{saw}(f \cdot t))$
 Square wave: $S_1 = 4 \cdot (2 \cdot \text{square}(f \cdot t) - 1)$

with the frequency $f = 0.5$ Hz.

Remarks concerning the Fourier transformation

A continuous time-variant signal S_1 is sampled during the computer-aided measurement at certain times. In this way, a digitized signal is obtained, which can be further processed using common methods of digital signal processing (improving the signal-to-noise ratio by means of Fourier transformation, smoothing the signal by averaging, etc.). The sampling theorem tells at what time intervals the signal value has to be measured so that the time dependence of the signal can be recovered from the digitized measured values (data points). For a digitization of the signal with a sufficient number of data points, the sampling frequency f_s has to be at least twice the maximum frequency f_{\max} that occurs in the signal and determines the width of the frequency spectrum. If this condition, $f_s \geq 2f_{\max}$ is not fulfilled, i.e., if the digitization takes place at a lower sampling frequency f_s , the shape of the signal is no longer captured (aliasing). The sampling frequency f_s of the measuring signal is determined by the interval $\Delta t = 1/f_s$ set in the Measuring Parameters (F5).

Fourier's theorem says that any time-dependent periodic signal S_1 can be represented by a weighted sum of sin or cos functions. For the delta and square-wave functions used in this experiment, the series expansions of S_1 in trigonometric functions up to order 9 read:

Delta:

$$S_3 = 4 \cdot 8/3.14^2 \cdot (\cos(360 \cdot f \cdot t) + 1/9 \cdot \cos(360 \cdot 3 \cdot f \cdot t) + 1/25 \cdot \cos(360 \cdot 5 \cdot f \cdot t) + 1/49 \cdot \cos(360 \cdot 7 \cdot f \cdot t)) + 1/81 \cdot \cos(360 \cdot 9 \cdot f \cdot t)$$

Square wave:

$$S_3 = 4 \cdot 4/3.14 \cdot (\sin(360 \cdot f \cdot t) + 1/3 \cdot \sin(360 \cdot 3 \cdot f \cdot t) + 1/5 \cdot \sin(360 \cdot 5 \cdot f \cdot t) + 1/7 \cdot \sin(360 \cdot 7 \cdot f \cdot t) + 1/9 \cdot \sin(360 \cdot 9 \cdot f \cdot t))$$

Thus a discrete frequency spectrum with different amplitudes corresponds to the time-dependent function S_1 . The generalization of this decomposition to non-periodic signals leads to the Fourier integral, which assigns a continuous frequency spectrum F_1 to the time-dependent signal S_1 .



The numerical computation of the frequency spectrum F_1 is particularly efficient if a digitized signal of $N=2^p$ data points is taken as a basis. In this case, only approx. $N \cdot \log_2(N)$ arithmetic operations have to be carried out instead of approx. N^2 operations. This procedure, which is significantly less time consuming, is called fast Fourier transformation (FFT).

CASSY Lab computes the frequency spectrum F_1 using such an algorithm. However, first of all the given measured points are weighted so that non-periodic portions on the boundaries do not play an important role (on the boundaries 0, in the middle maximum, Kaiser-Bessel window(4.0)). In order that always exactly 2^p measuring points are available, zeros are added for measuring points that may be missing.

As a result of the FFT, CASSY Lab displays a total of $N/2$ amplitudes (i.e., phase differences are not evaluated). These amplitudes are represented as "excess" amplitudes, i.e. $A_i := A_{i-1} + A_i + A_{i+1}$, in order that the amplitudes of sharp peaks are in approximate agreement with theory. Without this excess, an amplitude determination as it is carried out in this experiment would require the calculation of the sum over all amplitudes of a peak.

There are limitations to the use of FFT for frequency analysis due to two basic relations. The first one relates the highest frequency f_{\max} that can be analysed to the sampling frequency f_s :

$$f_{\max} = f_s/2.$$

Any frequency which is greater than f_{\max} appears in the frequency spectrum between zero and f_{\max} and can then no longer be distinguished from the frequency contributions which really arise from the range between 0 and f_{\max} . The resulting change in the signal shape is called aliasing.

The second relation relates the resolution of the frequency spectrum Δf (= distance of neighbouring points of the frequency spectrum) to the sampling frequency f_s :

$$\Delta f = f_{\max}/(N/2-1) = f_s/(N-2) = 1/\Delta t/(N-2) \approx 1/T$$

$$\text{with } T = (N-1) \cdot \Delta t.$$

That means that the resolution of the frequency spectrum can only be increased by a longer measuring time.

Carrying out the experiment

- Load settings (simulated square-wave signal)
- Load settings (simulated delta signal)
- Using the mouse, set the pointer of the display instrument f to the desired frequency.
- **F9** simulates the recording of measured values of the function S_1 . The simulation takes 50 s and records 500 values ($\Delta t = 100$ ms).
Longer recording times increase the frequency resolution of the FFT step by step whereas shorter recording times decrease the resolution.

Evaluation

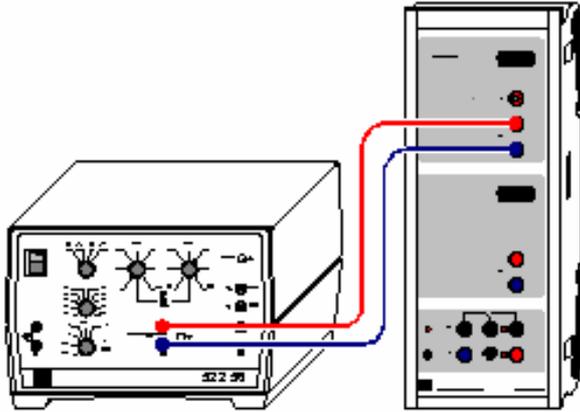
The $S_1(t)$ diagram of the numerically simulated signal appears already during the simulation of the measurement. After the simulation, the Fourier transform F_1 is available in the display **Frequency Spectrum**.

The frequency spectrum exhibits peaks at odd multiples of the set signal frequency f , i.e. at $f, 3^*f, 5^*f, 7^*f$, etc.. The amplitudes of the peaks can be read by clicking the curve or from the coordinate display.

Now enter the first 5 amplitudes as coefficients of the $\sin(360^*n^*f^*t)$ functions in the Settings A_1, A_3, A_5, A_7 and A_9 for the analysis. In the display **Fourier Analysis**, the time dependence of the individual terms A_1, A_3, A_5, A_7 and A_9 is shown.

In the diagram **Fourier Synthesis**, the series $S_2 = A_1 + A_3 + A_5 + A_7 + A_9$ which has been determined experimentally is compared with theoretical Fourier series S_3 and the numerically simulated function S_1 . It turns out that in practical applications the periodic signal S_1 is satisfactorily approximated by a trigonometric polynomial S_2 or S_3 , respectively, containing only a few terms.

Fourier analysis of signals of a function generator



can also be carried out with Pocket-CASSY

- Load example (square wave)
- Load example (delta)
- Load example (sawtooth)

Experiment description

Harmonic analysis is a common method in many applications where time-variant signals (or measured values) occur. In acoustics, for example, exact knowledge of the overtones of a sound is important for the artificial generation of sounds or language. In metrology, Fourier analysis is used, for example, for checking electromagnetic compatibility (EMC) of electronic devices.

In this experiment, the Fourier transform of simple periodic signal shapes is studied as an introduction to the topic of Fourier transformation. Electric (analog) signals of a function generator are read, and the Fourier transform of the digitized signal is calculated. From the frequency spectrum the amplitudes of the different harmonics (Fourier analysis) are calculated and compared with the theoretical values.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Function generator P	522 56
1	Pair of cables, 50 cm, red and blue	501 45
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Connect the continuously adjustable signal of the function generator to the input A of the Sensor CASSY.

Remark: This experiment concerns the Fourier analysis of digitized signals of a function generator. For remarks concerning fast Fourier analysis and the treatment of the Fourier synthesis of corresponding signal shapes see the previous simulation experiment.

Experiment notes

For some types of function generators it may be necessary to set the DC offset exactly to zero in order to avoid distorted frequency spectra.



Carrying out the experiment

- Load settings (square wave)
- Load settings (delta)
- Load settings (sawtooth)
- Set the desired signal shape and a frequency of approx. 500 Hz at the function generator (set the DC offset to zero).
- Start the measurement with **F9** for recording the signal.
- If necessary, adjust the sampling rate (interval) and the number of measuring points in the window Measuring Parameters (**F5**) corresponding to the selected signal frequency in order to obtain a frequency spectrum of sufficient resolution.

Evaluation

While the signal is recorded, the $U_{A1}(t)$ diagram already appears, representing a digitized version of the analog signal of the function generator. After the signal U_{A1} has been recorded, the Fourier transform of U_{A1} is available for the harmonic analysis in the display **Frequency Spectrum**.

For determining the amplitudes of the harmonics, carry out the following steps one after another:

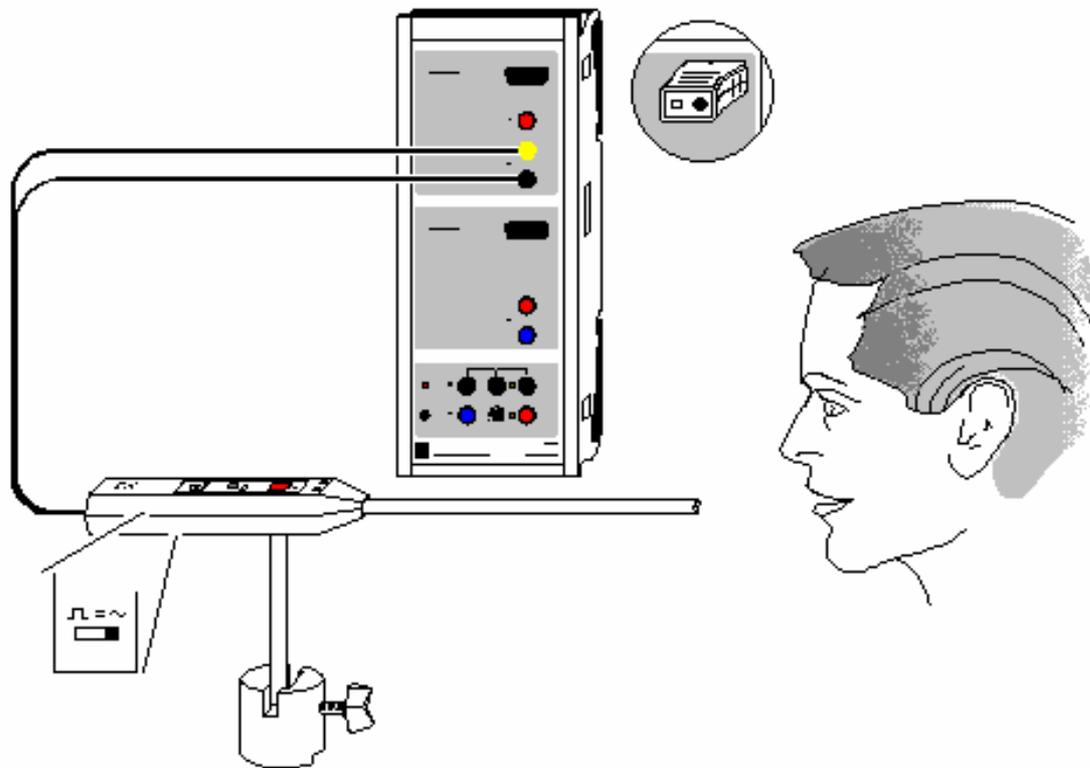
- Select the display **Frequency Spectrum**, and determine the amplitudes of the harmonics of order N with a horizontal line (**Alt+H**).
- Go to the display **Evaluation**, transfer the value of the amplitude from the status line into the prepared table in column A using the mouse (drag & drop), and enter the order N of the N -th harmonic.

The theoretical dependence of the amplitudes of the N -th harmonics can be confirmed for the respective signal shape by a subsequent free fit (**Alt+F**) to a hyperbola A/x^2 (delta: $N = 1, 3, 5, \dots$) or A/x (square wave: $N = 1, 3, 5, \dots$; sawtooth: $N = 1, 2, 3, 4, \dots$), respectively. Alternatively, the dependence of the amplitudes on N obtained by way of theoretical calculations can be checked by converting the x-axis into $1/x^2$ (delta) or $1/x$ (square wave, sawtooth) and a subsequent fit to a line through the origin.

Depending on the signal shape selected, the frequency spectrum also exhibits contributions of small amplitudes at frequencies between the theoretical frequencies (e.g. between $N = 1, 3, 5, \dots$ in the case of the delta signal). This is due to the fact that the signal shape is not ideal and that the signal is not strictly periodic over the range covered by the recording time window.

Remark: for an example of using Power CASSY as a function generator see the experiment on sonic synthesis.

Sound analysis



can also be carried out with Pocket-CASSY

- Load example (multi-purpose microphone)
- Load example (microphone S)

Experiment description

The object of this experiment is the analysis of sounds having different tones and pitches (e.g. sounds of the human voice or of musical instruments) by means of Fourier analysis. The resulting frequency spectrum shows the fundamental frequency f_0 and the harmonics.

The various vowels of a language differ mainly in the amplitudes of their harmonics. The fundamental frequency f_0 depends on the pitch of the voice. This is approx. 200 Hz for high-pitched voices and approx. 80 Hz for low-pitched voices. The vocal tone is determined by variations in the excitation of the harmonics. The same applies for the tone of musical instruments.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Multi-purpose microphone with Base	586 26 300 11
	or	
1	Microphone S	524 059
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Connect the multipurpose microphone to input A of Sensor-CASSY (don't forget to set the microphone to "Signal" mode and switch it on).



Carrying out the experiment

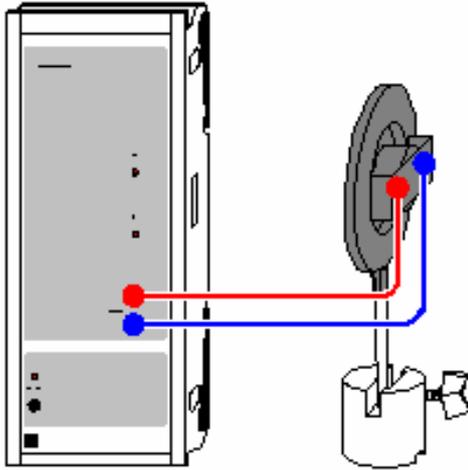
- Load settings (multi-purpose microphone)
- Load settings (microphone S)
- Start the measurement with **F9**.
- Select the **Standard** display and optimize the signal strength using the control on the microphone.
- Record and compare different sounds (**Standard** shows the signal form and **Frequency Spectrum** shows the Fourier analysis).
- To stop the measurement, deactivate **Repeating Measurement** in the Measuring Parameters dialog or press **F9** immediately after the end of a recording.
- To compare different frequency spectra, select **Append New Measurement Series** in the Measuring Parameters dialog and restart the measurement with **F9**.

Evaluation

The fundamental frequency and each harmonic can be determined easily in **Frequency Spectrum** (click with the mouse) using the coordinate display or by finding the peak centers. The amplitudes of the harmonics determine the tone of the recorded sound.

As the human ear perceives sound intensities in a logarithmic fashion, the logarithmic display of the frequency spectrum is better suited to the sensitivity of the human ear than a linear representation. Select the logarithmic representation by clicking on the y-axis of the frequency spectrum with the right mouse button (increase the lower limit, e.g. to -3).

Sonic synthesis



■ Load example

Experiment description

This experiment generates sounds of different timbre and pitch by defining the fundamental frequency f_0 as well as the amplitude ratio between the fundamental frequency and its harmonics. The result is visible as an oscillogram and a frequency spectrum, and audible as a tone.

This experiment verifies that the timbre of a sound is determined by the specific excitation of harmonics. Also, the experiment illustrates how periodic functions can be generated through the harmonic combination of sinusoidal oscillations.

Equipment list

1	Power-CASSY	524 011
1	CASSY Lab	524 200
1	Broad band speaker	587 08
1	Base	300 11
1	Pair of cables, 1 m, red and blue	501 46
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Connect the speaker to the output of Power-CASSY.

Carrying out the experiment

■ Load settings.

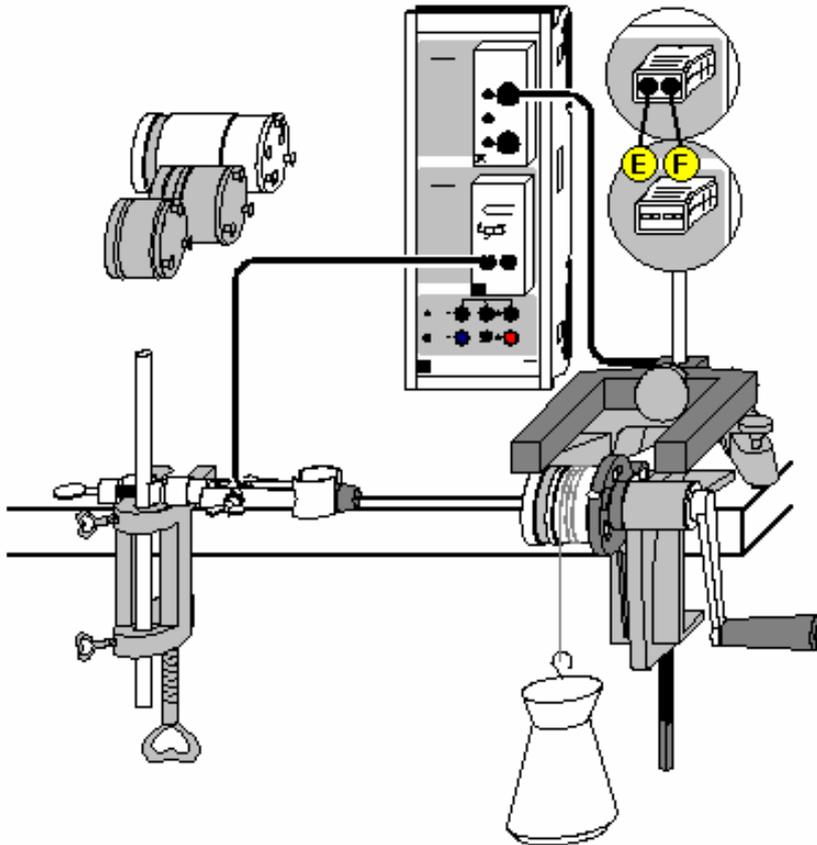
- A square-wave oscillation approximated using sinusoidal oscillations is output at the loudspeaker. The formula for the curve form was defined as **synth(1:0:1/3:0:1/5:0:1/7:0:1/9:0:1/11:0:1/13:0:1/15:0:1/17:0:1/19)**. This is an abbreviation for the long form $1 \cdot \sin(360^\circ x) + 0 \cdot \sin(2 \cdot 360^\circ x) + 1/3 \cdot \sin(3 \cdot 360^\circ x) + 0 \cdot \sin(4 \cdot 360^\circ x) + 1/5 \cdot \sin(5 \cdot 360^\circ x) + 0 \cdot \sin(6 \cdot 360^\circ x) + 1/7 \cdot \sin(7 \cdot 360^\circ x) + 0 \cdot \sin(8 \cdot 360^\circ x) + 1/9 \cdot \sin(9 \cdot 360^\circ x) + 0 \cdot \sin(10 \cdot 360^\circ x) + 1/11 \cdot \sin(11 \cdot 360^\circ x) + 0 \cdot \sin(12 \cdot 360^\circ x) + 1/13 \cdot \sin(13 \cdot 360^\circ x) + 0 \cdot \sin(14 \cdot 360^\circ x) + 1/15 \cdot \sin(15 \cdot 360^\circ x) + 0 \cdot \sin(16 \cdot 360^\circ x) + 1/17 \cdot \sin(17 \cdot 360^\circ x) + 0 \cdot \sin(18 \cdot 360^\circ x) + 1/19 \cdot \sin(19 \cdot 360^\circ x)$, which could also be entered.
- You can change the amplitudes of individual harmonics in the Settings U1. You can set the fundamental frequency and the amplitude here as well. The result is immediately audible, as well as visible using **F9** after the start of the measurement.
- To approximately synthesize a triangular signal, we can use the formula **synth(1:0:-1/3^2:0:1/5^2:0:-1/7^2:0:1/9^2:0:-1/11^2:0:1/13^2)**. You do not need to type in this formula; simply copy it from this help text and insert it in the formula box (right mouse button).



Evaluation

After recording with **F9**, we can readily observe a change in the ratios of the amplitudes of the harmonics in the **Frequency Spectrum** display (click on this tab with the mouse).

Conversion of mechanical energy into thermal energy



can also be carried out with Pocket-CASSY

■ Load example

Safety note

Make sure that the experimenter stands so that he or she cannot be injured when the 5 kg weight is dropped inadvertently.

Experiment description

Energy is one of the fundamental quantities in physics. Energy occurs in different forms, which can be converted one into the other. In a closed system, the total energy is conserved in the course of conversion processes.

In this experiment, the equivalence of mechanical energy E_m and thermal energy E_{th} is established experimentally. Mechanical work E_m is expended by turning a crank handle against the frictional force. This leads to a temperature rise of the calorimeter and thus to an increase in the thermal energy E_{th} . The two energy forms can be registered quantitatively in units of newton meter (Nm) and Joule (J) by measuring the temperature ϑ and the number of revolutions so that their numerical equivalence can be demonstrated experimentally: $E_m = E_{th}$.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Timer box or Timer S	524 034 or 524 074



1	Temperature box	524 045
1	Temperature sensor NiCr-Ni	666 193
or		
1	NiCr-Ni adapter S	524 0673
1	Temperature sensor NiCr-Ni, type K	529 676
1	Forked light barrier, infrared	337 46
1	Multicore cable, 6-pole, 1.5 m	501 16
1	Equivalent of heat, basic apparatus	388 00
1	Calorimeter	
	e.g.	
	water calorimeter	388 01
	or	
	copper calorimeter with heating	388 02
	or	
	aluminium calorimeter with heating	388 03
	or	
	large aluminium calorimeter with heating	388 04
1	Simple bench clamp	301 07
1	Stand base, V-shape, 20 cm	300 02
1	Stand rod, 10 cm	300 40
1	Stand rod, 25 cm	300 41
1	Clamp with jaw clamp	301 11
1	Weight, 5 kg	388 24
1	PC with Windows 95/98/NT	
	or higher version	

Experiment setup (see drawing)

- Fasten the equivalent of heat basic apparatus to a corner of the table.
- Fasten the bench clamp at the edge of the table at a distance of approx. 40 cm from the plastic mounting of the basic apparatus. Clamp the clamp with jaw clamp with the aid of the stand rod 25 cm in order to be able to fix the temperature sensor as shown in the drawing.
- Set up the calorimeter so that the bore points upwards and pour water into the opening.
- Insert the gasket in the bore, and hold it with the locking screw.
- Attach the filled calorimeter body to the basic apparatus by inserting the rivet pins in the sockets of the plastic mounting and twisting the calorimeter body to lock the pins in place.
- Insert the temperature sensor as deeply as possible in the opening of the calorimeter, and tighten the locking screw of the calorimeter. Fix the temperature sensor by means of the stand material that has already been prepared as shown in the drawing.
- Put the 5 kg weight under the calorimeter body.
- Wind the nylon band approx. 4 times (6 at maximum) around the calorimeter, and attach it to the weight on the floor. The weight has to hang down on the side of the crank on the front.
- Operate the crank handle, and check whether the 5 kg weight is lifted a few centimetres and is kept at a constant height when the handle is turned further. If it is lifted too high, reduce the number of turns of the nylon band; if it does not lift at all, increase the number of turns.
- For measuring the number of revolutions n_{EA1} (=number of obscurations), position the forked light barrier with the aid of the stand base as shown in the drawing, and connect it to the input A of the Sensor-CASSY via the timer box.
- Connect the temperature sensor to the input B of the Sensor CASSY via the temperature box (socket T1) for measuring the temperature ϑ_{B11} .

Carrying out the experiment

■ Load settings

- Set the obscurations to zero by clicking $\rightarrow 0 \leftarrow$ in Settings n_{EA1} .
- Start the measurement with **F9**.
- Turn the crank handle, and measure the increase in temperature as a function of the number of revolutions.
- Stop the measurement with **F9** at the desired final temperature ϑ_{B11} .

Evaluation

The temperature ϑ_{B11} is already displayed graphically as a function of the number of revolutions n_{EA1} during the measurement. In the prepared diagram **Evaluation**, the thermal energy is plotted against the mechanical energy that has been provided by turning the crank against the friction. The mechanical energy E_m is equal to the product of the frictional force and the covered path s :

$$E_m = F \cdot s$$

with $F = m \cdot g$ $F =$ frictional force
 $m =$ mass of the weight = 5 kg
 $g =$ acceleration of gravity = 9.81 m/s²

and $s = N \cdot d \cdot \pi$ $s =$ frictional path
 $N =$ number of revolutions
 $d =$ diameter of the calorimeter = 0.047 m

Thus the mechanical energy is: $E_m = m \cdot g \cdot d \cdot \pi \cdot N$.

The increase in thermal energy as a result of the temperature increase is given by:

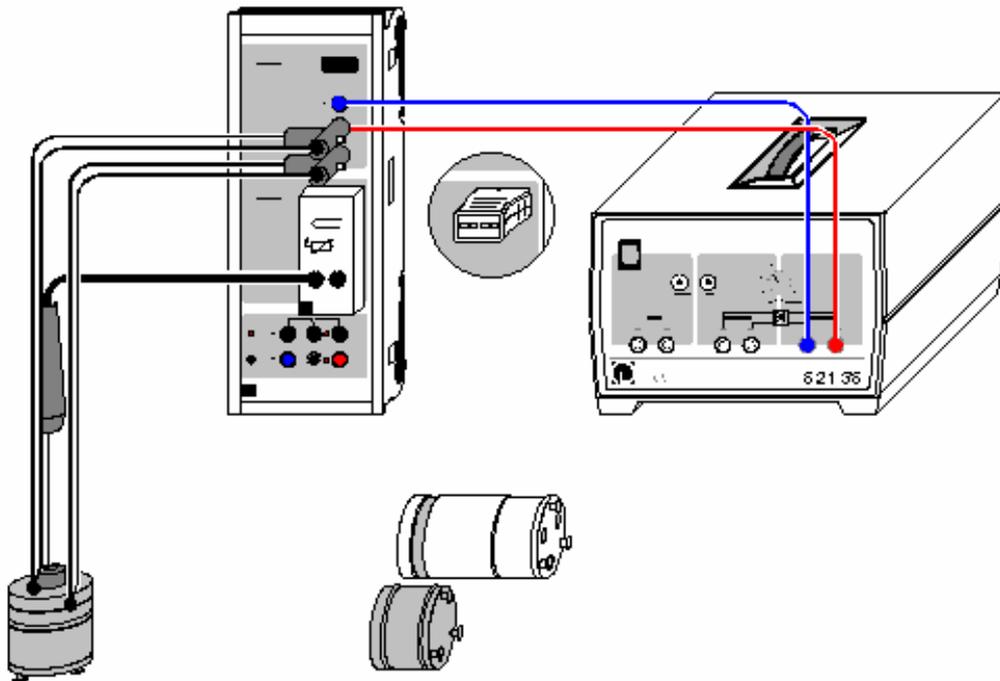
$$E_{th} = C \cdot (\vartheta_2 - \vartheta_1)$$

The heat capacity C depends on the calorimeter used and has to be entered in the Settings C according to the following table:

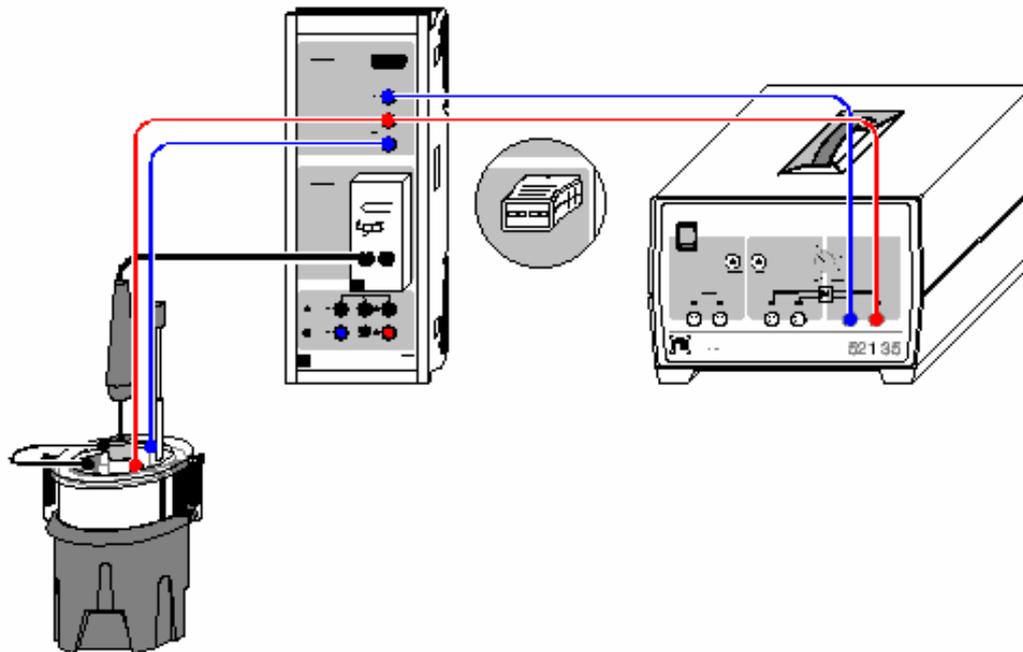
Calorimeter	Heat capacity $C/(J/K)$
Water (388 01)	$40 + m_{H_2O}/g \cdot 4.2$ (mass of the water in g)
Copper (388 02)	$264 + 4,2$ (for 1 g of water in the bore)
Aluminium (388 03)	$188 + 4,2$ (for 1 g of water in the bore)
Aluminium, large (388 04)	$384 + 4,2$ (for 1 g of water in the bore)

The equivalence of the mechanical energy E_m and the thermal energy E_{th} can be confirmed by means of a fit to a line through the origin. Usually the slope of the straight line through the origin is somewhat smaller than 1. This is due to heat loss which is not registered, e.g. by thermal contact of the calorimeter with the nylon band or the plastic mounting.

Conversion of electrical energy into thermal energy



Alternatively:



■ Load example

Safety notes

Danger of implosion: the Dewar vessel is a thin-walled, highly evacuated glass vessel which can break under mechanical stress.

Do not knock or drop the Dewar vessel.

Do not allow any hard objects to fall on or into the glass mantle.

Do not scratch the glass mantle with sharp objects.

Experiment description

Energy is a measure of stored work. It occurs in different forms, which can be converted one into the other. In a closed system, the total energy is conserved in conversion processes. therefore the energy is one of the fundamental quantities of physics.

In this experiment, the equivalence of electrical energy E_{el} and thermal energy E_{th} is established experimentally. The supplied electrical energy E_{el} is converted into heat E_{th} in the heating coil (or heating spiral). This leads to a temperature rise in the calorimeter (or water, in which the heating spiral is immersed). As the current I and the temperature ϑ are measured simultaneously as functions of the time, the constant voltage U being known, the two energy forms can be registered quantitatively in units of wattsecond (Ws) and Joule so that their numerical equivalence can be demonstrated experimentally: $E_{el} = E_{th}$.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Temperature box	524 045
1	Temperature sensor NiCr-Ni	666 193
	or	
1	NiCr-Ni adapter S	524 0673
1	Temperature sensor NiCr-Ni, type K	529 676
1	Voltage source, 0...12 V, e.g. variable extra-low voltage transformer S	521 35
1	Calorimeter with connecting cables, e.g.	
	copper calorimeter with heating	388 02
	pair of connecting cables for calorimeter	388 06
	or	
	aluminium calorimeter with heating	388 03
	pair of connecting cables for calorimeter	388 06
	or	
	large aluminium calorimeter with heating	388 04
	pair of connecting cables for calorimeter	388 06
	or	
	Electric calorimeter attachment	384 20
	Dewar vessel	386 48
	Beaker, squat shape Duran, 250 ml	664 103
	Graduated cylinder, plastic base, 250 ml	665 755
	Pair of cables, 50 cm, red and blue	501 45
	Connecting lead, 50 cm, black	501 28
1	Pair of cables, 50 cm, red and blue	501 45
1	PC with Windows 95/98/NT or higher version	

Experiment setup with calorimeter (see drawing)

- Set up the calorimeter so that the bore points upwards and pour water into the opening.
- Insert the gasket in the bore, and hold it with the locking screw.
- Insert the temperature sensor as deeply as possible in the opening of the calorimeter, and tighten the locking screw of the calorimeter.
- For the current and voltage measurement, connect the CASSY to the variable extra-low voltage transformer S as shown in the drawing.
- Connect the heating coil of the calorimeter to the input A of the Sensor-CASSY (plug the large banana plugs together and connect one cable to the blue safety socket and one cable to the red safety socket).
- For measuring the temperature ϑ_{B11} , connect the temperature sensor to the input B of the Sensor CASSY via the temperature box (socket T1).



Experiment setup with electric calorimeter attachment (see drawing)

- Using the graduated cylinder, pour approx. 200 ml of water into the Dewar vessel.
- Put the electric calorimeter attachment into the Dewar vessel, and fix the cover with the aid of the springs.
- Immerse the temperature sensor with the sealing washer in the Dewar vessel through the rubber stopper. The temperature sensor has to be held by the sealing washer so that the tip of the sensor is below the heating spiral. However, the tip of the temperature sensor must not touch the bottom of the Dewar vessel.
- For the current and voltage measurement, connect the CASSY to the variable extra-low voltage transformer S as shown in the drawing.
- Connect the heating spirals in series to the input A of the Sensor-CASSY (lay a cable from one heating spiral to the red safety socket and another cable from the other heating spiral to the blue safety socket, and connect the free connectors with a black cable).
- For measuring the temperature ϑ_{B11} , connect the temperature sensor to the input B of the Sensor CASSY via the temperature box (socket T1).

Experiment note

If the experiment is carried out with the electric calorimeter attachment, the water has to be stirred while the voltage is switched on in order that the warming takes place uniformly. Slowly move the stirrer up and down during the measurement.

Carrying out the experiment

■ Load settings

- Select the voltage **UA1** as measurement quantity in Settings IA1.
- Switch the variable extra-low voltage transformer S on, and set the voltage UA1 to approx. 9 V (calorimeter) or approx. 4 V (electric calorimeter attachment).
- Read the exact value of UA1, and enter it in Settings U as parameter.
- Switch the variable extra-low voltage transformer S off, and select the **current IA1** as measurement quantity and **0 .. 2.1 A** as range in Settings UA1.
- Start the measurement with **F9**.
- When the initial temperature ϑ_{B11} is constant, switch the variable extra-low voltage transformer S on, and switch it off again at the desired final temperature ϑ_{B11} .
- Stop the measurement with **F9** when a constant final temperature is reached.

Evaluation

The temperature ϑ_{B11} and the current IA1 are already displayed graphically as functions of the time during the measurement. The thermal energy $E_{th} = C \cdot (\vartheta_{B11} - \vartheta_1)$ is plotted against the electrical energy $E_{el} = \sum U \cdot I \cdot \Delta t$ in the prepared diagram **Evaluation**. The heat capacity C depends on the calorimeter used and has to be entered in the Settings C according to the following table:

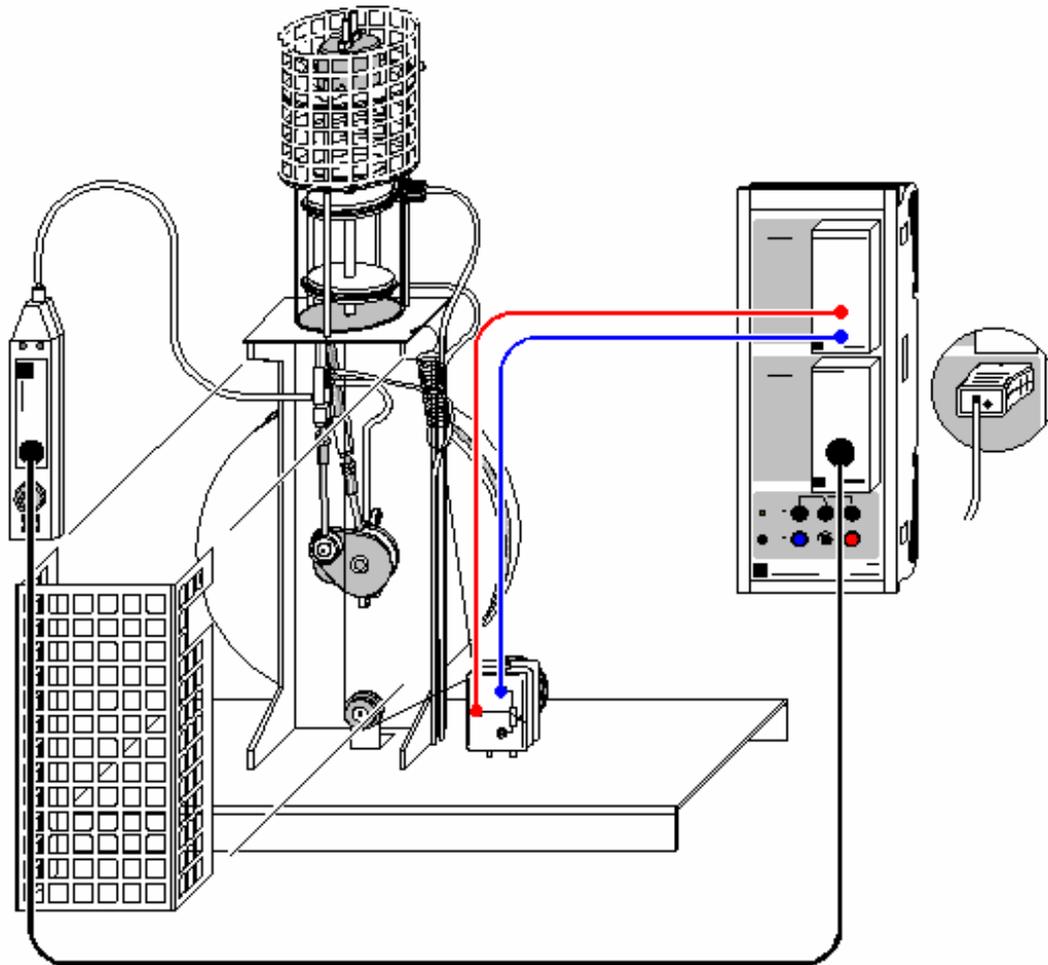
Calorimeter	Heat capacity C/(J/K)
Copper (388 02)	264 + 4.2 (for 1 g water in the bore)
Aluminium (388 03)	188 + 4.2 (for 1 g water in the bore)
Aluminium, large (388 04)	384 + 4.2 (for 1 g water in the bore)
Electr. calorimeter attachment (384 20)	
with Dewar vessel (386 48)	$(m_{H_2O}/g + 24) \cdot 4.2$ (with the mass of the water in g and the water equivalent $m_D = 24$ g of the Dewar vessel)

The equivalence of the electrical energy E_{el} and the thermal energy E_{th} can be confirmed by fitting a line through the origin. Usually the slope of the straight line through the origin is somewhat smaller than 1 because of heat loss due to emission of heat radiation. This becomes particularly obvious in the case of long measuring times, where the measuring data deviate significantly from the straight line through the origin.

Hint

As an alternative, the measurement can be evaluated manually: determine the mean value of the initial temperature ϑ_1 and the final temperature ϑ_2 (select Draw Mean Value with the right mouse button), and calculate the thermal energy $E_{th} = C \cdot (\vartheta_2 - \vartheta_1)$. Determine the time of electrical energy supply with Measure Difference (**Alt+D**), calculate $E_{el} = U \cdot I \cdot \Delta t$, and compare it with E_{th} .

pV diagram of a hot-air engine



can also be carried out with Pocket-CASSY

■ Load example

Safety notes

- Before each experiment, make sure that the hot plate is seated in the notches and the heating filament does not touch the displacement piston.
- The heating head of the hot air engine can become very hot and the connecting rods of the drive and displacement pistons can cause injury when the engine is running. Therefore always use the touch protection covers when the engine is in operation.
- Never use the engine without a cooling water flow. You can connect the engine to tap water or use a circulation pump with reservoir; in this case the use of distilled or boiled (scale-free) water is recommended.
If the flow should drop off when using tap water, flush the entire system with a warm scale-removing compound.
- Lubricate the two cylinders of the hot air engine regularly with silicone oil. The easiest way to do this to remove the hot plate, move the displacement piston to bottom dead center and, using a straw, drip silicone oil from a squeeze bottle so that it runs down the wall of the cylinder onto the top piston ring. As the seal is not fully tight, sufficient oil will reach the lower piston ring in a short time.
When lubrication is insufficient the engine becomes loud and only runs at a reduced speed!
- Never connect the mains coil (562 21) without the transformer core.

Experiment description

Thermodynamic cycles are often described as a closed curve in a pV diagram (p: pressure, V: volume). The work added to or withdrawn from the system (depending on the direction of rotation) corresponds to the area enclosed by the curve.

This experiment records the pV diagram of a hot air engine operated as a heat engine. The pressure sensor measures the pressure p in the cylinder and a displacement sensor measures the position s, from which the volume is calculated, as a function of the time t. The measured values are displayed on the screen directly in a pV diagram. In the further evaluation, the mechanical work performed as piston friction per cycle

$$W = - \int p \cdot dV$$

is calculated.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Current supply box	524 031
1	Displacement transducer	529 031
1	B box	524 038
	with Pressure sensor and	529 038
	Multicore cable, 6-pole	501 16
	or	
1	Pressure sensor S, ±2000 hPa	524 064
1	Hot air engine	388 182
1	Cord, 10 m	309 48
1	Helical spring	352 08
1	U-core with yoke	562 11
1	Clamping device	562 12
1	Mains coil, 500 turns	562 21
1	Low-voltage coil, 50 turns	562 18
2	PVC tubing, 8 mm dia.	307 70
1	Immersion pump 12 V	388 181
1	Low-voltage power supply	521 230
1	Can	604 307
2	Connecting leads, 100 cm, black	501 33
1	Pair of cables, 1 m, red and blue	501 46
1	Water reservoir 10 l	
1	PC with Windows 95/98/NT	
	or higher version	

Experiment setup (see drawing)

Set up the demountable transformer and clamp the yoke onto it.

Set up the hot plate as described in the experiment setup and connect the heater to the two outermost sockets of the low-voltage coil using the two connecting leads.

Connect the hose of the pressure sensor to the pressure fitting of the working-piston connecting rod. The pressure sensor is connected to the B box at input B of Sensor-CASSY. Attach the displacement transducer to the base plate with two coupling plugs and connect it to input A via the current source box; wind a cord as shown in the diagram. The working piston is provided with a pin with eyelet at the bottom end for attaching the cord. Hang the restoring spring in the hole on the frame head. This must be under tension when the cylinder is at bottom dead center. Wind the cord two times around the pulley of the displacement transducer to prevent slip! Set the potentiometer so that a volume of approx. 50 cm³ is indicated when the working cylinder is at top dead center.

Carrying out the experiment

■ Load settings

- Test the displacement transducer to ensure that it is working properly: turn the motor once by hand and observe whether the volume display is within the measuring range. If it is not, loosen the cord slightly and turn the wheel of the displacement transducer until the displayed value is correct.
- Turn on the heating using the switch at the mains coil. When starting the first time, you should wait approx. 1 minute before pushing the motor, until the gas is hot enough for easy starting. In subsequent experiments you can start the motor when the heating coil begins to glow.
- Start the measurement with **F9**. The software automatically records and displays the predefined number of measuring points; the measurement is set to run for just a few cycles to simplify the subsequent integration.

Evaluation

Determination of volume (already conducted in example): the inside diameter of the working cylinder is 60 mm, which gives us a piston surface area of 28.3 cm^2 . Together with the path SA1, we obtain the formula for the volume with the corresponding measuring instrument.

The work per cycle is determined from the enclosed area. We obtain this as follows: select Calculate Integral (Peak Area) in the Evaluations menu (click the right mouse button in the diagram) and mark one cycle (click on the starting point, hold down the left mouse button and drag the pointer along the cycle). The measuring points used for integration are highlighted. It is usually not possible to capture all measuring points of a cycle; however, it has no effect on the calculation of the area if one or two measuring points are substituted by a straight line. When you release the mouse button, the area is filled in and the corresponding value is displayed in the status line.

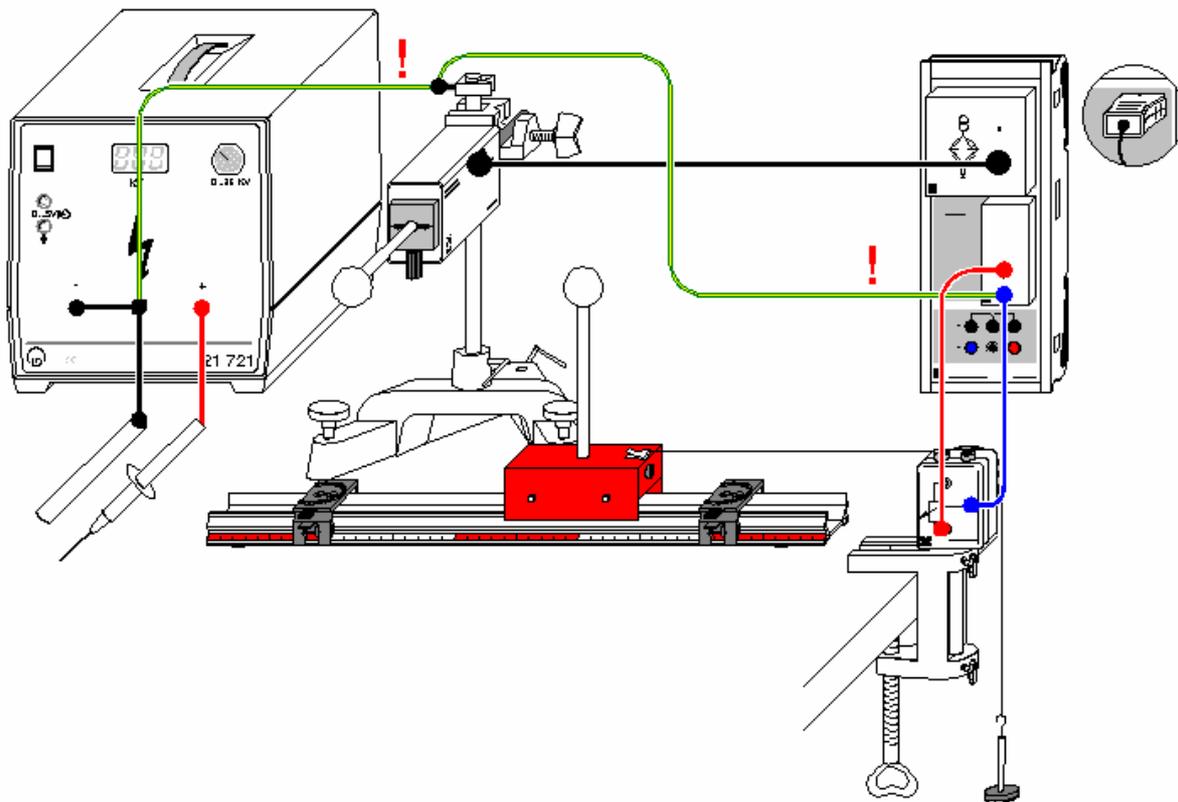
In this example, we obtain a value for work $W = 18,900 \text{ hPa} \cdot \text{cm}^3 = 1.89 \text{ Nm}$.

Remark

The power of the motor is $P = W \cdot f$ with the f being the no-load frequency or speed.

You can determine the frequency f using a light barrier and a counter. Another way is to use the **Frequency Spectrum** display (click on this tab with the mouse). However, better frequency resolution requires more measured values than recorded in the example (increase the number from 125 to e.g. 2000 in the Measuring Parameters dialog).

Coulomb's law



can also be carried out with Pocket-CASSY and Mobile-CASSY

■ Load example

Use caution when working with high voltage

The plug pin is under high voltage and must never be allowed to touch either the experimenter or any parts of the experiment setup! In particular, neither the force sensor nor Sensor-CASSY are protected against high voltage.

Besides see to it that the distance between the high-voltage cable and the other insulated cables is as large as possible during the whole experiment.

Experiment description

Two spheres with identical or opposing charges exert a force on each other. This force is proportional to the charge Q on each sphere and inversely proportional to the square of the distance x between the spheres. The experiment verifies the proportionality $F \propto 1/x^2$.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Bridge box with Force sensor and Multicore cable, 6-pole, 1.5 m	524 041 314 261 501 16
or		
1	Force sensor S, ± 1 N	524 060
1	Current supply box	524 031
1	Displacement transducer	529 031

1	High voltage power supply 25 kV	521 721
1	High-voltage cable	501 05
1	Set of bodies for electric charge	314 263
1	Precision metal rail	460 82
1	Trolley 1, 85 g	337 00
2	Clamp rider	460 95
1	Small clip plug	590 02
1	Connection rod	532 16
1	Stand rod, 25 cm	300 41
1	Stand base, V-shape, 20 cm	300 02
1	Leybold multiclamp	301 01
1	Set of driving weights	337 04
1	Bench clamp, simple	301 07
1	Cord, 10 m	309 48
1	Pair of cables, 1 m, red and blue	501 46
1	Connecting lead, 25 cm, black	500 414
3	Connecting leads, 100 cm, black	500 444
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The force sensor is connected to the bridge box at input A of Sensor-CASSY. Place one of the spheres from the set of bodies for electric charge on the force sensor using the insulating spacer. Place the second sphere on the trolley, which should be able to move freely along the precision metal rail as far as the clamp rider.

The distance between the spheres is measured by the displacement transducer connected to the current supply box at input B of Sensor-CASSY. To this end, lay a thread from the trolley over the deflection pulley of the motion transducer and tie a weight to it. Make sure the path indicator SB1 increases with the distance and reads approx. 0 cm at contact.

For safety reasons the current supply box and the force sensor have to be grounded. Connect the force sensor to the ground socket of the high voltage power supply using a clip plug and a connecting lead.

Experiment notes

Imparting sufficient charge to the spheres, and maintaining this charge (at least during the brief period of this experiment), is an essential prerequisite for the success of this experiment. After charging the two spheres, you should be able to measure a force of at least 5 mN at a distance of 0.5 cm, and this force should remain constant for a few seconds. If not:

- Clean the insulators and spheres (e.g. with water and dish soap; rinse with distilled water)
- Dry the insulators and spheres (e.g. carefully with the non-luminous flame of a Bunsen burner or with hot air from a blow dryer).
- Avoid open flames in the vicinity of the experiment while conducting the experiment (otherwise this ionizes the air).
- You can try other charge sources (e.g. a PVC rod rubbed in freshly washed hair) as an alternative to the high voltage source.
- However, you need dry weather for this.

Carrying out the experiment

■ Load settings

- Calibrate the path zero point: allow the spheres to touch, select **Correct** in the Settings SB1 dialog, set the first target value to 3.8 cm (distance between sphere centers) and click on **Correct Offset**.
- Put the spheres in the starting position with a gap of about 0.5 cm between them.
- Discharge both spheres using the grounded connection rod.
- Set the force zero point in Settings FA1 → 0 ← (repeat as required) and, where necessary, switch on the smoothing LED of the bridge box with **LED On/Off**.
- Charge the spheres with like or unlike charges by connecting one pole of the high voltage supply to ground and placing the other against the sphere for a few seconds. This should produce a force of at least 5 mN (see experiment notes above). If necessary, you can change the zero point of the force instrument (and thus the y-axis of the diagram) in Settings FA1 from center to left or right.



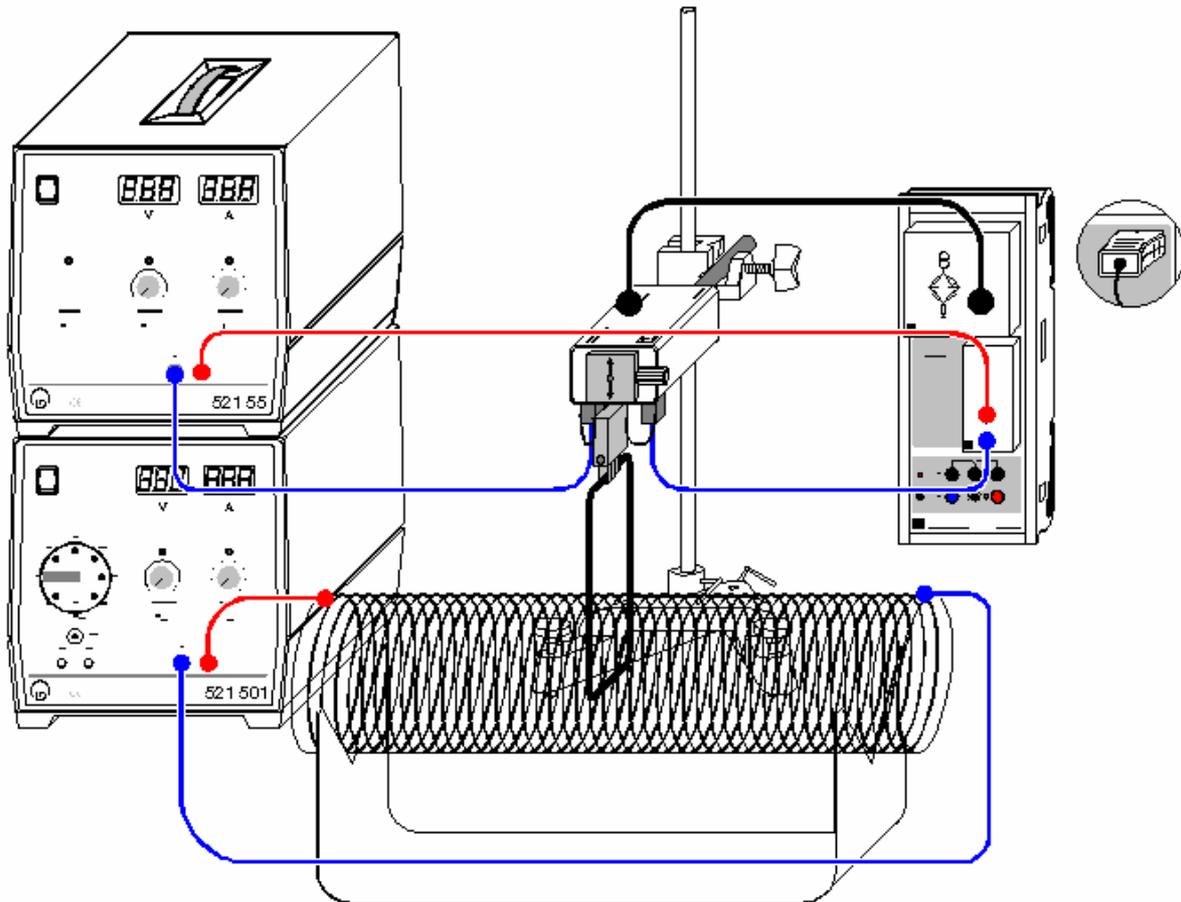
- Start the measurement with **F9**.
- Slowly move the trolley away from the force sensor by hand.
- Stop the measurement with **F9** at approx. 15 cm.

Evaluation

The $F(x)$ diagram appears during the measurement. You can verify Coulomb's law by fitting a hyperbola $1/x^2$ or by converting the x-axis to $1/x^2$ (click on the axis with the right mouse button) and then fitting a straight line.

It becomes apparent that the proportionality $F \propto 1/x^2$ does not apply until a distance of approx. 6 cm between the two sphere centers is reached. At shorter distances the spacing would have to be corrected, as these are not point-shaped charges.

Force in the magnetic field of an air coil



can also be carried out with Pocket-CASSY and Mobile-CASSY

■ Load example

Experiment description

Magnetic flux density, or more simply the magnetic field \mathbf{B} , is a vectorial quantity. A force \mathbf{F} acts on a charge q passing through a magnetic field \mathbf{B} with a velocity \mathbf{v} ; the size of the force depends on the strength and direction of the magnetic field. We can say

$$\mathbf{F} = q \cdot (\mathbf{v} \times \mathbf{B}).$$

The Lorentz force \mathbf{F} is also a vectorial quantity, and is perpendicular to the plane defined by \mathbf{v} and \mathbf{B} .

We can understand the force acting on a current-carrying conductor in a magnetic field as the sum of the individual forces acting on the moving charge carriers which make up the current. The Lorentz force \mathbf{F} acts on every single charge carrier q moving with the drift velocity \mathbf{v} . For a straight conductor, this gives us the total force

$$\mathbf{F} = q \cdot nAs \cdot (\mathbf{v} \times \mathbf{B}),$$

as the number of charge carriers in the conductor is the product of the density n of the charge carriers, the conductor cross-section A and the length s of the section of the conductor within the magnetic field.

It is common to introduce the vector \mathbf{s} , which points along the direction of the conductor segment. Also, the product $qnAv$ is equivalent to the current I . Thus, the force of a magnetic field on a straight, current-carrying conductor section is defined by

$$\mathbf{F} = I \cdot (\mathbf{s} \times \mathbf{B})$$



and the absolute value of the force by

$$F = I \cdot s \cdot B,$$

when \mathbf{s} and \mathbf{B} are perpendicular to each other. The force F and the current I are thus proportional to each other, and the proportionality factor is B .

This experiment measures the force on a conductor loop in a homogeneous magnetic field of an air coil as a function of the conductor loop current I . The homogeneous magnetic field is generated in a long, slotted air coil, and the conductor loop with the length $s = 8$ cm attached to the force sensor is inserted in the slit. Only the horizontal part of the conductor generates a force component that can be measured by the force sensor. Thus, the proportionality between force F and conductor loop current I can be used to determine the magnetic flux density B .

The advantage of the air coil is that the magnetic flux density B within it can be calculated easily and compared with the value arrived at through experiment. For a long air coil, we can say

$$B = \mu_0 \cdot N \cdot I_c / L$$

with the magnetic field constant $\mu_0 = 4\pi \cdot 10^{-7}$ Vs/Am, the number of turns N of the coils, the coil current I_c and the length L of the air coil.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Bridge box	524 041
	with Force sensor and	314 261
	Multicore cable, 6-pole, 1.5 m	501 16
	or	
1	Force sensor S, ± 1 N	524 060
1	30-A box	524 043
1	Support for conductor loops	314 265
1	Conductor loops for	
	force measurement	516 34
1	Field coil, $d = 120$ mm	516 244
1	Stand for coils and tubes	516 249
1	High current power supply	521 55
1	AC/DC power supply 0...15 V	521 501
1	Stand base, V-shape, 20 cm	300 02
1	Stand rod, 47 cm	300 42
1	Leybold multiclamp	301 01
1	Connecting lead, 50 cm, blue	501 26
2	Connecting leads, 100 cm, red	501 30
2	Connecting leads, 100 cm, blue	501 31
1	PC with Windows 95/98/NT	
	or higher version	

Experiment setup (see drawing)

The force sensor holds the 8 cm long conductor loop via the support and is positioned so that the conductor loop is inserted in the slot of the air coil. The conductor loop must not touch the air coil. The two 4-mm sockets on the bottom of the force sensor are intended for supplying the conductor loop support. They are not connected internally. The force sensor is connected to the bridge box at input A of Sensor-CASSY.

The current flows from the 20 A supply unit via the 30 A box on input B of Sensor-CASSY through the conductor loop and back to the power supply. The current of the second 5 A power supply flows through the air coil.

Carrying out the experiment

■ Load settings

- Set the force zero point in Settings Force FA1 with $\rightarrow 0 \leftarrow$ and, where necessary, switch on the smoothing LED of the bridge box with **LED On/Off**.

- You may want to **correct** the current value to 0 A in Settings Current IB1 (set the first target value to 0 A and click **Correct Offset**).
- At the power supply of the air coil, set about $I_c = 5$ A.
- Increase the conductor loop current I from 0-20 A in steps of 2 to 5 A, and record a measured value with **F9** each time. You can delete a faulty measurement from the table with **Delete Last Table Row** (click right mouse button over table).
- If only negative forces are measured, reverse the connections on the conductor loop support.
- Carry out the experiment rapidly, as the conductor loop and support may be subjected to loads of 20 A only briefly.
- At the end of the experiment, set the conductor loop current to 0 A.

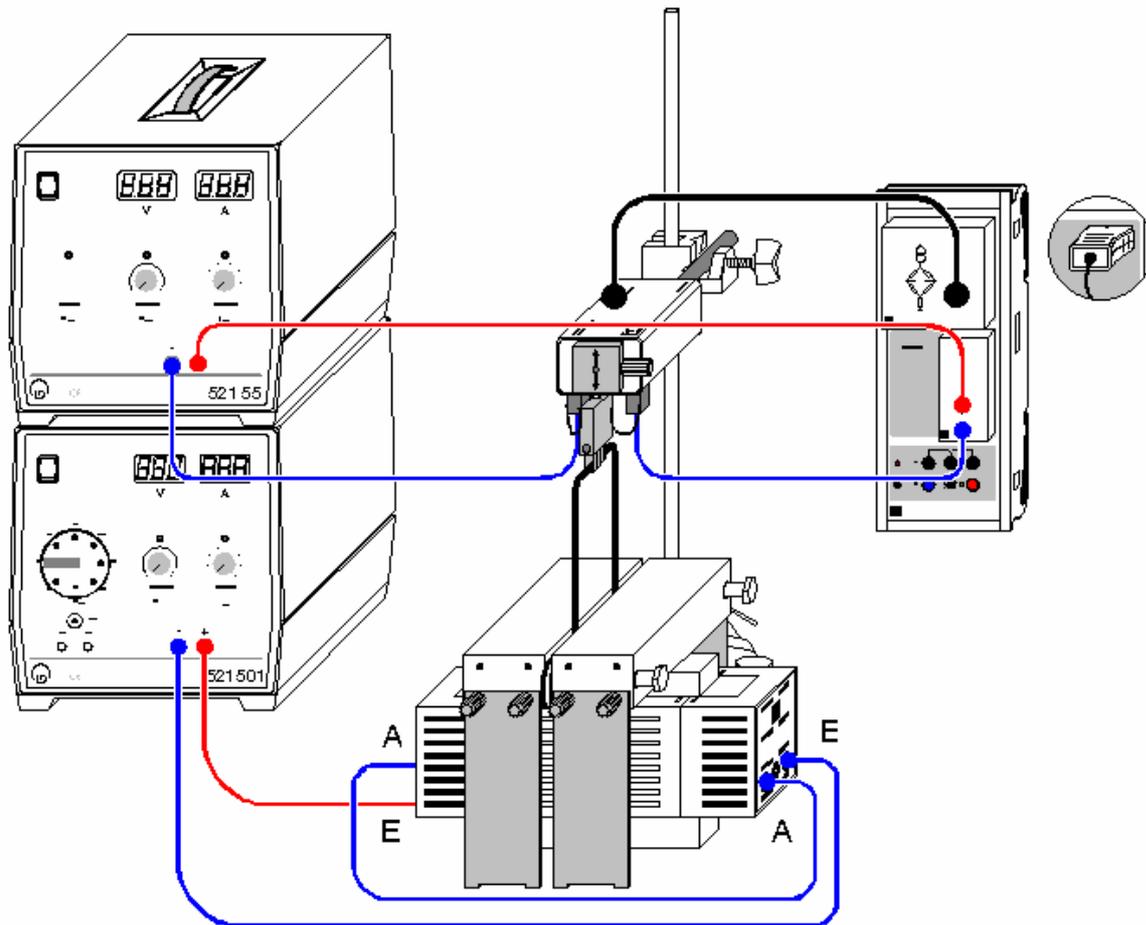
Evaluation

The force increases linearly with the current. The proportionality factor $F/I = B s$ is derived from the slope of the straight line fit. This in turn enables us to determine the magnetic field strength B .

In this example $F/I = 0.138$ mN/A and with $s = 0.08$ m it follows that $B = 1.725$ mT.

Using $B = \mu_0 \cdot N \cdot I_c / L$ the values $\mu_0 = 1.257$ $\mu\text{Vs/Am}$, $N = 120$, $I_c = 4.75$ A and $L = 0.41$ m give us the calculated value $B = 1.75$ mT. The two results agree very well within the limits of measuring accuracy.

Force in the magnetic field of an electromagnet



can also be carried out with Pocket-CASSY and Mobile-CASSY

■ Load example

Experiment description

In this experiment, a homogeneous magnetic field B is generated using an electromagnet with U core and pole-shoe yoke. The object is to measure the force F acting on a conductor loop as a function of the current I (F proportional to I). The measuring results for different conductor lengths s are compiled and evaluated in the overview graph (F/I proportional to s). The ultimate aim is to verify

$$F = I \cdot s \cdot B$$

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Bridge box	524 041
	with Force sensor and	314 261
	Multicore cable, 6-pole, 1.5 m	501 16
	or	
1	Force sensor S, ± 1 N	524 060
1	30-A box	524 043
1	Support for conductor loops	314 265

1	Conductor loops for force measurement	516 34
1	U-core with yoke	562 11
2	Coils with 500 turns	562 14
1	Pole-shoe yoke	562 25
1	High current power supply	521 55
1	AC/DC power supply 0...15 V	521 501
1	Stand base, V-shape, 20 cm	300 02
1	Stand rod, 47 cm	300 42
1	Leybold multiclamp	301 01
2	Connecting leads, 50 cm, blue	501 26
2	Connecting leads, 100 cm, red	501 30
2	Connecting leads, 100 cm, blue	501 31
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Slide the two coils onto the U-core. Place the two heavy pole pieces transversely on top of them. You can adjust the height using the lateral stand. The gap can be changed by moving one of the two pole pieces and adjusted with non-magnetic spacers.

The force sensor holds a conductor loop via the support and is positioned so that the conductor loop is inserted in the gap between the pole pieces of the electromagnet. The conductor loop must not touch the pole pieces. The two 4-mm sockets on the bottom of the force sensor are intended for supplying the conductor loop support. They are not connected internally. The force sensor is connected to the bridge box at input A of Sensor-CASSY.

The current flows from the 20 A supply unit via the 30 A box on input B of Sensor-CASSY through the conductor loop and back to the power supply. The current of the second 5 A power supply flows through the two coils on series. Make sure that the magnetic fields of the two coils add together (connect A to A and both E to the power supply as shown in the drawing).

Carrying out the experiment

■ Load settings

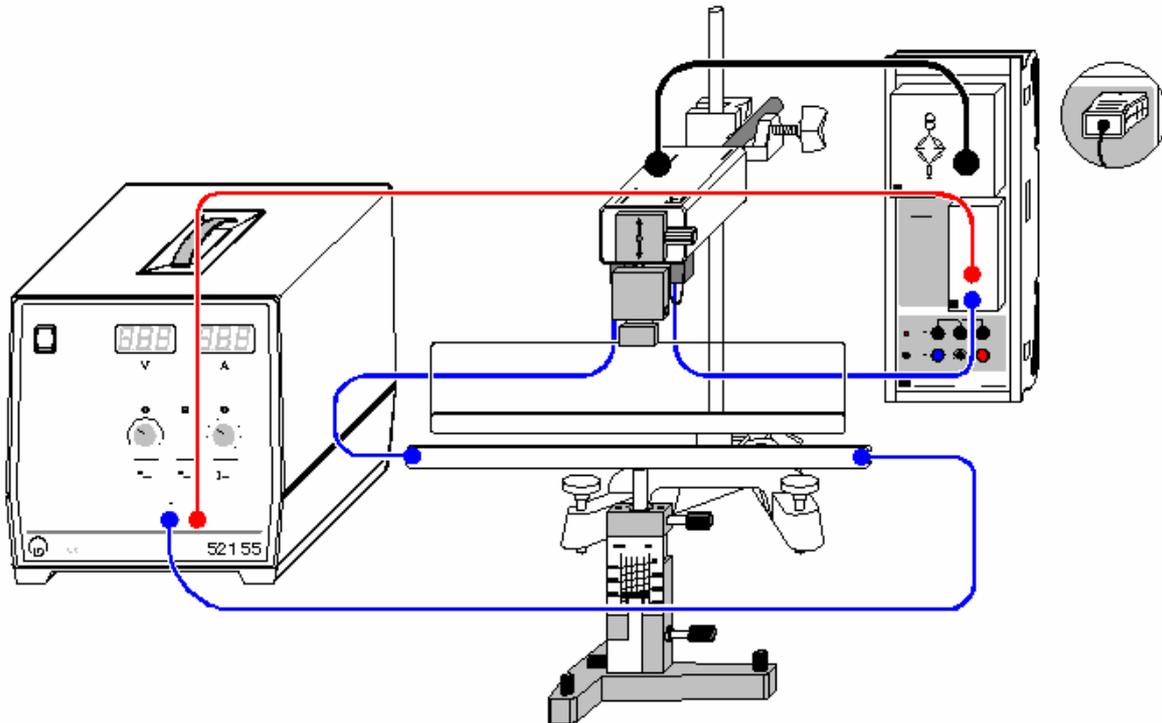
- Set the force zero point in Settings Force FA1 with → 0 ← and, where necessary, switch on the smoothing LED of the bridge box with **LED On/Off**.
- You may want to **correct** the current value to 0 A in Settings Current IB1 (set the first target value to 0 A and click **Correct Offset**).
- At the power supply of the coils, set about 2.5 A.
- Increase the conductor loop current I from 0-20 A in steps of 2 to 5 A, and record a measured value with **F9** each time. You can delete a faulty measurement series from the table with **Delete Last Table Row** (click right mouse button over table).
- If only negative forces are measured, reverse the connections on the conductor loop support.
- Carry out the experiment rapidly, as the conductor loop and support may be subjected to loads of 20 A only briefly.
- At the end of the experiment, set the conductor loop current to 0 A.
- Record additional measurement curves with a different conductor loop length s. In the Measuring Parameters dialog select **Append New Meas. Series**.

Evaluation

Fit a straight line to each measurement series F(I). After each best-fit straight line, switch to the display **Magnetic Field** (click the tab with the mouse). Here, an additional table is filled out by dragging the slope F/I just determined from the status line using the mouse and dropping it next to the respective conductor loop length (drag & drop). Enter the conductor loop length s directly via the keyboard. The desired diagram is generated as you enter the values.

In this display, the slope of the best-fit straight line gives us the magnetic field strength B between the pole pieces, as $F/I = B s$ (in this example, $B = 164 \text{ mN}/(\text{A}\cdot\text{m}) = 164 \text{ mT}$).

Force between two current-carrying conductors (ampere definition)



can also be carried out with Pocket-CASSY and Mobile-CASSY

■ Load example

Experiment description

The force F acting on a conductor with the length s and carrying a current I in a field with the magnetic flux density B is

$$F = I \cdot s \cdot B.$$

If the flux density B is generated by a long conductor at a distance r , we say

$$B = \text{const.} \cdot I / r.$$

Thus, the force F acting between two parallel conductors carrying the same current I is determined using

$$F = \text{const.} \cdot I^2 \cdot s / r.$$

Electrical current (the ampere) is defined as follows: the current I has the value 1 A when the absolute value of the force per unit of length s between two parallel, straight and infinitely long conductors with a diameter tending to zero and carrying the identical current is

$$F / s = 2 \cdot 10^{-7} \text{ N/m}$$

In other words, we say:

$$\text{const.} = 2 \cdot 10^{-7} \text{ N/A}^2.$$

Normally, const. is expressed as $\mu_0/2\pi$, which gives us:

$$F = \mu_0/2\pi \cdot I^2 \cdot s / r$$

where $\mu_0 = 4\pi \cdot 10^{-7} \text{ N/A}^2 = 4\pi \cdot 10^{-7} \text{ Vs/Am}$.

In this experiment a conductor with the length $s = 0.30 \text{ m}$ is suspended at a distance r of just a few millimeters above a somewhat longer conductor. This experiment measures the force F acting on the suspended conductor at different currents I and distances r . The result verifies the ampere definition.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Bridge box	524 041
	with Force sensor and	314 261
	Multicore cable, 6-pole, 1.5 m	501 16
	or	
1	Force sensor S, ± 1 N	524 060
1	30-A box	524 043
1	Support for conductor loops	314 265
1	Set of conductors for ampere definition	516 33
1	Vertically adjustable stand	516 31
1	High current power supply	521 55
1	Stand base, V-shape, 20 cm	300 02
1	Stand rod, 47 cm	300 42
1	Leybold multiclamp	301 01
2	Connecting leads, 50 cm, blue	501 26
1	Connecting lead, 100 cm, red	501 30
1	Connecting lead, 100 cm, blue	501 31
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The force sensor holds the top conductor loop with the support and is positioned so that the distance between the two conductor loops is about 5 mm for medium extension of the vertically adjustable stand.

The two 4-mm sockets on the bottom of the force sensor are intended for supplying the conductor loop support. They are not connected internally. The force sensor is connected to the bridge box at input A of Sensor-CASSY. The current flows from the 20 A supply unit via the 30 A box on input B of Sensor-CASSY through the two conductor loops in series and back to the power supply.

Now, slowly bring the conductor loop on the stand closer to the suspended conductor loop until the two are just touching (the wire centers now have the distance $r = 2$ mm). Check to make sure that the vertically adjustable stand is still parallel to the conductor loop, and adjust it if necessary using the adjusting screws.

Set the zero-point slider of the vertically adjustable stand to a defined mark and set the desired distance between the two conductor loops using the height adjustment mechanism (e.g. $r = 4$ mm).

Good measuring results require careful adjustment here.

Carrying out the experiment

■ Load settings

- Set the force zero point in Settings Force FA1 with $\rightarrow 0 \leftarrow$ and, where necessary, switch on the smoothing LED of the bridge box with **LED On/Off**.
- You may want to **correct** the current value to 0 A in Settings Current IB1 (set the first target value to 0 A and click **Correct Offset**).
- Increase the conductor loop current I from 0-20 A in steps of 2 A, and record measured values with **F9** each time. You can delete a faulty measurement series from the table with **Delete Last Table Row** (click right mouse button over table).
- If only negative forces are measured, reverse the connections on the conductor loop support.
- Carry out the experiment rapidly, as the conductor loop and support may be subjected to loads of 20 A only briefly.
- At the end of the experiment, set the conductor loop current to 0 A.
- Record additional measurement curves with different conductor spacings r. In the Measuring Parameters dialog select **Append New Meas. Series**.



Evaluation

Fit a parabola to each measurement series $F(I)$. After each best-fit straight line, switch to the display **Ampere Definition** (click the tab with the mouse). Here, an additional table is filled out by dragging the parameter F/I^2 of the parabola just determined from the status line using the mouse and dropping it next to the respective conductor loop spacing r in the table (drag & drop). Enter the conductor loop spacing r directly via the keyboard. The desired diagram is generated as you enter the values.

In this display, the parameter $F/I^2 \cdot r$ of a hyperbola $1/x$ gives us the constant for the ampere definition as

$$\mu_0/2\pi = F/I^2 \cdot r / s = F/I^2 \cdot r / 0.3 \text{ m}.$$

In our example this means

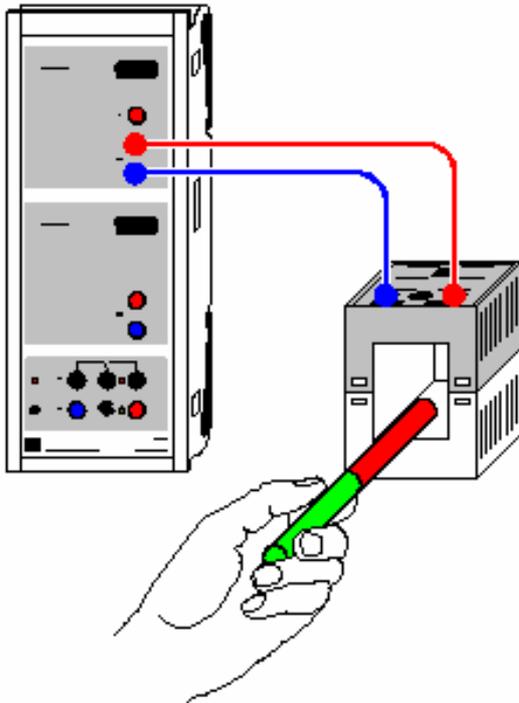
$$\mu_0/2\pi = 0.000062 \text{ mN}\cdot\text{m}/\text{A}^2 / 0.3 \text{ m} = 2.1 \cdot 10^{-7} \text{ N}/\text{A}^2 = 2.1 \cdot 10^{-7} \text{ Vs}/\text{Am}.$$

Alternatively, you can convert the x-axis from r to $1/r$ in the ampere definition display (click on the axis with the right mouse button). In this display, we obtain the value $\mu_0/2\pi$ by fitting a straight line.

Remark

This measurement contains systematic errors. For one thing, the conductor has a finite length. That means that the assumed magnetic field does not exist at the end of the conductor, so that the forces are less. Additionally, a minute opposing force component acts on the suspended conductor due to the conductor segment running upward.

Impulse of voltage (Faraday's law of induction)



can also be carried out with Pocket-CASSY

■ Load example

Experiment description

In 1831, Faraday discovered that each change in the magnetic flux Φ through a closed conductor loop generates an electrical voltage in that loop. The magnetic flux here is given by the integral of the conductor-loop area of the magnetic flux density resp. induction \mathbf{B}

$$\Phi = \int_A \mathbf{B} \cdot d\mathbf{A}$$

In particular, he demonstrated that this induced voltage is proportional to the derivation of the magnetic flux Φ over time, and thus that the voltage impulse

$$\int_1^2 U dt \sim \Phi_2 - \Phi_1 = \Delta\Phi$$

is dependent only on the change in the magnetic flux. He thus discovered Faraday's law of induction

$$U = -\frac{d\Phi}{dt}.$$

This experiment measures the induced voltage $U(t)$ for various magnetic flux densities \mathbf{B} and numbers of turns N for various coils, determines the time integral and thus the voltage impulse in the evaluation of a recorded curve and ultimately verifies Faraday's law of induction.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
2	Round bar magnets	510 11
1	Coil with 250 turns	562 13



1	Coil with 500 turns	562 14
1	Coil with 1000 turns	562 15
1	Pair of cables, 1 m, red and blue	501 46
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Connect a coil to input A of Sensor-CASSY.

Carrying out the experiment

a) Measuring as a function of the magnetic flux Φ

■ Load settings

- Connect the coil with 250 turns to input A.
- Start the measurement with **F9**.
- Insert one magnet half-way and remove it.
- Stop the measurement with **F9** (or the measurement stops automatically after 10 seconds).
- Start the measurement with **F9** and wait until the new measurement has proceeded far enough so that it no longer covers the old measurement.
- Insert two magnets half-way and remove them.
- Stop the measurement with **F9** (or the measurement stops automatically after 10 seconds).

b) Measuring as a function of the number of turns N

■ Load settings

- Connect the coil with 250 turns to input A.
- Start the measurement with **F9**.
- Insert the magnet half-way and remove it.
- Stop the measurement with **F9** (or the measurement stops automatically after 10 seconds).
- Connect the coil with 500 turns to input A.
- Start the measurement with **F9** and wait until the new measurement has proceeded far enough so that it no longer covers the old measurement.
- Insert the magnet half-way and remove it.
- Stop the measurement with **F9** (or the measurement stops automatically after 10 seconds).
- Connect the coil with 1000 turns to input A.
- Start the measurement with **F9** and wait until the new measurement has proceeded far enough so that it no longer covers the old measurement.
- Insert the magnet half-way and remove it.
- Stop the measurement with **F9** (or the measurement stops automatically after 10 seconds).

Evaluation

In experiment part a), the integral quickly reveals that the voltage impulses have the same absolute value but different signs when the magnet is inserted in and withdrawn from the coil, i.e.

$$\int_1 U(t) dt = - \int_1 U(t) dt.$$

The use of two magnets additionally verifies the proportionality between the voltage impulses and the number of magnets used resp. the difference in the magnetic flux produced in this manner:

$$\int_1^2 U(t) dt \sim \Phi_2 - \Phi_1 = \Delta\Phi.$$

By means of differentiation we verify Faraday's law of induction

$$U = - \frac{d\Phi}{dt}$$

The magnetic flux through a coil depends on the number of turns, as each individual turn causes a flux difference $\Delta\Phi_0$ and the total flux is calculated as $\Delta\Phi = N \cdot \Delta\Phi_0$.

When we look at experiment part b), the relationship between a voltage impulse and the number of turns N of the respective coil, we can also confirm this relationship. To do this we determine e.g. all positive

areas and enter these in the **Number of Turns** display together with the number of turns N (click on the correct table cells). Once again, the proportionality gives us

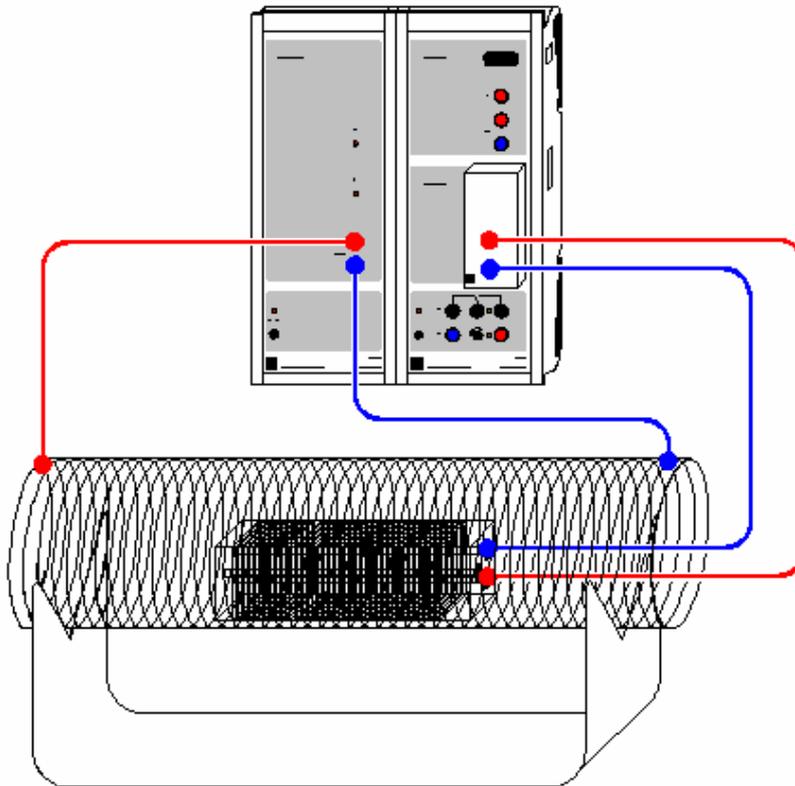
$$\int_1^2 U(t) dt \sim N \cdot \Delta\Phi_0 = \Delta\Phi.$$

The slope of the straight line in the display of voltage impulses as a function of the number of turns corresponds to the magnetic flux Φ_0 generated by the magnet in each individual coil winding.

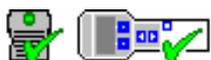
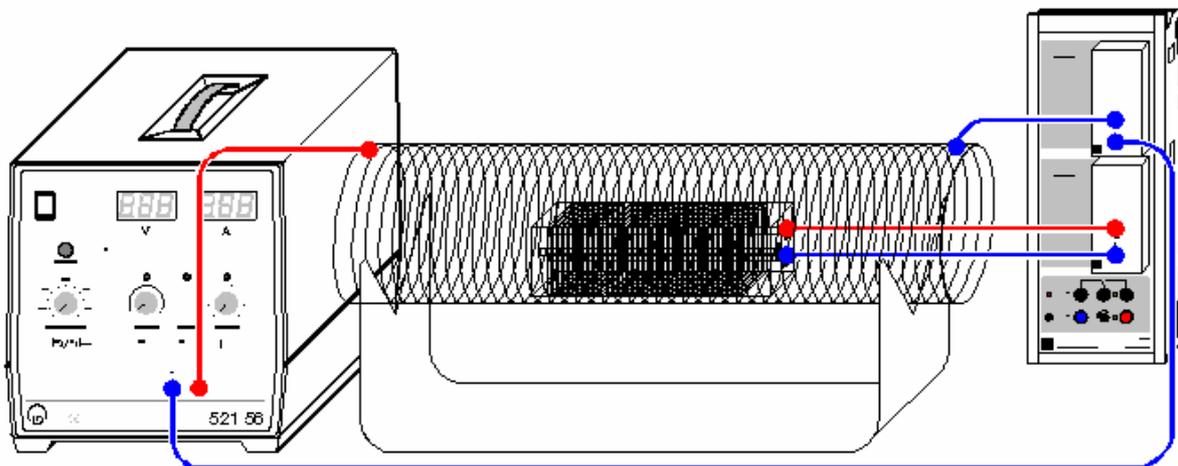
Hints on integration

To integrate, you need to find the start of the range, which is not always easy when multiple curves are superimposed. It is easier when the measurement is stopped with **F9** immediately following the voltage impulse (do not wait for the 10 seconds to elapse) and the integral is calculated immediately after measuring. If you wait until after the end of the previous measuring curve before starting the next voltage impulse measurement, no curve covers the others while integrating.

Induction in a variable magnetic field



Alternatively (without Power-CASSY):



can also be carried out with Pocket-CASSY and Mobile-CASSY

- Load example (with Power-CASSY)
- Load example (without Power-CASSY)

Experiment description

Voltages and currents which are produced as a result of variations in magnetic fields are called induction voltages and currents, and the phenomenon itself is referred to as electromagnetic induction. When a conductor loop is placed within a magnetic field \mathbf{B} , the magnetic flux permeating the loop is determined

by the integral of the conductor loop area

$$\Phi = \int_A \mathbf{B} \cdot d\mathbf{A}$$

If instead of a conductor loop we use a coil with N_1 turns, all perpendicular to the magnetic field, Φ increases correspondingly to

$$\Phi = B \cdot A \cdot N_1.$$

If the magnetic field B does not vary, the magnetic flux Φ remains constant. When the magnetic field, and thus the magnetic flux through the area of the coil, changes over time, a voltage and consequently a current as well are induced in the coil; their magnitude and direction depend on how the field varies. Faraday's law of induction applies:

$$U = -\frac{d\Phi}{dt}$$

and thus

$$U = -\frac{dB}{dt} \cdot A \cdot N_1.$$

Conversely, an electric current generates a magnetic field, e.g. when a current I flows through a coil. For the magnetic field inside a large cylindrical coil with the length L and the number of turns N_2 , the following applies:

$$B = \mu_0 \frac{N_2}{L} I$$

where $\mu_0 = 4\pi \cdot 10^{-7}$ Vs/Am (magnetic field constant).

This experiment uses a large cylindrical coil as a field coil through which a varying current $I(t)$ flows, which generates a varying magnetic field $B(t)$ within the coil. Rectangular induction coils having different cross-sections (areas) A and numbers of turns N_1 are placed inside this field coil. A voltage U is induced in these coils, which can be calculated as

$$U = -\frac{dI}{dt} \cdot \mu_0 \cdot A \cdot \frac{N_2}{L} \cdot N_1$$

This experiment verifies the proportionalities between the induced voltage U and the change over time dI/dt of the field-coil current I , the area A of the induction coils and the number of turns N_1 of the induction coils. Power-CASSY (524 011) or the triangular wave form power supply (521 56) are particularly suitable for this experiment, as the output current I over time can be controlled so that the slope $|dI/dt|$ is constant. The slope $|dI/dt|$ is continuously adjustable from 0.2 A/s to 2.2 A/s. Three induction coils are also provided, with 300 turns each. Coil 1 has the cross-section $A = 50 \times 50 \text{ mm}^2$, coil 2 $A = 30 \times 50 \text{ mm}^2$ and coil 3 $A = 20 \times 50 \text{ mm}^2$. Coil 1 is also provided with additional taps at 100 and 200 turns.

Equipment list

1	Sensor-CASSY	524 010
1	Power-CASSY	524 011
1	CASSY Lab	524 200
1	μ V box	524 040
1	Field coil, $d = 120 \text{ mm}$	516 244
1	Stand for coils and tubes	516 249
1	Set of induction coils	516 241
2	Connecting leads, 100 cm, red	501 30
2	Connecting leads, 100 cm, blue	501 31
1	PC with Windows 95/98/NT or higher version	



Alternatively (without Power-CASSY)

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	μ V box	524 040
1	30-A box	524 043
1	Field coil, $d = 120$ mm	516 244
1	Stand for coils and tubes	516 249
1	Set of induction coils	516 241
1	Triangular wave form power supply	521 56
1	Connecting lead, 50 cm, blue	501 26
2	Connecting leads, 100 cm, red	501 30
2	Connecting leads, 100 cm, blue	501 31
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The large coil is supplied with a constant $|dl/dt|$ using either Power-CASSY or the triangular wave form power supply. In the latter case, the flowing current must be measured at input A of Sensor-CASSY using the 30 A box. The induced voltage of the induction coils is measured using the μ V box at input B.

Carrying out the experiment

- Measuring the induction voltage U as a function of the area (cross-section) A of the induction coils
 - Load settings.
 - Place coil 1 ($A = 0.0025 \text{ m}^2$, $N_1 = 300$ turns) in the large field coil and connect it to the μ V-box.
 - Execute the measurement with **F9**.
 - Repeat the measurement with coils 2 ($A = 0.0015 \text{ m}^2$) and 3 ($A = 0.0010 \text{ m}^2$).
- Measuring the induction voltage U as a function of the number of turns N_1 of the coils
 - Load settings.
 - Connect coil 1 ($N_1 = 100$ turns) in the large field coil to the μ V box.
 - Execute the measurement with **F9**.
 - Repeat the measurement with $N_1 = 200$ and $N_1 = 300$ of coil 1.
- Measuring the induction voltage U as a function of dl/dt
 - Load settings.
 - Connect coil 1 ($N_1 = 300$ turns) in the large field coil to the μ V box.
 - Execute the measurement with **F9**.
 - Repeat the measurement with the reduced maximum current I_{\max} or dl/dt respectively; to do this, move the pointer of the display instrument to the desired position using the mouse.

Alternatively (without Power-CASSY)

- Measuring the induction voltage U as a function of the area A of the induction coils
 - Load settings
 - Place coil 1 ($A = 0.0025 \text{ m}^2$, $N_1 = 300$ turns) in the large field coil and connect it to the μ V box.
 - Turn the voltage knob on the triangular wave form power supply all the way to the right, and turn up the current knob until the power limiting (LED P_{\max}) is just below the cut-in threshold.
 - Choose the middle setting for dl/dt and press the key to activate triangle mode.
 - Start the measurement with **F9** (the measurement begins with a rising edge of the induction voltage U_{B1} ; you may need to deactivate the trigger).
 - Stop the measurement with **F9** after a few current periods.
 - Repeat the measurement with coils 2 ($A = 0.0015 \text{ m}^2$) and 3 ($A = 0.0010 \text{ m}^2$).
- Measuring the induction voltage U as a function of the number of turns N_1 of the coils
 - Load settings
 - Connect coil 1 ($N_1 = 100$ turns) to the μ V box inside the large field coil.
 - Turn the voltage knob on the triangular wave form power supply all the way to the right, and turn up the current knob until the power limiting (LED P_{\max}) is just below the cut-in threshold.

- Choose the middle setting for dl/dt and press the key to activate triangle mode.
- Start the measurement with **F9** (the measurement begins with a rising edge of the induction voltage U_{B1} ; you may need to deactivate the trigger).
- Stop the measurement with **F9** after a few current periods.
- Repeat the measurement with $N_1 = 200$ and $N_1 = 300$ of coil 1.

c) Measuring the induction voltage U as a function of the frequency of the excitation field

■ Load settings

- Connect coil 1 ($N_1 = 300$ turns) to the μV box inside the large field coil.
- Turn the voltage knob on the triangular wave form power supply all the way to the right, and turn up the current knob until the power limiting (LED P_{max}) is just below the cut-in threshold.
- Choose the middle setting for dl/dt and press the key to activate triangle mode.
- Start the measurement with **F9** (the measurement begins with a rising edge of the induction voltage U_{B1} ; you may need to deactivate the trigger).
- During the measurement increase dl/dt in steps of about 0.4 A/s.
- Stop the measurement with **F9**.

Evaluation

Depending on the experiment section, activate the appropriate display (click on **Area**, **Number of Turns** or **dl/dt**) with the mouse. A further table is filled out in which the induction voltage is determined for the respective parameter A , N_1 or dl/dt (by entering via the keyboard; dl/dt can be determined by fitting a straight line). You can find the induction voltage U e.g. by determining the mean value. You can then use the mouse to drag this value from the status line and drop it into the table (drag & drop). The desired diagram is generated as you enter the values.

All three diagrams confirm the proportionalities between the induction voltage U and the area A , number of turns N_1 and dl/dt .

In this example, we obtain the proportionality factor $U/A = 101 \text{ mV/m}^2$ (or 129 mV/m^2 without Power-CASSY) between the induction voltage U and the coil cross-section A . Theory expects the proportionality factor

$$\frac{U}{A} = -\frac{dI}{dt} \cdot \mu_0 \cdot \frac{N_2}{L} \cdot N_1 .$$

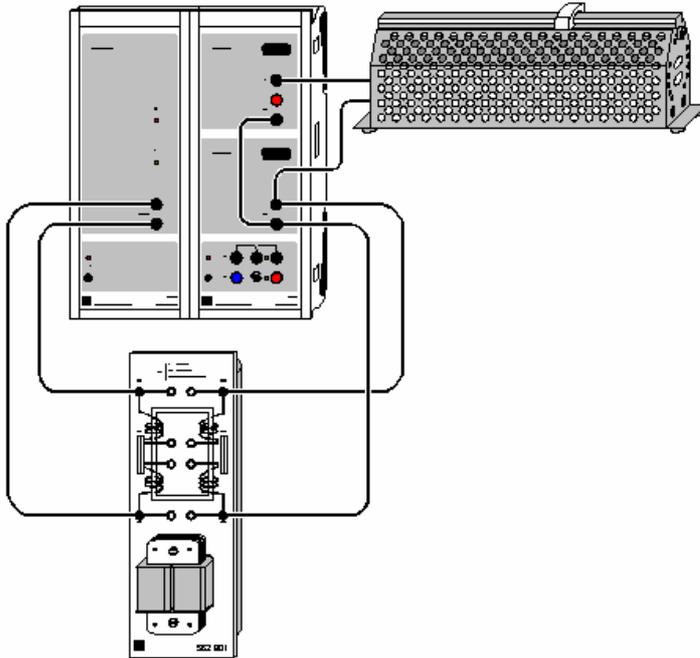
By comparison, the number of turns of the induction coil $N_1 = 300$ and $N_2 = 120$ of the air coil, the air coil length $L = 0.4 \text{ m}$, the calculated current increase $dl/dt = 1.00 \text{ A/s}$ (resp. 1.19 A/s) and the magnetic field constant $\mu_0 = 4\pi \cdot 10^{-7} \text{ Vs/Am}$ taken together give us the proportionality factor $U/A = -110 \text{ mV/m}^2$ (resp. -131 mV/m^2), which agrees with the experiment result. The sign depends on the direction of the turns and the connection to the μV box.

Notes

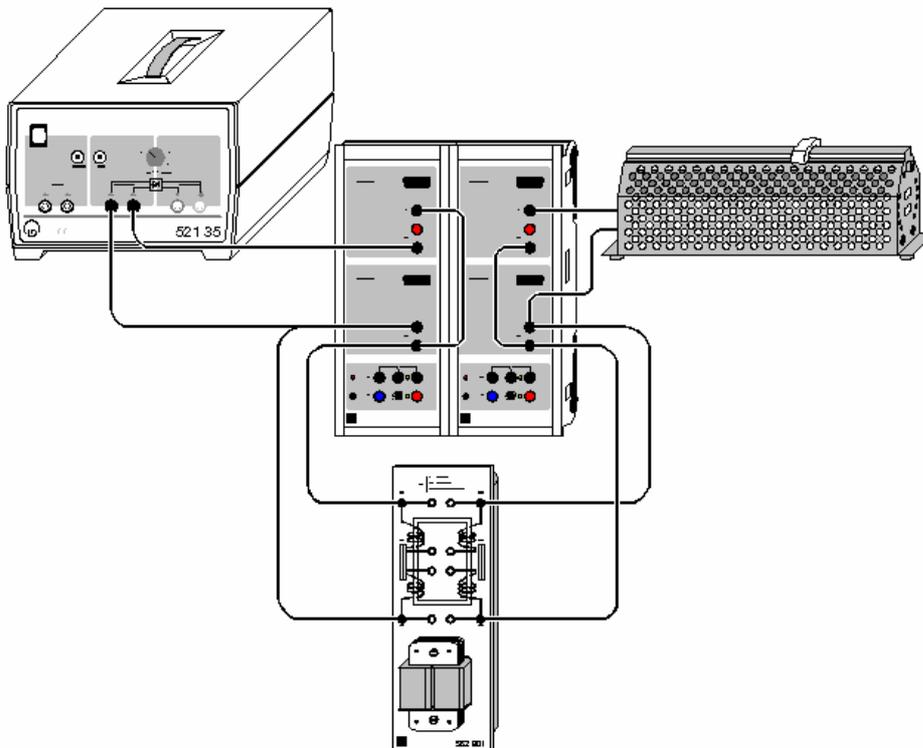
The μV box may have a slight offset, which can be corrected in Settings by selecting **Correct**, setting value 0 mV and choosing **Correct Offset**; be sure to interrupt the circuit of the air coil first.

Power-CASSY can also output a significantly higher frequency, and thus make the μV box unnecessary. However, note that in this case the current regulation of Power-CASSY tends to slight overshoots at higher frequencies and inductive loads, which negatively affect the induced voltage (1st derivation of the current). You can resolve this by connecting a resistor of around 10Ω in series.

Voltage and current curves of a transformer as a function of time



Alternatively (without Power-CASSY):



can also be carried out with Pocket-CASSY

- Load example (with Power-CASSY)
- Load example (without Power-CASSY)

Experiment description

This experiment records the primary and secondary currents and voltages of a transformer under load as time-dependent quantities. From these, CASSY Lab directly calculates the time-dependent power values in the primary and secondary circuit, as well as the RMS values of current and voltage, the phase relation and the active power values.

Equipment list

1	Power-CASSY	524 011
1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Transformer for students' experiments	562 801
1	Rheostat 100 Ω	537 34
1	Connecting lead, 25 cm, black	500 414
6	Connecting leads, 100 cm, black	500 444
1	PC with Windows 95/98/NT or higher version	

Alternatively (without Power-CASSY)

2	Sensor-CASSYs	524 010
1	CASSY Lab	524 200
1	Variable extra-low voltage transformer S	521 35
1	Transformer for students' experiments	562 801
1	Rheostat 100 Ω	537 34
2	Connecting leads, 25 cm, black	500 414
8	Connecting leads, 100 cm, black	500 444
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The primary side of the transformer is supplied by Power-CASSY or by the variable transformer (approx. 6 V AC). In the latter case, the primary voltage, primary current and phase relation ($\cos \varphi$) must be measured using a second Sensor-CASSY unit.

Sensor-CASSY performs the necessary measurements of voltage, current and phase relation ($\cos \varphi$) on the secondary side. The transformer is under resistive load ($\cos \varphi = 1$) in the form of a rheostat. However, where available the transformer can also be operated under inductive or capacitive load ($\cos \varphi < 1$). You can improve the response of the transformer to load by connecting two coils each in parallel on the primary and secondary side of the transformer for students' experiments.

In place of the transformer for students' experiments, you can also use the demountable transformer.

Carrying out the experiment

- Load settings (with Power-CASSY)
- Load settings (without Power-CASSY)
- Start the measurement with **F9**.
- Vary the load (e.g. also inductive or capacitive load) and observe the effect on the secondary and primary circuits.
- Vary the number of coils on the primary and secondary side of the transformer and observe the behavior under load.
- If desired, alter the curve form or the frequency of the primary voltage in Settings U1 on Power-CASSY and observe the result.
- Stop the measurement with **F9**.

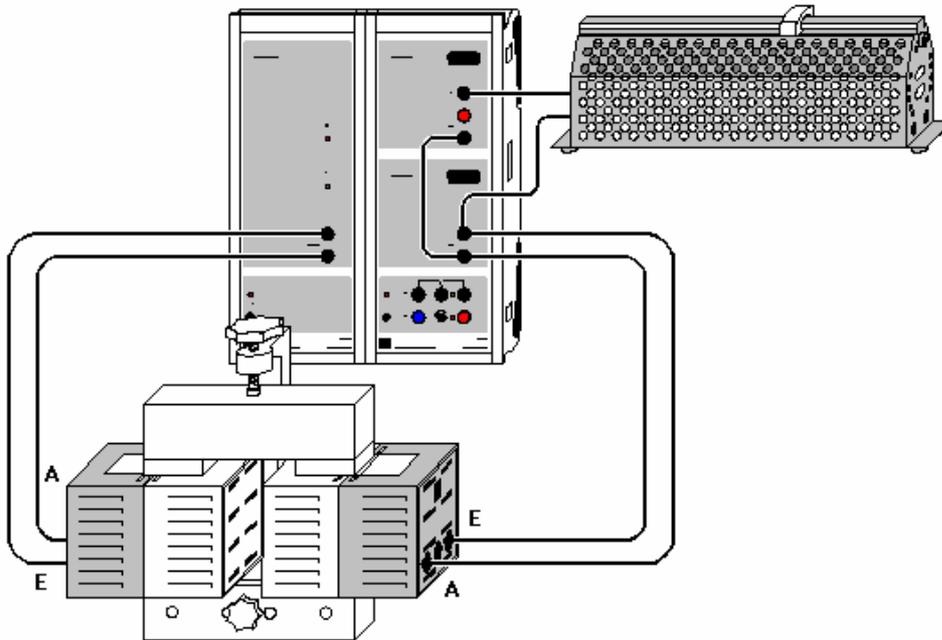
Evaluation

You can change to the **Power** display with the mouse during or after measuring. This display shows both power values as a function of time.

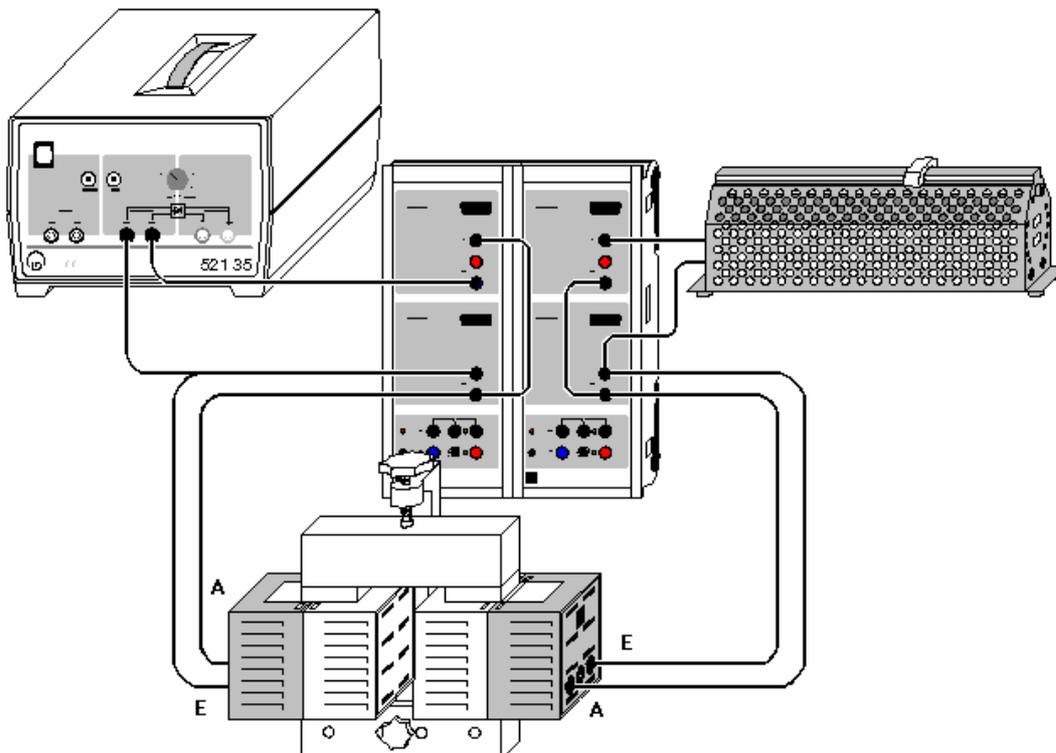
Hint

You can show and hide all measuring instruments simultaneously with **F7**.

Power transfer of a transformer



Alternatively (without Power-CASSY):



can also be carried out with Pocket-CASSY

- Load example (with Power-CASSY)
- Load example (without Power-CASSY)

Experiment description

This experiment examines the power transfer of a transformer. This is done by simultaneously measuring the RMS values of the primary and secondary voltage as well as the primary and secondary current for a variable load resistor $R = 0-100 \Omega$. The experiment also determines the phase shift between the voltage and current on the primary and secondary side. The evaluation determines the primary power P_1 , the secondary power P_2 and the efficiency $\eta = P_2/P_1$ and plots these as a function of the load resistance R .

Equipment list

1	Power-CASSY	524 011
1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	U-core with yoke	562 11
1	Clamping device	562 12
2	Coils with 250 turns	562 13
1	Rheostat 100 Ω	537 34
1	Connecting lead, 25 cm, black	500 414
6	Connecting leads, 100 cm, black	500 444
1	PC with Windows 95/98/NT or higher version	

Alternatively (without Power-CASSY)

2	Sensor-CASSYs	524 010
1	CASSY Lab	524 200
1	Variable extra-low voltage transformer S	521 35
1	U-core with yoke	562 11
1	Clamping device	562 12
2	Coils with 250 turns	562 13
1	Rheostat 100 Ω	537 34
2	Connecting leads, 25 cm, black	500 414
8	Connecting leads, 100 cm, black	500 444
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The primary side of the transformer is supplied by Power-CASSY or by the variable transformer (approx. 6 V AC). In the latter case, the primary voltage, primary current and phase relation ($\cos \varphi$) must be measured using a second Sensor-CASSY unit.

Sensor-CASSY performs the necessary measurements of the RMS values of voltage, current and their phase relation ($\cos \varphi$) on the secondary side. The transformer is under resistive load ($\cos \varphi = 1$) in the form of a rheostat.

Instead of the demountable transformer, you can use the transformer for students' experiments.

Carrying out the experiment

- Load settings (with Power-CASSY)
- Load settings (without Power-CASSY)
 - Set the rheostat to the minimum position (approx. 0 Ω).
 - Start the measurement with **F9**.
 - Increase the resistance in steps and record measured values for each step with **F9**.

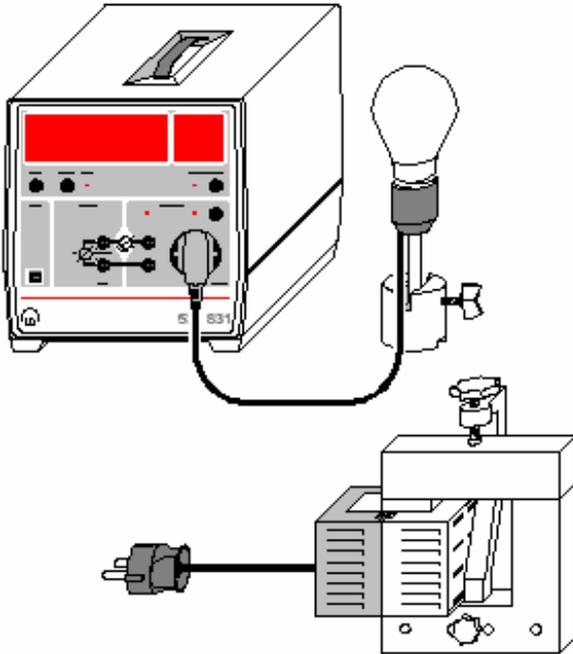
Evaluation

The points of maximum power output and maximum efficiency can be easily read from the diagram.

Hint

You can show and hide all measuring instruments simultaneously with **F7**.

Power of arbitrary loads operated with mains AC voltage



- Load example (incandescent lamp)
- Load example (energy-saving lamp)
- Load example (mains coil)

Safety note

At the socket of the joule and wattmeter, the mains voltage is present. Even though this voltage can be switched off through the software settings, it remains a potential danger. The voltage is present again at the latest when the software is left.

Experiment description

The time dependent quantities $U(t)$, $I(t)$ and $P(t)$ are recorded for several loads connected to the mains AC voltage. In addition, the active power P , the apparent power S , the reactive power Q and the power factor $\cos\varphi$ are displayed and can be compared with one another.

The active power P is the mean value of the instantaneous power $P(t)=U(t)\cdot I(t)$. The apparent power S is defined as the product of the two RMS values U and I , i.e. $S=U\cdot I$. The power factor $\cos\varphi$ is the ratio of the active and the apparent power, i.e. $\cos\varphi = P/S$. This also applies in the case of an arbitrary shape of the voltage $U(t)$ and the current $I(t)$. Yet, φ cannot be interpreted as the phase shift between the current and the voltage in this case. Finally, the reactive power Q is calculated from the active power P and the apparent power S :

$$Q = \sqrt{S^2 - P^2}$$

Equipment list

1	Joule and wattmeter	531 831
1	Lamp socket E 27	451 17
1	Incandescent lamp 60 W, E 27	505 301
1	Energy-saving lamp 14 W, E 27	505 3181
1	Saddle base	300 11
1	U-core with yoke	562 11
1	Clamping device	562 12
1	Mains coil, 230 V	562 21
1	PC with Windows 98/2000 or higher version	

Experiment setup (see drawing)

Screw the lamps into the lamp socket or put the mains coil onto the U-core, close the U-core with the yoke and fasten the yoke firmly using the clamping device.

Connect the plug of the lamp socket or the mains coil (switch the mains coil on) to the socket of the joule and wattmeter.

Carrying out the experiment

- Load settings (incandescent lamp)
- Load settings (energy-saving lamp)
- Load settings (mains coil)
- Switch the load on by clicking on the display instrument Switch X.
- Start the measurement with **F9**.
- Switch the load off again.

Evaluation

The mains AC voltage $U(t)$ has always an approximately sinusoidal shape.

Incandescent lamp

The functions $I(t)$ and $P(t)$ are approximately sinusoidal. The instantaneous power $P(t)$ takes only positive values. The active and the apparent power are identical. The reactive power is negligible. The power factor $\cos\varphi$ is 1.

Energy-saving lamp

The functions $I(t)$ and $P(t)$ are not sinusoidal. The instantaneous power $P(t)$ takes only positive values. The active power is smaller than the apparent and the reactive power. The power factor $\cos\varphi$ is approximately 0.64.

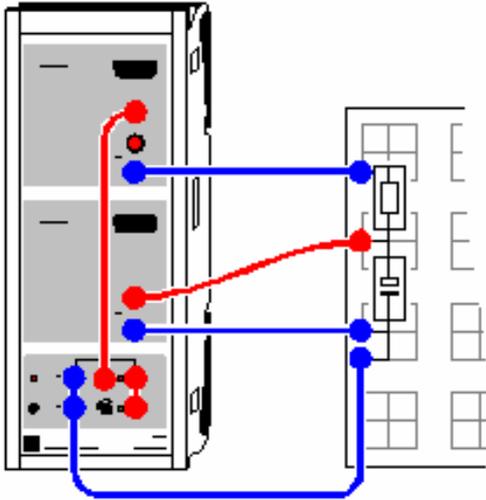
Mains coil with iron core

The functions $I(t)$ and $P(t)$ are not sinusoidal. The instantaneous power $P(t)$ takes both positive and negative values. The active power is much smaller than the apparent and the reactive power. The power factor $\cos\varphi$ is approximately 0.18.

Remark

Other loads can be investigated as well. However, it may be necessary to adjust the measuring range of the current (right mouse button on the I button). Then formulas and units for S and Q may have to be adjusted (e. g. $U \cdot I / 1000$, if U and I are to be displayed in V and A, but S in kW).

Charging and discharging of a capacitor



■ Load example

Experiment description

A capacitor is charged or discharged via a resistor. This experiment measures the voltage curves at the capacitor and the charging or discharge current. From these it is possible to calculate the time constant $\tau = RC$ and the energy content of the capacitor.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Plug-in board DIN A4	576 74
3	STE capacitors 100 μF	578 39
1	STE resistor 100 Ω	577 32
1	Connecting leads, 50 cm, blue	500 422
1	Pair of cables, 25 cm, red and blue	501 44
2	Pairs of cables, 50 cm, red and blue	501 45
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Connect the charging and discharging circuit to Sensor-CASSY inputs A (current) and B (voltage) as shown in the drawing. The relay R charges the capacitor with the voltage from the voltage source S in the ON position (LED on) and discharges the capacitor in the OFF position (LED off).

Carrying out the experiment

a) Discharging

■ Load settings

- Set the charging voltage U_{B1} at the capacitor to about 9.5 V using the knob on the voltage source S.
- Start the discharge with **F9**.
- Repeat the discharge with different capacitances (e.g. 200 μF and 300 μF).

b) Charging

- Switch the relay manually: in Settings Relay R1 change the formula from **1** to **0** and press Enter.
- Start charging with **F9**.
- Repeat charging with different capacitances (e.g. 200 μF and 300 μF).

Evaluation

To determine the time constant $\tau = RC$ you can apply a logarithmic representation to the **Voltage** and **Current** displays. Simply click on the y-axis with the right mouse button to convert it. To optimize the display, you may want to specify the minima manually when applying logarithmic representation (e.g. -1 for $\log U$ and -3 for $\log I$). In both cases, the slope A of a best-fit straight line is $A = -0.4343/RC$.

The time constant is obtained either from a fit to an exponential function or a free fit of the function $A \cdot \exp(-x/B)$ or $A \cdot (1 - \exp(-x/B))$ with suitable starting values for the charging voltage A and the time constant $B = RC = \tau$.

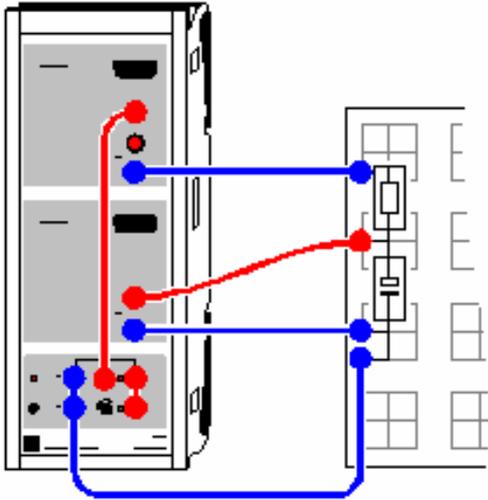
However, you can also determine the capacitances C from the applied or discharged charges Q . The charge Q is determined from the integral of the $I(t)$ diagrams, and $Q = CU$ (where U is the charging voltage).

The stored energy is the integral of the $P(t)$ diagrams in the display **Power**.

Hint

The easiest way to define a time zero point is by setting a trigger. The most suitable quantity is the current I_{A1} (when charging e.g. 0.001 A, rising edge, when discharging e.g. -0.001 A, falling edge). When the trigger is switched on, an external changeover switch can be used instead of the relay for more clarity of the circuit.

Charging and discharging of a capacitor (with modelling)



- Load example (Charging of a capacitor)
- Load example (Discharging of a capacitor)

Experiment description

A capacitor is charged and discharged via a resistor. The voltage curve at the capacitor is measured.

As a supplement to the previous experiment, the measured voltage curve is now compared with the voltage curve $U_C(t)$ which is obtained from energy conservation. The power $U \cdot I(t)$ supplied by an external source has to be equal to the sum of the power at the capacitor $d(1/2 \cdot C \cdot U_C(t)^2)/dt$ and the power at the resistor $R \cdot I(t)^2$, i.e.

$$U \cdot I(t) = U \cdot Q'(t) = d(1/2 \cdot Q(t)^2/C)/dt + R \cdot I(t)^2 = Q(t)/C \cdot Q'(t) + R \cdot Q'(t)^2$$

and, after solving for $Q'(t)$,

$$Q'(t) = I(t) = -Q(t)/RC + U/R.$$

U is the voltage supplied by an external source and is equal to the voltage at the end of the charging or discharging process. The constants R and C correspond to the resistor and to the capacitor used. The voltage $U_C(t)$ at the capacitor is $Q(t)/C$.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Plug-in board DIN A4	576 74
3	STE capacitors 100 μ F	578 39
1	STE resistor 100 Ω	577 32
1	Connecting lead, 50 cm, blue	500 422
1	Pair of cables, 25 cm, red and blue	501 44
2	Pairs of cables, 50 cm, red and blue	501 45
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Connect the charging and discharging circuit to Sensor-CASSY inputs A (current) and B (voltage) as shown in the drawing. The relay R charges the capacitor with the voltage from the voltage source S in the ON position (LED on) and discharges the capacitor in the OFF position (LED off).

Carrying out the experiment

a) Discharging

■ Load settings

- Set the charging voltage U_{B1} at the capacitor to about 9.5 V using the knob at the voltage source S.
- Start the discharge with **F9**.
- Repeat the discharge with different capacitances (e.g. 200 μF and 300 μF).

b) Charging

■ Load settings

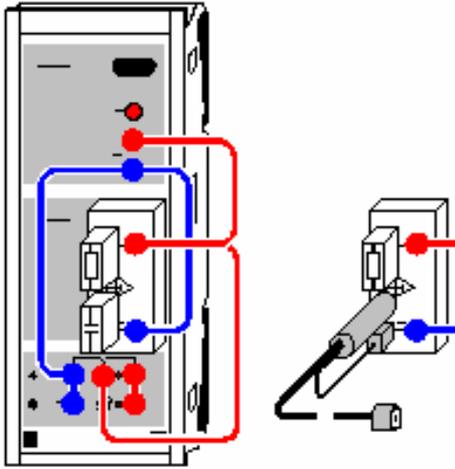
- Start charging with **F9**.
- Repeat charging with different capacitances (e.g. 200 μF and 300 μF).

Modelling

When the capacitor is charged, the initial condition is $Q(t=0)=0$. The constants R (resistance) and C (capacitance) and the voltage U supplied by an external source can be altered by dragging the pointer of the corresponding display instrument (or by clicking to the left or to the right of the pointer) until the model agrees with the measurement.

When the capacitor is discharged, the initial condition is $Q(t=0)=C \cdot U_0$. The constants R (resistance) and C (capacitance) and the initial voltage U of the capacitor can be altered by dragging the pointer of the corresponding display instrument (or by clicking to the left or to the right of the pointer) until the model agrees with the measurement.

Charging and discharging of a small capacitor (cable capacitances)



■ Load example

Experiment description

A capacitor is charged or discharged via a resistor. This experiment measures the voltage curves $U_B(t)$ at the capacitor and the charging or discharge current $I_A(t) = (U_A - U_B(t))/R$. From these it is possible to calculate the time constant $\tau = RC$ and the energy content of the capacitor.

Small STE capacitors or a BNC cable, whose cable capacitance can be determined, are used as capacitors.

For the high-resistance measurement on a capacitor, the electrometer box is used.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Electrometer box	524 054
1	STE resistor 1 G Ω	577 02
1	STE capacitor 47 pF	578 21
1	STE capacitor 100 pF	578 22
1	STE capacitor 220 pF	578 23
1	Screened cable BNC/4 mm, 120 pF	575 24
3	Pair of cables, 25 cm, red and blue	501 44
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Connect the charging and discharging circuit to Sensor-CASSY inputs A and B as shown in the drawing. The relay R charges the capacitor with the voltage from the voltage source S in the ON position (LED on) and discharges the capacitor in the OFF position (LED off).

Carrying out the experiment

a) Discharging

■ Load settings

- Set the charging voltage U_{B1} at the capacitor to about 7.5 V using the knob on the voltage source S.
- Start the discharge with **F9**.
- Repeat the discharge with different capacitances (e.g. 100 pF and 220 pF).

b) Charging

- Switch the relay manually: in Settings Relay R1 change the formula from **1** to **0** and press Enter.
- Start charging with **F9**.
- Repeat charging with different capacitances (e.g. 100 pF and 220 pF).

Evaluation

To determine the time constant $\tau = RC$ you can apply a logarithmic representation to the **Voltage** and **Current** displays. Simply click on the y-axis with the right mouse button to convert it. To optimize the display, you may want to specify the minima manually when applying logarithmic representation (e.g. -1 for $\log U$ and -3 for $\log I$). In both cases, the slope A of a best-fit straight line is $A = -0.4343/RC$.

The time constant is obtained either from a fit to an exponential function or a free fit of the function $A \cdot \exp(-x/B)$ or $A \cdot (1 - \exp(-x/B))$ with suitable starting values for the charging voltage A and the time constant $B = RC = \tau$. For $R = 1 \text{ G}\Omega$, the time constant in s corresponds to the capacitance in nF.

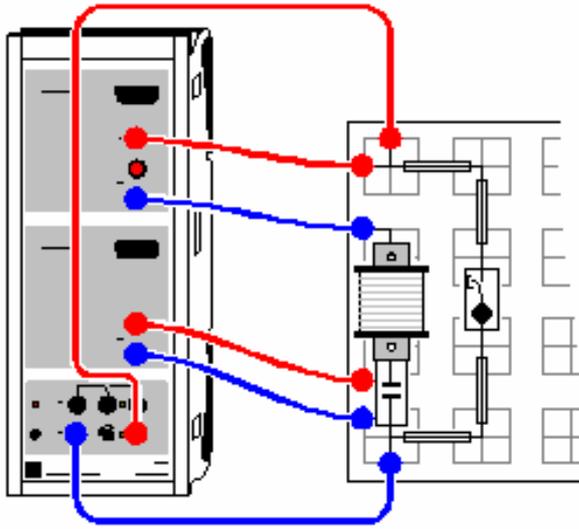
However, you can also determine the capacitances C from the applied or discharged charges Q . The charge Q is determined from the integral of the $I(t)$ diagrams, and $Q = CU$ (where U is the charging voltage).

The stored energy is the integral of the $P(t)$ diagrams in the display **Power**.

Hint

The easiest way to define a time zero point is by setting a trigger. The most suitable quantity is the voltage UA_1 (when charging e.g. 0.5 V, rising edge, when discharging e.g. 0.5 V, falling edge). When the trigger is switched on, an external changeover switch can be used instead of the relay for more clarity of the circuit.

Damped oscillator circuit



■ Load example

Experiment description

An electrical oscillator is excited and the free oscillation is recorded. The damping and the phase difference between $U(t)$ and $I(t)$ become apparent. In the evaluation the calculated frequency ω and damping coefficient δ of the oscillation are compared with theory.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Plug-in board DIN A4	576 74
1	STE coil, 1000 turns	590 84
1	STE capacitor 1 μ F, 5 %	578 15
1	STE key switch (n.o.)	579 10
1	Set of bridging plugs	501 48
3	Pairs of cables, 50 cm, red and blue	501 45
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Set up the oscillator circuit on the plug-in board as shown in the drawing. The current flows via input A of Sensor-CASSY and the capacitor voltage is measured at input B. At the start of the experiment the capacitor is charged from voltage source S. The oscillation is started with the key switch, which shorts the voltage source S.

Note

You can also use relay R instead of the key switch. However, this can bounce so hard when switching that the oscillation is disturbed in the first few milliseconds.

Carrying out the experiment

■ Load settings

- Set the charging voltage U_{B1} at the capacitor to about 9.5 V using the knob at voltage source S.
- Start the measurement with **F9** (software waits for the trigger signal).
- Close the oscillator circuit with the key switch (generates trigger signal).

Evaluation

The easiest way to determine the frequency f is in the **Frequency Spectrum** display (click on this tab and calculate the peak center). The initial amplitude and time constant of the damping can be determined from parameters A and B by fitting an envelope.

These parameters can demonstrate impressive agreement of $U(t)$ with $y(t) = A \cdot \exp(-t/B) \cdot \sin(f \cdot t \cdot 360)$. To realize this, change parameters A , B and f in the formula settings and select the display tab **Matching**.

Example

From the $U(t)$ envelope the experiment example gives us the initial amplitude $A = 6.64$ V and the time constant $B = 1.77$ ms. The oscillation frequency is determined to be 1235 Hz. The function of the oscillation is thus

$$y(t) = 6.64 \cdot \exp(-t/0,00177) \cdot \sin(1235 \cdot t \cdot 360)$$

and is entered as the function for matching to $U(t)$. The same time constant and frequency apply for $I(t)$, but with a different initial amplitude and phase relation.

The calculated parameters also enable conclusions regarding the parameters R , L and C of the oscillator circuit, as in a damped oscillator the following applies:

$$U(t) = U_0 \exp(-\delta t) \sin(\omega t) \text{ where}$$

$$(1) \omega^2 = \omega_0^2 - \delta^2,$$

$$(2) \omega_0^2 = 1/LC \text{ and}$$

$$(3) \delta = R/2L (= 1/B \text{ of envelope}).$$

When we insert the determined values we obtain:

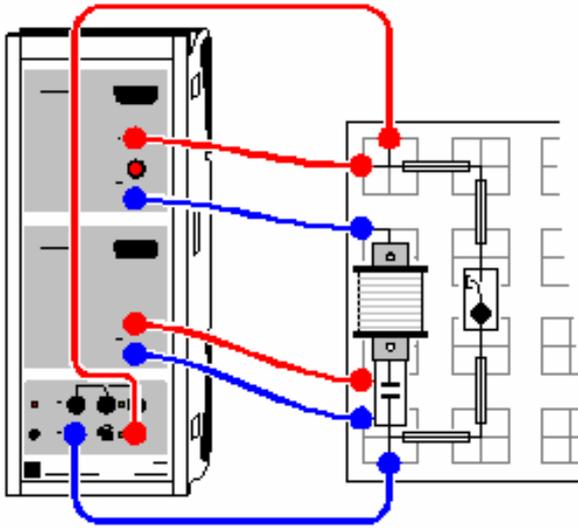
$$\omega = 2\pi f = 7760 \text{ /s}$$

$$\delta = 565 \text{ /s}$$

$$\omega_0 = 7781 \text{ /s from (1).}$$

(2) now allows us to calculate the inductance L of the coil when the capacitance C is known. In this example we obtain $L = 0.0165$ H (with $C = 1 \mu\text{F}$). (3) gives us the damping resistance $R = 18.6 \Omega$. This agrees well with the specification of the coil used here ($R = 18 \Omega$).

Damped oscillator (with modelling)



■ Load example

Experiment description

An electrical oscillator is excited and the free oscillation is recorded in terms of the current flowing in the circuit.

As a supplement to the previous experiment, the measured current curve is now compared with the current curve $I(t)$ which is obtained from energy conservation. The sum of the power at the capacitor $d(1/2 \cdot C \cdot U_C(t)^2)/dt$, the power at the coil $d(1/2 \cdot L \cdot I(t)^2)/dt$ and the power at the resistor $R \cdot I(t)^2$ has to be zero because no energy is supplied during the free oscillation, i.e.

$$d(1/2 \cdot Q(t)^2/C)/dt + d(1/2 \cdot L \cdot I(t)^2)/dt + R \cdot I(t)^2 = Q(t)/C \cdot Q'(t) + L \cdot Q'(t) \cdot Q''(t) + R \cdot Q'(t)^2 = 0$$

and, after solving for $Q''(t)$,

$$Q''(t) = I'(t) = -Q(t)/LC - R \cdot Q'(t)/L.$$

The constants R , L and C correspond to the resistor, the coil and the capacitor used.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Plug-in board DIN A4	576 74
1	STE coil, 1000 turns	590 84
1	STE capacitor 1 μ F, 5 %	578 15
1	key switch (n.o.)	579 10
1	Set of bridging plugs	501 48
3	Pairs of cables, 50 cm, red and blue	501 45
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Set up the oscillator circuit on the plug-in board as shown in the drawing. The current flows via input A of Sensor-CASSY and the capacitor voltage is measured at input B. At the start of the experiment, the capacitor is charged from voltage source S . The oscillation is started with the key switch, which shorts the voltage source S .

Carrying out the experiment

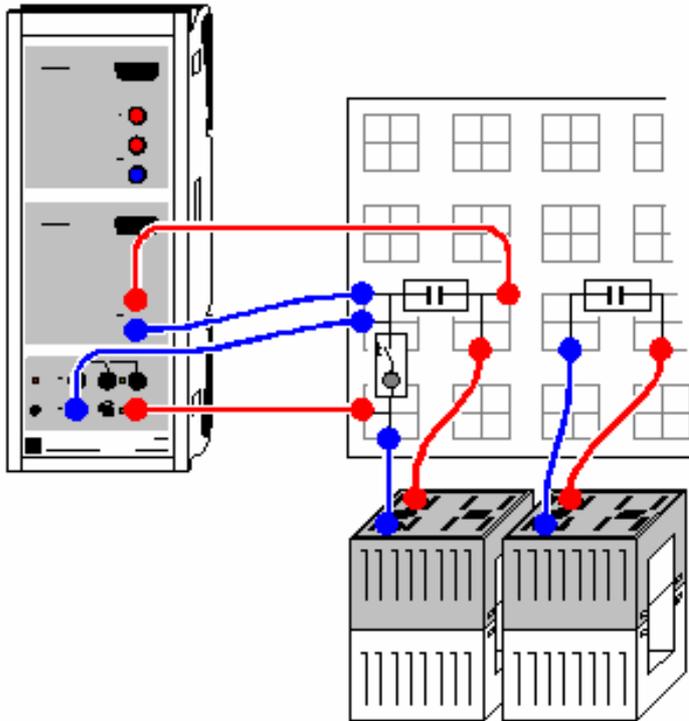
■ Load settings

- Set the charging voltage U_{B1} at the capacitor to about 9.5 V using the knob at voltage source S.
- Start the measurement with **F9** (software waits for the trigger signal).
- Close the oscillator circuit with the key switch (generates trigger signal).

Modelling

The initial condition for the charge Q of the capacitor is $Q(t=0)=-U_0 \cdot C$ with the initial voltage U_0 . This voltage U_0 is not exactly the charging voltage of the capacitor because the measurement is only triggered somewhat later. Therefore the second initial condition is simply $I(t=0)=0$. The constants R (resistance), C (capacitance) and L (inductance) and the initial voltage U_0 can be altered by dragging the pointer of the corresponding display instrument (or by clicking to the left or to the right of the pointer) until the model agrees with the measurement. The ohmic resistance of the coil (approx. 20 Ω) has to be taken into account when the attenuation resistance R is determined.

Coupled oscillators



■ Load example

Experiment description

The frequency spectrum of coupled electric oscillator circuits is compared with the spectrum of an uncoupled oscillator circuit. The Fourier-transformed signal of the coupled oscillator circuits shows the split into two distributions lying symmetrically around the uncoupled signal, with their spacing depending on the coupling of the oscillator circuits.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Plug-in board DIN A4	576 74
1	STE key switch	579 10
2	STE capacitors 1 μF , 5 %	578 15
2	Coils with 500 turns	562 14
4	Pairs of cables, 50 cm, red and blue	501 45
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Assemble the first oscillator circuit as shown in the drawing. The capacitor voltage is measured at input B of Sensor-CASSY. At the start of the experiment the capacitor is charged from voltage source S. The oscillation is started with the key switch, which shorts the voltage source S.

Assemble the second oscillator circuit separately. To couple the oscillators, place its coil directly beside the first coil.

Note

You can also use relay R instead of the key switch. However, this can bounce so hard when switching that the oscillation is disturbed in the first few milliseconds.

Carrying out the experiment

■ Load settings

- Set the charging voltage U_{B1} at the capacitor to about 9.5 V using the knob at voltage source S.
- Start the measurement with **F9** (software waits for the trigger signal).
- Close the oscillator circuit with the key switch (generates trigger signal).
- Place the coil of the second oscillator directly beside that of the first to couple the oscillators.
- Start the measurement with **F9** (software waits for the trigger signal).
- Close the oscillator circuit with the key switch (generates trigger signal).

Evaluation

The uncoupled case produces a damped harmonic oscillation. The coupled oscillation is a beat with the same envelope and the same oscillation frequency.

In the uncoupled case, the **Frequency Spectrum** display shows only one peak, for which the frequency can be calculated as the peak center.

In the coupled case the frequency splits symmetrically into two frequencies. The amplitudes are just half as great as in the uncoupled case, and the interval depends on the coupling.

Given the differential equations of the coupled oscillation circuits

$$\begin{aligned} L\ddot{I}_1 + kL\ddot{I}_2 + I_1/C &= 0 \\ L\ddot{I}_2 + kL\ddot{I}_1 + I_2/C &= 0 \end{aligned}$$

with coupling k ($0 \leq k < 1$), we can calculate the two natural frequencies ω_1 and ω_2 as

$$\frac{\omega_0}{\sqrt{1+k}} = \omega_1 < \omega_0 < \omega_2 = \frac{\omega_0}{\sqrt{1-k}}$$

In particular, the oscillation frequency of the coupled system is equal to

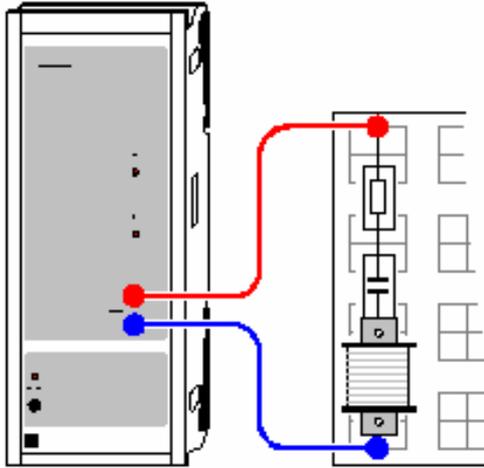
$$\frac{\omega_1 + \omega_2}{2} = \frac{\omega_0}{\sqrt{1-k^2}} \approx \omega_0$$

and is thus practically unchanged with respect to the uncoupled system (for small k values).

Note

The split into two peaks of precisely the same size is only possible with completely identical oscillators. This is not always precisely the case due to the tolerances of the inductances L and capacitances C .

Forced oscillations (resonance)



■ Load example

Experiment description

In this experiment, a sinusoidal oscillation with the frequency f and a constant amplitude is applied to an electric RLC series oscillator circuit. After a short settling time, the oscillator also oscillates with the frequency f .

This experiment investigates the RMS value of the flowing current I and the phase relation φ of the current to the applied voltage as a function of the frequency f and the attenuating resistance R . The loci illustrate the addition of complex resistances.

Equipment list

1	Power-CASSY	524 011
1	CASSY Lab	524 200
1	Plug-in board DIN A4	576 74
1	STE coil, 500 turns	590 83
1	STE capacitor 4.7 μF , 5 %	578 16
2	STE resistors 1 Ω	577 19
1	STE resistor 5.1 Ω	577 21
1	STE resistor 10 Ω	577 20
1	STE resistor 20 Ω	577 23
1	STE resistor 47 Ω	577 28
1	Pair of cables, 50 cm, red and blue	501 45
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Set up the oscillator as shown in the drawing and connect it to Power-CASSY. Connect additional attenuating resistors in series as needed.

Carrying out the experiment

■ Load settings.

- Start the measurement with **F9**. The frequency f is automatically increased in small steps. After a short settling time, the software measures and displays the RMS value of the current I and the phase relation $\cos \varphi$ between the current and the voltage for each frequency. The step size is variable and depends on the specifications of the number n_0 , the starting frequency f_0 and the approximate value f_1 of the resonance frequency. Between the two frequencies f_0 and f_1 , n_0 measuring values are recorded. Then the frequency f is further increased in a way that

around $f=f_1$, i.e. the resonance frequency, values are recorded at a particularly high density. Thereby the measuring time required is considerably reduced as compared with equally spaced frequency steps. The specifications can be changed by shifting the pointer with the mouse or by changing the parameter value after clicking with the right mouse key.

The measuring condition $f < 5 \cdot f_1$ and $f < 5000$ and $\Delta t > 2/f+2$ allows measured values to be recorded up to 5 kHz (or 5 times the resonance frequency), but not before $2/f+2$ s after a frequency increase (transient time).

- Stop the measurement with **F9** when the desired frequency is reached.
- Repeat the measurement with other attenuation resistances as necessary.

Evaluation

The resonance frequency can be exactly determined, for example, by determining the peak centre in the display **Resonance**.

In other displays, also the **Power** and the **Phase** are shown as functions of the frequency.

The last two displays show the **Loci** for the complex resistance Z of the oscillating circuit and the complex conductance Y . In the Z representation, the addition of complex resistances in series connection is nicely displayed: $Z = R + i\omega L + 1/i\omega C$. As in the example only the frequency ω , that is the imaginary part of Z , is varied for each damping resistance, the real ohmic part remains constant. Thus vertical lines are generated in the complex plane whose distance from the imaginary axis is equal to the ohmic resistance R . The coil in the example has an ohmic internal resistance of approximately 4Ω . Therefore the distance from the imaginary axis is larger than the individual damping resistances by approximately 4Ω .

Remark

For an AC circuit we can write

$$U = |U| \cdot e^{i\omega t} \quad \text{and} \quad I = |I| \cdot e^{i(\omega t + \varphi)}$$

where the complex resistance $Z = U/I$ no longer depends on t

$$Z = |U|/|I| \cdot e^{-i\varphi} = |Z| \cdot e^{-i\varphi} \quad (\text{Z locus})$$

On the other hand we have

$$Y = 1/Z = 1/|Z| \cdot e^{i\varphi} \quad (\text{Y locus})$$

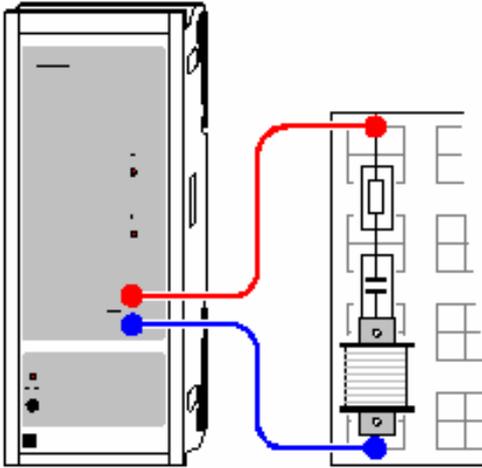
The Y locus corresponds to the complex inversion of the Z locus ($r \rightarrow -r$, $\varphi \rightarrow -\varphi$). This transformation turns the straight lines $Z = R + i\omega L + 1/i\omega C$ of the Z loci into circles in the Y representation (inversion with respect to the unit circle).

Hints

With **F7** the measuring instruments can be hidden and unhidden at the same time.

You can logarithmically scale the frequency axis or the current axis easily by clicking on the corresponding axis with the right mouse button.

Forced oscillations (resonance, with modelling)



■ Load example

Experiment description

A sinusoidal oscillation with the frequency f and a constant amplitude is applied to an electric RLC series oscillator circuit. After a short settling time, the oscillator also oscillates with the frequency f .

As a supplement to the previous experiment, the measured current curve is now compared with the current curve $I(t)$ which is obtained from energy conservation. The power $U(t) \cdot I(t)$ supplied by an external source has to be equal to the sum of the power at the capacitor $d(1/2 \cdot C \cdot U_C(t)^2)/dt$, the power at the coil $d(1/2 \cdot L \cdot I(t)^2)/dt$ and the power at the resistor $R \cdot I(t)^2$, i.e.

$$U(t) \cdot I(t) = U(t) \cdot Q'(t) = d(1/2 \cdot Q(t)^2/C)/dt + d(1/2 \cdot L \cdot I(t)^2)/dt + R \cdot I(t)^2 = Q(t)/C \cdot Q'(t) + L \cdot Q'(t) \cdot Q''(t) + R \cdot Q'(t)^2$$

and, after solving for $Q''(t)$,

$$Q''(t) = I'(t) = U(t)/L - Q(t)/LC - R \cdot Q'(t)/L.$$

The constants R , L and C correspond to the resistor, the coil and the capacitor used.

Equipment list

1	Power-CASSY	524 011
1	CASSY Lab	524 200
1	Plug-in board DIN A4	576 74
1	STE coil, 500 turns	590 83
1	STE capacitor 4.7 μ F, 5 %	578 16
2	STE resistors 1 Ω	577 19
1	STE resistor 5.1 Ω	577 21
1	STE resistor 10 Ω	577 20
1	STE resistor 20 Ω	577 23
1	STE resistor 47 Ω	577 28
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Connect the oscillator to Power-CASSY as shown in the drawing. Connect additional attenuating resistors in series as needed.

Carrying out the experiment

■ Load settings

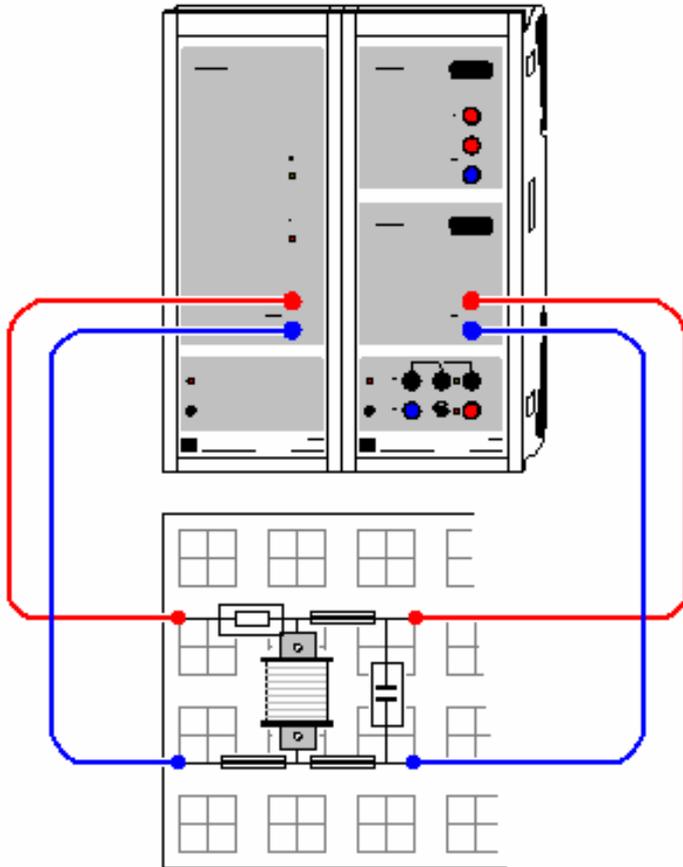
- Start the measurement with **F9**.
- Repeat the measurement with another frequency f (shift the pointer in the display instrument) or with other attenuation resistances as necessary.

Modelling

The initial conditions for the charge Q and the current I are both zero as there is no voltage and no current in the oscillator circuit before the measurement. The constants R (resistance), C (capacitance) and L (inductance) can be altered by dragging the pointer of the corresponding display instrument (or by clicking to the left or to the right of the pointer) until the model agrees with the measurement. The ohmic resistance of the coil (approx. 4Ω) has to be taken into account when the attenuation resistance R is determined.

The Power-CASSY only switches the exciting frequency on when the measurement is started. Therefore the transient oscillation process of the oscillator circuit is seen. Depending on the attenuation and the frequency, you see that the oscillator circuit first oscillates at its natural frequency (resonance frequency) before it is forced to oscillate at the exciting frequency.

RLC filter (low pass, high pass, band pass)



■ Load example

Experiment description

A sinusoidal oscillation with frequency f and having a constant amplitude is applied to an electrical filter consisting of a resistor and a capacitor (RC), resistor and coil (RL) or a resistor and a parallel LC oscillator circuit (RLC). After a short settling time, the output of the filter also oscillates with the frequency f .

This experiment examines the RMS values of the output voltage U and the flowing current I , the impedances $Z_1 = 1/(1/i\omega C) + i\omega L$ (LC only) and $Z = R + 1/(1/i\omega C) + i\omega L$ (R with LC) and the phase relation φ between the current and the applied voltage as a function of the frequency f .

This experiment illustrates in a particularly clear fashion the function of a low pass (RC), high pass (RL) and band pass (FLC) filter, as well as impedances, phase shifts and the parallel resonance of the RLC filter. The loci illustrate the addition of complex resistances.

Equipment list

1	Sensor-CASSY	524 010
1	Power-CASSY	524 011
1	CASSY Lab	524 200
1	Plug-in board DIN A4	576 74
1	STE resistor 100 Ω	577 32
1	STE coil, 500 turns	590 83
1	STE capacitor 4.7 μF , 5 %	578 16
2	Pair of cables, 50 cm, red and blue	501 45
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Connect the electrical filter to Power-CASSY and Sensor-CASSY as shown in the diagram. You can vary the type of filter (RC, RL or RLC) during the experiment by removing or plugging in the coil (L) or the capacitor (C).

Carrying out the experiment

■ Load settings.

- Realize the RC filter by removing the coil.
- Start the measurement with **F9**. The frequency f is automatically increased in small steps. After a short setting time, the software measures and displays the respective RMS value of the output voltage U and the current I .

The step size is variable and depends on the specifications of the number n_0 , the starting frequency f_0 and the approximate value f_1 of the resonance frequency. Between the two frequencies f_0 and f_1 , n_0 measuring values are recorded. Then the frequency f is further increased in a way that around $f=f_1$, i.e. the resonance frequency, values are recorded at a particularly high density. Thereby the measuring time required is considerably reduced as compared with equally spaced frequency steps. The specifications can be changed by shifting the pointer with the mouse or by changing the parameter value after clicking with the right mouse key.

The measuring condition $f < 5 \cdot f_1$ and $f < 5000$ and $\Delta t > 2/f+3$ allows measured values to be recorded up to 5 kHz (or 5 times the resonance frequency), but not before $2/f+3$ s after a frequency increase (transient time).

- Stop the measurement with **F9** when the desired frequency is reached.
- Repeat the measurement with the RL filter and the RLC filter.

Evaluation

The **Output Voltage** and **Input Current** displays (accessible with the mouse) show the curves of the output voltage and the current as function of the frequency. The RC filter attenuates the output voltage at high frequencies by about half (low pass) for each octave (doubling of frequency). The RL filter, on the other hand, attenuates the lower frequencies by about half (high pass) for each octave (half frequency). The RLC filter attenuates frequencies outside of the resonance frequency of the parallel LC oscillator corresponding to the individual filters. However, the output voltage shows a visible maximum in the resonance range (band pass). The resonance frequency is independent of R .

The two impedances Z_1 (LC only) and Z (R with LC) are also calculated and displayed. The resistance of the parallel LC oscillator reaches its maximum at its resonance frequency (in an ideal circuit this would be infinite). The flowing current is thus minimal, as is the voltage drop at the resistor. Consequently, the output voltage reaches its maximum where resonance occurs.

The **Phase** view shows the phase shift between the applied voltage and the flowing current.

The last two displays show the **Loci** for the complex resistance Z of the filter and the complex conductance Y . In the Z representation, the addition of complex resistances in series connection is nicely displayed. For a low pass we have $Z = R + 1/i\omega C$ and for a high pass $Z = R + i\omega L$. As only the frequency ω , that is the imaginary part of Z , is varied, the real ohmic part remains constant. Thus vertical lines are generated in the complex plane whose distance from the imaginary axis is equal to the ohmic resistance R . The coil in the example has an ohmic internal resistance of approximately 4Ω . In the case of the high pass, the distance from the imaginary axis is therefore larger by approximately 4Ω than in the case of the low pass.

Remark

For an AC circuit we can write

$$U = |U| \cdot e^{i\omega t} \quad \text{and} \quad I = |I| \cdot e^{i(\omega t + \varphi)}$$

where the complex resistance $Z = U/I$ no longer depends on t

$$Z = |U|/|I| \cdot e^{-i\varphi} = |Z| \cdot e^{-i\varphi} \quad (\text{Z locus})$$

On the other hand we have

$$Y = 1/Z = 1/|Z| \cdot e^{i\varphi} \quad (\text{Y locus})$$



The Y locus corresponds to the complex inversion of the Z locus ($r \rightarrow -r$, $\varphi \rightarrow -\varphi$). This transformation turns the straight lines $Z = R + 1/i\omega C$ and $Z = R + i\omega L$ of the Z loci into semicircles in the Y representation (inversion with respect to the unit circle).

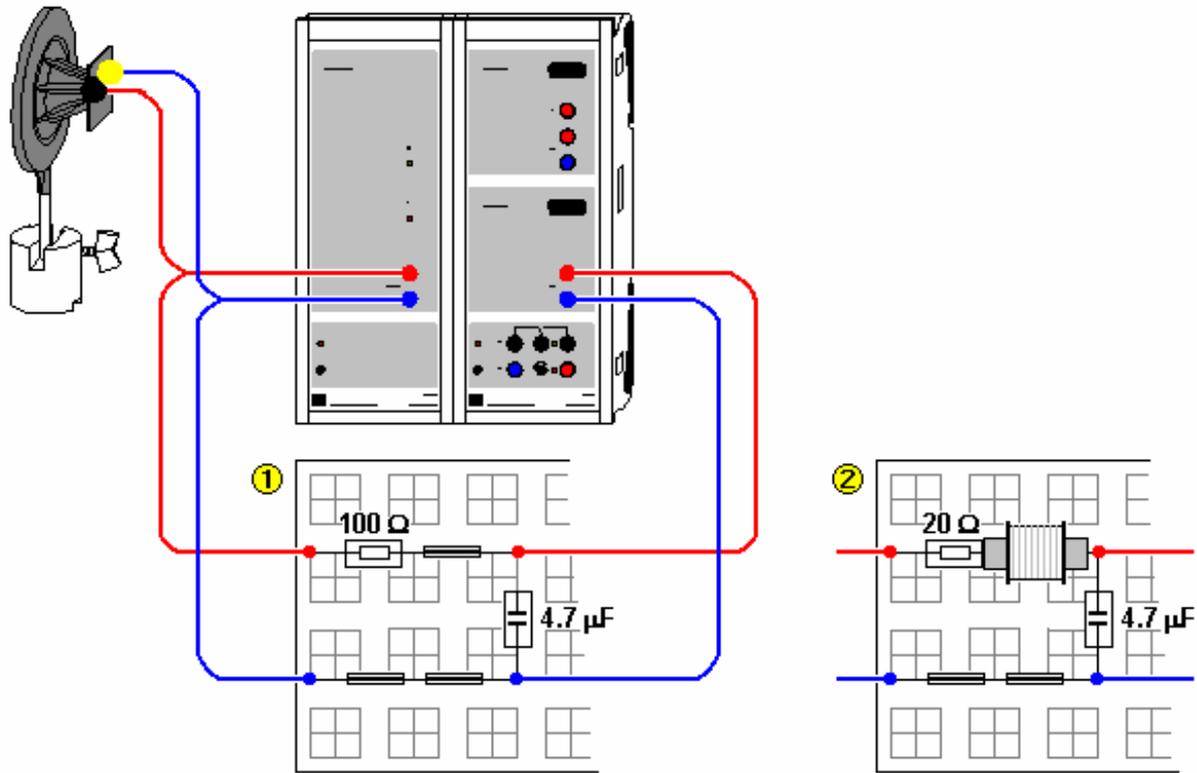
Hints

With **F7** the measuring instruments can be hidden and unhidden at the same time.

You can logarithmically scale the coordinate axes easily by clicking on the corresponding axis with the right mouse button.

The attenuations of 6 dB/octave (resp. 20 dB/decade) can be read off easily in a log-log display as the slope ± 1 .

Low-pass filter (with modelling)



- Load example (step response)
- Load example (amplitude response)

Experiment description

In the first experiment, rectangular pulses with a constant amplitude are applied to a first-order low-pass filter **1** consisting of a resistor and a capacitor (RC) or a second-order low-pass filter **2** consisting of a resistor, a coil and a capacitor (RLC). The response of the filter to these pulses is investigated (step response) and compared with a model.

In the second experiment, an input signal of variable frequency (chirp) is applied to the low-pass filter. A Fourier transform is applied to both the input signal and the measured output signal, and the two frequency spectra are divided one by the other. The frequency-dependent amplitude change (amplitude response) obtained in this procedure is displayed and compared with a model.

The equations of the first-order (RC) and second-order (RLC) models follow from energy conservation. The power $U(t) \cdot I(t)$ supplied by an external source has to be equal to the sum of the power at the capacitor $d(1/2 \cdot C \cdot U_C(t)^2)/dt$, the power at the coil $d(1/2 \cdot L \cdot I(t)^2)/dt$ and the power at the resistor $R \cdot I(t)^2$, i.e.

$$U(t) \cdot I(t) = U(t) \cdot Q'(t) = d(1/2 \cdot Q(t)^2/C)/dt + d(1/2 \cdot L \cdot I(t)^2)/dt + R \cdot I(t)^2 = Q(t)/C \cdot Q'(t) + L \cdot Q'(t) \cdot Q''(t) + R \cdot Q'(t)^2.$$

For a first-order low pass ($L = 0$) this gives

$$QRC'(t) = -QRC(t)/RC + U(t)/R$$

and for a second-order low pass ($L > 0$)

$$QRLC''(t) = IRLC'(t) = U(t)/L - QRLC(t)/LC - R \cdot QRLC'(t)/L.$$

The constants R , L and C correspond to the resistor, the coil and the capacitor used. Depending on the order, the output voltage of the filter is $U_{RC}(t) = QRC(t)/C$ or $U_{RLC}(t) = QRLC(t)/C$, respectively.



Equipment list

1	Sensor-CASSY	524 010
1	Power-CASSY	524 011
1	CASSY Lab	524 200
1	Plug-in board DIN A4	576 74
1	STE resistor 20 Ω	577 23
1	STE resistor 47 Ω	577 28
1	STE resistor 100 Ω	577 32
1	STE coil, 500 turn	590 83
1	STE capacitor 4.7 μF , 5 %	578 16
2	Pairs of cables, 50 cm, red and blue	501 45
1	PC with Windows 95/98/NT or higher version	

recommended:

1	Tweeter	587 07
1	Saddle base	300 11
1	Iron core, laminated	from 593 21
1	Pair of cables, 50 cm, red and blue	501 45

Experiment setup (see drawing)

Connect the first-order or second-order low-pass filter to the Power-CASSY and the Sensor-CASSY as shown in the drawing. In order to increase the inductance L of the coil, you may use a laminated iron core. It is recommended to connect the tweeter to the output of the Power-CASSY for a better understanding of the measurement of the amplitude response.

Carrying out the experiment

a) Step response

■ Load settings

- Realize the RC filter (first order) or RLC filter (second order).
- Start the measurement with **F9**.
- Repeat the measurement with another frequency f (shift the pointer in the display instrument) or with another order as necessary.

b) Amplitude response

■ Load settings

- Realize the RC filter (first order) or RLC filter (second order).
- Start the measurement with **F9**.
- Repeat the measurement with another order as necessary.

Modelling

The constants R (resistance), C (capacitance) and L (inductance) can be altered by dragging the pointer of the corresponding display instrument (or by clicking to the left or to the right of the pointer) until the model agrees with the measurement. The ohmic resistance of the coil (approx. 4 Ω) has to be taken into account when the attenuation resistance R is determined.

a) Step response

The displays **Model RC** and **Model RLC** (select using the mouse) show the comparison of the measured filter response with the corresponding model. The Power-CASSY outputs the exciting frequency continuously. Therefore the transient oscillation process of the filter is not seen in the measured signal. The start time for the computation was chosen a period before zero, i.e. $t_0 = -1/f$, in order that the transient oscillation process is also invisible in the model.

The additional displays **Frequency Spectrum RC** and **Frequency Spectrum RLC** make it possible to compare the attenuation of the input signal depending on the frequency and the order of the filter. This comparison is also possible by direct measurement of the amplitude response.

b) Amplitude response

The Power-CASSY excites the filter at a variable frequency (chirp). In this chirp the frequency is increased very quickly from 0 Hz to approx. 2500 Hz. In the **Amplitude Response**, the ratio of the amplitudes of the output signal and the input signal of the filter is displayed. The black curve is the measured curve, the red curve is the result of the first-order model, and the blue curve shows the second-order model.

During the measurement, the filter response must not overdrive the Sensor-CASSY (see **Standard display**). If necessary, repeat the measurement with a decreased amplitude A or an increased resistance R .

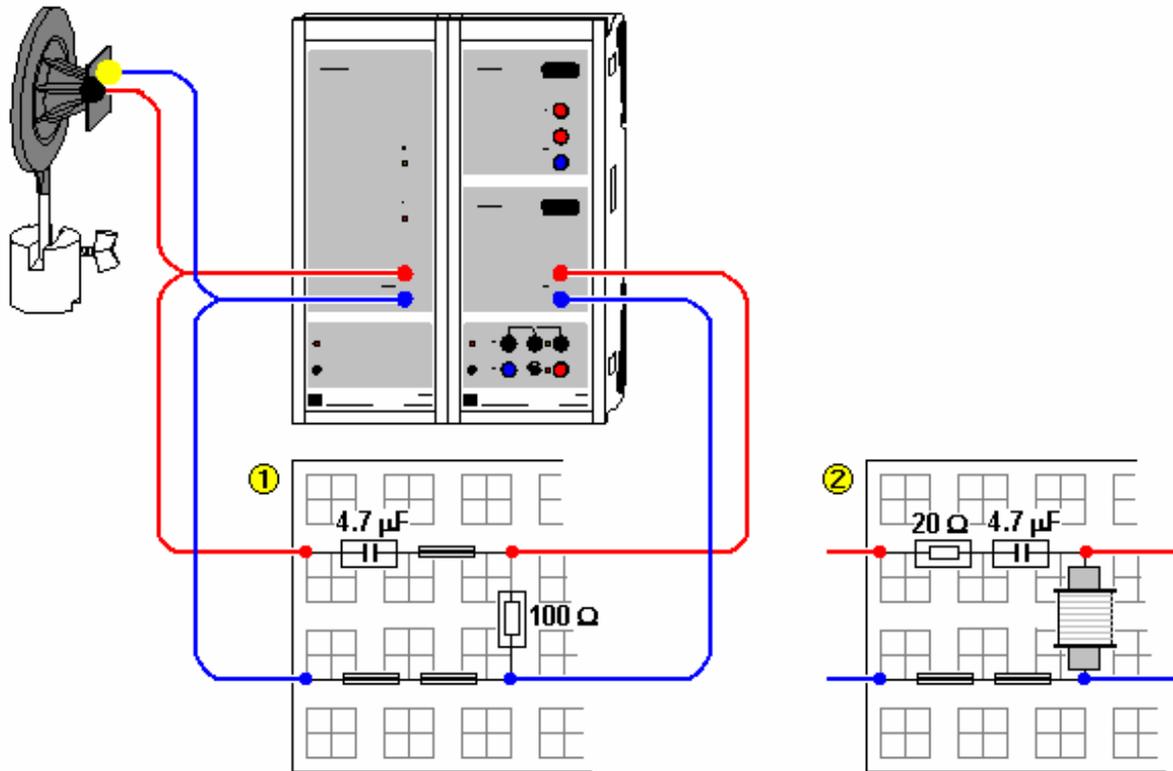
Remark concerning the measurement of the amplitude response

When the basic frequency f of the chirp ($f = 2.5$ Hz in the example) is changed, the measuring interval has to be changed, too, so that the measuring time T corresponds to the chirp period again ($T = 400$ ms in the example).

Moreover, the range of the amplitudes A_B , A_{RC} and A_{RLC} has to be adjusted. In the example, the amplitude ratios are only defined if the amplitude of the FFT in the denominator is at least 1.5 % of the input amplitude A .

The computation time of the models is limited to 5 s. If this is not sufficient in the case of slow computers, the subsequent Fourier analysis is only computed for the incomplete solution. In this case, please increase the maximum computation time of the models.

High-pass filter (with modelling)



- Load example (step response)
- Load example (amplitude response)

Experiment description

In the first experiment, rectangular pulses with a constant amplitude are applied to a first-order high-pass filter **1** consisting of a resistor and a capacitor (RC) or a second-order high-pass filter **2** consisting of a resistor, a coil and a capacitor (RLC). The response of the filter to these pulses is investigated (step response) and compared with a model.

In the second experiment, an input signal of variable frequency (chirp) is applied to the high-pass filter. A Fourier transform is applied to both the input signal and the measured output signal, and the two frequency spectra are divided one by the other. The frequency-dependent amplitude change (amplitude response) obtained in this procedure is displayed and compared with a model.

The equations of the first-order (RC) and second-order (RLC) models follow from energy conservation. The power $U(t) \cdot I(t)$ supplied by an external source has to be equal to the sum of the power at the capacitor $d(1/2 \cdot C \cdot U_C(t)^2)/dt$, the power at the coil $d(1/2 \cdot L \cdot I(t)^2)/dt$ and the power at the resistor $R \cdot I(t)^2$, i.e.

$$U(t) \cdot I(t) = U(t) \cdot Q'(t) = d(1/2 \cdot Q(t)^2/C)/dt + d(1/2 \cdot L \cdot I(t)^2)/dt + R \cdot I(t)^2 = Q(t)/C \cdot Q'(t) + L \cdot Q'(t) \cdot Q''(t) + R \cdot Q'(t)^2.$$

For a first-order high pass ($L = 0$) this gives

$$QRC'(t) = -QRC(t)/RC + U(t)/R$$

and for a second-order high pass ($L > 0$)

$$QRLC''(t) = IRLC'(t) = U(t)/L - QRLC(t)/LC - R \cdot QRLC'(t)/L$$

The constants R , L and C correspond to the resistor, the coil and the capacitor used. Depending on the order, the output voltage of the filter is $URC(t) = U(t) - R \cdot I(t)$ or $URLC(t) = U(t) - R \cdot I(t) - QRLC(t)/C$, respectively.

Equipment list

1	Sensor-CASSY	524 010
1	Power-CASSY	524 011
1	CASSY Lab	524 200
1	Plug-in board DIN A4	576 74
1	STE resistor 20 Ω	577 23
1	STE resistor 47 Ω	577 28
1	STE resistor 100 Ω	577 32
1	STE coil, 500 turns	590 83
1	STE capacitor 4.7 μF , 5 %	578 16
2	pairs of cables, 50 cm, red and blue	501 45
1	PC with Windows 95/98/NT or higher version	

recommended:

1	Tweeter	587 07
1	Saddle base	300 11
1	Iron core, laminated	from 593 21
1	Pair of cables, 50 cm, red and blue	501 45

Experiment setup (see drawing)

Connect the first-order or second-order high-pass filter to the Power-CASSY and the Sensor-CASSY as shown in the drawing. In order to increase the inductance L of the coil, you may use a laminated iron core. It is recommended to connect the tweeter to the output of the Power-CASSY for a better understanding of the measurement of the amplitude response.

Carrying out the experiment

a) Step response

■ Load settings

- Realize the RC filter (first order) or RLC filter (second order).
- Start the measurement with **F9**.
- Repeat the measurement with another frequency f (shift the pointer in the display instrument) or with another order as necessary.

b) Amplitude response

■ Load settings

- Realize the RC filter (first order) or RLC filter (second order).
- Start the measurement with **F9**.
- Repeat the measurement with another order as necessary.

Modelling

The constants R (resistance), C (capacitance) and L (inductance) can be altered by dragging the pointer of the corresponding display instrument (or by clicking to the left or to the right of the pointer) until the model agrees with the measurement. The ohmic resistance of the coil (approx. 4 Ω) has to be taken into account when the attenuation resistance R is determined.

a) Step response

The displays **Model RC** and **Model RLC** (select using the mouse) show the comparison of the measured filter response with the corresponding model. The Power-CASSY outputs the exciting frequency continuously. Therefore the transient oscillation process of the filter is not seen in the measured signal. The start time for the computation was chosen a period before zero, i.e. $t_0 = -1/f$, in order that the transient oscillation process is also invisible in the model.

The additional displays **Frequency Spectrum RC** and **Frequency Spectrum RLC** make it possible to compare the attenuation of the input signal depending on the frequency and the order of the filter. This comparison is also possible by direct measurement of the amplitude response.



b) Amplitude response

The Power-CASSY excites the filter at a variable frequency (chirp). In this chirp the frequency is decreased very quickly from approx. 2500 Hz to 0 Hz. In the **Amplitude Response**, the ratio of the amplitudes of the output signal and the input signal of the filter is displayed. The black curve is the measured curve, the red curve is the result of the first-order model, and the blue curve shows the second-order model.

During the measurement, the filter response must not overdrive the Sensor-CASSY (see **Standard display**). If necessary, repeat the measurement with a decreased amplitude A or an increased resistance R .

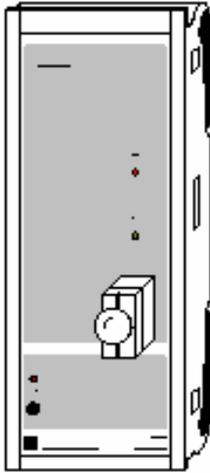
Remark concerning the measurement of the amplitude response

When the basic frequency f of the chirp ($f = 2.5$ Hz in the example) is changed, the measuring interval has to be changed, too, so that the measuring time T corresponds to the chirp period again ($T = 400$ ms in the example).

Moreover, the range of the amplitudes A_B , A_{RC} and A_{RLC} has to be adjusted. In the example, the amplitude ratios are only defined if the amplitude of the FFT in the denominator is at least 1.5 % of the input amplitude A .

The computation time of the models is limited to 5 s. If this is not sufficient in the case of slow computers, the subsequent Fourier analysis is only computed for the incomplete solution. In this case, please increase the maximum computation time of the models.

Characteristic of an incandescent lamp



- Load example

Experiment description

In an incandescent lamp the voltage and current are not proportional to one another. Their resistance depends greatly on the temperature. As an incandescent lamp heats up when electricity is supplied, different characteristics are obtained when the current is switched on and off. The characteristic also depends on the rate of increase dU/dt of the voltage.

Equipment list

1	Power-CASSY	524 011
1	CASSY Lab	524 200
1	Set of 10 lamps 12 V /3 W	505 08
1	STE Lamp holder E 10, top	579 06
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

You can attach the lamp directly to Power-CASSY.

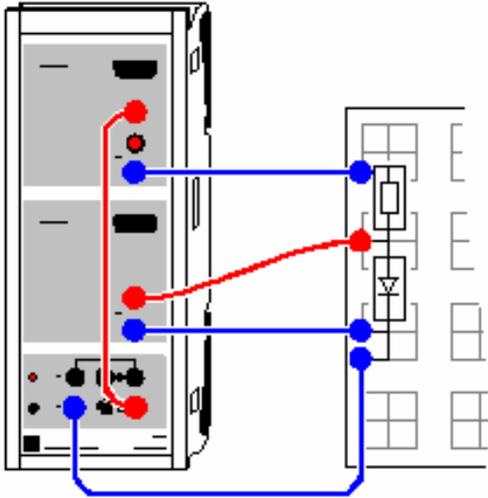
Carrying out the experiment

- Load settings
- Execute the measurement with **F9** (the lamp is switched on and then off).
- If desired, vary the switching frequency of the lamp in Settings U1 and the measuring time in the Measuring Parameters dialog and repeat the experiment.

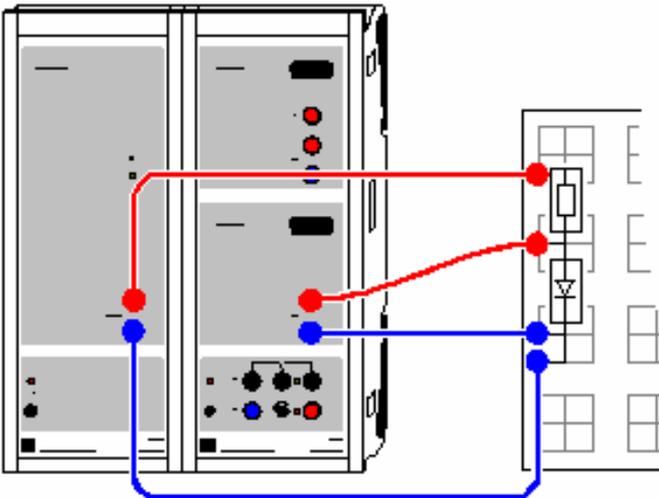
Evaluation

In the characteristic, you can determine the inverse values of the cold and hot resistance of the incandescent lamp by fitting a straight line.

Characteristic of a diode



Alternatively (with Power-CASSY):



- Load example (without Power-CASSY)
- Load example (with Power-CASSY)

Experiment description

The semiconductor diodes are among the simplest semiconductor components. They consist of a semiconductor crystal in which an n-conducting zone meets a p-conducting zone. Recombination of the charge carriers, i.e. the electrons in the n-conducting and the holes in the p-conducting zones, creates a low-conductivity zone at the boundary layer. The conductivity is increased when electrons or holes are removed from the boundary layer by an external electric field. This direction of the electric field is called the reverse direction. Reversing the electric field drives the electrons and holes into the boundary layer, allowing current to flow more easily through the diode.

This experiment records and compares the current-voltage characteristics of various diodes (Si, Ge and light-emitting diodes).

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Plug-in board DIN A4	576 74
1	STE resistor 100 Ω	577 32
1	STE Si-diode 1N4007	578 51
1	STE Ge-diode AA118	578 50
1	STE Light emitting diode green	578 57
1	STE Light emitting diode yellow	578 47
1	STE Light emitting diode red	578 48
1	STE Light emitting diode infrared	578 49
1	Connecting leads, 50 cm, blue	500 422
2	Pairs of cables, 50 cm, red and blue	501 45
1	PC with Windows 95/98/NT or higher version	

Alternatively (with Power-CASSY)

1	Sensor-CASSY	524 010
1	Power-CASSY	524 011
1	CASSY Lab	524 200
1	Plug-in board DIN A4	576 74
1	STE resistor 100 Ω	577 32
1	STE Si-diode 1N4007	578 51
1	STE Ge-diode AA118	578 50
1	STE Light emitting diode green	578 57
1	STE Light emitting diode yellow	578 47
1	STE Light emitting diode red	578 48
1	STE Light emitting diode infrared	578 49
2	Pairs of cables, 50 cm, red and blue	501 45
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Connect the circuit to Sensor-CASSY inputs A (current) and B (voltage across the diode) as shown in the drawing. The diode is protected by a 100 Ω series resistor.

When using Power-CASSY place this to the left of Sensor-CASSY to supply the circuit and measure the current.

Carrying out the experiment

■ Load settings (without Power-CASSY)

- Reverse the polarity of voltage source S (for negative characteristic segment) and set UB1 to about -3 V.
- Start the measurement with **F9**.
- Slowly reduce the voltage to zero (turn to the left; the negative characteristic segment is recorded simultaneously).
- Restore the original polarity of voltage source S (for positive characteristic segment).
- Slowly increase the voltage (the positive characteristic segment is recorded simultaneously); be sure not to exceed the maximum current of the LED.
- Stop the measurement with **F9**.
- Repeat the measurement with a different diode; reverse the polarity of voltage source S and start the measurement with **F9**.

Alternative (with Power-CASSY)

■ Load settings (with Power-CASSY)

- Record the characteristic of each diode with **F9** (Power-CASSY sweeps the voltage range automatically).

**Evaluation**

At negative voltages the current is zero regardless of the applied voltage (reverse direction). At positive voltages, a current appears starting at a conducting-state voltage U (conducting direction).

We can compare the conducting-state voltages U of various diodes. For the LEDs, we can use the equation

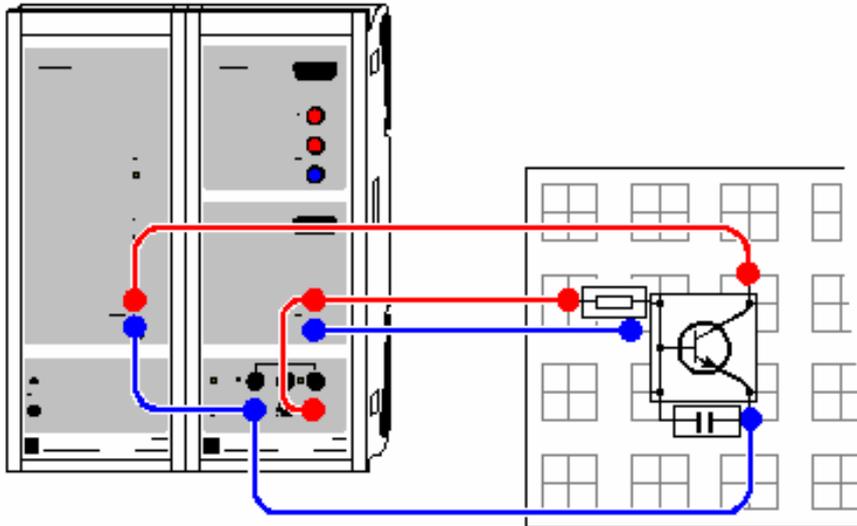
$$e \cdot U = h \cdot c / \lambda$$

to estimate roughly the wavelength λ of the emitted light. In this example the conducting-state voltage of the red LED is approx. $U = 1.4$ V. From this we obtain $\lambda = hc/eU = 880$ nm.

Remark

It is not possible to precisely determine the wavelength of light emitted by LEDs, as these emit a relatively broad frequency band that is usually filtered through a colored housing. Therefore the above wavelength determination is merely a rough estimate.

Characteristic of a transistor



- Load example (collector current as a function of base current)
- Load example (collector current as a function of collector-emitter voltage)

Experiment description

Transistors are among the most important semiconductor components in electronic circuit technology. The electrodes of a bipolar transistor are called the emitter, the base and the collector. The transistor consists of a total of three n-conducting and p-conducting layers, in the order npn or pnp.

This experiment measures the two output characteristics of an npn transistor, i.e. the collector current I_C as a function of the base current I_B (at a constant collector-emitter voltage) and the collector current I_C as a function of the collector-emitter voltage U_{CE} (at different constant base currents I_B).

Equipment list

1	Sensor-CASSY	524 010
1	Power-CASSY	524 011
1	CASSY Lab	524 200
1	Plug-in board DIN A4	576 74
1	STE transistor BD 137	578 67
1	STE resistor 10 kΩ, 0.5 W	577 56
1	STE capacitor 0.1 μF	578 31
1	Pair of cables, 25 cm, red and blue	501 44
2	Pairs of cables, 50 cm, red and blue	501 45
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Power-CASSY supplies the collector-emitter voltage U_{CE} and simultaneously measures the collector current I_C that is flowing. The cascaded Sensor-CASSY (mounted directly to the right of Power-CASSY) supplies an adjustable base current I_B and simultaneously measures the voltage drop across a 10 kΩ resistor. The small 0.1 μF capacitor connected between the base and the emitter suppresses interference during measurement.

This experiment uses base currents up to about 1 mA and collector currents up to about 100 mA. Be sure to use suitable transistors (e.g. BD 137).



Carrying out the experiment

a) Control characteristic of collector current I_C as a function of base current I_B

■ Load settings

- Power-CASSY maintains the collector-emitter voltage at a constant $U_{CE} = 2 \text{ V}$ and measures the collector current I_C continuously.
- Set the displayed base current I_B at voltage source S of Sensor-CASSY to 0 mA.
- Start the measurement with **F9**.
- Slowly increase the base current until the characteristic is recorded.
- Stop the measurement with **F9**.

b) Characteristic of collector current I_C as a function of collector-emitter voltage U_{CE}

■ Load settings

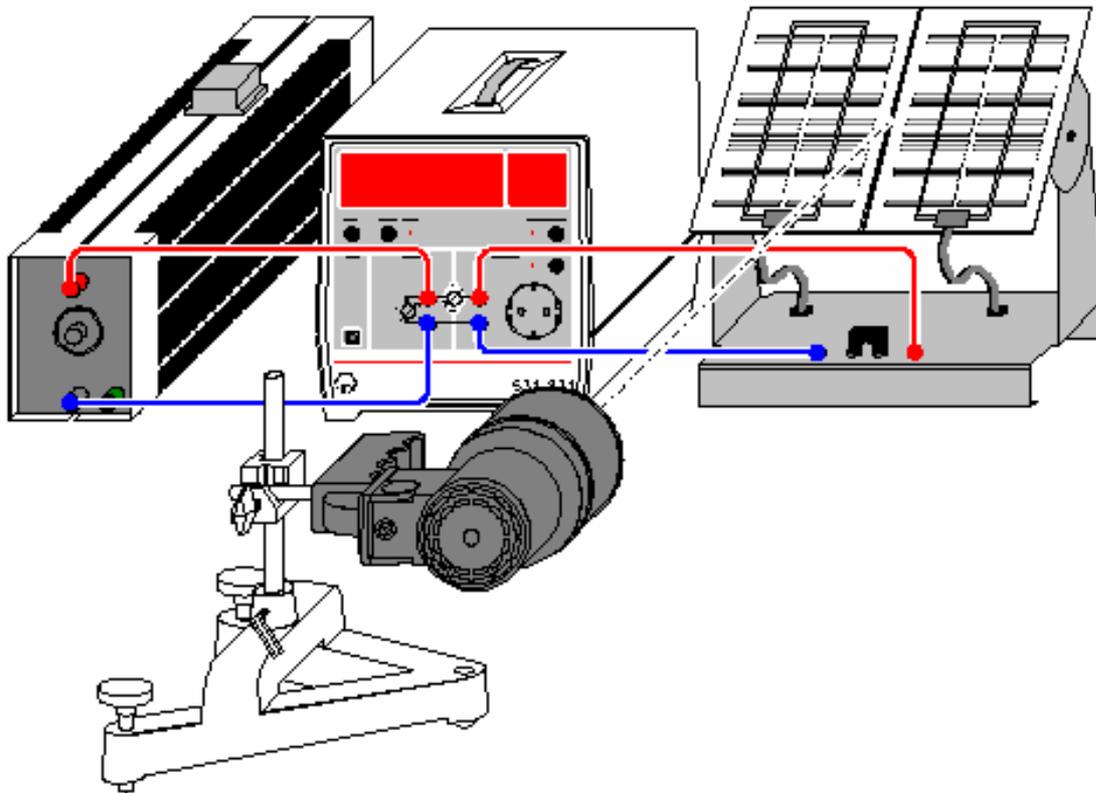
- Power-CASSY increases the collector-emitter voltage to $U_{CE} = 2 \text{ V}$ during the measurement and measures the collector current I_C .
- Set the displayed base current I_B at voltage source S of Sensor-CASSY to 0.1 mA.
- Start the measurement with **F9** (the characteristic is recorded automatically).
- Increase the base current I_B in steps of 0.1 mA and record additional characteristics with **F9**.

Evaluation

The current gain can be determined easily from control characteristic a) by fitting a straight line. In the example, we obtain a current gain factor of $I_C/I_B = 149.6$.

Characteristic b) also shows the current gain of a transistor in an impressive manner. Starting from a relatively low collector-emitter voltage U_{CE} , the output current I_C remains virtually constant, depending only on the base current I_B .

Power characteristic of a solar cell



■ Load example

Experiment description

The power P of a solar cell is recorded for various illuminances as a function of a load resistance R_1 . From the shapes of the curves, the optimal load resistances R_{\max} are determined at which the maximum power of the solar cell is reached in each case.

Moreover, at each illuminance (different angles of inclination α of the solar cell), the open-circuit voltage and the short-circuit current are measured and the internal resistances R_0 of the solar cell are calculated: $R_0 = U_0 / I_0$. The internal resistances R_0 are compared with R_{\max} .

Equipment list

1	Joule- and wattmeter	531 831
1	Solar cell	664 431
1	Floodlight lamp, 1000 W	450 70
1	Rheostat	537 34
1	Steel tape measure	311 77
1	Stand base, V-shape, 28 cm	300 01
1	Stand rod, 100 mm	300 40
1	Leybold multiclamp	301 01
2	Pairs of cables, 100 cm	501 46
1	PC with Windows 98/2000 or higher version	

Experiment setup (see drawing)

Set up the floodlight lamp at a distance of approx. 40 cm from the solar cell. First set up the solar cell perpendicularly to the incident light and connect it to the 4 mm sockets on the OUTPUT panel. Connect the load resistor to the 4 mm sockets on the INPUT panel.

Remark

The power of the solar cell also varies with the temperature. To ensure that the temperature remains essentially constant during the measurement, the solar cell should be illuminated by the light source already 15 min before measured values are recorded.

Carrying out the experiment

■ Load settings

a) Recording the characteristic

- Adjust the rheostat so that a resistance of $2\ \Omega$ is displayed in the display instrument Load Resistance R1.
- Take the measured value into the table manually with **F9**.
- Increase the load resistance in steps of $2\ \Omega$, and record further measured values.
- In order to vary the illuminance, incline the solar cell by an angle of 45° or 30° , respectively, relative to the incident light. Repeat the experiment for each angle.
- For each illuminance, determine the load resistance R_{\max} at which the maximum power of the solar cell is reached.

b) Measuring the open-circuit voltage and the short-circuit current

- Open the display instruments U, I, U_0 , I_0 and R_0 by clicking on .
- Connect the solar cell to the 4 mm sockets of the joule and wattmeter marked with U.
- Using the mouse, take the value measured in the display instrument U to the display instrument Open-Circuit Voltage U_0 (drag & drop).
- Connect the solar cell to the socket of the joule and wattmeter marked with I.
- Using the mouse, take the value measured in the display instrument I to the display instrument Short-Circuit Current I_0 (drag & drop). Read the internal resistance R_0 of the solar cell.

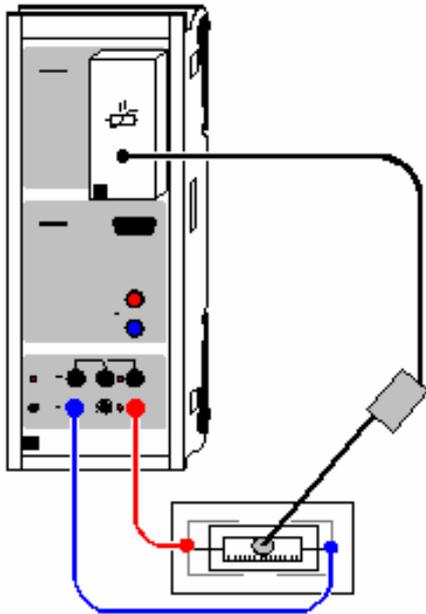
Evaluation

The power supplied by a solar cell depends on the load resistance and on the illuminance.

The maximum power of the solar cell is reached if the load resistance is approximately equal to the internal resistance of the solar cell.

The maximum power of the solar cell is the larger, the larger the illuminance is (at constant temperature).

Temperature control



- Load example (two-position control)
- Load example (PI control)

Experiment description

A temperature controller is an ideal application for demonstrating the function of a two-position controller and a PI controller. The inertia of the controlled temperature system leaves sufficient time for exact observation of the control algorithms.

In a two-position controller, the heating element is switched on when the temperature falls below threshold ϑ_1 , and switched off when the temperature exceeds a second threshold ϑ_2 .

Alternatively, the temperature can be controlled using PI control. A PI controller determines the system deviation $w-x$ from the measured value $x = \vartheta_{A1}$ (temperature) and the reference variable w (set value of the temperature).

Together with the base load y_0 , this gives us the manipulated variable $y = y_0 + K_P \cdot (w-x) + K_I \int (w-x) \cdot dt$ for the PI controller. The proportional-action coefficient K_P and the integral-action coefficient K_I as control parameters can be optimized so that after a deviation (e.g. a change in the reference variable w) the system returns to a system deviation $w-x$ of about 0 as soon as possible. The base load y_0 can be assumed as constant here.

If only a P-controller is used ($K_I = 0$), a residual system deviation $w-x$ occurs which does not disappear until an I-component is applied.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	KTY-box	524 036
1	KTY-sensor	529 036
1	Socket board section	576 71
1	Heating element, 100 Ω , 2 W	579 38
1	Pair of cables, 1 m, red and blue	501 46
1	PC with Windows 95/98/NT or higher version	



Experiment setup (see drawing)

The voltage source S supplies the heating element. The temperature of the heating element is measured using a KTY-sensor with the KTY-box at CASSY connector site A. For this purpose, fill a few drops of water in the heating element and immerse the KTY-sensor in the water.

Carrying out the experiment

a) Two-position controller

■ Load settings.

- Turn the potentiometer of the voltage source S all the way to the right.
- Replace switching thresholds ϑ_1 and ϑ_2 with individual values by moving the pointer of the display instrument with the mouse or changing the value of the parameter in the Settings ϑ_1 or ϑ_2 (right mouse button).
- If desired, you can record the temperature curve during control, and stop recording, with **F9**.

b) PI controller

■ Load settings.

- Turn the potentiometer of the voltage source S all the way to the right.
- Set the reference variable w about 5 °C above the current temperature ϑ_{A1} by moving the pointer of the display instrument with the mouse or changing the value of the reference variable in the Settings w (right mouse button).
- Replace the proportional-action (KP) and integral-action (KI) coefficients using individual values of the parameter in the Settings KP or KI (right mouse button).
- Start (and stop) temperature control with **F9**.

Evaluation

For the two-position controller, we can set horizontal lines to mark the two switching thresholds ϑ_1 and ϑ_2 .

The quality of the PI controller depends significantly on the choice of the proportional-action coefficient KP and the integral-action coefficient KI. The black line represents the reference variable w (set value). The red curve represents the controlled variable x (measured value) and should converge with the black curve quickly following a deviation. The blue curve represents the manipulated variable y and thus corresponds to the heating voltage.

Empirically optimizing the PI temperature controller

The controlled temperature system is very slow. This is why the effects of changes in KP and KI can only be seen with a large delay. Empirical optimization will thus take a certain amount of time.

- Set KI to 0, and increase KP in moderate steps (e.g. by 1) until the control loop oscillates.
- Reduce KP again until the oscillations die out. A residual system deviation is created.
- Increase KI in moderate steps (e.g. by KP/200) until the system oscillates again.
- Reduce KI again until the oscillations die out. Note that the controller becomes slower, the lower KI becomes.

In this example, we have used $K_P=5$ and $K_I=0.05$ /s.

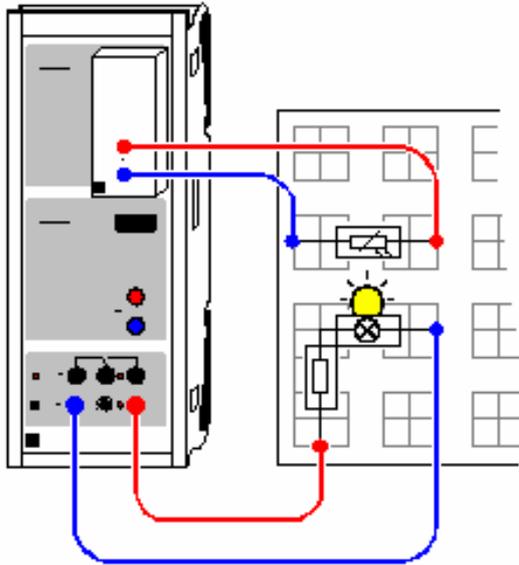
Automatically varying the reference variable

The reference variable w (set value) can be varied not only manually, but automatically as well. We can do this, for example, by entering the formula **$30+\sin(360*t/1000)$** in the Settings w. This controls a sinusoidal temperature curve between 29 °C and 31 °C with a period of 1000 s.

Using the temperature box (524 045)

The temperature box (524 045) with NiCr-Ni sensor or NTC can also be used in place of the KTY box. To do this, first delete the temperature in the Settings ϑ_{A1} ; then in the CASSY Settings (**F5**) click on the temperature box at input A and additionally activate **Averaged Values** and **Zero Point Left**. Then, just set the measuring range from 0 °C to 120 °C in the Settings w and modify the formula to **$(w-\&JA11)/50$** in Settings w-x.

Brightness control



■ Load example

Experiment description

This experiment realizes a brightness control for a light bulb using variable series resistors. A PI controller is used here. A PI controller determines the system deviation $w-x$ from the measured value $x = RA_1$ (resistance of an LDR) and the reference variable w (set value of the LDR resistance).

Together with the base load y_0 , this gives us the manipulated variable $y = y_0 + K_P \cdot (w-x) + K_I \int (w-x) \cdot dt$ for the PI controller. The proportional-action coefficient K_P and the integral-action coefficient K_I as control parameters can be optimized so that after a deviation (e.g. an additional series resistor, a change in the reference variable w or the base load y_0) the system returns to a system deviation $w-x$ of about 0 as soon as possible.

If only a P-controller is used ($K_I = 0$), a residual system deviation $w-x$ occurs which does not disappear until an I-component is applied.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Current supply box	524 031
1	Plug-in board DIN A4	576 74
1	Lamp socket E10, side	579 05
1	Set of 10 lamps 3.8 V/0.07 A	505 10
1	Toggle-switch, single-pole	579 13
1	Photoresistor LDR 05	578 02
1	STE resistor 10 Ω , 2 W	577 20
1	STE resistor 20 Ω , 2 W	577 23
1	STE resistor 47 Ω , 2 W	577 28
1	STE resistor 100 Ω , 2 W	577 32
2	Pair of cables, 1 m, red and blue	501 46
1	PC with Windows 95/98/NT or higher version	



Experiment setup (see drawing)

The voltage source S supplies the lamp via a 100 Ω protective resistor. The brightness of the lamp is measured using a light-dependent resistor together with the current source box at CASSY input A.

Additional series resistors can be switched on with the toggle switch to produce deviations. A closed toggle switch shorts the series resistor, and an open toggle switch leaves it in the circuit.

Carrying out the experiment

■ Load settings.

- Turn the potentiometer of the voltage source S all the way to the right.
- The lamp lights up already, as a base load y_0 of 0.5 has been set. This means that PWM output S is operating at a duty factor of 50 %.
- Change the base load y_0 as you like, by setting the corresponding parameter value in the Settings y_0 (right mouse button).
- Enter the measured resistance as the reference variable w by moving the pointer of the display instrument with the mouse or changing the value of the parameter in the Settings w (right mouse button).
- Start and stop control at the appropriate times with **F9**.
- During control, a deviation can be applied, e.g. by switching a series resistor or changing the reference variable or base load.
- You can optimize your controller by varying the proportional-action (K_P) and integral-action (K_I) coefficients; set the corresponding values in Settings K_P or K_I (right mouse button).

Evaluation

The recorded curves illustrate the quality of the controller. The black line represents the reference variable w (set value). The red curve represents the controlled variable x (measured value) and should converge with the black curve quickly following a deviation. The blue curve represents the manipulated variable y and thus corresponds to the lamp voltage.

Empirically optimizing the PI brightness controller

Set negative values for K_P and K_I , as the measured resistance value of the sensor box becomes less the greater the voltage at the voltage source S is.

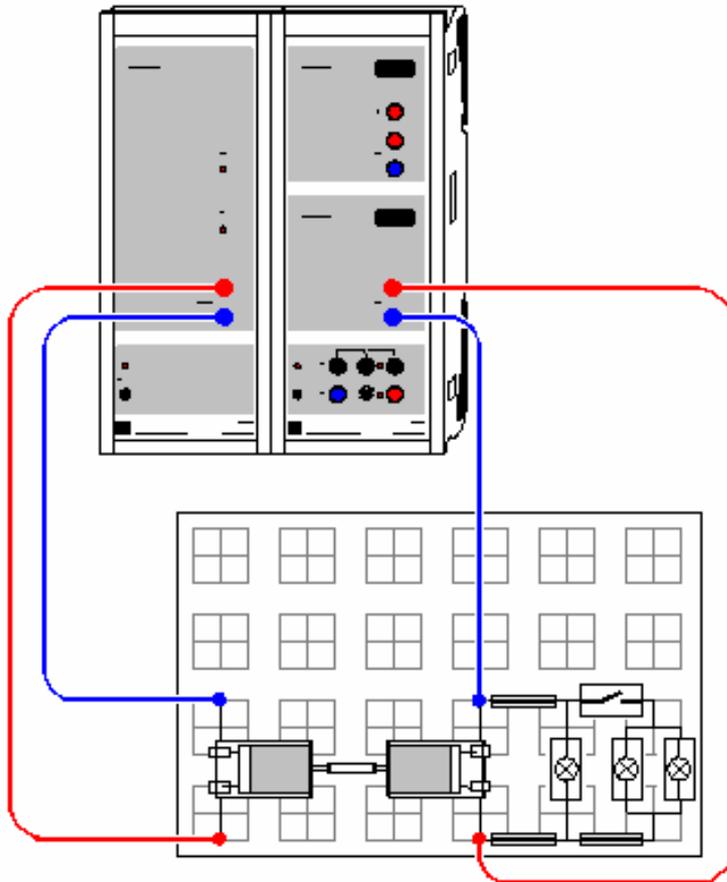
- Set K_I to 0, and increase K_P in moderate steps (e.g. by -0,1) until the control loop oscillates.
- Reduce K_P again until the oscillations die out. A residual system deviation is created.
- Increase K_I in moderate steps (e.g. by $10 \cdot K_P$) until the system oscillates again.
- Reduce K_I again until the oscillations die out. Note that the controller becomes slower, the lower K_I becomes.

In this example, we have used $K_P = 0.5$ and $K_I = 5 /s$.

Automatically varying the reference variable

The reference variable w (set value) can be varied not only manually, but automatically as well. We can do this, for example, by entering the formula **$1+0.5 \cdot \sin(360 \cdot t/20)$** in the Settings w . This results in control of a sinusoidal resistance curve of the LDR between 0.5 k Ω and 1.5 k Ω with a period of 20 s.

Voltage control



■ Load example

Experiment description

This experiment realizes voltage control of a generator under a variable load. A PI controller is used here. A PI controller determines the system deviation $w-x$ from the measured value $x = U_{B2}$ (voltage of the generator) and the reference variable w (set value of the generator).

Together with the base load y_0 , this gives us the manipulated variable $y = y_0 + K_P \cdot (w-x) + K_I \int (w-x) \cdot dt$ for the PI controller. The proportional-action coefficient K_P and the integral-action coefficient K_I as control parameters can be optimized so that after a deviation (e.g. an additional load, a change in the reference variable w or the base load y_0) the system returns to a system deviation $w-x$ of about 0 as soon as possible.

If only a P-controller is used ($K_I = 0$), a residual system deviation $w-x$ occurs which does not disappear until an I-component is applied.

Equipment list

1	Sensor-CASSY	524 010
1	Power-CASSY	524 011
1	CASSY Lab	524 200
1	Plug-in board DIN A4	576 74
2	DC motors and tacho generators	579 43
1	Toggle-switch, single-pole	579 13
3	Lamp socket E10, top	579 06
1	Set of 10 lamps 3.8 V/0.07 A	505 10
1	Plastic tubing, 6 mm	307 641
1	Set of bridging plugs	501 48



- 2 Pair of cables, 1 m, red and blue 501 46
- 1 PC with Windows 95/98/NT or higher version

Experiment setup (see drawing)

Power-CASSY supplies the motor (left), which drives the generator (right) via a section of plastic tubing approx. 25 mm long. The voltage of the generator is measured at input B of Sensor-CASSY. Make sure that the connections of either the motor or the generator are reversed, as the motor and the generator are linked in opposing directions.

The load on the generator is varied using three light bulbs, two of which can be switched on using a toggle switch.

Carrying out the experiment

- Load settings.
 - The motor is already turning, as a base load y_0 of 6 V has been set.
 - Change the base load y_0 as you like, by setting the corresponding parameter value in the Settings y_0 (right mouse button).
 - Check the measured voltage UB_2 ; this must be positive (reverse polarity if necessary).
 - Enter the measured voltage as the reference variable w by moving the pointer of the display instrument with the mouse or changing the value of the parameter in the Settings w (right mouse button).
 - Start and stop control at the appropriate times with **F9**.
 - During control, a deviation can be applied, e.g. by varying the generator load or changing the reference variable or base load.
 - You can optimize your controller by varying the proportional-action (K_P) and integral-action (K_I) coefficients; set the corresponding values in Settings K_P or K_I (right mouse button).

Evaluation

The recorded curves clearly illustrate the quality of the controller. The black line represents the reference variable w (set value). The red curve represents the controlled variable x (measured value) and should converge with the black curve quickly following a deviation. The blue curve represents the manipulated variable y and thus corresponds to the motor voltage.

Empirically optimizing the PI voltage controller

- Set K_I to 0, and increase K_P in moderate steps (e.g. by 0,1) until the control loop oscillates.
- Reduce K_P again until the oscillations die out. A residual system deviation is created.
- Increase K_I in moderate steps (e.g. by $10 \cdot K_P$) until the system oscillates again.
- Reduce K_I again until the oscillations die out. Note that the controller becomes slower, the lower K_I becomes.

In this example, we have used $K_P=0.5$ and $K_I=4$ /s.

Automatically varying the reference variable

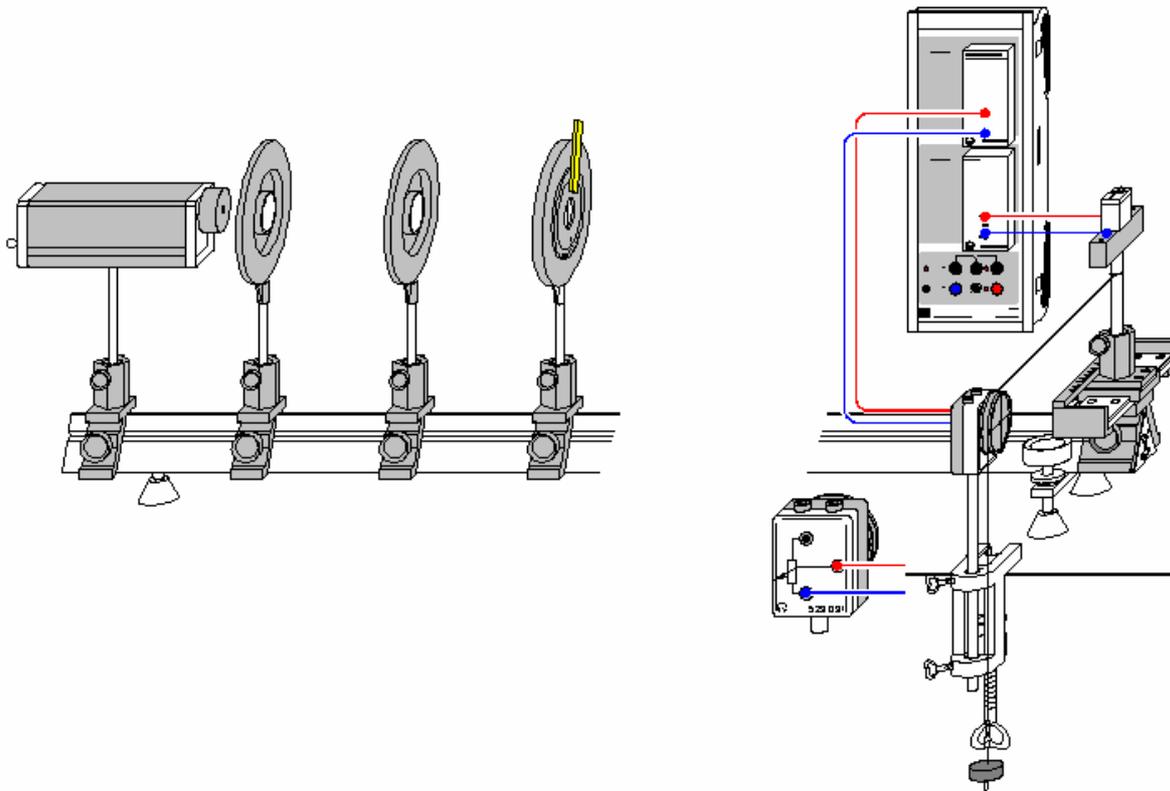
The reference variable w (set value) can be varied not only manually, but automatically as well. We can do this, for example, by entering the formula **$4+\sin(360 \cdot t/20)$** in the Settings w . This controls a sinusoidal voltage curve between 3 V and 5 V with a period of 20 s.

Other control loops

This example can also be adapted to other control loops. As long as the controlled variable is a voltage, it is only necessary to modify the correcting range and the measuring range as well as the control parameters K_P and K_I .

When the controlled variable is supplied by a sensor box, you must first delete channel UB_2 by selecting **Delete** in Settings UB_2 , so that the sensor box at input B of Sensor-CASSY can be recognized. Then, in the CASSY Settings (**F5**), activate the sensor box with the mouse and again select **Averaged Values**. The unit and symbol of the reference variable w and the system deviation $w-x$ must also be modified, as well as the calculation formula for system deviation (e.g. **$w-RB_2$** instead of **$w-UB_2$**). As in all CASSY experiments, you can change the settings by clicking on channel w or $w-x$ with the right mouse button.

Diffraction at a single slit



can also be carried out with Pocket-CASSY

■ Load example

Be careful when experimenting with the He-Ne laser

The He-Ne laser meets the requirements according to class 2 of EN 60825-1 "Safety of laser equipment". If the corresponding notes of the instruction sheet are observed, experimenting with the He-Ne laser is safe.

Never look into the direct or reflected laser beam.

No observer must feel dazzled.

Experiment description

Diffraction phenomena always occur when the free propagation of light is changed by obstacles such as iris diaphragms or slits. The deviation from the rectilinear propagation of light observed in this case is called diffraction.

The voltage of a photodiode is measured as a function of the diffraction angle. It is observed that the diffraction pattern moves more and more into the geometrical shadow area as the slit width decreases. The measuring values recorded are compared with the prediction of a model calculation for the diffraction intensity
$$U \propto \left(\frac{\sin(\pi b/\lambda \cdot \alpha)}{\pi b/\lambda \cdot \alpha} \right)^2$$
 where the slit width b and the wavelength λ enter as parameters. For small diffraction angles α , α is easily determined from the distance L between the diffraction object and the photodiode and the path of displacement s of the photodiode as $\alpha \approx \tan \alpha = s/L$.



Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	μ V-box	524 040
1	Current supply box	524 031
1	Displacement sensor	529 031
1	He-Ne laser, linearly polarized	471 840
1	Precision optical bench, 2 m	460 33
4	Riders, H=90 mm/B=60 mm	460 374
1	Sliding rider	460 383
1	Lens in frame, $f = +5$ mm	460 01
1	Lens in frame, $f = +50$ mm	460 02
1	Adjustable slit	460 14
1	Holder for plug-in elements	460 21
1	Photocell STE 2/19	578 62
1	Simple bench clamp	301 07
1	Fishing line, 10 m	309 48
1	Set of 12 weights, each 50 g	342 61
2	Pairs of cables, 100 cm, red and blue	501 46
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Remark: the adjustment should be carried out in a slightly darkened room.

- Using a rider, mount the He-Ne laser to the optical bench as shown in the drawing.
- Set up the photocell at a distance of approx. 1.90 m from the laser by means of the sliding rider and the holder for plug-in elements. The photocell should be located in the middle of the sliding rider. Stick two strips of dark paper on the photocell so that an entrance slit of approx. 1 mm is left.
- Direct the laser towards the photocell, and switch it on.
- Adjust the height of the laser so that the laser beam impinges on the centre of the photocell.
- Place the spherical lens with the focal length $f = +5$ mm in front of the laser at a distance of approx. 1 cm. The laser beam has to cover the photocell.
- Position the converging lens with the focal length $f = +50$ mm in front of the spherical lens at a distance of approx. 55 mm and displace it on the optical bench towards the spherical lens until the laser beam is sharply imaged on the photocell.
- Displace the converging lens on the optical bench somewhat further towards the spherical lens until the diameter of the laser beam on the photocell is approx. 6 mm. Now the laser beam should have a circular profile of constant diameter along the optical axis.
- Put the adjustable slit on the optical bench, and displace it until the distance L between the photocell and the slit diaphragm is 1.50 m.
- Fix the bench clamp with the displacement sensor to the table as shown in the drawing.
- The path of displacement s_{A1} perpendicular to the optical axis is measured via the displacement sensor at the current supply box on input A of the Sensor-CASSY.
- In order to measure the voltage, the photocell is connected to input B of the Sensor-CASSY via the μ V-box.

Carrying out the experiment

■ Load settings

- Set the photocell to the position -6.0 cm opposite the displacement sensor.
- Turn the wheel of the displacement sensor to the stop so that the display of the path s_{A1} is approximately -6.0 cm. If it turns out that the path measurement will lead to a wrong sign, connect the current supply box to the other arm of the displacement sensor.
- Tie a piece of fishing line to the holder for plug-in elements, wind it once around the wheel of the displacement sensor, and suspend a weight from it.
- Calibrate the zero of the path – for this place the photocell in the middle of the sliding rider (= zero of the scale or of the position of the principal intensity maxima, respectively).

- Enter the **target value** 0 cm in settings SA1 **Correct**, and then select **Correct Offset**.
- Slide the photocell back to the position opposite the displacement sensor, and keep it there.
- If necessary, **Correct** the background brightness in the settings UB1. For this enter the target value 0 mV, and then select **Correct Offset**.
- Start the measurement with **F9** (the message **No Trigger Signal** appears).
- Displace the photocell very slowly by hand towards the displacement sensor. As soon as you pass the starting point at -5.5 cm, recording of measured values begins.
- Stop the measurement with **F9**.

Evaluation

The intensity distribution of the diffraction pattern appears already during the measurement. The measured intensity distribution can now be compared with the result of the model calculation for small diffraction angles $\alpha \approx \tan \alpha = s_{A1}/L$ by performing a Free fit (**Alt+F**). Use the following formula:

$$A * (\sin(180 * B / 0.633 * (x - C) / 150) / (180 * B / 0.633 * (x - C) / 150))^2$$

with

x: displacement s_{A1} perpendicular to the optical axis

A: intensity I_0

B: slit width b in μm

C: correction of the position of the principal maximum

L: distance between the diaphragm and the photocell (here: $L = 150 \text{ cm}$)

λ : wavelength of the He-Ne laser (here: $\lambda = 0.633 \mu\text{m}$)

In this fit, the wavelength $\lambda = 0.633 \mu\text{m}$ of the He-Ne laser has been assumed to be known and the slit width b has been determined. The other way round, the wavelength λ of the laser can be determined if the slit width b is known. For this, the formula can be modified, e.g., in the following way:

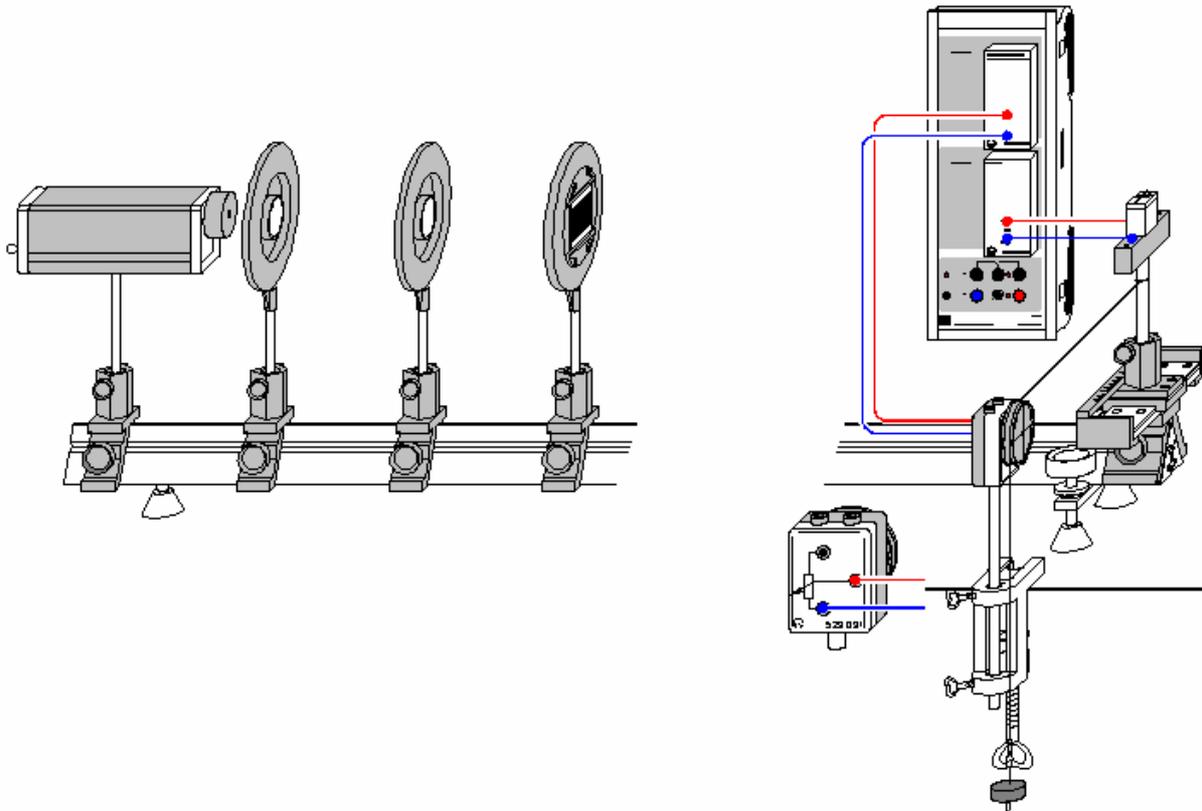
$$A * (\sin(180 * 240 / B * (x - C) / 150) / (180 * 240 / B * (x - C) / 150))^2$$

For the Free fit, always a reasonable starting value for the slit width should be chosen, e. g., $B = 240 (\mu\text{m})$ for $b = 0.24 \text{ mm}$.

Remark

In this experiment on diffraction of light at a single slit, the intensity distribution is recorded manually. The measuring values can be recorded automatically with the aid of VideoCom (experiment P5.3.1.6).

Diffraction at multiple slits



can also be carried out with Pocket-CASSY

- Load example (Diaphragm with 4 double slits (469 85): $N = 2$, $b = 0.20$ mm, $d = 0.50$ mm)
- Load example (Diaphragm with 5 multiple slits (469 86): $N = 4$, $b = 0.20$ mm, $d = 0.25$ mm)

Be careful when experimenting with the He-Ne laser

The He-Ne laser meets the requirements according to class 2 of EN 60825-1 "Safety of laser equipment". If the corresponding notes of the instruction sheet are observed, experimenting with the He-Ne laser is safe.

Never look into the direct or reflected laser beam.

No observer must feel dazzled.

Experiment description

Diffraction phenomena always occur when the free propagation of light is changed by obstacles such as iris diaphragms or slits. The deviation from the rectilinear propagation of light observed in this case is called diffraction.

The voltage of a photocell is measured as a function of the diffraction angle. It is observed that the diffraction pattern moves more and more into the geometrical shadow area as the slit width decreases. The measuring values recorded are compared with the prediction of a model calculation for the diffraction intensity $U \propto (\sin(\pi b/\lambda \cdot \alpha)/(\pi b/\lambda \cdot \alpha))^2$, where the slit width b , the slit spacing d , the number of slits N , and the wavelength λ enter as parameters. For small diffraction angles α , α is easily determined from the distance L between the diffraction object and the photocell and the path of displacement s of the photocell as $\alpha \approx \tan \alpha = s/L$.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	μ V-box	524 040
1	Current supply box	524 031
1	Displacement sensor	529 031
1	He-Ne laser, linearly polarized	471 840
1	Precision optical bench, 2 m	460 33
4	Riders, H=90 mm/B=60 mm	460 374
1	Sliding rider	460 383
1	Lens in frame, $f = +5$ mm	460 01
1	Lens in frame, $f = +50$ mm	460 02
1	Diaphragm with 3 double slits	469 84
1	Diaphragm with 4 double slits	469 85
1	Diaphragm with 5 multiple slits	469 86
1	Holder with spring clips	460 22
1	Photocell STE 2/19	578 62
1	Holder for plug-in elements	460 21
1	Simple bench clamp	301 07
1	Fishing line, 10 m	309 48
1	Set of 12 weights, each 50 g	342 61
2	Pairs of cables, 100 cm, red and blue	501 46
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Remark: the adjustment should be carried out in a slightly darkened room.

- Using a rider, mount the He-Ne laser to the optical bench as shown in the drawing.
- Set up the photocell at a distance of approx. 1.90 m from the laser by means of the sliding rider and the holder for plug-in elements. The photocell should be located in the middle of the sliding rider. Stick two strips of dark paper on the photocell so that an entrance slit of approx. 1 mm is left.
- Direct the laser towards the photocell, and switch it on.
- Adjust the height of the laser so that the laser beam impinges on the centre of the photocell.
- Place the spherical lens with the focal length $f = +5$ mm in front of the laser at a distance of approx. 1 cm. The laser beam has to cover the photocell.
- Position the converging lens with the focal length $f = +50$ mm in front of the spherical lens at a distance of approx. 55 mm and displace it on the optical bench towards the spherical lens until the laser beam is sharply imaged on the photocell.
- Displace the converging lens on the optical bench somewhat further towards the spherical lens until the diameter of the laser beam on the photocell is approx. 6 mm. Now the laser beam should have a circular profile of constant diameter along the optical axis.
- Put the holder with spring clips on the optical bench with the diaphragm being clamped, and displace it until the distance L between the photocell and the slit diaphragm is 1.50 m.
- Fix the bench clamp with the displacement sensor to the table as shown in the drawing.
- The path of displacement s_{A1} perpendicular to the optical axis is measured via the displacement sensor at the current supply box on input A of the Sensor-CASSY.
- In order to measure the voltage, the photocell is connected to input B of the Sensor-CASSY via the μ V-box.

Carrying out the experiment

- Load settings (Diaphragm with 4 double slits (469 85): $N = 2$, $b = 0.20$ mm, $d = 0.50$ mm)
- Load settings (Diaphragm with 5 multiple slits (469 86): $N = 4$, $b = 0.20$ mm, $d = 0.25$ mm)
- Set the photocell to the position -6.0 cm opposite the displacement sensor.
- Turn the wheel of the displacement sensor to the stop so that the display of the path s_{A1} is approximately -6.0 cm. If it turns out that the path measurement will lead to a wrong sign, connect the current supply box to the other arm of the displacement sensor.



- Tie a piece of fishing line to the holder for plug-in elements, wind it once around the wheel of the displacement sensor, and suspend a weight from it.
- Calibrate the zero of the path – for this place the photocell in the middle of the sliding rider (= zero of the scale or of the position of the principal intensity maxima, respectively).
- Enter the **target value** 0 cm in settings SA1 **Correct**, and then select **Correct Offset**.
- Slide the photocell back to the position opposite the displacement sensor, and keep it there.
- If necessary, **Correct** the background brightness in the settings UB1. For this enter the target value 0 mV, and then select **Correct Offset**.
- Start the measurement with **F9** (the message **No Trigger Signal** appears).
- Displace the photocell very slowly by hand towards the displacement sensor. As soon as you pass the starting point at -5.5 cm, recording of measured values begins.
- Stop the measurement with **F9**.

Evaluation

The intensity distribution of the diffraction pattern appears already during the measurement. The measured intensity distribution can now be compared with the result of the model calculation for small diffraction angles $\alpha \approx \tan \alpha = s_{A1}/L$ by performing a Free fit (**Alt+F**). Use the following formula:

$$A * (\sin(180 * B / 0.633 * (x - C) / 150) / (180 * B / 0.633 * (x - C) / 150))^2 * (\sin(2 * 180 * D / 0.633 * (x - C) / 150) / \sin(180 * D / 0.633 * (x - C) / 150))^2$$

with

x: displacement SA1 perpendicular to the optical axis

A: intensity I_0

B: slit width b in μm

C: correction of the position of the principal maximum

D: slit spacing d in μm

N: number of slits (here double slit: $N = 2$)

L: distance between the diaphragm and the photocell (here: $L = 150$ cm)

λ : wavelength of the He-Ne laser (here: $\lambda = 0.633$ μm)

In this fit, the wavelength $\lambda = 0.633$ μm of the He-Ne laser has been assumed to be known and the slit width b and the slit spacing d have been determined. The other way round, the wavelength λ of the laser can be determined if the slit width b and the slit spacing d are known.

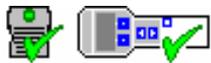
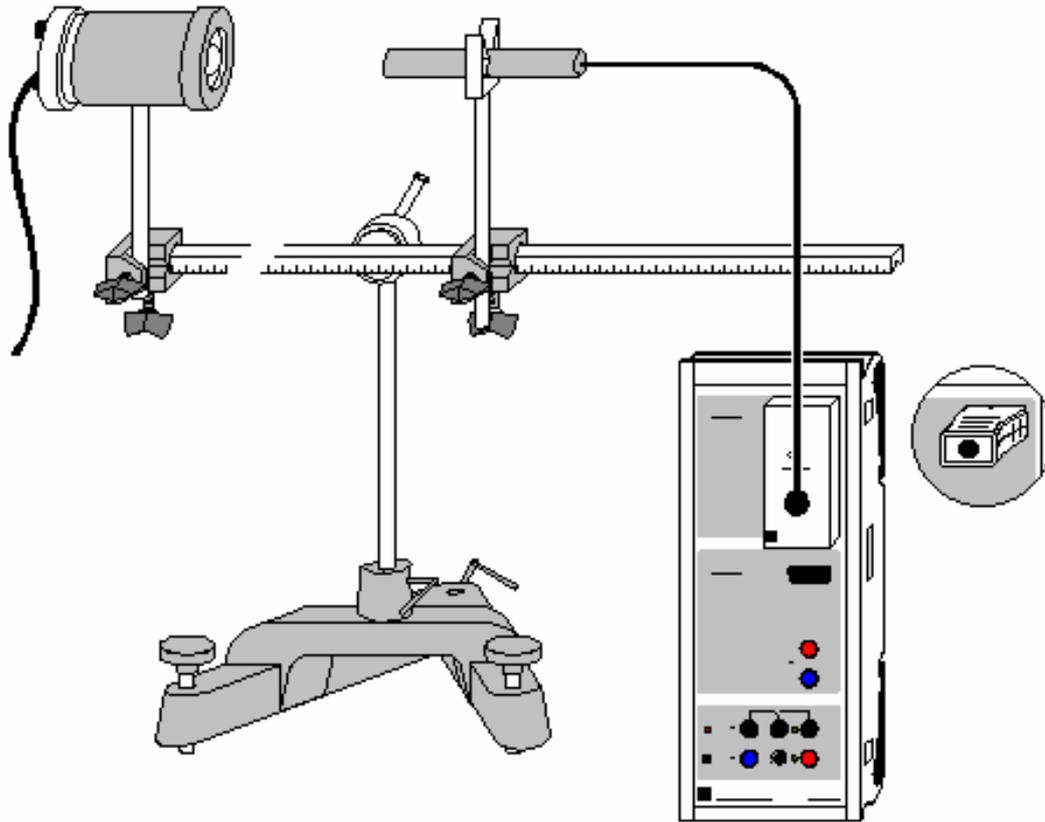
For the Free fit, always reasonable starting values for the slit width and the slit spacing should be chosen, e. g., $B=200$ (μm) for $b=0.2$ mm and $D=250$ (μm) for $d=0.25$ mm.

If the secondary maxima are not clearly seen for $N > 2$, the slit spacing d cannot be determined by the Free fit. In this case, the correct slit spacing d should be entered in μm as a starting value for the fit and then be kept constant (e. g. 250 for 0.25 mm).

Remark

In this experiment on diffraction of light at multiple slits, the intensity distribution is recorded manually. The measuring values can be recorded automatically with the aid of VideoCom (experiment P5.3.1.7).

Inverse square law for light



can also be carried out with Pocket-CASSY and Mobile-CASSY

■ Load example

Experiment description

This experiment measures the illuminance E as a function of the distance d between an incandescent lamp filament and a lux sensor. It demonstrates that E is proportional to $1/d^2$.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Lux box or Lux adapter S	524 051(1)
1	Lux sensor	666 243
1	Lamp, 6 V, 30 W	450 51
1	Lamp housing	450 60
1	Voltage source, 6 V, 30 W, e.g.	521 210
1	Small optical bench	460 43
2	Leybold multiclamps	301 01
1	Small clip plug	590 02
1	Perforated stand rod	590 13
1	Stand base, V-shape, 20 cm	300 02
1	PC with Windows 95/98/NT or higher version	



Experiment setup (see drawing)

Set up the lamp housing with lamp and the lux sensor on the optical bench. Attach the lux sensor to the perforated stand rod using the small clip plug. Slide the movable insert of the lamp housing all the way in.

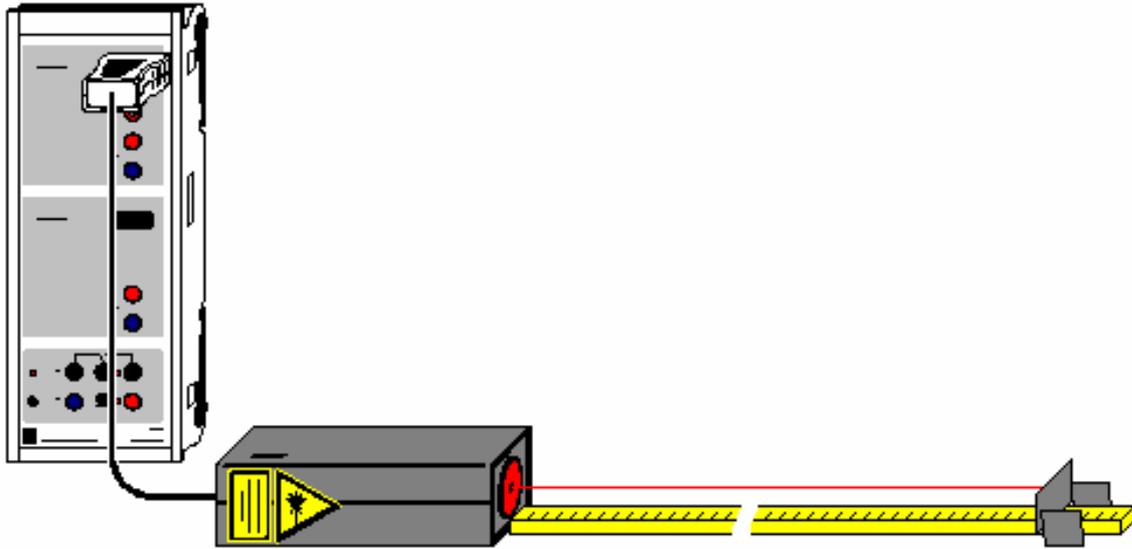
Carrying out the experiment

- Load settings
- Enter the correction factor F of your particular lux sensor (stamped on device) by opening Settings EA1, selecting **Correct**, entering the factor and clicking **Correct Factor**.
- Correct the background brightness with Settings EA1, **Correct**, **Correct Offset**.
- Switch on the lamp and set a distance of 10 cm between the lamp filament and the lux sensor.
- Enter this value in the table (click on the column **d** in the first table row and type in the value).
- Transfer the illuminance value to the table with **F9**.
- Increase the distance in steps, write the distances in the table and accept each new illuminance value with **F9**.

Evaluation

The measurements are displayed in the diagram while the measurement is running. To confirm the inverse square law for light, you can fit a hyperbola $1/x^2$ to the diagram, or alternatively convert the x-axis to $1/x^2$ (click on the axis with the mouse) and fit a straight line.

Velocity of light on air



can also be carried out with Pocket-CASSY and Mobile-CASSY

■ Load example

Safety note

Mind the safety notes in the instruction sheet of the laser motion sensor S.

Experiment description

Modern distance meters use a periodically modulated laser beam for the measurement. They determine the phase shift between the emitted and the reflected modulated laser beam and, with the modulation frequency being known, obtain the time-of-flight t of the light on its path to and back from the reflector. Only afterwards do the distance meters calculate the distance with the aid of the known velocity of light.

In this experiment, the laser motion sensor S (laser S) is used as a time-of-flight meter because it is also capable of outputting the time-of-flight t directly. The proportionality between the distance and the time-of-flight of light is confirmed, and the velocity of light is calculated.

Equipment list

1	Sensor-CASSY		524 010
1	CASSY Lab		524 200
1	Laser motion sensor S		524 073
1	End buffer	from	337 116
1	Wooden ruler		311 03
1	PC with Windows 95/98/NT or higher version		

Experiment setup (see drawing)

Lay the laser S on the table with its broad side down, and connect it to the input A of the CASSY. Stick a piece of retroreflecting foil enclosed with the laser S to the end buffer, and put the end buffer on the ruler at a distance of 30 cm from the laser so that the laser beam impinges perpendicularly on the centre of the foil.

Before the measurement, allow the laser S to warm up for approximately 5 minutes in order that the zero shift becomes as small as possible.



Carrying out the experiment

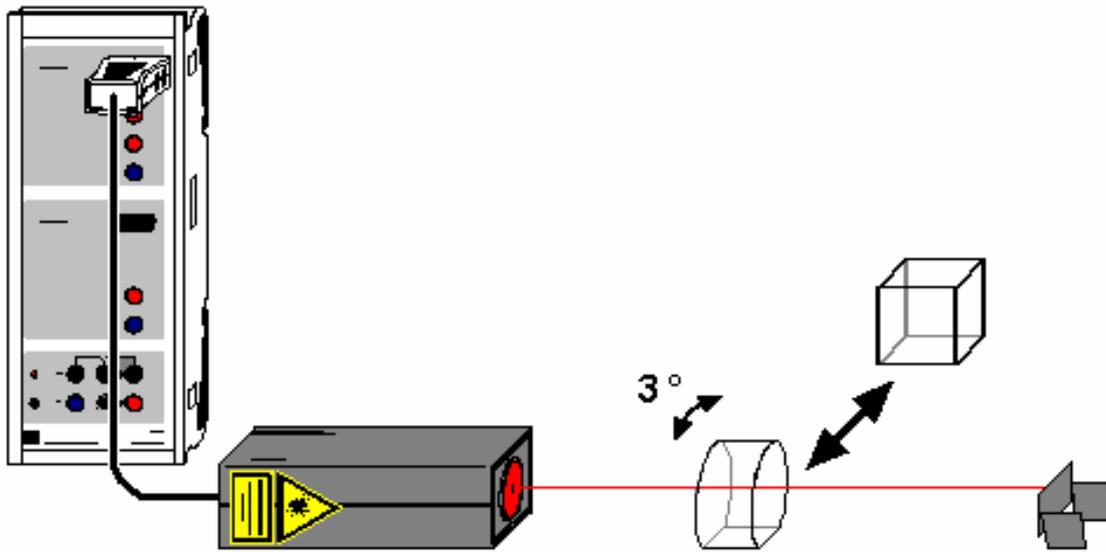
■ Load settings

- Define the zero of the time-of-flight ($\rightarrow 0 \leftarrow$ in Settings Δt_{A1}).
- Enter the distance $d=0$ in the first column of the table (click on the first field of the table with the mouse).
- Record the first measuring point ($d=0$, $\Delta t=0$) with **F9**.
- Displace the end buffer away from the laser by 10 cm, and enter the distance 0.1 m in the first column of the table (click on the second field of the table with the mouse).
- Record the second measuring point ($d=0.1$ m, Δt) with **F9**.
- Repeat the measurement for greater distances up to approximately 50 cm.

Evaluation

The optical path s of the laser beam is equal to twice the distance d . This is already taken into account in the $s(t)$ diagram in the **Velocity of Light** display. The proportionality between s and t , i.e. $s = c \cdot t$, is confirmed by the $s(t)$ diagram. Fitting a straight line through the origin leads to the proportionality constant $c = 0.3 \text{ m/ns} = 300,000 \text{ km/s}$.

Velocity of light in various materials



can also be carried out with Pocket-CASSY and Mobile-CASSY

■ Load example

Safety note

Mind the safety notes in the instruction sheet of the laser motion sensor S.

Experiment description

Modern distance meters use a periodically modulated laser beam for the measurement. They determine the phase shift between the emitted and the reflected modulated laser beam and, with the modulation frequency being known, obtain the time-of-flight t of the light on its path to and back from the reflector. Only afterwards do the distance meters calculate the distance with the aid of the known velocity of light.

In this experiment, the laser motion sensor S (laser S) is used as a time-of-flight meter because it is also capable of outputting the time-of-flight t directly. Water and acrylic glass of thickness d are held into the path of the beam, and then the resulting increase of the time-of-flight Δt is measured. With the velocity of light c in air measured in the previous experiment, the velocity of light c_M in matter can now be determined:

$$c_M = 2d / (2d/c + \Delta t) = 1 / (1/c + \Delta t / 2d).$$

Finally, the refractive index n is determined according to

$$n = c / c_M = c \cdot (1/c + \Delta t / 2d) = 1 + c / 2d \cdot \Delta t.$$

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Laser motion sensor S	524 073
1	End buffer	from 337 116
1	Plate glass cell, 50 mm × 50 mm × 50 mm	477 03
1	Acrylic glass block	476 34
1	PC with Windows 95/98/NT or higher version	



Experiment setup (see drawing)

Lay the laser S on the table with its broad side down, and connect it to the input A of the CASSY. Stick a piece of retroreflecting foil enclosed with the laser S to the end buffer, and put the end buffer on the ruler at a distance of approximately 50 cm from the laser so that the laser beam impinges perpendicularly on the centre of the foil.

Before the measurement, allow the laser S to warm up for approximately 5 minutes in order that the zero shift becomes as small as possible.

Carrying out the experiment

■ Load settings

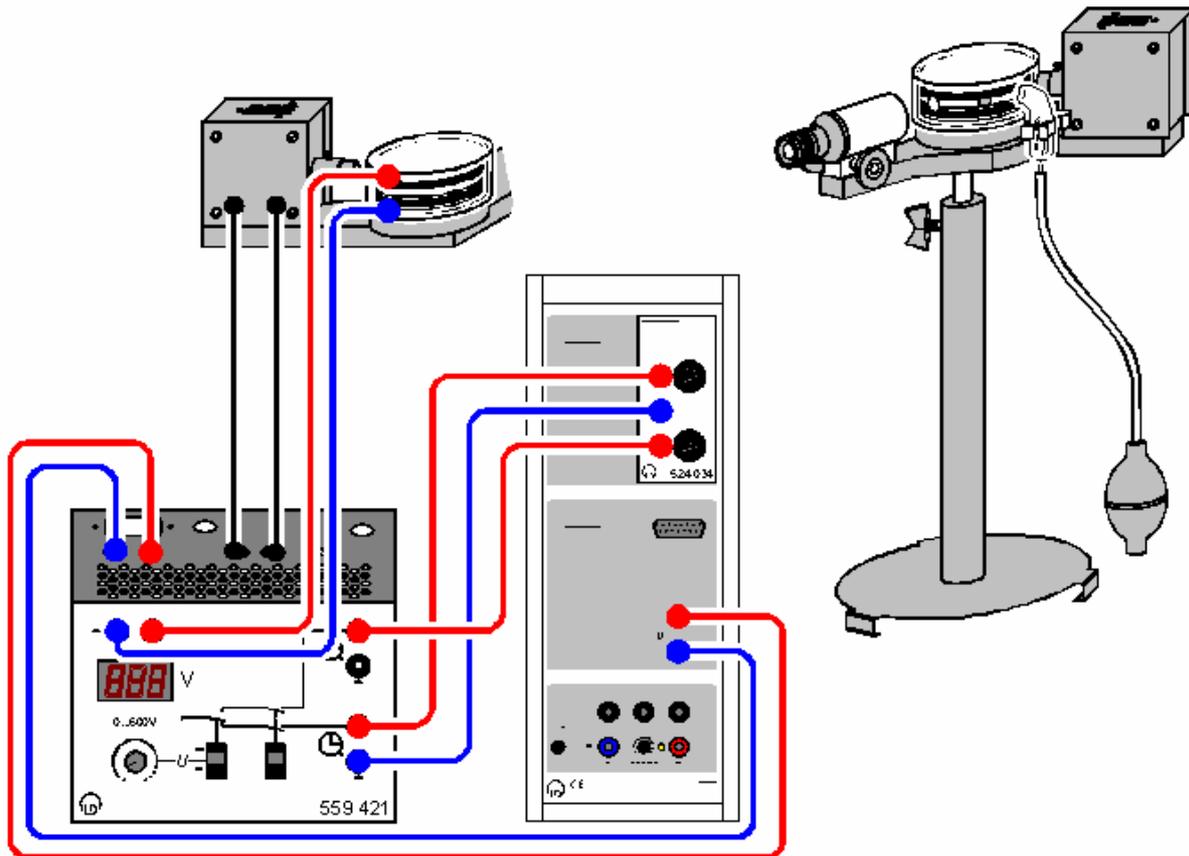
- Hold the empty and dry plate glass cell into the path of the beam such that the visible reflections of the laser beam from the glass surface are not reflected back to the laser (rotate the cell by approximately 3°). Otherwise the laser also sees these reflections and will not be able to determine the time-of-flight correctly. The increase of the length of the path resulting from this rotation is smaller than 1 % and can thus be neglected.
- Define the zero of the time-of-flight ($\rightarrow 0 \leftarrow$ in Settings $\Delta tA1$).
- Record the first "measuring point" (air) with **F9**.
- Fill the plate glass cell with water.
- Record the second measuring point (water) with **F9**.
- Remove the plate glass cell.
- Define the zero of the time-of-flight ($\rightarrow 0 \leftarrow$ in Settings $\Delta tA1$) anew.
- Hold the acrylic glass block into the path of the beam such that the visible reflections of the laser beam from the glass surface are not reflected back to the laser (rotate the acrylic glass block by approximately 3°).
- Record the third measuring point (acrylic glass) with **F9**.

Evaluation

The two displays **Velocity of Light** and **Refractive Index** show the measuring results in the form of bar diagrams. The velocity of light in materials having a greater optical density decreases and the refractive index increases.

The literature values of the refractive indices of water and acrylic glass are $n=1.33$ and $n=1.5$.

Millikan's experiment



can also be carried out with Pocket-CASSY

- Load example (floating method)
- Load example (falling/rising method)

Experiment description

In 1910, R. A. Millikan succeeded in demonstrating the quantized occurrence of smallest amounts of electrical charge using his famous oil droplet method. He observed charged oil droplets in a vertical electrical field of a plate capacitor with the plate distance d and determined the charge q of a floating droplet from its radius r and the electrical field $E=U/d$. In his experiment, he found that q only occurs as integral multiples of an elementary charge e , i.e. $q = n \cdot e$.

Theory

When an oil droplet with radius r_0 falls with the velocity $-v_1$, this droplet is subject to Stokes friction, which leads to the upward directed force $F_1 = 6\pi \cdot \eta \cdot r_0 \cdot v_1$ (η = viscosity of air). When the oil droplet rises with the velocity v_2 in an external electrical field E , the downward directed force due to Stokes friction is $F_2 = -6\pi \cdot \eta \cdot r_0 \cdot v_2$. The difference between these two forces is exactly the force $q_0 \cdot E$ exerted by the applied electrical field E , i.e.

$$q_0 \cdot E = q_0 \cdot U/d = F_1 - F_2 = 6\pi \cdot \eta \cdot r_0 \cdot (v_1 + v_2) \quad \text{or}$$

$$q_0 = 6\pi \cdot \eta \cdot r_0 \cdot d \cdot (v_1 + v_2) / U.$$

In order to determine the charge q_0 , only the radius r_0 of the oil droplet under consideration is required, which, however, is easily obtained from the equilibrium of forces between its resultant gravitational force $F = -V \cdot \Delta\rho \cdot g$ and the Stokes frictional force F_1 in the case of the falling droplet, where $\Delta\rho$ is the difference between the densities of oil and air.



Thus we have:

$$0 = F + F_1 = -\frac{4}{3} \pi \cdot r_0^3 \cdot \Delta \rho \cdot g + 6 \pi \cdot \eta \cdot r_0 \cdot v_1 \quad \text{or}$$

$$r_0 = \sqrt{(9 \eta v_1 / 2 \Delta \rho g)}.$$

For a more precise determination of the charge q , it has to be taken into account that Stokes friction has to be corrected for very small radii r because these are of the order of magnitude of the mean free path of the air molecules. The corrected formula for the frictional force, which depends on the air pressure p , reads

$$F = 6 \pi \eta r v / (1 + b/rp)$$

with $b = 80 \mu\text{m} \cdot \text{hPa}$ (constant).

With the abbreviation $A = b/p$, the corrected radius r is

$$r = \sqrt{(r_0^2 + A^2/4)} - A/2$$

and the corrected charge q is

$$q = q_0 / (1 + A/r)^{1.5}.$$

Floating method

In this version of the experiment, the voltage U at the plate capacitor is adjusted such that a particular oil droplet floats, i.e. the rising velocity is $v_2=0$. The falling velocity v_1 is measured after switching off the voltage U at the capacitor. Because of $v_2=0$, the above formulas are slightly simplified.

However, $v_2=0$ cannot be adjusted very precisely for fundamental reasons. Therefore the floating method leads to larger measurement errors and broader scattering in the frequency distribution than in the case of the following method.

Falling/rising method

In the second version, the two velocities v_1 and v_2 the voltage U are measured. This method makes possible more precise measured values than the floating method because the velocity v_2 is really measured.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Timer box	524 034
1	Millikan apparatus	559 411
1	Millikan supply unit	559 421
1	Connecting lead, 50 cm, red	500 421
3	Pairs of cables, 50 cm, red and blue	501 45
1	Pair of cables, 50 cm, black	501 451
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Set up the Millikan apparatus as described in the instruction sheet, fill in oil, and set up the circuit as shown in the drawing. Connect the stopwatch output 1 to the input E and the stopwatch output 2 to the input F of the timer box. Connect the voltage output of the supply unit to the input B of the Sensor-CASSY.

Attention: the microscope creates an inverted image. Therefore all directions of motions are inverted. In the following, however, the real motion is described.

For a better demonstration of the oil droplets, it is recommended to record the image of the microscope by means of a video camera (e. g. VideoFlex from ken-a-vision). In this case, the camera can record upside down so that the visible direction of motion corresponds to the real direction of motion.

Carrying out the experiment

a) Floating method

■ Load settings

- Orient the eyepiece micrometer vertically and turn the lens holder of the eyepiece until you can clearly see the micrometer scale.
- First set the switches U and t in the down position.
- Switch the voltage at the capacitor on with the switch U and adjust it with the rotary potentiometer so (400-600 V) that a selected oil droplet rises with a velocity of approximately 1-2 scale graduation marks per second (i.e. it is seen falling when observed through the eyepiece). Then reduce the voltage until the oil droplet floats.
- Switch the voltage at the capacitor off with the switch U.
- As soon as the oil droplet is located at the height of a selected scale graduation mark, start the time measurement with the switch t.
- As soon as the oil droplet has fallen by another 20 scale graduation marks (corresponds to 1 mm), stop the time measurement with the switch t and switch the voltage at the capacitor on again with the switch U.
- Enter the measured values of the falling time t_1 and the voltage U in the table with **F9**. The calculated charge q is entered in the histogram automatically.
- Repeat the measurement for other oil droplets.

b) Falling/rising method

■ Load settings

- Orient the eyepiece micrometer vertically and turn the lens holder of the eyepiece until you can clearly see the micrometer scale.
- First set the switches U and t in the down position.
- Switch the voltage at the capacitor on with the switch U and adjust it with the rotary potentiometer so (400-600 V) that a selected oil droplet rises with a velocity of approximately 1-2 scale graduation marks per second (i.e. it is seen falling when observed through the eyepiece).
- Switch the voltage at the capacitor off with the switch U.
- As soon as the oil droplet is located at the height of a selected scale graduation mark, start the time measurement with the switch t.
- As soon as the oil droplet has fallen (i.e. risen as observed in the eyepiece) by another 20 scale graduation marks (corresponds to 1 mm), switch the voltage at the capacitor on again with the switch U. Thereby the time measurement t_2 is started automatically.
- As soon as the oil droplet is at the height of the first scale graduation mark again, stop the time measurement with the switch t.
- Enter the measured values of the falling time t_1 , the rising time t_2 and the voltage U in the table with **F9**. The calculated charge q is entered in the histogram automatically.
- Repeat the measurement for other oil droplets.

Evaluation

In the evaluation, mean values can be drawn the in measured frequency distribution and the relation $q = n \cdot e$ (with $e = 1.6022 \cdot 10^{-19} \text{ C}$) can be confirmed.

Remarks

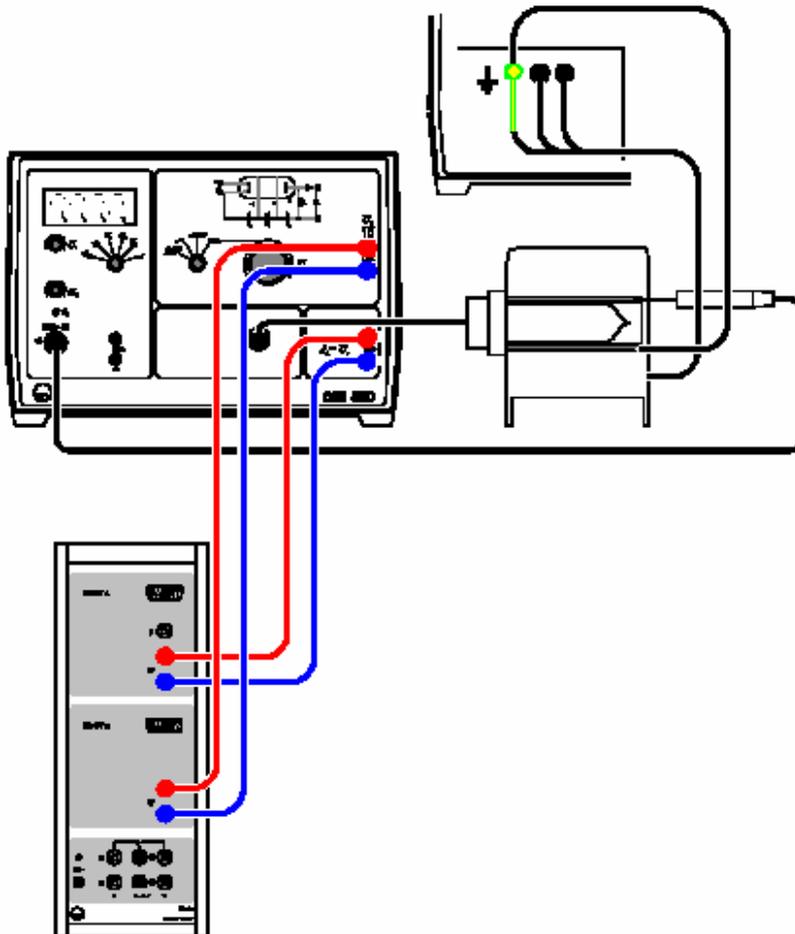
If oil droplets with a small charge are selected, statistical significance is achieved more quickly. Oil droplets carrying a small charge are identified by their small size and their slow motion in the electric field.

If there is not enough time during the lessons for observing about 20-30 oil droplets, the example with its measured values can be loaded instead of merely the settings. The new measured values then appear in the histogram as red bars thus confirming the results of the example drawn in black within the usual statistical uncertainty.

In order to measure negative charges q, the connections at the plate capacitor and at the input B of the CASSY have to be exchanged.

If the local air pressure differs considerably from 1013 hPa, the air pressure should be changed correspondingly in the formula defining the correction parameter A. However, the displayed example values may then be wrong.

Franck-Hertz experiment with mercury



can also be carried out with Pocket-CASSY

■ Load example

Experiment description

In 1914, James Franck and Gustav Hertz reported an energy loss occurring in distinct "steps" for electrons passing through mercury vapour, and a corresponding emission at the ultraviolet line ($\lambda = 254 \text{ nm}$) of mercury. Just a few months later, Niels Bohr recognized this as evidence confirming his model of the atom. The Franck-Hertz experiment is thus a classic experiment for confirming quantum theory.

In this experiment, the acceleration voltage U_2 is increased from 0 to 30 V while the driving potential U_1 and the braking voltage U_3 are held constant, and the corresponding collector current I_A is measured. This current initially increases, much as in a conventional tetrode, but reaches a maximum when the kinetic energy of the electrons closely in front of grid G_2 is just sufficient to transfer the energy required to excite the mercury atoms ($E_{\text{Hg}} = 4.9 \text{ eV}$) through collisions. The collector current drops off dramatically, as after collision the electrons can no longer overcome the braking voltage U_3 .

As the acceleration voltage U_2 increases, the electrons attain the energy level required for exciting the mercury atoms at ever greater distances from grid G_2 . After collision, they are accelerated once more and, when the acceleration voltage is sufficient, again absorb so much energy from the electrical field that they can excite a mercury atom. The result is a second maximum, and at greater voltages U_2 further maxima of the collector current I_A .

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Hg Franck-Hertz tube	555 854
1	Socket for Hg Franck-Hertz tube	555 864
1	Electric oven, 230 V	555 81
1	Franck-Hertz supply unit	555 880
1	Temperature sensor NiCr-Ni	666 193
2	Pairs of cables, 100 cm, red/blue	501 46
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

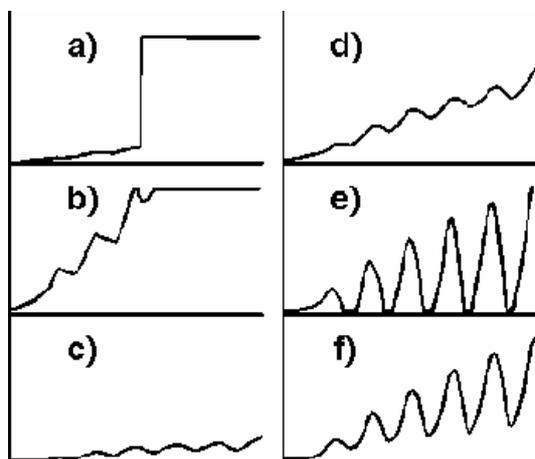
- Make sure the Franck-Hertz supply unit is switched off.
- Connect the heating oven via the 4-mm safety sockets on the rear of the supply unit. In particular, ensure that the yellow and green plug is connected to the yellow and green safety socket (earth).
- Additionally, connect the copper lead of the copper sleeve with 4-mm plug to the green-yellow safety socket (to screen the Franck-Hertz tube from interference fields).
- Connect temperature sensor to the "NiCr-Ni" DIN socket and Franck-Hertz tube to the "Franck-Hertz tube" DIN socket of the supply unit.
- Insert the temperature sensor in the corresponding blind hole of the heating oven as far as it will go and slide the Franck-Hertz tube with copper sleeve into the oven.
Note: If the thermal contact of the temperature sensor is poor, the measured oven temperature will be too low, resulting in overheating of the tube.
- Turn the operating-mode switch to RESET and switch on the supply unit (after a few seconds, the LED indicator for mercury (Hg) changes from green to red).
- Check the default setting $\vartheta_s = 180\text{ }^\circ\text{C}$ and wait until the operating temperature is reached (LED indicator changes from red to green; the temperature ϑ first reaches a maximum, and then declines to the final value).

If the indicator in the display flashes:

- There is a mistake in the setup for temperature measurement (see the Instruction Sheet).
- Connect voltage input A for the Sensor-CASSY to output UA for the voltage proportional to the collector voltage and the voltage input B of Sensor-CASSY at output U2/10 for the acceleration voltage.

Carrying out the experiment
■ Load settings

- Set the driving potential $U_1 = 1.5\text{ V}$ and the braking voltage $U_3 = 1.5\text{ V}$ and record the Franck-Hertz curve in the "Ramp" operating mode. To do this, start the measurement by pressing **F9** and immediately set the operating mode switch to "Ramp". The measurement is automatically stopped after 15 s, then return the operating mode switch to RESET.





1) Optimizing ϑ

If the Franck-Hertz curve rises abruptly (a) and you can see a gas discharge in the Franck-Hertz tube through the insertion opening of the oven (blue glow):

- Immediately turn the operating-mode switch to RESET and wait until the setup reaches the operating temperature.
- If necessary, raise the set value ϑ_S using the screwdriver potentiometer (e.g. by 5 °C) and wait a few minutes until the system settles into the new thermal equilibrium.

2) Optimizing U_1

A higher driving potential U_1 results in a greater electron emission current.

If the Franck-Hertz curve rises too steeply, i.e. the overdrive limit of the current measuring amplifier is reached at values below $U_2 = 30$ V and the top of the Franck-Hertz curve is cut off (b):

- Reduce U_1 until the curve steepness corresponds to (d).

If the Franck-Hertz curve is too flat, i.e. the collector current I_A remains below 5 nA in all areas (c):

- Increase U_1 until the curve steepness corresponds to (d).

If the Franck-Hertz curve is flat even after increasing U_1 :

- Reduce the set value ϑ_S for the oven temperature using the screwdriver potentiometer.

3) Optimizing U_3

A greater braking voltage U_3 causes better-defined maxima and minima of the Franck-Hertz curve; at the same time, however, the total collector current is reduced.

If the maxima and minima of the Franck-Hertz curve are insufficiently defined (d):

- Alternately increase first the braking voltage U_3 and then the driving potential U_1 until you obtain the curve form shown in (f).

If the minima of the Franck-Hertz curve are cut off at the bottom (e):

- Alternately reduce first the braking voltage U_3 and then the driving potential U_1 until you obtain the curve form shown in (f).

The Hg Franck-Hertz tube in the experimental example was measured using the parameters $U_1 = 2.58$ V, $U_3 = 1.95$ V und $\vartheta_S = 180$ °C.

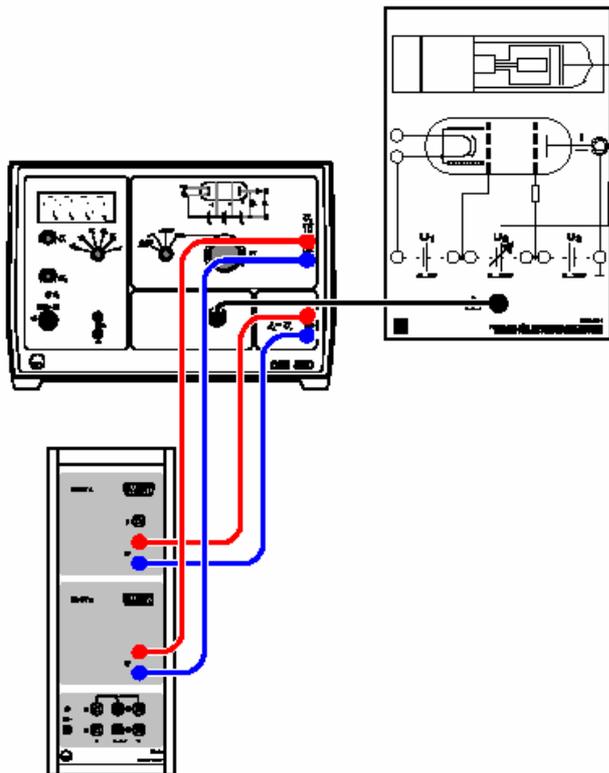
Evaluation

The recorded curve is evaluated by drawing vertical lines or peak centers to find the distance between the subsequent maxima. In the experimental example, an average value of $U_2 = 5.07$ V is found. This corresponds to an energy transfer $\Delta E = 5.07$ eV.

The value found in the literature for the transfer energy of the mercury atoms from the basic state $1S_0$ to the first $3P_1$ state is $E_{Hg} = 4.9$ eV.

The position of the first maximum is determined through the contact voltage of the electrode materials used and the driving potential U_1 . The larger distance between the maxima of higher order is caused by superposition of the Franck-Hertz curve by the characteristic tube line.

Franck-Hertz experiment with neon



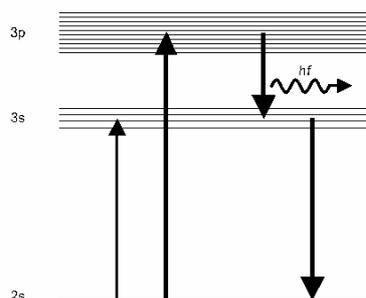
can also be carried out with Pocket-CASSY

■ Load example

Experiment description

In 1914, James Franck and Gustav Hertz reported an energy loss occurring in distinct "steps" for electrons passing through mercury vapour, and a corresponding emission at the ultraviolet line ($\lambda = 254 \text{ nm}$) of mercury. Just a few months later, Niels Bohr recognized this as evidence confirming his model of the atom. The Franck-Hertz experiment is thus a classic experiment for confirming quantum theory.

In this experiment, the energy loss of free electrons through inelastic scattering (excitation through impact) from neon atoms is investigated. Most probably the excitation occurs from the ground state to the ten 3p states, which are 18.4 eV and 19.0 eV above the ground state. The four slightly lower 3s states at 16.6 eV to 16.9 eV are less likely to be excited. The de-excitation of the 3p states to the ground state by emission of photons is only possible with a detour via the 3s states. The light emitted during this process within the visible range between red and green and can therefore be observed without any equipment.



An evacuated glass tube is filled with neon at room temperature to a gas pressure of about 10 hPa. The glass tube contains a system of four electrodes. Electrons are emitted by the hot cathode and form a charge cloud. These electrons are attracted by the driving potential U_1 between the cathode and the grid-shaped control electrode G_1 and then accelerated by the acceleration voltage U_2 in the direction of grid G_2 . Between G_2 and the collector electrode, a braking voltage U_3 is applied. Only electrons with sufficient kinetic energy can reach the collector and contribute to the collector current.

In this experiment, the acceleration voltage U_2 is increased from 0 to 80 V while the driving potential U_1 and the braking voltage U_3 are held constant, and the corresponding collector current I_A is measured. This current initially increases, much as in a conventional tetrode, but reaches a maximum when the kinetic energy of the electrons closely in front of grid G_2 is just sufficient to transfer the energy required to excite the neon atoms through collisions. The collector current drops off dramatically, as after collision the electrons can no longer overcome the braking voltage U_3 .

As the acceleration voltage U_2 increases, the electrons attain the energy level required for exciting the neon atoms at ever greater distances from grid G_2 . After collision, they are accelerated once more and, when the acceleration voltage is sufficient, again absorb so much energy from the electrical field that they can excite a neon atom. The result is a second maximum, and at greater voltages U_2 further maxima of the collector current I_A .

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Ne Franck-Hertz tube	555 870
1	Holder with socket	555 871
1	Connecting cable for Ne-FH	555 872
1	Franck-Hertz supply unit	555 880
2	Pairs of cables, 100 cm, red/blue	501 46
1	PC with Windows 95/98/NT or higher version	

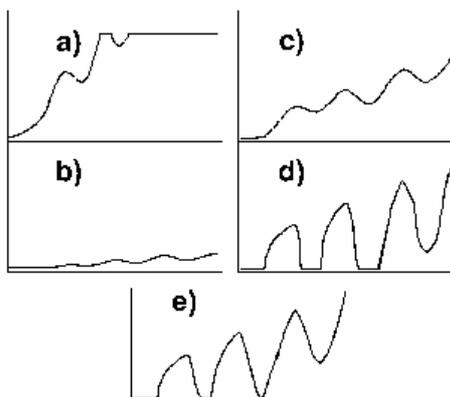
Experiment setup (see drawing)

- Clamp the Ne Franck-Hertz tube in the socket on the holder and connect by means of a connection cable to the socket "Franck-Hertz tube" of the Franck-Hertz supply unit.
- Set the operating-mode switch on the Franck-Hertz supply unit to RESET.
- Connect voltage input A for the Sensor-CASSY to output U_A for the voltage proportional to the collector voltage and the voltage input B of Sensor-CASSY at output $U_2/10$ for the acceleration voltage.

Carrying out the experiment

■ Load settings

- Set the driving potential $U_1 = 1.5$ V and the braking voltage $U_3 = 5$ V and record the Franck-Hertz curve in the "Ramp" operating mode. To do this, start the measurement by pressing **F9** and immediately set the operating mode switch to "Ramp". The measurement is automatically stopped after 40 s, then return the operating mode switch to RESET.



1) Optimizing U_1

A higher driving potential U_1 results in a greater electron emission current.

If the Franck-Hertz curve rises too steeply, i.e. the overdrive limit of the current measuring amplifier is reached at values below $U_2 = 80$ V and the top of the Franck-Hertz curve is cut off (a):

- Reduce U_1 until the curve steepness corresponds to (c).

If the Franck-Hertz curve is too flat, i.e. the collector current I_A remains below 5 nA in all areas (b):

- Increase U_1 until the curve steepness corresponds to (c).
- If necessary, optimize the cathode heating as described in the Instruction Sheet for the Franck-Hertz supply unit.

2) Optimizing U_3

A greater braking voltage U_3 causes better-defined maxima and minima of the Franck-Hertz curve; at the same time, however, the total collector current is reduced.

If the maxima and minima of the Franck-Hertz curve are insufficiently defined (c):

- Alternately increase first the braking voltage U_3 and then the driving potential U_1 until you obtain the curve form shown in (e).

If the minima of the Franck-Hertz curve are cut off at the bottom (d):

- Alternately reduce first the braking voltage U_3 and then the driving potential U_1 until you obtain the curve form shown in (e).

The Ne Franck-Hertz tube in the experimental example was measured using the parameters $U_1 = 1.5$ V and $U_3 = 7.9$ V.

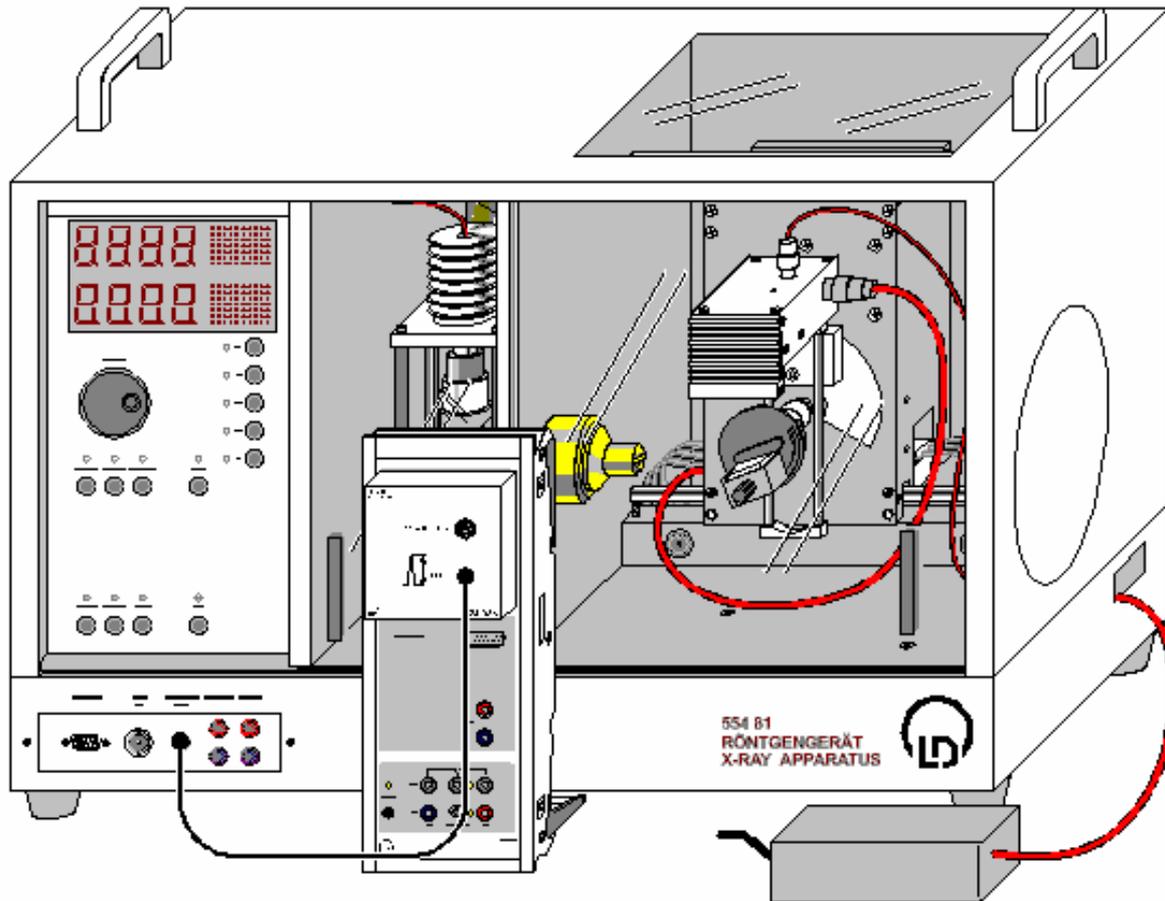
Evaluation

The recorded curve is evaluated by drawing vertical lines (by eye) to find the distance between the subsequent maxima. In the experimental example, an average value of $U_2 = 18.2$ V is found. This value is much closer to the excitation energies for the 3p-levels of neon (18.4-19.0 eV) than to the energies of the 3s-levels (16.6–16.9 eV). Thus, the probability of excitation to the latter due to inelastic electron collision is significantly less.

The substructure in the measured curve shows that the excitation of the 3s-levels cannot be ignored altogether. Note that for double and multiple collisions, each combination of excitation of a 3s-level and a 3p-level occurs.

In the Ne Franck-Hertz tube, luminous zones can be observed which depend on the acceleration voltage. They directly correlate with the minima of the Franck-Hertz curve.

Moseley's law (K-line x-ray fluorescence)



can also be carried out with Pocket-CASSY

■ Load example

Safety notes

The X-ray apparatus fulfils all regulations on the design of an X-ray apparatus and fully protected device for instructional use and is type approved for school use in Germany (NW 807 / 97 Rö).

The built-in protective and shielding fixtures reduce the dose rate outside the X-ray apparatus to less than $1 \mu\text{Sv/h}$, which is of the order of magnitude of the natural background radiation.

- Before putting the X-ray apparatus into operation, inspect it for damage and check whether the voltage is switched off when the sliding doors are opened (See instruction sheet of the X-ray apparatus).
- Protect the X-ray apparatus against access by unauthorized persons.

Avoid overheating of the anode in the X-ray tube.

- When switching the X-ray apparatus on, check whether the ventilator in the tube chamber starts rotating.

The goniometer is positioned solely by means of electric stepper motors.

- Do not block the target arm and the sensor arm of the goniometer and do not use force to move them.

When handling heavy metals or allergen substances from the target set, observe their operating instructions.

Experiment description

X-ray fluorescence occurs when electrons are knocked out of the inner shells of an atom through x-ray radiation. The atom ionised in this way then has a vacancy (electron hole) in a lower shell which previously had been full. These electron holes can be filled with electrons from other, less strongly bound shells of the atom: e.g. the K-shell can be closed by the transition of an electron from the L-shell. Such a transition is connected with the emission of a photon. This radiation has only particular discrete photon energies corresponding to the energy difference of the levels involved, and it is characteristic for every chemical element.

The designations of the characteristic x-ray lines are a combination of the symbol for the electron shell (K, L, M etc.) and a Greek letter (α , β , γ , etc.). The electron shell being referred to is the one which was ionised before the electron transition. For example, the designation $K\alpha$ -line describes the transition from the L-shell into the K-shell, $K\beta$ -line refers to the transition from the M-shell to the K-shell. The $L\alpha$ - and $L\beta$ -lines refer to the transitions from the M-shell and the N-shell to the L-shell.

For the energies E of the characteristic lines Moseley discovered in 1913 the following law

$$\sqrt{\frac{E}{Ry}} = (Z - \sigma) \sqrt{\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)}$$

with the atomic number Z , the screening constant σ , the constant $Ry = m_e e^4 / 8 \epsilon_0^2 h^2 = 13.6 \text{ eV}$ and the main quantum numbers n_1 and n_2 for the electron shells involved ($n_1 < n_2$).

In the experiment, the energies of the $K\alpha$ and $K\beta$ -lines for Ti, Fe, Ni, Cu, Zn, Zr, Mo and Ag are determined, Moseley's law is confirmed and the screening constants σ_α and σ_β are determined.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	MCA Box	524 058
1	X-ray apparatus with x-ray tube Mo	554 811
1	Target set for K-lines fluorescence	554 844
1	X-ray energy detector	559 938
1	BNC cable, 1 m	501 02
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

- Guide the connection cable for the table-top power supply through the empty channel of the x-ray apparatus and connect it to the mini-DIN socket of the x-ray energy detector.
- Secure the sensor holder with the mounted x-ray energy detector in the goniometer sensor arm
- Connect the signal output of the x-ray energy detector to the BNC socket SIGNAL IN of the x-ray apparatus by means of the BNC cable included
- Feed enough connection cable through to make complete movement of the sensor arm possible
- Press the SENSOR button and set the sensor angle with the rotary adjuster ADJUST manually to 90°
- Set the distances between the slit aperture of the collimator and the axis of rotation as well as between the axis of rotation and the window of the x-ray energy detector both to 5 to 6 cm
- Press the TARGET button and adjust the target angle manually using the rotary button ADJUST to 45° .
- Connect Sensor-CASSY to the computer and connect the MCA box
- Connect the SIGNAL OUT output in the connection panel of the x-ray apparatus to the MCA box by means of the BNC cable.

Carrying out the experiment

- Load settings
 - Connect the table-top power supply to the mains (after approx. 2 min the LED will glow green and the x-ray energy detector will be ready for use).
 - Place the titanium (Ti) target from the target set for K-lines fluorescence onto the target table
 - Set the tube high voltage $U = 35 \text{ kV}$, emission current $I = 1.00 \text{ mA}$ and switch the high voltage on



- Start the measurement by pressing **F9**
- Then record the spectra for the other targets (Fe, Ni, Cu, Zn, Zr, Mo and Ag) in the target set for K-lines fluorescence

Energy calibration

The energy calibration of the spectra is made using the $K\alpha$ lines of iron (Fe) and molybdenum (Mo).

- Open in the context menu of the diagram (right mouse button) or select with **Alt+E** the Energy calibration, select **global energy calibration** and enter on the right-hand side the energies of the Fe $K\alpha$ -line (6.40 keV) and of the Mo $K\alpha$ -line (17.48 keV). Do not yet close the **Energy calibration** window.
- In the context menu of the diagram select under Other evaluations Calculate peak center, mark the Fe $K\alpha$ -line (2nd spectrum) and enter the result in the left-hand side of the energy calibration (e.g. with drag & drop from the status line)
- Then determine the centre of the Mo $K\alpha$ line (7th spectrum) and also enter the result on the left-hand side
- Close the **Energy calibration** window

Evaluation

As the atomic number Z increases the energy of the characteristic lines also increases and so does the separation between the α - and the β -component in the K spectral series. For a quantitative analysis, the energies of the individual lines can be determined.

- Select a spectrum in the diagram
- In the context menu of the diagram (right mouse button) or with **Alt+V** choose Vertical line and mark approximately the positions of the $K\alpha$ and $K\beta$ -line.
- In the context menu of the diagram select under Other evaluations Gaussians of equal width and mark the area of the desired peak (also mark sufficient background!)
- Read the determined peak positions from the status line and enter them together with the atomic numbers Z of Ti ($Z=22$), Fe ($Z=26$), Ni ($Z=28$), Cu ($Z=29$), Zn ($Z=30$), Zr ($Z=40$), Mo ($Z=42$) and Ag ($Z=47$) into the **Energy** diagram (click with mouse) (e.g. by drag & drop from the status line)

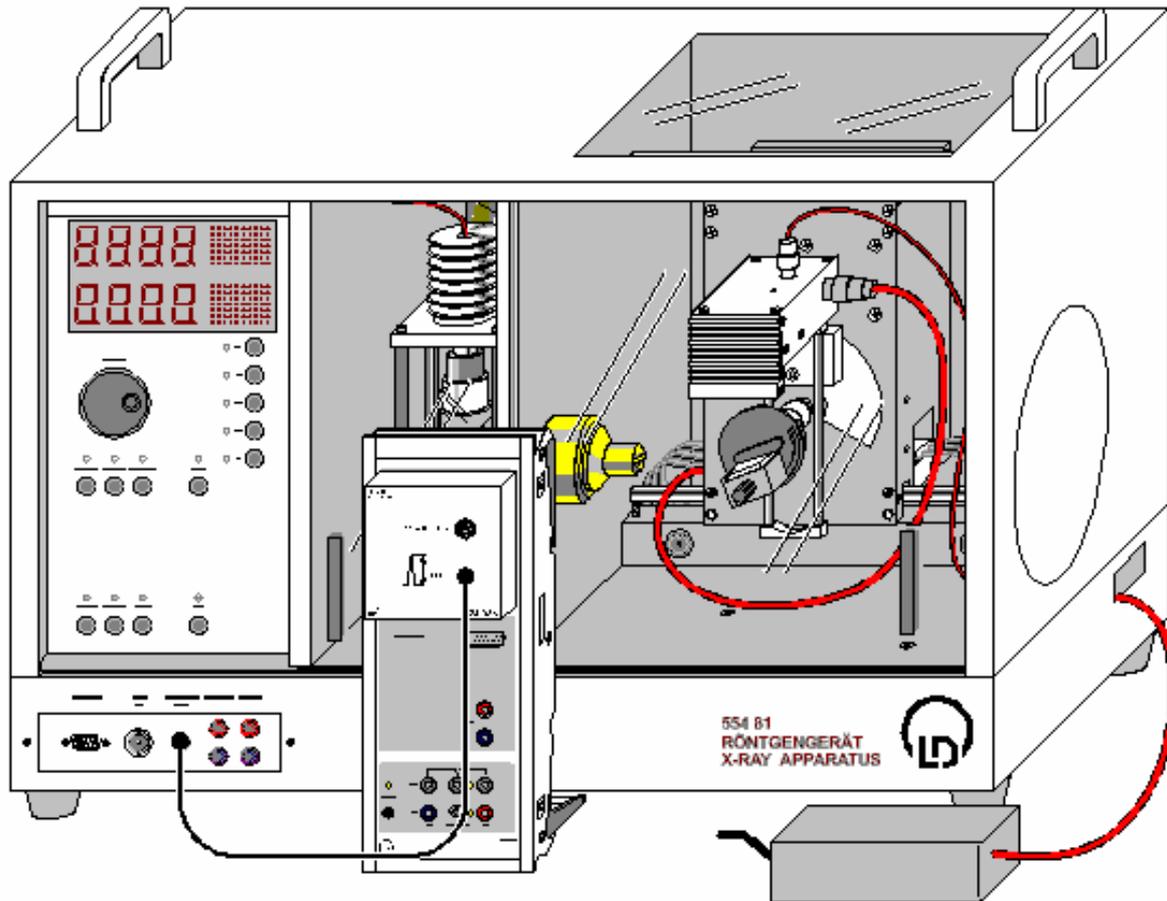
For each line, the expression $\sqrt{E/Ry}$ is automatically calculated and plotted in the **Moseley** diagram as a function of the atomic number Z . The same applies to the screening constants σ_α and σ_β and the **Screening** diagram.

In the **Moseley** diagram, by a free fit with the formula $(x-1)\sqrt{3/4}$, the theoretical line for the $K\alpha$ -line can be entered, which corresponds well to the measured values.

The **Screening** diagram shows for the $K\alpha$ -line that the deviation from the theoretically expected $\sigma_\alpha=1$ grows with increasing atomic number Z . This is explained by the fact that the influence of the external electrons increases as the number of electrons increases.

The screening constants σ_β for the $K\beta$ -lines have a value $\sigma_\beta\approx 2$ which indicates, as expected, a stronger effective screening of the nucleus charge for the electron transitions from the higher level $n_2=3$.

Moseley's law (L-line x-ray fluorescence)



can also be carried out with Pocket-CASSY

■ Load example

Safety notes

The X-ray apparatus fulfils all regulations on the design of an X-ray apparatus and fully protected device for instructional use and is type approved for school use in Germany (NW 807 / 97 Rö).

The built-in protective and shielding fixtures reduce the dose rate outside the X-ray apparatus to less than $1 \mu\text{Sv/h}$, which is of the order of magnitude of the natural background radiation.

- Before putting the X-ray apparatus into operation, inspect it for damage and check whether the voltage is switched off when the sliding doors are opened (See instruction sheet of the X-ray apparatus).
- Protect the X-ray apparatus against access by unauthorized persons.

Avoid overheating of the anode in the X-ray tube.

- When switching the X-ray apparatus on, check whether the ventilator in the tube chamber starts rotating.

The goniometer is positioned solely by means of electric stepper motors.

- Do not block the target arm and the sensor arm of the goniometer and do not use force to move them.

When handling heavy metals or allergen substances from the target set, observe their operating instructions.



Experiment description

X-ray fluorescence occurs when electrons are knocked out of the inner shells of an atom through x-ray radiation. The atom ionised in this way then has a vacancy (electron hole) in a lower shell which previously had been full. These electron holes can be filled with electrons from other, less strongly bound shells of the atom: e.g. the K-shell can be closed by the transition of an electron from the L-shell. Such a transition is connected with the emission of a photon. This radiation has only particular discrete photon energies corresponding to the energy difference of the levels involved, and it is characteristic for every chemical element.

The designations of the characteristic x-ray lines are a combination of the symbol for the electron shell (K, L, M etc.) and a Greek letter (α , β , γ , etc.). The electron shell being referred to is the one which was ionised before the electron transition. For example, the designation $K\alpha$ -line describes the transition from the L-shell into the K-shell, $K\beta$ -line refers to the transition from the M-shell to the K-shell. The $L\alpha$ - and $L\beta$ -lines refer to the transitions from the M-shell and the N-shell to the L-shell.

For the energies E of the characteristic lines Moseley discovered in 1913 the following law

$$\sqrt{\frac{E}{Ry}} = (Z - \sigma) \sqrt{\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)}$$

with the atomic number Z , the screening constant σ , the constant $Ry = m_e e^4 / 8\epsilon_0^2 h^2 = 13.6$ eV and the main quantum numbers n_1 and n_2 for the electron shells involved ($n_1 < n_2$).

In the experiment the energies of the $L\alpha$ and $L\beta$ -lines for Ag, In, Sn, W, Au and Pb are determined, Moseley's law is confirmed and the screening constants σ_α and σ_β are determined. The fine structure of the lines, e.g. $L\alpha_1$ and $L\alpha_2$, cannot be resolved in this experiment. Therefore they appear in the spectrum as a single ($L\alpha$) line.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	MCA-Box	524 058
1	X-ray apparatus with x-ray tube Mo	554 811
1	Target set for L-lines fluorescence	554 846
1	X-ray energy detector	559 938
1	HF cable, 1 m	501 02
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

- Guide the connection cable for the table-top power supply through the empty channel of the x-ray apparatus and connect it to the mini-DIN socket of the x-ray energy detector.
- Secure the sensor holder with the mounted x-ray energy detector in the goniometer sensor arm
- Connect the signal output of the x-ray energy detector to the BNC socket SIGNAL IN of the x-ray apparatus by means of the BNC cable included
- Feed enough connection cable through to make complete movement of the sensor arm possible
- Press the SENSOR button and set the sensor angle with the rotary adjuster ADJUST manually to 90°
- Set the distances between the slit aperture of the collimator and the axis of rotation as well as between the axis of rotation and the window of the x-ray energy detector both to 5 to 6 cm
- Press the TARGET button and adjust the target angle manually using the rotary button ADJUST to 45° .
- Connect Sensor-CASSY to the computer and connect the MCA box
- Connect the SIGNAL OUT output in the connection panel of the x-ray apparatus to the MCA box by means of the BNC cable.

Carrying out the experiment

- Load settings
- Connect the table-top power supply to the mains (after approx. 2 min the LED will glow green and the x-ray energy detector will be ready for use)

- Place the first target (Ag) from the target set for L-lines fluorescence onto the target table
- Set the tube high voltage $U = 35$ kV, emission current $I = 1.00$ mA and switch the high voltage on
- Start the measurement by pressing **F9**
- Then record spectra for the other targets (In, Sn, W, Au and Pb) in the target set for L-lines fluorescence.

Energy calibration

The energy calibration of the spectra is made using the $L\alpha$ -line of tungsten (W) and the $K\alpha$ -line of silver (Ag).

- Open in the context menu of the diagram (right mouse button) or select with **Alt+E** the Energy calibration, select **global energy calibration** and enter on the right-hand side the energies of the W $L\alpha$ -line (8.40 keV) and of the Ag $K\alpha$ -line (22.17 keV). Do not yet close the **Energy calibration** window.
- In the context menu of the diagram select under Other evaluations Calculate peak center, mark the W $L\alpha$ -line (4th spectrum) and enter the result on the left-hand side of the Energy calibration (e.g. with drag & drop from the status line)
- Then determine the centre of the Ag $K\alpha$ line (1st spectrum) and also enter it on the left-hand side
- Close the **Energy calibration** window

Evaluation

As the atomic number Z increases, the energy of the characteristic lines also increases and so does the separation between the α - and the β -components in the L spectral series. For the heavier elements, in addition to the $L\alpha$ and $L\beta$ -components, the relatively small $L\gamma$ and $L\delta$ -components can also be demonstrated with the x-ray energy detector. For a quantitative analysis, the energies of the individual lines can be determined:

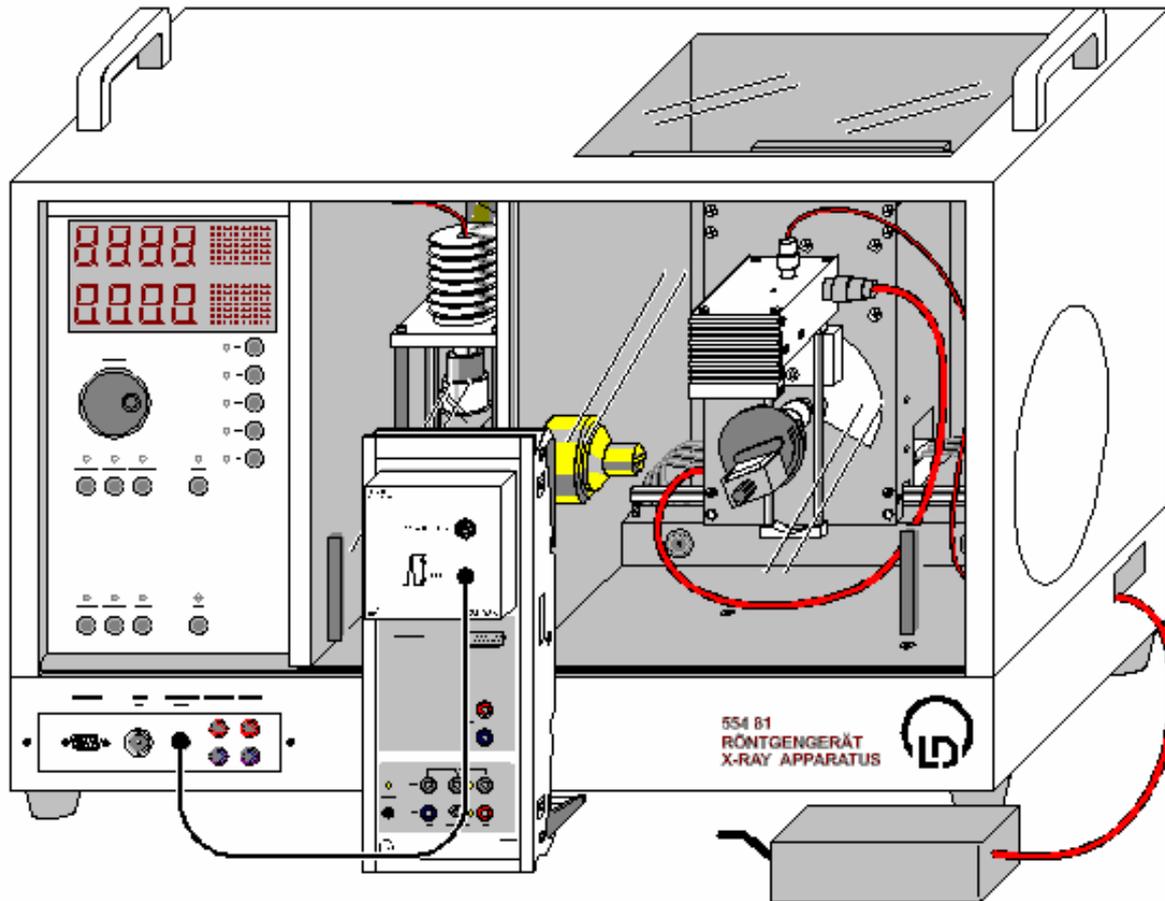
- Select spectrum in the diagram
- In the context menu of the diagram (right-hand mouse button) or with **Alt+V** choose Vertical line and mark the approximate positions of the $L\alpha$ and $L\beta$ -line. Because for the elements silver, indium and tin the $L\alpha$ -line and $L\beta$ -line are not resolved, they will be treated in the evaluation as a single line.
- In the context menu of the diagram select under Other evaluations Gaussians of equal width and mark the area of the desired peak (also mark sufficient background!)
- Read the determined peak positions from the status line and enter them together with the atomic numbers Z of Ag ($Z=47$), In ($Z=49$), Sn ($Z=50$), W ($Z=74$), Au ($Z=79$) and Pb ($Z=82$) into the **Energy** diagram (click with mouse) (e.g. by drag & drop from the status line)

For each line, the expression $\sqrt{E/Ry}$ is automatically calculated and plotted in the **Moseley** diagram as a function of the atomic number Z . The same applies to the screening constants σ_α and σ_β and the **Screening** diagram.

In the **Moseley** diagram, by means of a Best-fit straight line for $L\alpha$ and $L\beta$, the linear relationship in Moseley's law can be confirmed.

In the **Screening** diagram, the very different dependence of the atomic screening constants for the $L\alpha$ -lines and $L\beta$ -lines of the atomic number Z indicates the differences in structure of the sublevels in the M-shell and the L-shell. It is remarkable that the atomic screening constant for the $L\alpha$ -lines has a value of ≈ 7 . This means that the screening is provided by the seven electrons remaining in the L-shell after ionisation. This again indicates that the p-orbitals and s-orbitals (L-shell or K-shell respectively) have such a form that the two electrons in the K-shell are ineffective at screening the $L\alpha$ -transition.

Energy dispersive Bragg reflection into different orders of diffraction



can also be carried out with Pocket-CASSY

■ Load example

Safety notes

The X-ray apparatus fulfils all regulations on the design of an X-ray apparatus and fully protected device for instructional use and is type approved for school use in Germany (NW 807 / 97 Rö).

The built-in protective and shielding fixtures reduce the dose rate outside the X-ray apparatus to less than $1 \mu\text{Sv/h}$, which is of the order of magnitude of the natural background radiation.

- Before putting the X-ray apparatus into operation, inspect it for damage and check whether the voltage is switched off when the sliding doors are opened (See instruction sheet of the X-ray apparatus).
- Protect the X-ray apparatus against access by unauthorized persons.

Avoid overheating of the anode in the X-ray tube.

- When switching the X-ray apparatus on, check whether the ventilator in the tube chamber starts rotating.

The goniometer is positioned solely by means of electric stepper motors.

- Do not block the target arm and the sensor arm of the goniometer and do not use force to move them.

Experiment description

According to a model first described by W.H. and W.L. Bragg in 1913, the regular arrangement of atoms in a crystal can be interpreted in such a way that they are arranged on parallel lattice planes.

If parallel x-rays hit the crystal these are elastically scattered by each of the atoms. If two conditions apply, the waves scattered at the individual atoms will interfere constructively. These conditions are:

Incident angle α_1 = defracted angle $\alpha_2 = \alpha$

and

$n \cdot \lambda = 2 \cdot d \cdot \sin \alpha$ (Bragg's condition)

with d the distance between the lattice planes and order of diffraction n being an integer number. The angle α applies relative to the lattice planes.

When recording the spectrum by means of an energy resolving detector, not the wavelengths, but the energies are recorded. For this case, Bragg's condition can be rewritten with $E = h\nu = hc/\lambda$ as follows:

$E_n = nhc / 2d\sin\alpha$

or

$E_n/n = hc / 2d\sin\alpha \approx 620 \text{ pm}\cdot\text{keV} / d\sin\alpha$

Here E_n is the energy of the x-ray radiation reflected in the order of diffraction n . It is apparent that with a fixed angle α the lowest energy E_1 occurs in the first order of diffraction. The ratio of the radiation energy in the order of diffraction n with the radiation energy in the first order E_n/E_1 corresponds to the order of diffraction. The ratio E_n/n is constant for every set of lattice planes.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	MCA-Box	524 058
1	X-ray apparatus with goniometer	554 811
1	X-ray tube Cu	554 85
1	X-ray energy detector	559 938
1	BNC cable, 1 m	501 02
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

- If necessary exchange the Mo x-ray tube for the Cu x-ray tube (see operating instructions for the x-ray apparatus)
- Guide the connection cable for the table-top power supply through the empty channel of the x-ray apparatus and connect it to the mini-DIN socket of the x-ray energy detector.
- Secure the sensor holder with the mounted x-ray energy detector in the goniometer sensor arm
- Connect the signal output of the x-ray energy detector to the BNC socket SIGNAL IN of the x-ray apparatus by means of the BNC cable included
- Feed enough connection cable through to make complete movement of the sensor arm possible
- Connect Sensor-CASSY to the computer and connect the MCA box
- Connect the SIGNAL OUT output in the connection panel of the x-ray apparatus to the MCA box by means of the BNC cable.
- Set the distances between the slit aperture of the collimator and the axis of rotation as well as between the axis of rotation and the window of the x-ray energy detector both to 5 to 6 cm
- Lay the NaCl crystal from the scope of delivery of the X-ray apparatus on the target stage and clamp it gently.
- Press the COUPLED pushbutton, and, using the ADJUST knob, adjust a target angle of 4.5° manually.



Note

For the experiment, the Cu x-ray tube is inserted, because, due to its thinner window, the radiation provided covers a wider energy range: approx. 5 to 35 keV at the high voltage 35 kV. The crystal angles are selected in such a way that the bremsstrahlung and not the characteristic lines are reflected by the crystal. Otherwise the much larger intensity in the characteristic line can considerably falsify the intensity ratio of various orders of diffraction.

Carrying out the experiment

■ Load settings

- Connect the table-top power supply to the mains (after approx. 2 min the LED will glow green and the x-ray energy detector will be ready for use).
- Set the tube high voltage $U = 35$ kV, emission current $I = 1.00$ mA and switch the high voltage on
- Record the calibration spectrum (start the spectrum recording by pressing **F9**)
- Set the emission current to $I = 0.40$ mA
- Record the spectra for the target angles 5° , 10° , 15° and 20°

Energy calibration

In the housing of the Si-PIN photodiode of the x-ray energy detector the x-ray radiation produces additional x-ray fluorescence radiation which will also be recorded. In the primary spectrum therefore, in addition to the peaks of the reflected radiation, the gold (Au) and the silver (Ag) lines are also to be expected. With the help of these lines the energy calibration of the spectra can be carried out.

Through the scatter of the Cu $K\alpha$ -line of the primary spectrum of the x-ray tube, on the left-hand side a peak occurs at $E=8.1$ keV. The subsequent smaller peaks at $E=9.7$ keV, 11.4 keV and 22.2 keV have been caused by the fluorescence of the housing (Au $L\alpha$, $L\beta$ and Ag $K\alpha$) and the large peak on the right-hand side is the reflected radiation (Bragg's condition).

- Select spectrum N1 (4.5°)
- Open in the context menu of the diagram (right mouse button) or select with **Alt+E** the Energy calibration, **select global energy calibration** and enter on the right-hand side the energies of the Au $L\alpha$ -line (9.71 keV) and of the Ag $K\alpha$ -line (22.16 keV). Do not yet close the **Energy calibration window**.
- In the context menu of the diagram select under Other evaluations Calculate peak center, mark the Au $L\alpha$ -line and enter the result in the left-hand side of the Energy calibration (e.g. with drag & drop from the status line)
- Then determine the centre for the Ag $K\alpha$ -line and also enter it on the left-hand side.
- Close the **Energy calibration** window

Note

In order to excite the silver K-lines in the housing material, the energy of the reflected radiation must exceed the K-edge of silver (25.52 keV). For this reason the energy calibration is carried out on the spectrum for $\alpha=4.5^\circ$.

Evaluation

For confirmation that the remaining peaks associated with the various orders of diffraction belong to the same set of lattice planes, the ratios of the peak energies must be analysed.

For the determination of the peak energies as a function of the scatter angle

- Select energy spectrum (5° , 10° , 15° and 20°).
- In the context menu of the diagram select under Other evaluations Calculate peak centre and mark the desired peak
- Read the determined peak positions from the status line and enter as $E_{n=1}$, $E_{n=2}$, $E_{n=3}$ or $E_{n=4}$ together with the angle α into the **Energy** diagram (click with mouse) (e.g. by drag & drop from the status line)

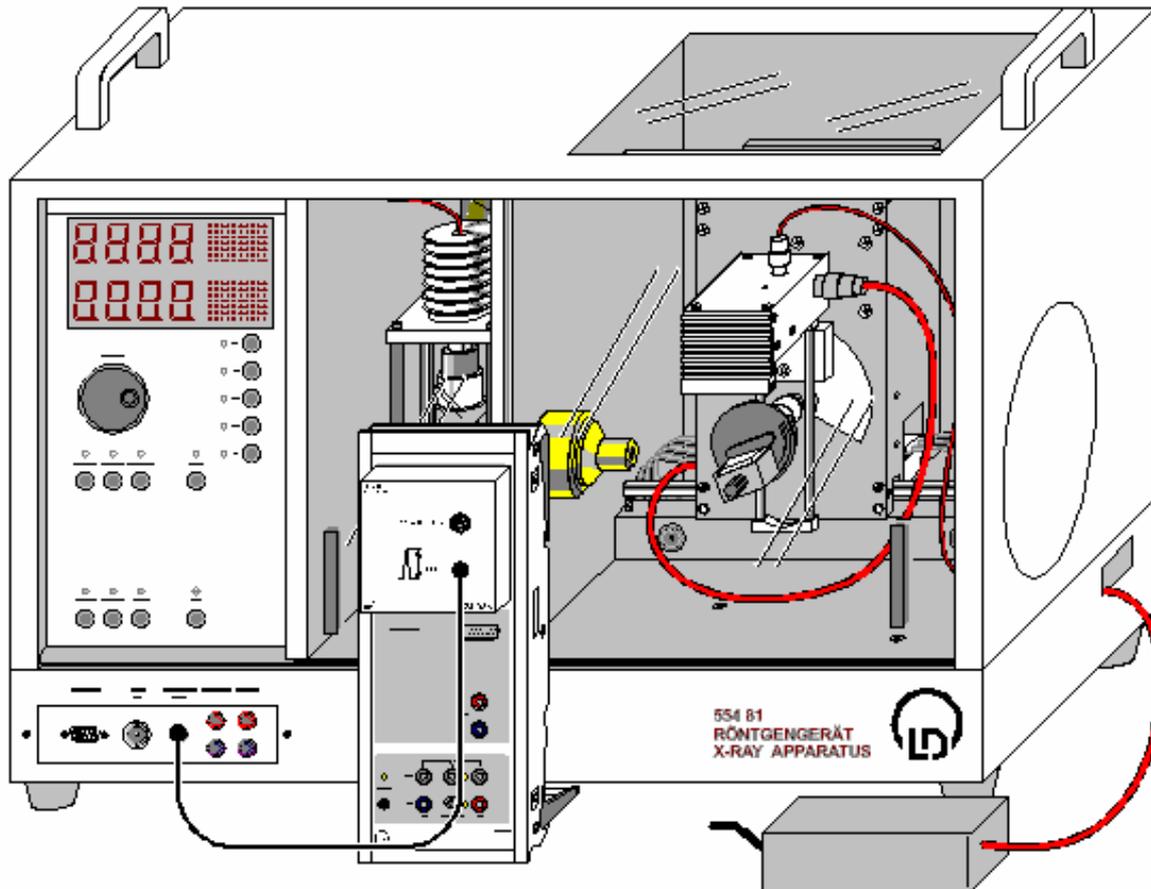
In the **Order** diagram a table is formed in which the ratios E_n/E_1 of the radiation energy in the order of diffraction n with the first order radiation energy are given. They have approximately integer values which confirms the assumption that they belong to different orders of diffraction from the same set of lattice planes.

In the **Lattice plane spacing** diagram the lattice plane spacing d was calculated for each crystal angle from the determined values E_n/n . It becomes apparent that the diffraction for all angles was observed from the same set of lattice planes with a spacing of $d \approx 280$ pm. By comparing with the data given in the literature for NaCl (grid constant 564 pm) it becomes apparent that this is the diffraction from the (200) lattice planes ($d = 282$ pm).

Additional information

For a Bragg spectrum recorded using a Geiger-Müller counter as the detector, the photons which are reflected in the various orders of diffraction are counted together. A spectrum recorded in this way is therefore a combination of several components which cannot easily be separated. In the 20° spectrum it is particularly clear how incorrect the statement about the intensity of radiation would be if only the first order of diffraction were taken into account and the existence of higher orders of diffraction were ignored.

Compton effect on X-rays



can also be carried out with Pocket-CASSY

■ Load example

Safety notes

The X-ray apparatus fulfils all regulations on the design of an X-ray apparatus and fully protected device for instructional use and is type approved for school use in Germany (NW 807 / 97 Rö).

The built-in protective and shielding fixtures reduce the dose rate outside the X-ray apparatus to less than $1 \mu\text{Sv/h}$, which is of the order of magnitude of the natural background radiation.

- Before putting the X-ray apparatus into operation, inspect it for damage and check whether the voltage is switched off when the sliding doors are opened (See instruction sheet of the X-ray apparatus).
- Protect the X-ray apparatus against access by unauthorized persons.

Avoid overheating of the anode in the X-ray tube Mo.

- When switching the X-ray apparatus on, check whether the ventilator in the tube chamber starts rotating.

The goniometer is positioned solely by means of electric stepper motors.

- Do not block the target arm and the sensor arm of the goniometer and do not use force to move them.

Experiment description

When X-rays pass through matter, part of them is scattered. According to classical physics, the frequency of the radiation should not be changed by the scattering process. However, in 1923 the American physicist A. H. Compton observed that the frequency was reduced in some of the scattered X-rays.

In order to explain this phenomenon, the entire scattering process has to be treated in terms of quantum physics, and the X-rays have to be considered, for example, according to the particle aspect. Moreover, it is assumed that the scattering electron are free, which is a good approximation for the outer atomic electron shells at energies in the range of X-rays. Thus, in a scattering process, a photon with the frequency ν_1 , i.e. with the energy $E_1 = h \cdot \nu_1$, hits a free electron at rest with the rest mass m_0 . The photon is scattered by the angle ϑ .

Assuming energy and momentum conservation, Compton calculated the energy E_2 of the scattered radiation and obtained

$$E_2 = E_1 / (1 + E_1/m_0 \cdot c^2 \cdot (1 - \cos \vartheta)).$$

In the experiment, Compton's investigations are repeated on a scattering body made of plexiglass. The results are compared with the above equation. The spectrum is recorded by means of the X-ray energy detector.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	MCA-Box	524 058
1	X-ray apparatus with X-ray tube Mo	554 811
1	Compton accessory X-ray II	554 837
1	X-ray energy detector	559 938
1	BNC cable, 1 m	501 02
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

- Put the Zr filter (from the scope of delivery of the X-ray apparatus) onto the beam entrance side of the circular collimator (from the scope of delivery of the Compton accessory X-ray II)
- Mount the circular collimator in the collimator mount of the X-ray apparatus
- Guide the connection cable of the table power supply through the empty duct of the X-ray apparatus, and connect it to the Mini-DIN socket of the X-ray energy detector
- Fasten the assembly of the X-ray detector and the sensor holder in the sensor arm of the goniometer
- Use the BNC cable supplied with the X-ray energy detector to connect the signal output of the detector to the BNC socket SIGNAL IN of the X-ray apparatus
- Push a sufficient length of the connection cable into the duct so that the sensor arm can perform a complete rotation
- Press the SENSOR key and, using the ADJUST knob, adjust a sensor angle of 150° manually. If necessary, push the goniometer to the right
- Adjust the distance between the X-ray energy detector and the axis of rotation so that the detector housing just does not cover the X-ray beam at this sensor angle
- Then push the goniometer to the left so that the detector housing just does not touch the circular collimator (approx. 8 cm distance between the circular collimator and the axis of rotation)
- Connect the Sensor-CASSY to the computer, and plug in the MCA box
- Use a BNC cable to connect the output SIGNAL OUT on the terminal panel of the X-ray apparatus to the MCA box

Experiment preparation

- Load settings
- Connect the table power supply to the mains (after approx. 2 minutes the LED shines green and the X-ray energy detector is ready for operation)



For an accurate measurement of the small energy shifts, it has to be taken into account that the calibration of the X-ray energy detector undergoes a slight shift at high counting rates. Therefore it is sensible to restrict the counting rates to 200 /s.

Estimating the counting rate in the scattering arrangement:

- Put the plexiglass scattering body on the target stage, and clamp it
- Press the TARGET pushbutton, and, using the ADJUST knob, adjust the target angle manually to 20°
- Adjust the tube high voltage $U = 35$ kV and the emission current $I = 1.00$ mA, and switch the high voltage on
- Start recording the spectrum with **F9**
- Vary the sensor angle slowly between 150° and 30° each time reading the total counting rate above on the right in the CASSY Lab window
- Reduce the emission current if the total counting rate clearly exceeds 200 /s

Adjusting the counting rate of the primary beam:

- Remove the target holder with the target stage, and take the sensor into the 0° position
- Put the absorption screen onto the circular collimator, and align it carefully (the screws should point upwards and downwards, respectively)
- Reduce the emission current to 0.1 mA, and switch the high voltage on
- Start recording the spectrum with **F9**
- In steps of 0.1° look for the sensor angle at which the total counting rate is only slightly greater than the counting rates measured in the scattering arrangement (if necessary, change the emission current slightly)

If no or only a small counting rate is measured:

- Check the alignment of the absorption screen (with the screws pointing upwards and downwards, you may try to turn the screen by 180°)

Carrying out the experiment

The X-rays to be measured produce additional fluorescence X-rays in the housing of the Si-PIN photodiode of the X-ray energy detector, which are also registered. Therefore the Au $L\alpha$ and the Au $L\beta$ lines are to be expected in the primary spectrum apart from the Mo $K\alpha$ - and the Mo $K\beta$ lines. With the aid of these lines, the energy calibration of the spectra can be carried out.

■ Load settings

- Record the primary spectrum (0° position) with **F9**
- Next open the energy calibration in the context menu of the diagram (right mouse button) or with **Alt+E**, select **Global Energy Calibration**, and enter the energies of the Au $L\alpha$ line (9.72 keV) and the Mo $K\alpha$ line (17.48 keV) on the right
- Select Calculate Peak Center from **Other Evaluations** in the context menu of the diagram, mark the Au $L\alpha$ line (small peak on the left hand side of the Au $L\beta$ line, which is also small), and enter the result in the energy calibration on the left
- Then determine the peak center of the Mo $K\alpha$ line (high peak), and enter it on the left as well
- Remove the absorption screen
- Mount the target holder with the target stage on the goniometer
- Put the plexiglass scattering body on the target stage, and clamp it
- Adjust the emission current $I = 1.00$ mA (or the emission current determined previously for estimating the counting rate), and switch the high voltage on
- Adjust a target angle of 20° and a sensor angle of 30°
- Record a new spectrum (30° position) with **F9**
- Then record further spectra at constant target angle for the sensor angles 60° , 90° , 120° and 150°

Evaluation

The energy of the scattered radiation decreases with increasing scattering angle. The intensity of the scattered radiation takes its minimum at $\vartheta = 90^\circ$.

For further evaluation, you can zoom in on the region around the scattered peak and select Calculate Peak Center from Other Evaluations for each energy-shifted peak. Starting from a scattering angle of ϑ

= 90°, the energy resolution of the detector is sufficient for separating the unshifted peak (elastic scattering from strongly bound electrons) and the shifted peak (inelastic scattering from quasi-free electrons). For the determination of the peak center, only the region of the energy-shifted peak should be marked.

For each peak center, the energy is entered in the **Evaluation** display together with the corresponding scattering angle. The energy can be taken from the status line into the table using the mouse (drag & drop). The angle has to be entered manually in the table.

For a comparison of the measured energies with the energies calculated from energy and momentum conservation, a free fit of the equation

$$17.48/(1+17.48*(1-\cos(x))/A)$$

can be selected in the **Evaluation** display with the starting value $A = 511$ (=constant).

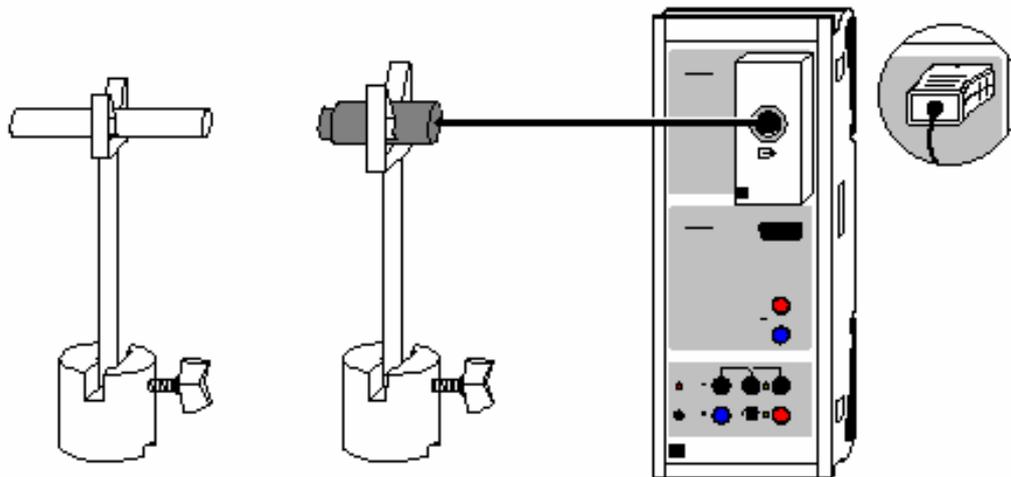
The result corresponds to the theoretical curve with the parameters $E_1 = 17.48$ keV and $m_0 \cdot c^2 = 511$ keV, which is in good agreement with the measured values.

When X-rays pass through matter, part of them is scattered and experiences an energy shift (Compton effect). The energy shift can be calculated by describing the scattering process as a collision between an X-ray photon and a free electron at rest and by postulating the conservation of energy and momentum in this process.

Remark

Alternatively, the comparison between measurement and theory can be carried out as a free fit with the free fit parameter A (the rest mass of the collision partner of the X-ray photon). As a result a value for the parameter A is obtained, which agrees with the "rest mass" of an electron ($m_0 \cdot c^2 = 511$ keV) to a good approximation.

Poisson distribution



can also be carried out with Pocket-CASSY

- Load example

Experiment description

The number x of decay events of a radioactive preparation over a time interval Δt is not constant. A large number of individual measurements can be represented as a frequency distribution $H(x)$ scattered around the mean value μ . By comparing this frequency distribution with the Poisson distribution, we can confirm that x shows a Poisson distribution around the mean value μ .

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	GM box with End-window counter	524 033 559 01
or		
1	GM counter tube S	524 0331
1	Set of radioactive preparations	559 83
1	Large clip plug	591 21
1	Small clip plug	590 02
2	Connection rods	532 16
2	Bases	300 11
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The end-window counter is connected to the GM box at input A of Sensor-CASSY. Handle the counter tube and the preparation with care.

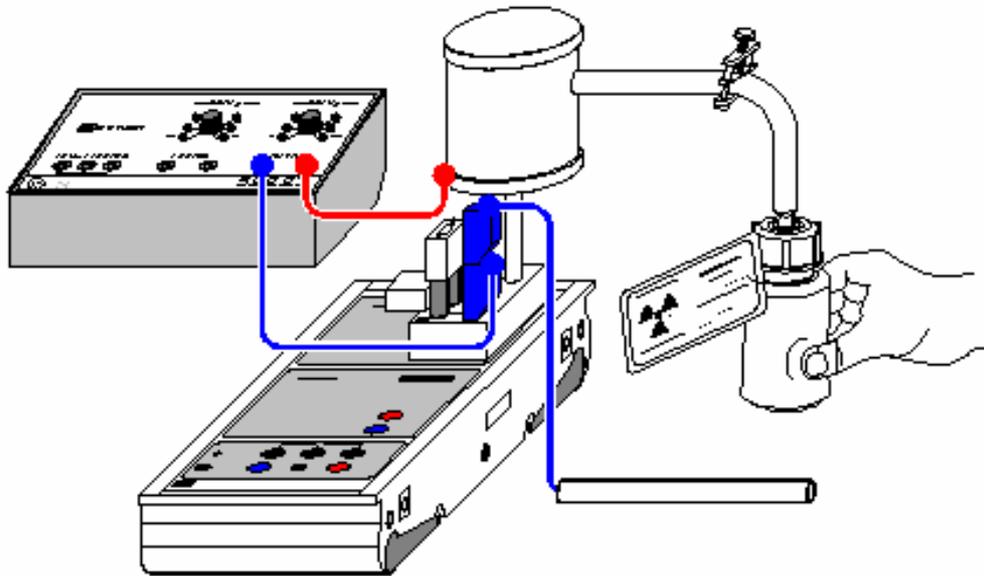
Carrying out the experiment

- Load settings
- If necessary, modify the gate time Δt (Settings RA1).
- Preset the measurement if necessary. Enter the number of measurements as the measuring condition in the Measuring Parameters dialog opened with **F5** (e.g. $n < 1000$ for 1000 individual measurements).
- Start the measurement series with **F9**, and stop it again with **F9** after recording the series.

Evaluation

In the evaluation, you can compare the measured frequency distribution with a Poisson distribution. For higher mean values μ the Poisson distribution develops into a Gaussian distribution.

Half-life of radon



can also be carried out with Pocket-CASSY and Mobile-CASSY

■ Load example

Experiment description

From the fact that all radioactive nuclei of an isotope decay with the same probability, it follows that over the time interval dt , the number N of radioactive nuclei will decrease by

$$dN = -\lambda \cdot N \cdot dt$$

(λ : decay constant). Thus, for the number N , the law of radioactive decay applies:

$$N(t) = N(t=0) \cdot e^{(-\lambda \cdot t)}$$

Among other things, this law states that after the half-life

$$t_{1/2} = \ln 2 / \lambda$$

the number of radioactive nuclei will be reduced by half.

To determine the half-life of radon 220 (Rn-220), a plastic bottle with thorium salt is sealed in an ionization chamber, and the inert gas radon, which is formed in the course of the decay sequence of natural thorium, is pumped into the chamber by squeezing the bottle. This gas contains the isotope Rn-220, which has a half-life of about 55 s. The half-lives of other radon isotopes differ greatly from this value, and can thus be ignored in these experiments.

This experiment measures the curve over time of the ionization current proportional to the radioactivity of the gas. Here, the electrometer box in high-ohm configuration serves as a highly sensitive ammeter.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Electrometer box	524 054
1	Ionization chamber	546 25
1	Thorium source	546 36
1	Power supply 450 V DC	522 27
1	STE resistor 10 G Ω	577 03
1	STE capacitor 100 pF	578 22

2	Clamping plugs	590 011
1	Coupling plugs	340 89
2	Connection rods	532 16
1	Set of bridging plugs	501 48
1	Connecting leads, 50 cm, blue	500 422
1	Pair of cables, 1 m, red and blue	501 46
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Set up the experiment directly on the electrometer box at Sensor-CASSY input A. Plug in the ionization chamber at the top right socket of the box using the coupling plug and the connection rod; jumper the two top left sockets with a bridging plug, and connect the 10 G Ω measuring resistor and the 100 pF smoothing capacitor to the bottom left sockets (use clamping plugs to attach these two components).

The remaining ground socket of the electrometer box is used to ground the experimenter (who holds a grounded connection rod during the experiment) to minimize external influences on this sensitive measurement.

Carrying out the experiment

■ Load settings

- If necessary, correct the offset of the electrometer box - ground the connection rod of the ionization chamber, select **Correct** in Settings UA1, enter the first target value 0 V and click **Correct Offset**.
- Apply a voltage of 450 V between the ground of the electrometer box and the cylinder of the ionization chamber.
- Squeeze the thorium source several times to charge the ionization chamber with radon 220.
- After a short settling pause, start the measurement with **F9** (the measurement stops automatically after 180 s).

Evaluation

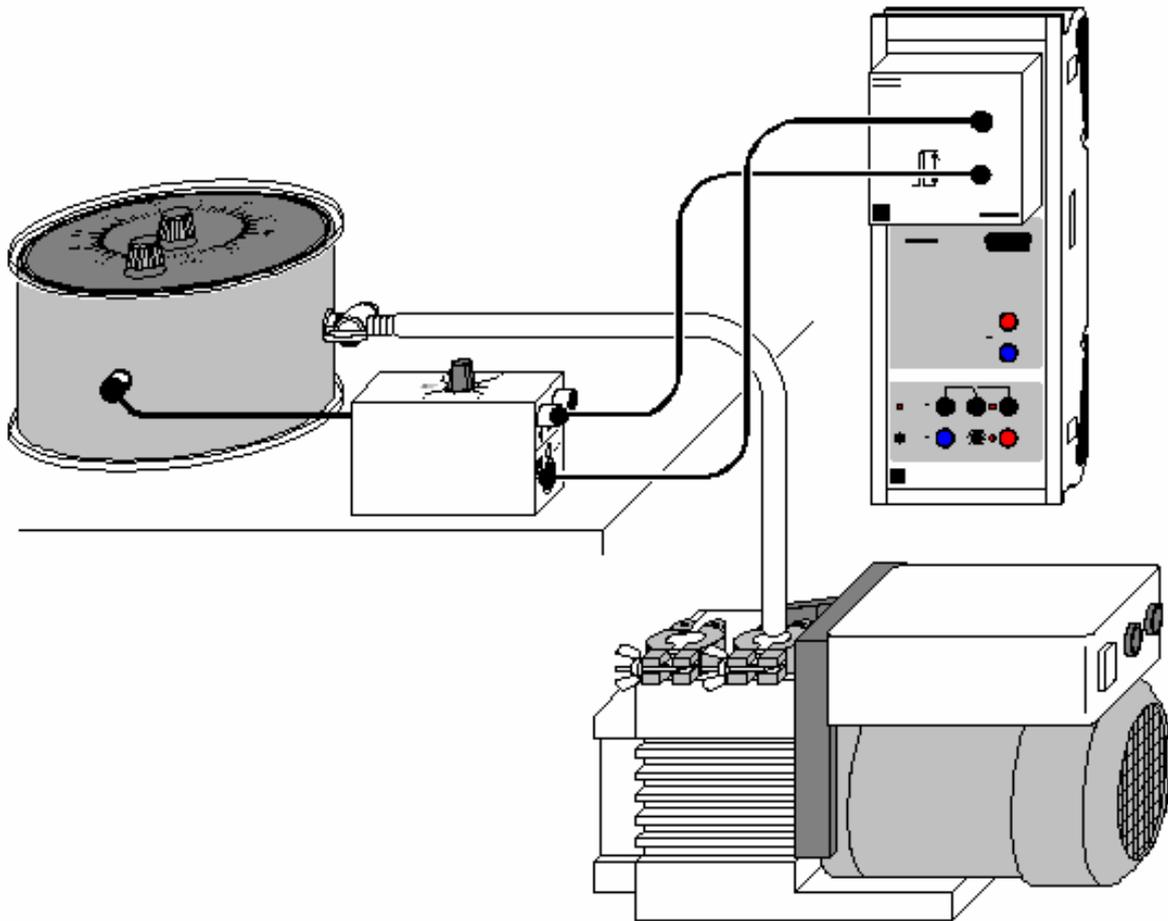
You can determine the half-life in one of several ways. You can graphically illustrate and read off the half-life by marking your diagram with horizontal and vertical lines.

Fitting an exponential function to the $I(t)$ curve gives us the inverse of the decay constant λ as parameter B of this operation. The half-life is thus $t_{1/2} = \ln 2 \cdot B = 0.693 \cdot B$.

Parameter A of a best-fit straight line of the logarithmic display (press the right mouse button over the y-axis to select logarithmic display) gives us a half-life of $t_{1/2} = -\log 2 / A = -0.301 / A$.

This example gives us the literature value $t_{1/2} = 55.6$ s.

α spectroscopy of radioactive samples (Am-241)



can also be carried out with Pocket-CASSY

■ Load example

Safety note

When radioactive preparations are handled, country specific regulations must be observed, e.g. the Radiation Protection Regulation (StrlSchV) in Germany. The radioactive substances used in this experiment are approved for teaching purposes at schools in accordance with the StrlSchV. Since they produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the preparations by **unauthorized persons**.
- Before using the preparations make sure that they are **intact**.
- For the purpose of **shielding**, keep the preparations in their safety container.
- To ensure **minimum exposure time** and **minimum activity**, take the preparations out of the safety container only as long as is necessary for carrying out the experiment.
- To ensure **maximum distance**, hold the preparations only at the upper end of the metal holder.

Experiment description

The α spectrum of the Am-241 preparation is recorded, and an energy calibration is carried out with known lines.

Equipment list

1	Sensor CASSY	524 010
1	CASSY Lab	524 200
1	MCA box	524 058
1	Am-241 preparation	559 82
1	Rutherford scattering chamber	559 56
1	Discriminator-preamplifier	559 93
1	Multicore cable, 6-pole, 1.5 m long	501 16
1	BNC cable, 1 m long	501 02
1	BNC cable, 0.25 m long	501 01
1	Rotary vane vacuum pump	378 73
1	Small flange DN 16 KF with hose nozzle	378 031
1	Vacuum tubing, 8/18 dia.	307 68
1	PC with Windows 95/98/NT or higher version	

additionally recommended

1	Two-channel oscilloscope 303	575 211
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Experiment setup (see drawing)

The preparation and the detector are placed in the Rutherford scattering chamber. The detector is connected to the discriminator-preamplifier via the short BNC cable. The discriminator-preamplifier is connected to the MCA box. The pump is connected to the Rutherford scattering chamber.

Carrying out the experiment

■ Load settings

- Evacuate the Rutherford scattering chamber
- Start the measurement with **F9**
- Vary the gain of the MCA box until the spectrum covers all available channels. This typically occurs at gains around 5.
- In measurements with the semiconductor detector, a relatively high background level arises, which cannot be removed entirely even if the experiment is grounded. The counting rate in the lower 100 channels is therefore rather high. The line itself is hard to see then because of the automatic scaling of the spectrum. Here a zoom should be used in the diagram. Because of the internal architecture of the MCA box working at gains below 4.6 is recommendable in this case.
- After every change of the gain the measured spectrum should be deleted with **F4** to avoid mixing of different spectra. The measurement goes on then, and the measuring time is restarted.
- When the set measuring time is over, the measurement is stopped.

Evaluation

The isotope Am-241 decays into Np-237 by emitting an α particle. As several excited states of neptunium are available, α particles of different energies are emitted in this decay. In 100 decays, 84 α particles with an energy of 5486 keV are emitted and 13 with an energy of 5443 keV. However, this small energy difference is not visible in the experiment.

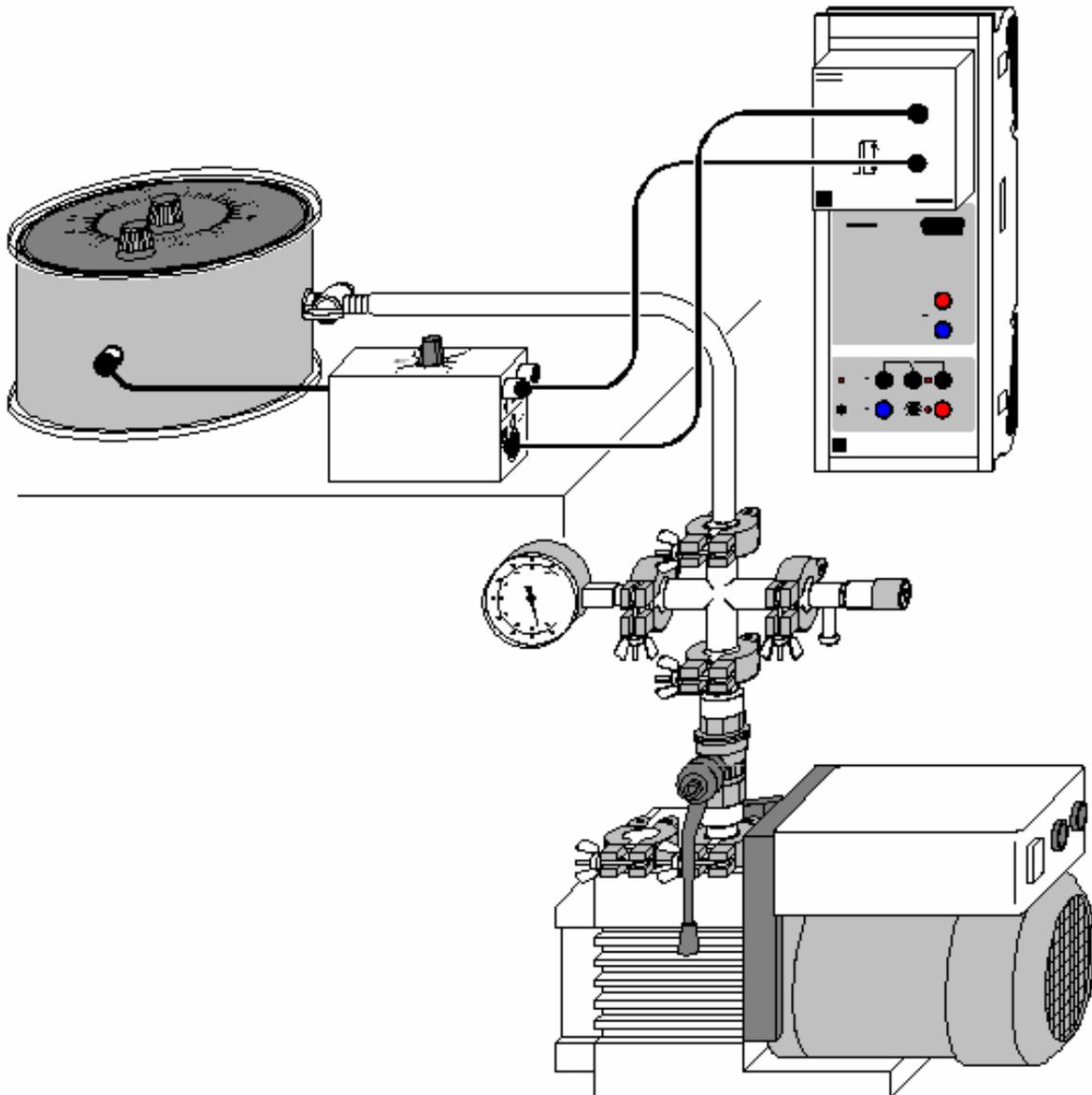
After the measurement the spectrum is not yet calibrated. An energy calibration has to be carried out in order to display it as an energy spectrum.

Remark

The semiconductor detector is sensitive to light. Therefore avoid direct illumination of the vacuum chamber in order that the results of the measurement are not distorted.

Due to the cover of the preparations, there is a strong offset in energy. The measured spectrum starts only at an energy of 1-2 MeV. Particles with lower energy are stopped before reaching the detector.

Determining the energy loss of α radiation in air



can also be carried out with Pocket-CASSY

■ Load example

Safety note

When radioactive preparations are handled, country specific regulations must be observed, e.g. the Radiation Protection Regulation (StrlSchV) in Germany. The radioactive substances used in this experiment are approved for teaching purposes at schools in accordance with the StrlSchV. Since they produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the preparations by **unauthorized persons**.
- Before using the preparations make sure that they are **intact**.
- For the purpose of **shielding**, keep the preparations in their safety container.
- To ensure **minimum exposure time** and **minimum activity**, take the preparations out of the safety container only as long as is necessary for carrying out the experiment.
- To ensure **maximum distance**, hold the preparations only at the upper end of the metal holder.

Experiment description

The energy loss of the α radiation from the Am-241 sample is measured in the scattering chamber in dependence on the air pressure. From this the energy loss at normal pressure is calculated as a function of the distance. The range of the α radiation in air is obtained.

Equipment list

1	Sensor CASSY	524 010
1	CASSY Lab	524 200
1	MCA Box	524 058
1	Am-241 preparation	559 82
1	Rutherford scattering chamber	559 56
1	Discriminator-preamplifier	559 93
1	Multicore cable, 6-pole, 1.5 m	501 16
1	BNC cable, 1 m long	501 02
1	BNC cable, 0.25 m long	501 01
1	Rotary-vane vacuum pump	378 73
1	Small flange DN 16 KF	378 031
1	Vacuum tubing, 8/18 mm dia.	307 68
1	Cross DN 16 KF	378 015
1	Variable leak valve DN 16 KF	378 776
1	Pointer manometer	378 510
4	Centering ring DN 16 KF	378 045
4	Clamping ring DN 10/16 KF	378 050
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The preparation and the detector are placed in the Rutherford scattering chamber. The detector is connected to the discriminator-preamplifier via the short BNC cable. The discriminator-preamplifier is connected to the MCA box. The pump and the vacuum meter are connected to the Rutherford scattering chamber.

Carrying out the experiment

- Load settings
 - After inserting the preparation and the detector, cautiously evacuate the Rutherford scattering chamber.
 - When the vacuum is established, record the spectrum (**F9**) varying the gain until the Am-241 line is approximately in the middle of the spectrum.
 - Make an energy calibration ,see remark.
 - Open the variable leak valve until the pressure in the vacuum chamber is approx. 300 mbar. Record another spectrum.
 - Increase the pressure in the vacuum chamber, first in steps of about 100 mbar, from 800 mbar on in smaller steps. Record an α spectrum at each pressure (**F9**).

Evaluation

The energy of the α line is determined from the individual spectra. The air pressure is converted into an effective path in air at normal pressure. From the representation of the energy as a function of the effective path in air the range of the α radiation in air is read.

Remarks

The range in air can, of course, also be measured directly without using the scattering chamber. It can be determined by varying the distance. In this case, however, the setup requires some improvisation with respect to fixing the preparation. The detector can be attached to the discriminator-preamplifier directly. In this case, it provides stronger pulses as the load of the capacitance of the BNC cable is missing.

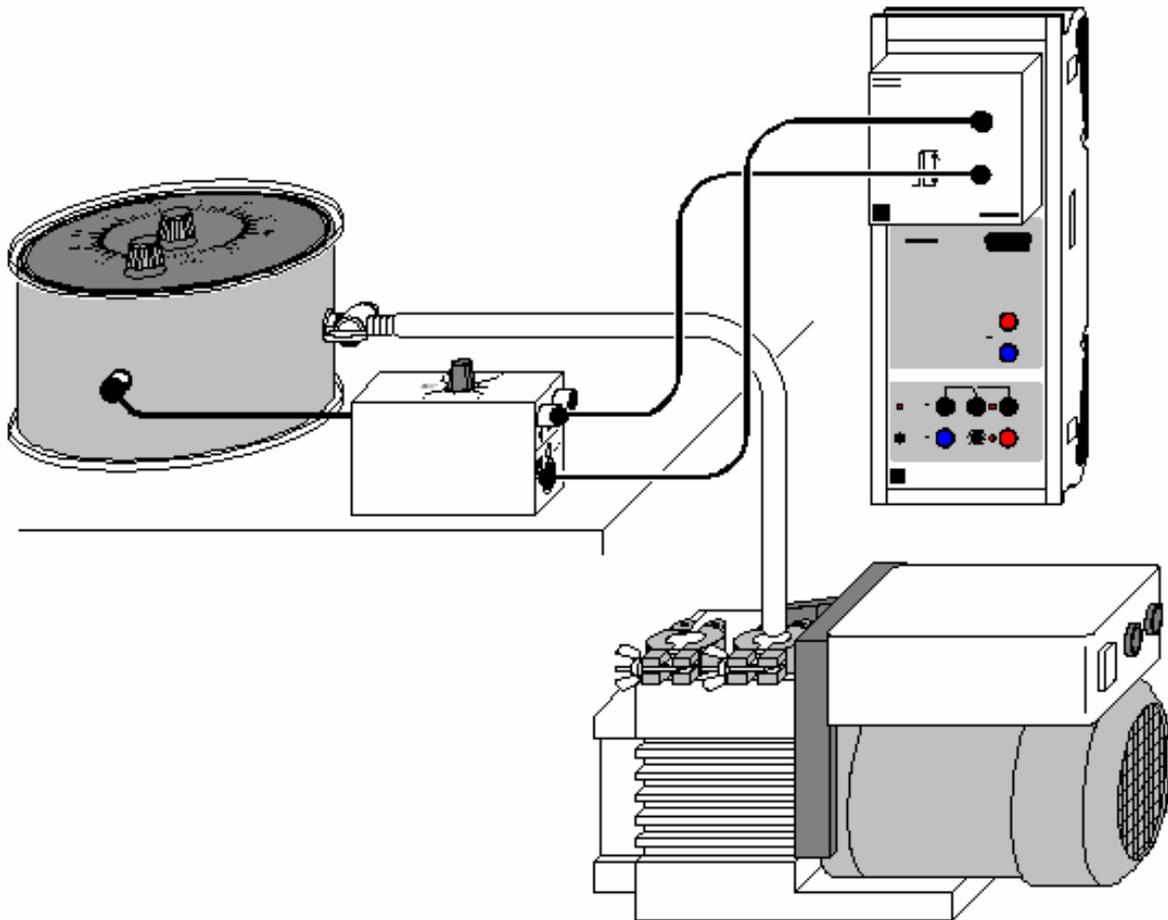
The semiconductor detector is sensitive to light. Therefore avoid direct illumination of the vacuum chamber in order that the results of the measurement are not distorted.



In measurements with the semiconductor detector, a relatively high background level arises, which cannot be removed entirely even if the experiment is grounded. The counting rate in the lower 100 channels is therefore rather high. The line itself is hard to see then because of the automatic scaling of the spectrum. Here a zoom should be used in the diagram. Because of the internal architecture of the MCA box working at gains below 4.6 is recommendable in this case.

Due to the cover of the preparations, there is a strong offset in energy. The measured spectrum starts only at an energy of 1-2 MeV. Particles with lower energy are stopped before reaching the detector.

Determining the energy loss of a radiation in aluminium and in gold



can also be carried out with Pocket-CASSY

■ Load example

Safety note

When radioactive preparations are handled, country specific regulations must be observed, e.g. the Radiation Protection Regulation (StrlSchV) in Germany. The radioactive substances used in this experiment are approved for teaching purposes at schools in accordance with the StrlSchV. Since they produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the preparations by **unauthorized persons**.
- Before using the preparations make sure that they are **intact**.
- For the purpose of **shielding**, keep the preparations in their safety container.
- To ensure **minimum exposure time** and **minimum activity**, take the preparations out of the safety container only as long as is necessary for carrying out the experiment.
- To ensure **maximum distance**, hold the preparations only at the upper end of the metal holder.

Experiment description

The energy loss of α radiation in an aluminium or gold foil is determined as a function of the α energy.



Equipment list

1	Sensor CASSY	524 010
1	CASSY Lab	524 200
1	MCA Box	524 058
1	Am-241 preparation	559 82
1	Ra-226 preparation	559430
1	Rutherford scattering chamber	559 56
1	Aluminium foil in holder	559 52
1	Discriminator-preamplifier	559 93
1	Multicore cable, 6-pole, 1.5 m	501 16
1	BNC cable, 1 m long	501 02
1	BNC cable, 0.25 m long	501 01
1	Rotary-vane vacuum pump	378 73
1	Small flange DN 16 KF	378 031
1	Vacuum tubing, 8/18 mm dia.	307 68
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The preparation, the foil and the detector are mounted in the Rutherford scattering chamber. The detector is connected to the discriminator-preamplifier via the short BNC cable. The discriminator-preamplifier is connected to the MCA box. The pump is connected to the Rutherford scattering chamber.

Carrying out the experiment

■ Load settings

- Mount the Ra-226 preparation in the scattering chamber
- Evacuate the chamber
- Swivel the gold foil (thickness 2 μm) out of the path of ray, record the spectrum (**F9**), and set the gain so that the spectrum is well displayed
- Use the outer lines of the spectrum (4785 keV, 7687 keV) for the energy calibration
- Swivel the gold foil into the path of ray, and record the spectrum (**F9**)
- Let air into the chamber, mount the aluminium foil (thickness 8 μm) in the chamber, evacuate the chamber, and record the spectrum
- Let air into the chamber, mount the Am-241 preparation, and repeat the measurements with gold and aluminium foil without changing the energy calibration

Evaluation

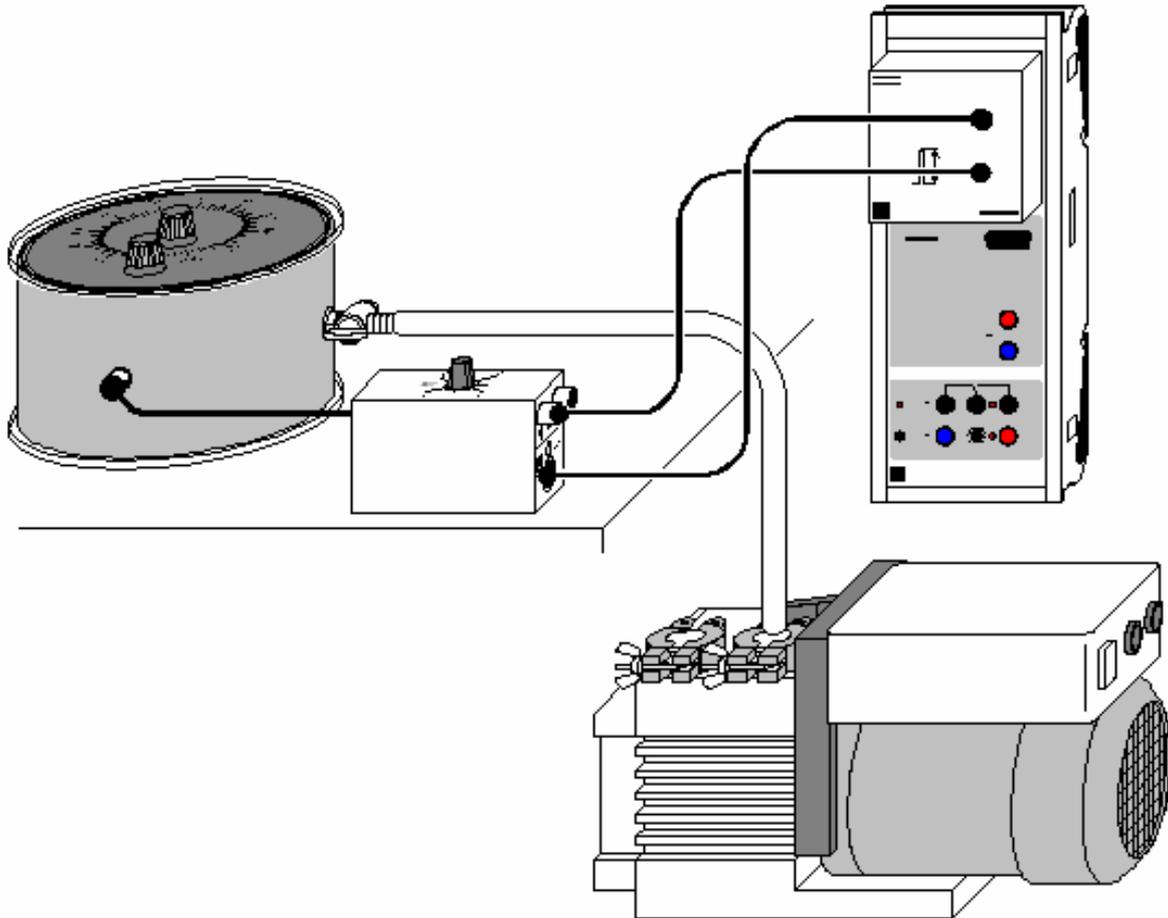
From each of the spectra the energy of the lines is determined. The energy loss per path length in aluminium and gold is plotted as a function of the energy and compared with the results from the Bethe-Bloch formula.

Remark

The semiconductor detector is sensitive to light. Therefore avoid direct illumination of the vacuum chamber in order that the results of the measurement are not distorted.

Due to the cover of the preparations, there is a strong offset in energy when the energy calibration is made with values taken from the literature. The measured spectrum starts only at an energy of 1-2 MeV. Particles with lower energy are stopped before reaching the detector.

Determining the age of a Ra-226 sample



can also be carried out with Pocket-CASSY

■ Load example

Safety note

When radioactive preparations are handled, country specific regulations must be observed, e.g. the Radiation Protection Regulation (StrlSchV) in Germany. The radioactive substances used in this experiment are approved for teaching purposes at schools in accordance with the StrlSchV. Since they produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the preparations by **unauthorized persons**.
- Before using the preparations make sure that they are **intact**.
- For the purpose of **shielding**, keep the preparations in their safety container.
- To ensure **minimum exposure time** and **minimum activity**, take the preparations out of the safety container only as long as is necessary for carrying out the experiment.
- To ensure **maximum distance**, hold the preparations only at the upper end of the metal holder.

Experiment description

The relative activity of the nuclides Ra-226 and Pb-210 in a Ra-226 sample is determined and used to determine the age of the sample.



Equipment list

1	Sensor CASSY	524 010
1	CASSY Lab	524 200
1	MCA Box	524 058
1	Ra-226 preparation	559430
1	Rutherford scattering chamber	559 56
1	Discriminator preamplifier	559 93
1	Multicore cable, 6-pole, 1.5 m	501 16
1	BNC cable, 1 m long	501 02
1	BNC cable, 0.25 m long	501 01
1	Rotary-vane vacuum pump	378 73
1	Small flange DN 16 KF	378 031
1	Vacuum tubing, 8/18 mm dia.	307 68
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The preparation and the detector are placed in the Rutherford scattering chamber. The detector is connected to the discriminator-preamplifier via the short BNC cable. The discriminator-preamplifier is connected to the MCA box. The pump is connected to the Rutherford scattering chamber.

Carrying out the experiment

■ Load settings

- Mount the Ra-226 preparation in the scattering chamber
- Evacuate the chamber, and record a spectrum (**F9**)
- Vary the gain of the MCA box until the spectrum covers all available channels. This typically occurs at gains around 5.
- Use the outer lines of the spectrum (4785 keV, 7687 keV) for the energy calibration

Evaluation

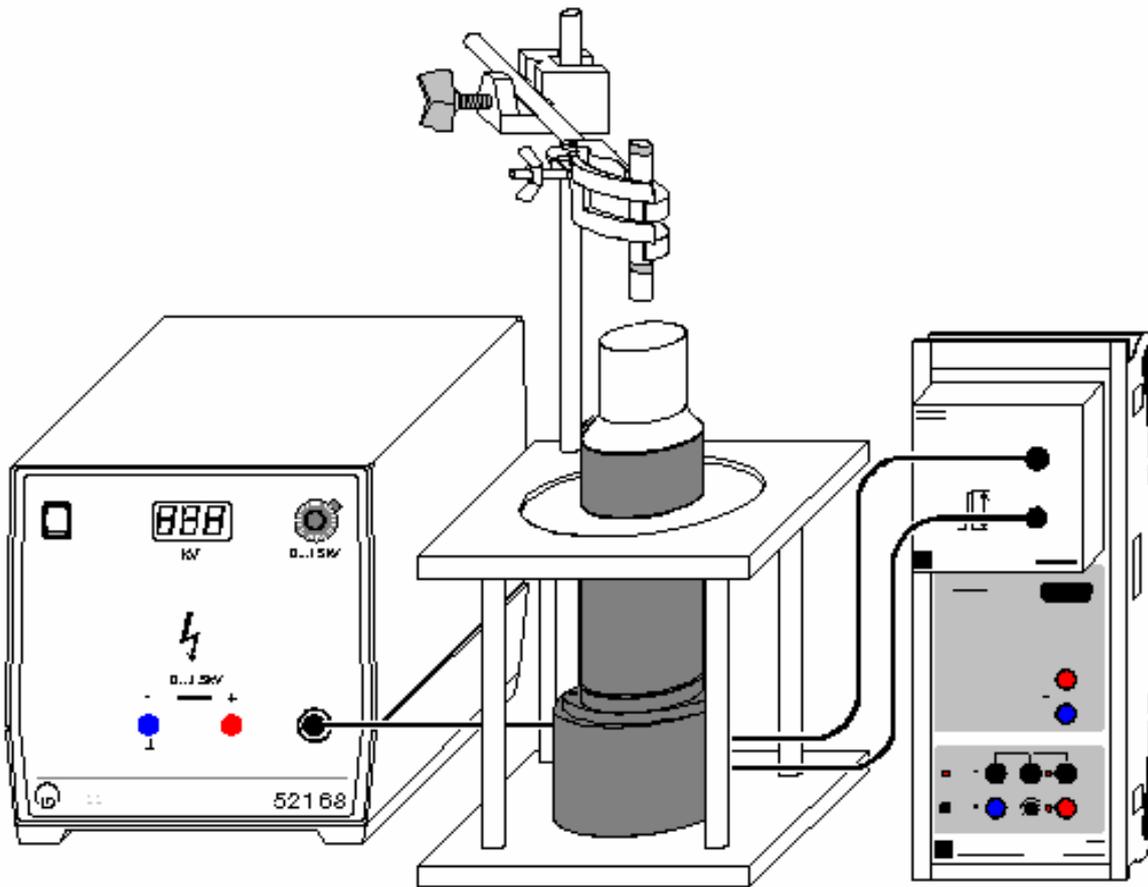
The age of the preparation is calculated from the counting rates of the observed lines. The evaluation is complicated by the fact that the α energies of Po-210 and Ra-222 are very close to one another so that the two nuclides contribute to one common peak (that in the middle of the group of three peaks). The counting rate for Rn-222 is therefore determined by a linear fit from the counting rates for Ra-226, Po-218 and Po-214. From the ratio of the counting rates for Po-210 and Ra-226 the age of the preparation can be calculated.

Remark

The semiconductor detector is sensitive to light. Therefore avoid direct illumination of the vacuum chamber in order that the results of the measurement are not distorted.

Due to the cover of the preparations, there is a strong offset in energy when the energy calibration is made with values taken from the literature. The measured spectrum starts only at an energy of 1-2 MeV. Particles with lower energy are stopped before reaching the detector.

Detecting γ radiation with a scintillation counter (Cs-137)



can also be carried out with Pocket-CASSY

■ Load example

Safety note

When radioactive preparations are handled, country specific regulations must be observed, e.g. the Radiation Protection Regulation (StrlSchV) in Germany. The radioactive substances used in this experiment are approved for teaching purposes at schools in accordance with the StrlSchV. Since they produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the preparations by **unauthorized persons**.
- Before using the preparations make sure that they are **intact**.
- For the purpose of **shielding**, keep the preparations in their safety container.
- To ensure **minimum exposure time** and **minimum activity**, take the preparations out of the safety container only as long as is necessary for carrying out the experiment.
- To ensure **maximum distance**, hold the preparations only at the upper end of the metal holder.

Experiment description

The γ spectrum of the mixed preparation (Cs-137, Am-241, Sr-90) is recorded, and an energy calibration is carried out with known lines.



Equipment list

1	Sensor CASSY	524 010
1	CASSY Lab	524 200
1	MCA Box	524 058
1	Mixed preparation α , β , γ	559 84 or from 559 83
1	Scintillation counter	559 901
1	Detector output stage	559 912
1	High-voltage power supply 1.5 kV	521 68
1	Socket for scintillator screening	559 891
1	Stand rod, 47 cm	300 42
1	Leybold multiclamp	301 01
1	Universal clamp, 0...80 mm dia.	666 555
1	PC with Windows 95/98/NT or higher version	

additionally recommended

1	Two-channel oscilloscope 303	575 211
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Experiment setup (see drawing)

The output stage of the scintillation counter is connected to the MCA box and to the high-voltage power supply. The preparation is placed a few centimetres above the detector with the stand material. In order to prevent the scintillation counter from toppling over, it is recommended to use the socket (559 891) for the setup. This socket is provided with a fixture for the stand rod.

Carrying out the experiment

■ Load settings

- Set the high-voltage power supply to zero, and switch it on.
- Start the measurement with **F9**
- Without high voltage, no pulses should be counted at the scintillation counter.
- Slowly increase the high voltage until the spectrum covers the available channels at a voltage of 700-900 V.
- Each time when the high voltage is changed the measured spectrum should be deleted with **F4** to avoid mixing of different spectra. The measurement goes on then, and the measuring time is re-started.
- When the set measuring time is over, the measurement is stopped.

Evaluation

The two isotopes Cs-137 and Am-241 in the mixed preparation emit γ radiation, which is registered by the scintillation counter. Am-241 emits one line at 59.5 keV and Cs-137 one line at 662 keV. The measured spectrum exhibits some more details between these two lines. They arise because of the Compton effect taking place in the preparation and in the detector.

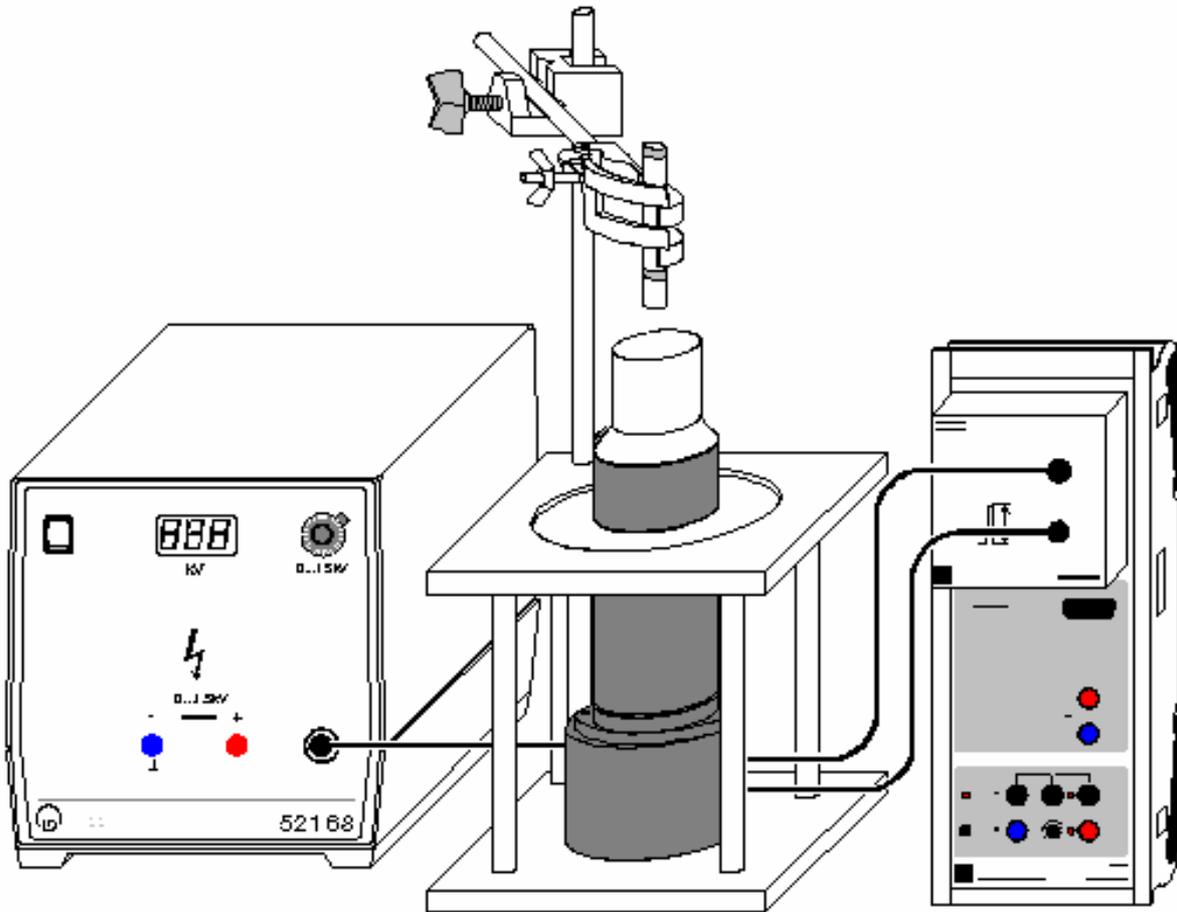
After the measurement the spectrum is not yet calibrated. An energy calibration has to be carried out in order to display it as an energy spectrum. For this the two known lines in spectrum are used (59.5 and 662 keV).

Remark

For the measurement the preparation should not be put directly onto the detector but placed at a distance of a few centimetres. If the preparation is too close to the detector, the counting rate will be so high that individual pulses add up. This addition with the rest of the previous pulse shifts the lines towards higher energies.

The NaI(Tl) crystal at the end of the scintillation counter is very sensitive to mechanical stress and may easily be destroyed. The NaI(Tl) crystal is also sensitive to quick changes in temperature, which can occur, e.g., on unpacking after transport. In both cases cracks in the crystal arise and lead to a reduced sensitivity and, above all, to a worse energy resolution because of scattering.

Recording and calibrating a γ spectrum



can also be carried out with Pocket-CASSY

■ Load example

Safety note

When radioactive preparations are handled, country specific regulations must be observed, e.g. the Radiation Protection Regulation (StrlSchV) in Germany. The radioactive substances used in this experiment are approved for teaching purposes at schools in accordance with the StrlSchV. Since they produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the preparations by **unauthorized persons**.
- Before using the preparations make sure that they are **intact**.
- For the purpose of **shielding**, keep the preparations in their safety container.
- To ensure **minimum exposure time** and **minimum activity**, take the preparations out of the safety container only as long as is necessary for carrying out the experiment.
- To ensure **maximum distance**, hold the preparations only at the upper end of the metal holder.

Experiment description

The γ spectra of some standard preparations (Cs-137, Co-60, Na-22) are measured. After an energy calibration of the scintillation counter, the γ transitions are identified with the help of values quoted in the literature.



Equipment list

1	Sensor CASSY	524 010
1	CASSY Lab	524 200
1	MCA Box	524 058
1	Set of 5 radioactive preparations	559 83
1	Scintillation counter	559 901
1	Detector output stage	559 912
1	High-voltage power supply 1.5 kV	521 68
1	Socket for scintillator screening	559 891
1	Stand rod, 47 cm	300 42
1	Leybold multiclamp	301 01
1	Universal clamp, 0...80 mm dia.	666 555
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The output stage of the scintillation counter is connected to the MCA box and the high-voltage power supply. The preparation to be studied is placed a few centimetres above the scintillation counter with stand material. In order to prevent the scintillation counter from toppling over, it is recommended to use the socket (559 891) for the setup.

Carrying out the experiment

■ Load settings

- Record the spectra of Co-60, Na-22 and Cs-137 (**F9**) one after another. It is recommendable to begin with the Co-60 preparation because the radiation it emits has the highest energy so that the high voltage and the gain can be adjusted appropriately from the very beginning.
- In order to get an energy spectrum, an energy calibration has to be carried out. For this e.g. the lines of Na-22 at 511 keV and 1275 keV can be used.

Evaluation

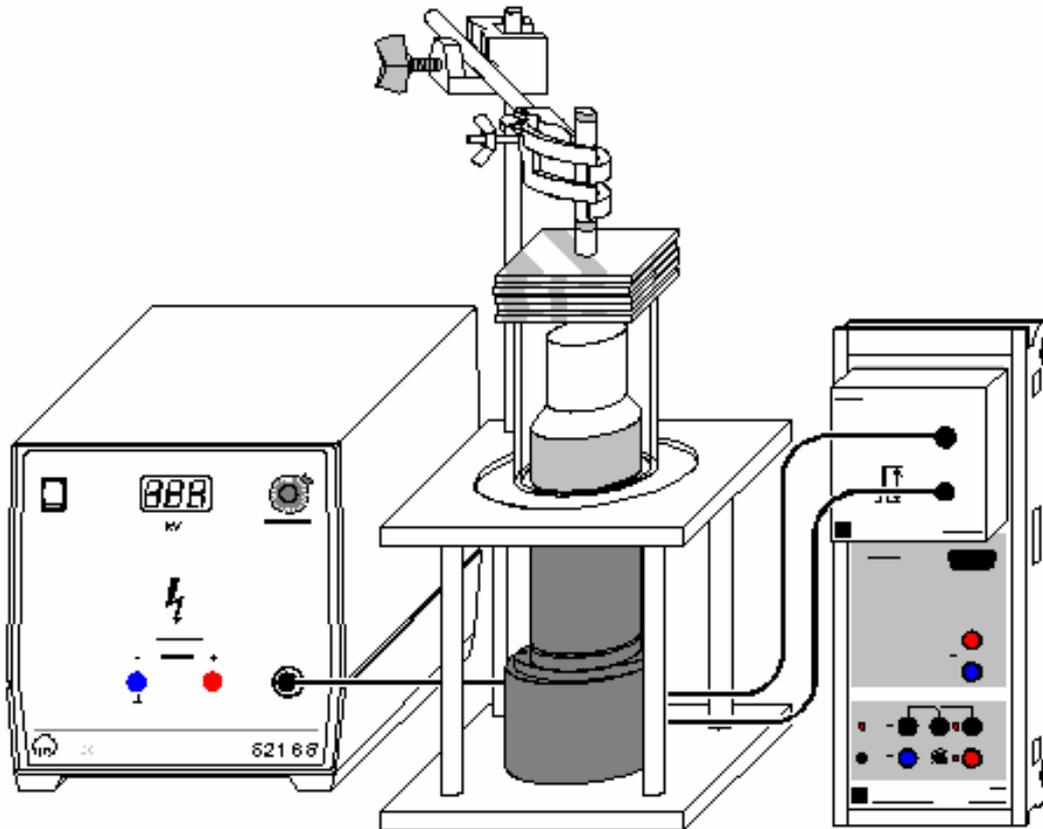
The energies of the individual lines are determined. For this the function Fit Gaussian curves can be used. The radiating isotopes are identified by comparison with values from the literature.

Remarks

There are several databases available in the internet where the known energies of all radioactive substances are listed, e.g. under <http://nucleardata.nuclear.lu.se/nucleardata/toi/>. These may be used for identifying the radioactive nuclides.

For the measurement the preparation should not be put directly onto the detector but placed at a distance of a few centimetres. If the preparation is too close to the detector, the counting rate will be so high that individual pulses add up. This addition with the rest of the previous pulse shifts the lines towards higher energies.

Absorption of γ radiation



can also be carried out with Pocket-CASSY

■ Load example

Safety note

When radioactive preparations are handled, country specific regulations must be observed, e.g. the Radiation Protection Regulation (StrlSchV) in Germany. The radioactive substances used in this experiment are approved for teaching purposes at schools in accordance with the StrlSchV. Since they produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the preparations by **unauthorized persons**.
- Before using the preparations make sure that they are **intact**.
- For the purpose of **shielding**, keep the preparations in their safety container.
- To ensure **minimum exposure time** and **minimum activity**, take the preparations out of the safety container only as long as is necessary for carrying out the experiment.
- To ensure **maximum distance**, hold the preparations only at the upper end of the metal holder.

Experiment description

The intensity of γ radiation behind an absorber is measured as a function of the thickness of the absorber in order to confirm Lambert's law of absorption. The linear attenuation coefficient μ and the half-value depth $d_{1/2}$ are derived.



Equipment list

1	Sensor CASSY	524 010
1	CASSY Lab	524 200
1	MCA box	524 058
1	Set of 5 radioactive preparations	559 83
1	Set of absorbers and targets	559 94
1	Scintillation counter	559 901
1	Detector output stage	559 912
1	High-voltage power supply 1.5 kV	521 68
1	Socket for scintillator screening	559 891
1	Stand rod, 47 cm	300 42
1	Leybold multiclamp	301 01
1	Universal clamp, 0...80 mm dia.	666 555
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The output stage of the scintillation counter is connected to the MCA box and to the high-voltage power supply. The scintillation counter is mounted in the socket and the tip of the scintillation counter covered with the plexiglass tube. The preparation is placed a few centimetres above the detector with the stand material. The absorbers are laid on the plexiglass tube.

Carrying out the experiment

■ Load settings

- First clamp the Co-60 preparation, and record the spectrum without absorber (**F9**) setting the high voltage so that the spectrum covers the range of measurement.
- Lay the absorbers (aluminium, iron, lead) with different layer thicknesses on the plexiglass tube one after another, and record a spectrum each time (**F9**).
- Repeat the measurements for the Cs-137 and the Am-241 preparation.

Evaluation

The counting rates associated with the lines of the spectra are determined using the function Calculate Integral. The counting rates are represented for the individual energies and absorbers as functions of the absorber thickness. From this the linear attenuation coefficient μ and the half-value depth $d_{1/2}$ are derived.

$$I = I_0 e^{-\mu \cdot x}$$

Typical values for μ are:

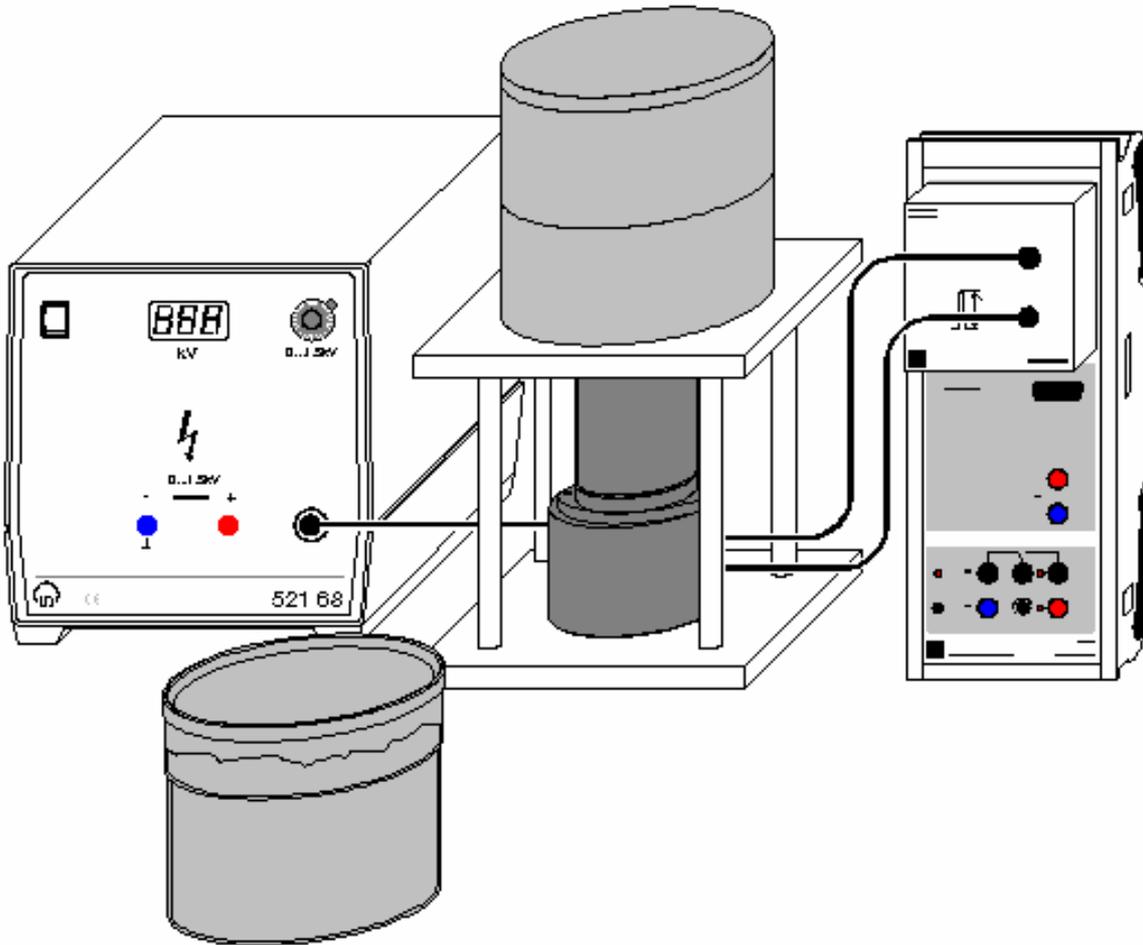
E	60 keV	662 keV	1253 keV
Al	0.51 1/cm	0.16 1/cm	0.13 1/cm
Fe	7.4 1/cm	0.43 1/cm	0.36 1/cm
Pb		0.86 1/cm	0.55 1/cm

Remark

The NaI(Tl) crystal at the end of the scintillation counter is sensitive to mechanical damage. Be careful when laying the absorbers on the detector.

Otherwise cracks in the crystal arise and lead to a reduced sensitivity and, above all, to a worse energy resolution because of scattering.

Identifying and determining the activity of weakly radioactive samples



can also be carried out with Pocket-CASSY

■ Load example

Safety note

When radioactive preparations are handled, country specific regulations must be observed, e.g. the Radiation Protection Regulation (StrlSchV) in Germany. The radioactive substances used in this experiment are approved for teaching purposes at schools in accordance with the StrlSchV. Since they produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the preparations by **unauthorized persons**.
- Before using the preparations make sure that they are **intact**.
- For the purpose of **shielding**, keep the preparations in their safety container.
- To ensure **minimum exposure time** and **minimum activity**, take the preparations out of the safety container only as long as is necessary for carrying out the experiment.
- To ensure **maximum distance**, hold the preparations only at the upper end of the metal holder.

Experiment description

The detection probability of the scintillation counter is determined at several γ energies with calibrating preparations. The γ spectrum of a weakly radioactive sample is recorded, and its radioactive components are determined.

Equipment list

1	Sensor CASSY	524 010
1	CASSY Lab	524 200
1	MCA box	524 058
2	Marinelli beaker	559 88
1	Calibrating preparation Cs-137, 5kBq	559 885
4	Potassium chloride, 250 g	672 5210
1	Scintillation counter	559 901
1	Detector output stage	559 912
1	High-voltage power supply 1.5 kV	521 68
1	Scintillator screening	559 89
1	Socket for scintillator screening	559 891
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The output stage of the scintillation counter is connected to the MCA box and to the high-voltage power supply. The scintillation counter is mounted in the socket from above with the lead screening. The preparation in the Marinelli beaker is placed above the scintillation counter.

Carrying out the experiment

■ Load settings

- Fill 1 kg of potassium chloride into a Marinelli beaker and place it above the scintillation counter.
- Record the spectrum (**F9**) varying the high voltage until the full range of measurement is covered.
- Remove the Marinelli beaker and insert the calibrating preparation Cs-137
- Record the spectrum
- Make an energy calibration using the lines at 1460 keV and 662 keV in the two spectra.
- Remove the preparation
- Equally distribute the test substance in a Marinelli beaker, place the beaker above the scintillation counter, and record the spectrum of the sample.
- Make a background measurement without preparation. The measuring time should be equal to that with the sample.

Evaluation

The activities of potassium chloride (17 kBq/kg) and the Cs-137 calibrating preparation (approx. 5 kBq, see calibration certificate, mind the half-life) are known. From the integrated counting rate below the lines of the two spectra the detection probability of the scintillation counter at 1460 keV and 662 keV can be determined for this particular geometry.

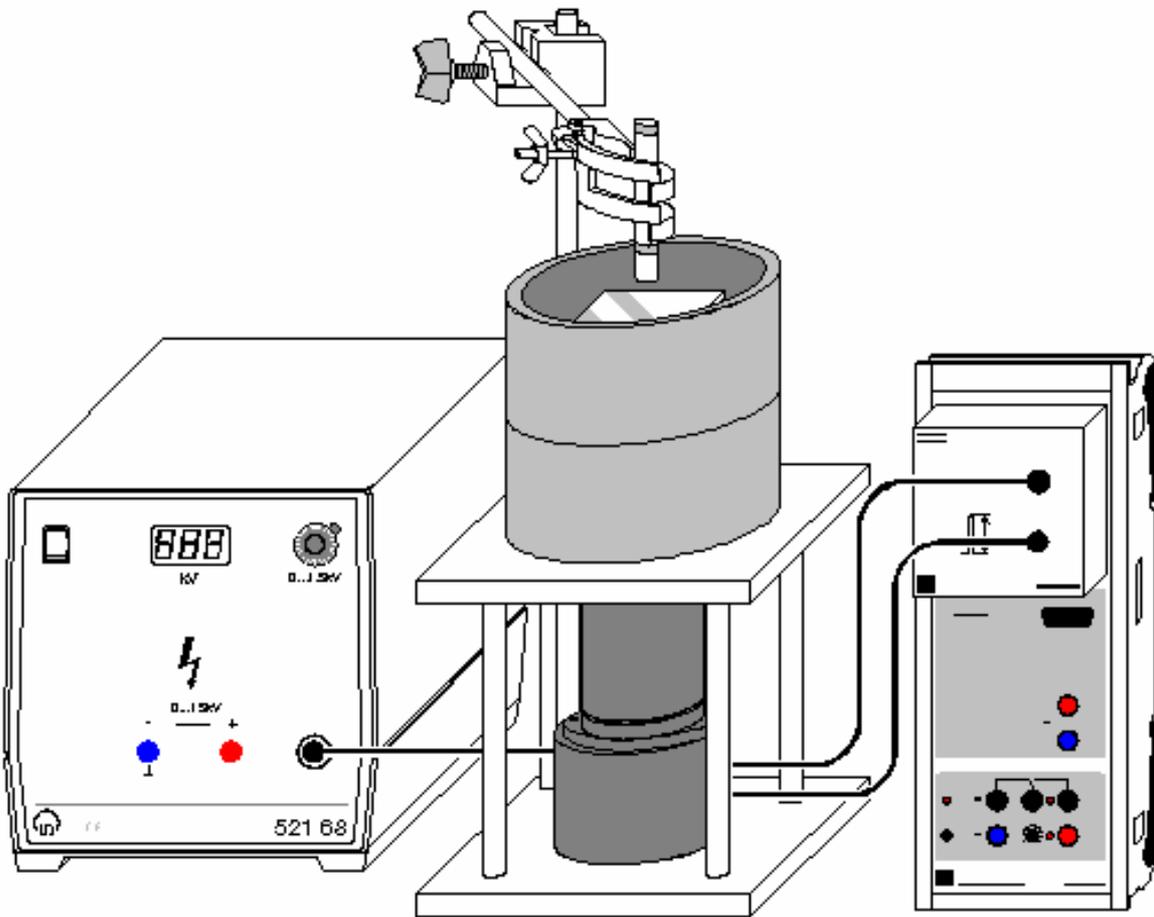
The background spectrum is subtracted from the spectrum of the sample. From the resulting spectrum and the previously determined detection probability the radioactive contamination of the sample can be determined. The observed energies enable the radiating isotope in the sample to be determined, and with the detection probabilities just determined, the quantity can be estimated.

Remark

The NaI(Tl) crystal at the end of the scintillation counter is sensitive to mechanical damage. Be careful when inserting the Marinelli beaker.

When making measurements with strongly radiating samples heed the display of the dead time and, if necessary, dilute the sample.

Recording a β spectrum using a scintillation counter



can also be carried out with Pocket-CASSY

■ Load example

Safety note

When radioactive preparations are handled, country specific regulations must be observed, e.g. the Radiation Protection Regulation (StrlSchV) in Germany. The radioactive substances used in this experiment are approved for teaching purposes at schools in accordance with the StrlSchV. Since they produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the preparations by **unauthorized persons**.
- Before using the preparations make sure that they are **intact**.
- For the purpose of **shielding**, keep the preparations in their safety container.
- To ensure **minimum exposure time** and **minimum activity**, take the preparations out of the safety container only as long as is necessary for carrying out the experiment.
- To ensure **maximum distance**, hold the preparations only at the upper end of the metal holder.

Experiment description

The β spectrum of Sr-90 is recorded with a scintillation counter. The energy loss per path length dE/dx of the β particles in aluminium is measured.



Equipment list

1	Sensor CASSY	524 010
1	CASSY Lab	524 200
1	MCA box	524 058
1	Set of 5 radioactive preparations	559 83
1	Set of absorbers and targets	559 94
1	Scintillation counter	559 901
1	Detector output stage	559 912
1	High-voltage power supply 1.5 kV	521 68
1	Scintillator screening	559 89
1	Socket for scintillator screening	559 891
1	Stand rod, 47 cm	300 42
1	Leybold multiclamp	301 01
1	Universal clamp, 0...80 mm dia.	666 555
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The output stage of the scintillation counter is connected to the MCA box and to the high-voltage power supply and put into the socket. The scintillation counter is mounted in the socket from above with the lead screening. The plexiglass tube is put over the scintillation counter within the lead screening. The preparation is placed a few centimetres above the scintillation counter with stand material. The absorber plates are laid on the plexiglass tube so that they are located between the detector and the preparation.

Carrying out the experiment

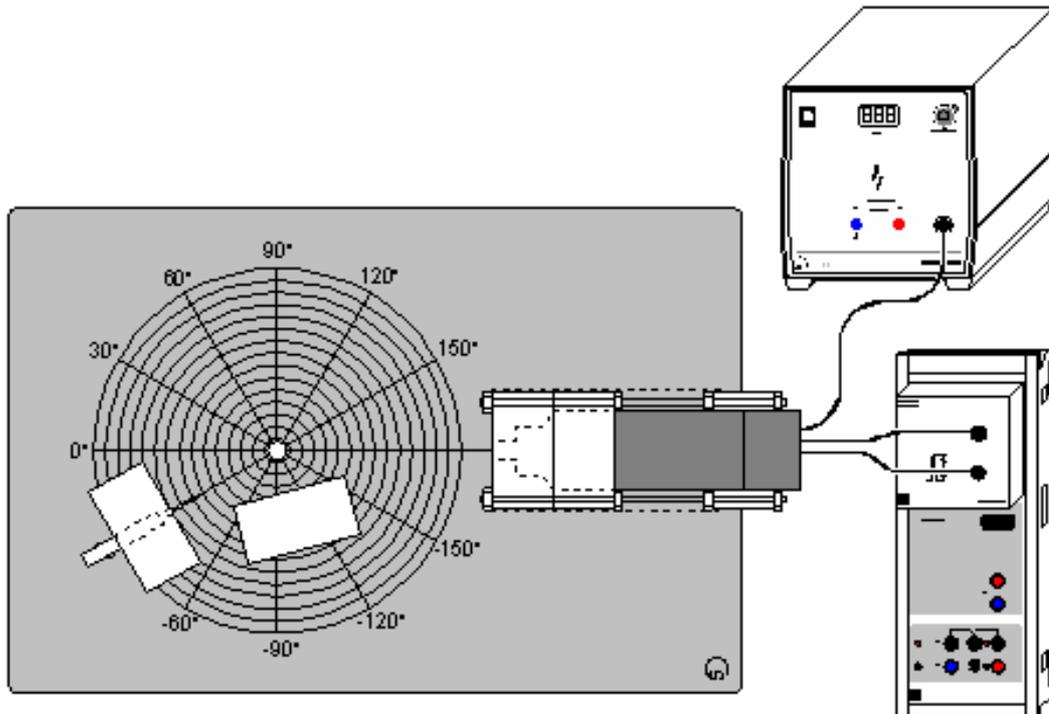
■ Load settings

- Mount the Sr-90 preparation, and record the spectrum (**F9**). Set the high voltage so that the spectrum is not cut off on the right side.
- For the energy calibration, mount the Na-22 preparation, and calibrate the energy axis with the 511 keV and the 1275 keV line. The Sr-90 spectrum extends to approx. 2000 keV.
- It is recommendable to determine the background without preparation.
- Mount the Sr-90 preparation once more, and see to it that there is enough space for the absorbers.
- One after another record the spectra without absorber, with a 0.5 mm thick aluminium absorber, 1 mm aluminium, and so on up to 3 mm aluminium.

Evaluation

The aluminium absorber reduces the maximum energy of the electron reaching the detector. The highest energy of each Sr-90 spectrum at which electrons are detected is determined. These energies are compiled in a table together with the corresponding thickness of the absorber. The slope of the regression line gives the energy loss per path length dE/dx , which, in this case, amounts to about 400 – 450 keV/mm.

Quantitative observation of the Compton effect



can also be carried out with Pocket-CASSY

■ Load example

Safety note

When radioactive preparations are handled, country specific regulations must be observed, e.g. the Radiation Protection Regulation (StrlSchV) in Germany. The radioactive substances used in this experiment are approved for teaching purposes at schools in accordance with the StrlSchV. Since they produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the preparations by **unauthorized persons**.
- Before using the preparations make sure that they are **intact**.
- For the purpose of **shielding**, keep the preparations in their safety container.
- To ensure **minimum exposure time** and **minimum activity**, take the preparations out of the safety container only as long as is necessary for carrying out the experiment.
- To ensure **maximum distance**, hold the preparations only at the upper end of the metal holder.

Experiment description

An energy calibration of the scintillation counter is made. The energy distribution of γ quanta scattered in an aluminium scatterer is recorded for several angles between the source and the detector. From this the quantitative confirmation of the Compton effect is obtained.

Equipment list

1	Sensor CASSY	524 010
1	CASSY Lab	524 200
1	MCA box	524 058
1	Mixed preparation α , β , γ	559 84 or from 559 83
1	Equipment set Compton	559 800
1	Cs-137 preparation, 3.7 MBq	559 809



1	Scintillation counter	559 901
1	Detector output stage	559 912
1	High-voltage power supply 1.5 kV	521 68
1	PC with Windows 95/98/NT or higher version	

Experiment description (see drawing)

The output stage of the scintillation counter is connected to the MCA box and to the high-voltage power supply. The experiment panel from the Equipment set Compton is put down and the lead screening set up correspondingly.

Carrying out the experiment

■ Load settings

- First make an energy calibration of the scintillation counter. For this insert the mixed preparation in the sample holder from the Equipment set Compton, align it at the 0° mark. Leave the aluminium scatterer aside.
- Record the spectrum (**F9**), and make the energy calibration with the lines at 662 keV and 59.5 keV.
- Replace the mixed preparation with the Cs-137 preparation, set up the preparation at 10°, and set up the aluminium scatterer. Place the additional screening in the direct line of vision between the preparation and the detector.
- Record the spectrum (**F9**), then remove the aluminium scatterer, and record a new spectrum.
- The difference between the two spectra (with and without the aluminium scatterer) is the scattering spectrum.
- Repeat the measurement at various angles of the preparation, each time subtracting a spectrum without the aluminium scatterer from a spectrum with the aluminium scatterer. Always shift the additional screening in the setup so that the direct line of vision between the preparation and the detector is blocked.

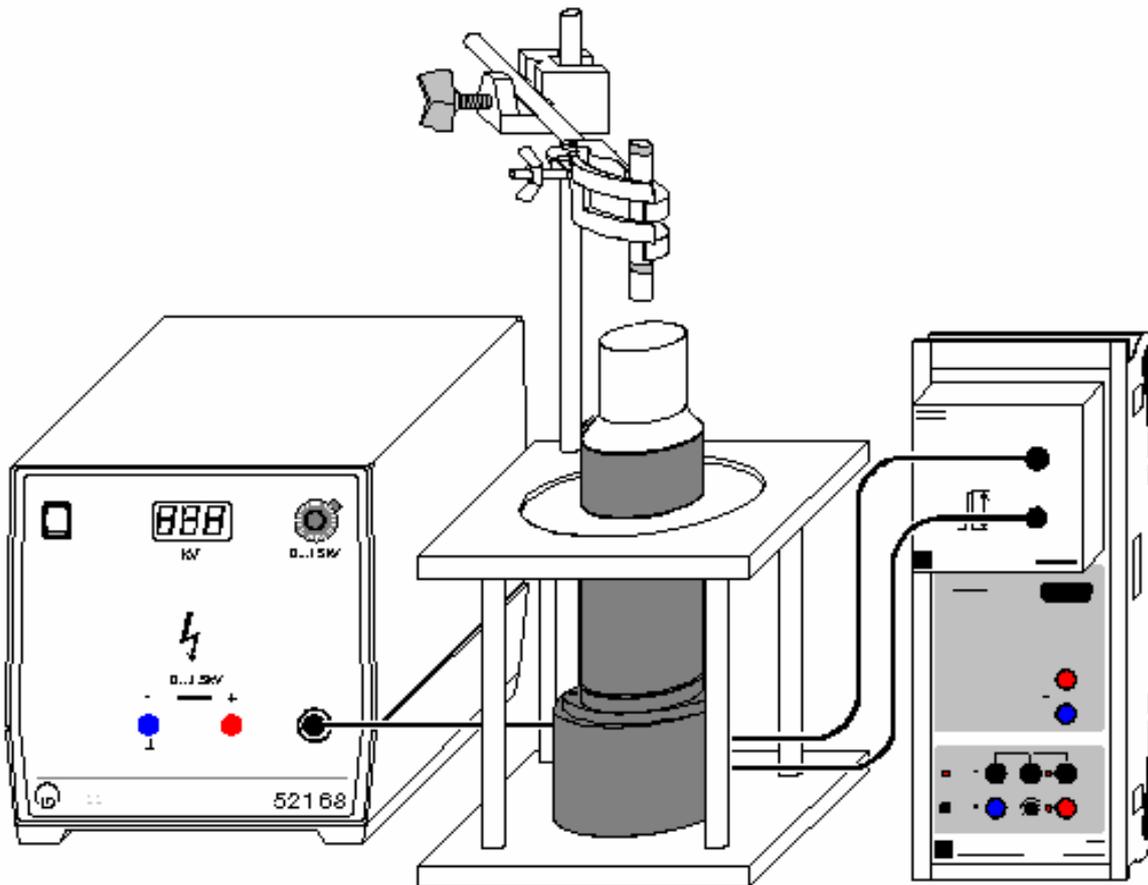
Evaluation

From the scattering spectra (difference with and without aluminium scatterer) the energy of the scattered γ quanta is determined. The values are plotted against the associated angles and compared with the theoretical values

$$E'_\gamma = E_\gamma / \left(1 + \frac{E_\gamma}{m_0 c^2} (1 - \cos \Theta) \right)$$

Alternatively a Free fit can be performed.

Recording the complex γ spectrum of Ra-226 and its decay products



can also be carried out with Pocket-CASSY

■ Load example

Safety note

When radioactive preparations are handled, country specific regulations must be observed, e.g. the Radiation Protection Regulation (StrlSchV) in Germany. The radioactive substances used in this experiment are approved for teaching purposes at schools in accordance with the StrlSchV. Since they produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the preparations by **unauthorized persons**.
- Before using the preparations make sure that they are **intact**.
- For the purpose of **shielding**, keep the preparations in their safety container.
- To ensure **minimum exposure time** and **minimum activity**, take the preparations out of the safety container only as long as is necessary for carrying out the experiment.
- To ensure **maximum distance**, hold the preparations only at the upper end of the metal holder.

Experiment description

The complex spectrum of Ra-226 and its decay products is recorded.



Equipment list

1	Sensor CASSY	524 010
1	CASSY Lab	524 200
1	MCA box	524 058
1	Mixed preparation α , β , γ	559 84 or from 559 83
1	Ra-226 preparation	559 430
1	Scintillation counter	559 901
1	Detector output stage	559 912
1	High-voltage power supply 1.5 kV	521 68
1	Scintillator screening	559 89
1	Socket for scintillator screening	559 891
1	Stand rod, 47 cm	300 42
1	Leybold multiclamp	301 01
1	Universal clamp, 0...80 mm dia.	666 555
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The output stage of the scintillation counter is connected to the MCA box and to the high-voltage power supply. The preparation is placed a few centimetres above the scintillation counter with the stand material.

Carrying out the experiment

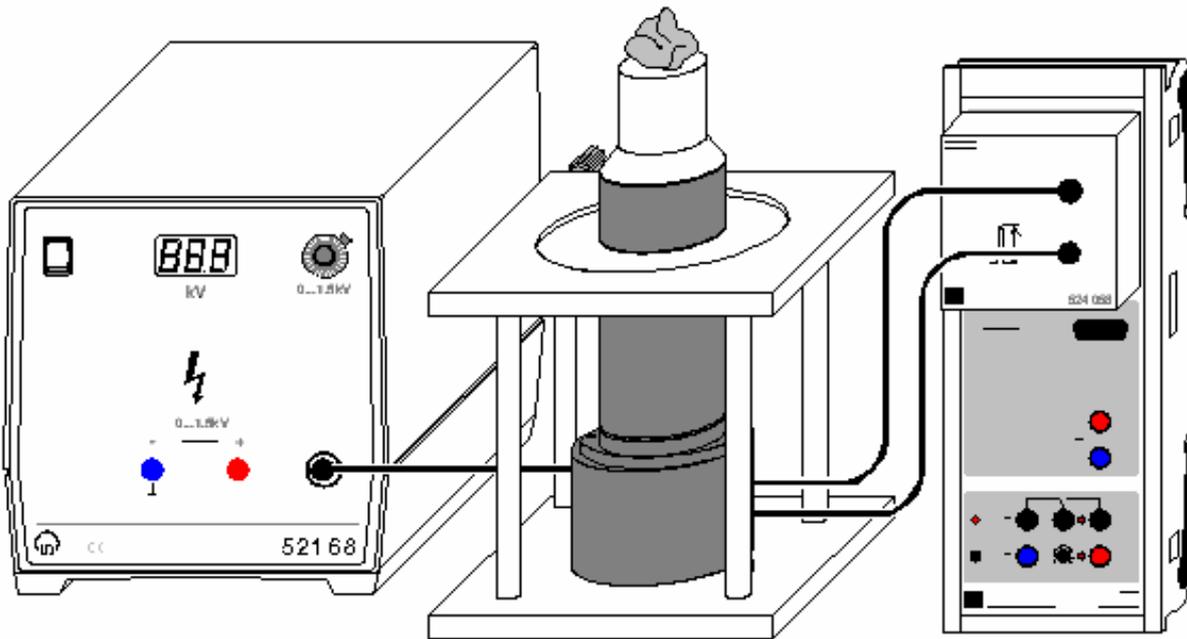
■ Load settings

- For the energy calibration mount the mixed preparation above the detector, record the spectrum (**F9**), and make the calibration with the lines at 662 keV and 59.5 keV.
- Remove the mixed preparation, and mount the Ra-226 preparation. Record the spectrum.

Evaluation

The measured lines are assigned to the corresponding isotopes of the radium radioactive series with the help of values taken from the literature or from the internet (see e.g. <http://nucleardata.nuclear.lu.se/nucleardata/toi/>).

Recording the complex γ spectrum of an incandescent gas hood



can also be carried out with Pocket-CASSY

■ Load example

Safety note

When radioactive preparations are handled, country specific regulations must be observed, e.g. the Radiation Protection Regulation (StrlSchV) in Germany. The radioactive substances used in this experiment are approved for teaching purposes at schools in accordance with the StrlSchV. Since they produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the preparations by **unauthorized persons**.
- Before using the preparations make sure that they are **intact**.
- For the purpose of **shielding**, keep the preparations in their safety container.
- To ensure **minimum exposure time** and **minimum activity**, take the preparations out of the safety container only as long as is necessary for carrying out the experiment.
- To ensure **maximum distance**, hold the preparations only at the upper end of the metal holder.

Experiment description

The complex γ spectrum of Th-232 and its decay products is recorded. The use of radioactive substances in household articles in the past is demonstrated.

Equipment list

1	Sensor CASSY	524 010
1	CASSY Lab	524 200
1	MCA box	524 058
1	Mixed preparation α , β , γ	559 84 or from 559 83
1	Incandescent gas hood	from 588 855
1	Scintillation counter	559 901
1	Detector output stage	559 912
1	High-voltage power supply 1.5 kV	521 68
1	Scintillator screening	559 89
1	Socket for scintillator screening	559 891



1	Stand rod, 47 cm	300 42
1	Leybold multiclamp	301 01
1	Universal clamp, 0...80 mm dia.	666 555
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The output stage of the scintillation counter is connected to the MCA box and to the high-voltage power supply. The preparation is placed above the scintillation counter with the stand material or simply laid on the detector.

Carrying out the experiment

■ Load settings

- For the energy calibration mount the mixed preparation above the detector, record the spectrum (**F9**), and make the calibration with the lines at 662 keV and 59.5 keV.
- Remove the mixed preparation, and mount the incandescent gas hood (Th-232). Record the spectrum.

Evaluation

The measured lines are assigned to the corresponding isotopes of the thorium radioactive series with the help of values taken from the literature or from the internet (see e.g. <http://nucleardata.nuclear.lu.se/nucleardata/toi/>).

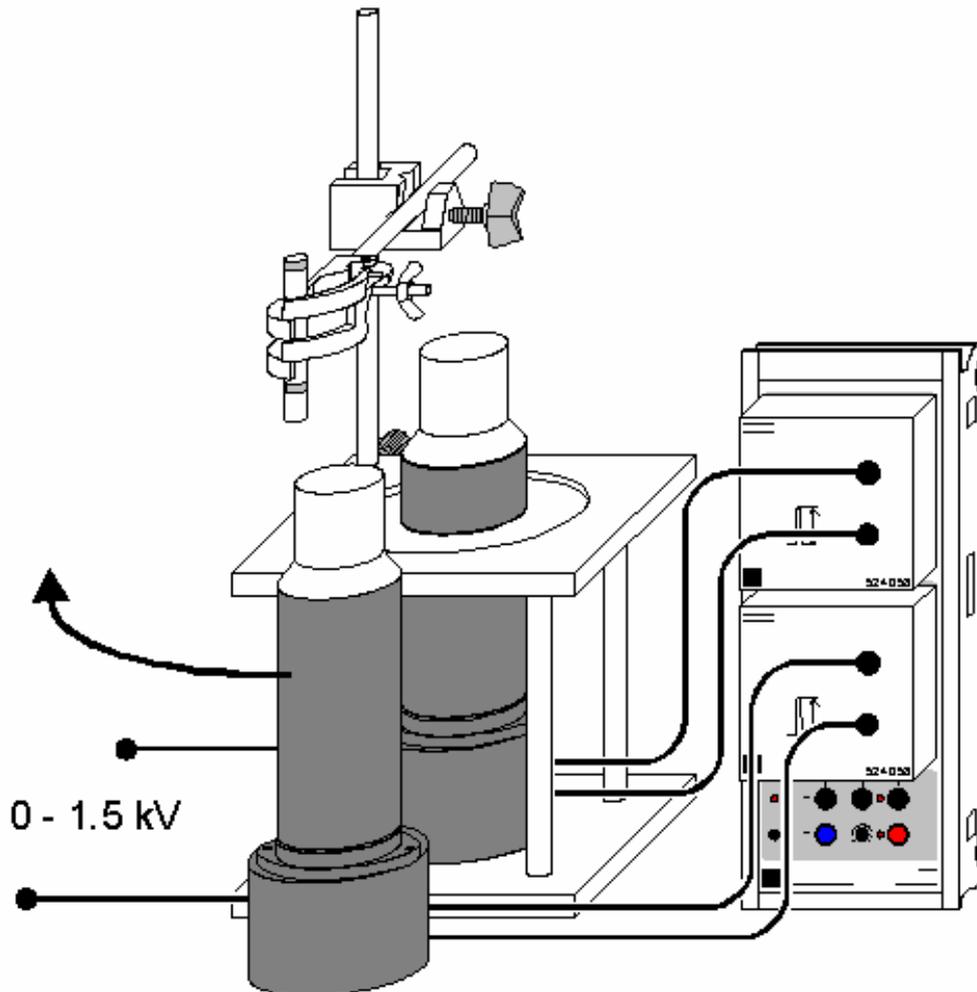
Remark

Incandescent gas hoods manufactured in recent time no longer contain thorium but yttrium.

During the first years after manufacture the intensity of some lines changes until a new radioactive equilibrium has been reached. In particular the intensity of the lines at 338 and 911 keV (decay of Ac-228 into Th-228) behaves in another manner than the other lines. This also influences the $K\alpha$ lines.

Incandescent gas hoods which have already been used in a lamp should not be used for the experiment because of the dust released by them.

Coincidence and γ - γ angular correlation in positron decay



■ Load example

Safety note

When radioactive preparations are handled, country specific regulations must be observed, e.g. the Radiation Protection Regulation (StrlSchV) in Germany. The radioactive substances used in this experiment are approved for teaching purposes at schools in accordance with the StrlSchV. Since they produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the preparations by **unauthorized persons**.
- Before using the preparations make sure that they are **intact**.
- For the purpose of **shielding**, keep the preparations in their safety container.
- To ensure **minimum exposure time** and **minimum activity**, take the preparations out of the safety container only as long as is necessary for carrying out the experiment.
- To ensure **maximum distance**, hold the preparations only at the upper end of the metal holder.

Experiment description

The spatial coincidence of the two γ quanta in electron-positron pair annihilation is demonstrated. The conservation of momentum requires emission of the two quanta at an angle of 180° , which is visualized in the experiment. Selective measurement of a coincidence spectrum leads to the suppression of non-correlated lines.



Equipment list

1	Sensor CASSY	524 010
1	CASSY Lab	524 200
2	MCA boxes	524 058
1	Set of 5 radioactive preparations	559 83
2	Scintillation counters	559 901
2	Detector output stages	559 912
2	High-voltage power supplies 1.5 kV	521 68
2	Sockets for scintillation counter	559 891
1	Stand rod, 47 cm	300 42
1	Leybold multiclamp	301 01
1	Universal clamp, 0...80 mm dia.	666 555
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The output stages of the scintillation counters are connected to the MCA boxes and to the high-voltage power supply / to the high-voltage power supplies. Both MCA boxes must be plugged in the same CASSY. The preparation is placed near one scintillation counter with the stand material so that the other detector can be moved around the setup, in order that the angle detector 1 - preparation - detector 2 can be varied.

Carrying out the experiment

■ Load settings

- First record the normal Na-22 spectrum with one of the detectors at a time. Calibrate one of the two detectors.
- Choose the coincidence mode, thereby measuring the spectrum with the calibrated detector. Set the coincidence window of the other detector around the 511 keV line.
- Place the movable detector so that the preparation is located between the detectors. Record the coincidence spectrum.
- Place the movable detector so that it is located perpendicularly to the connecting line preparation - other detector. Record the coincidence spectrum.
- Further coincidence spectra may be recorded at intermediate angles.
- Fix the Cs-137 preparation together with the Na-22 preparation between the detectors, place the movable detector so that the preparations are located between the detectors. Record the coincidence spectrum.
- Record the normal MCA spectrum of this arrangement.
- Remove the Cs-137 preparation, set the coincidence window around the 1275 keV line, and record the coincidence spectrum at 180° and at 90°.

Evaluation

The normal Na-22 spectrum consists of a line at 1275 keV and the pair annihilation radiation at 511 keV. The two 511 keV quanta are correlated in time and space (emission under 180°). The 1275 keV quanta are correlated with the 511 keV quanta in time as the delay of 3.7 ps cannot be detected with this setup. This emission is not correlated in space.

In the normal MCA spectrum both lines are visible. At 180° coincidence, the 511 keV line clearly stands out because the other components of the spectrum (1275 keV line, Compton distribution) are correlated in time only and not in space so they are weakened by the solid angle of the second detector relative to the 511 keV line, which is correlated in space. Thereby the absolute counting rate of the 511 keV line drops according to the detection probability of the second detector.

If the detector is swivelled out of the 180° direction, the 511 keV line disappears, whereas those components that are not correlated in space remain unchanged.

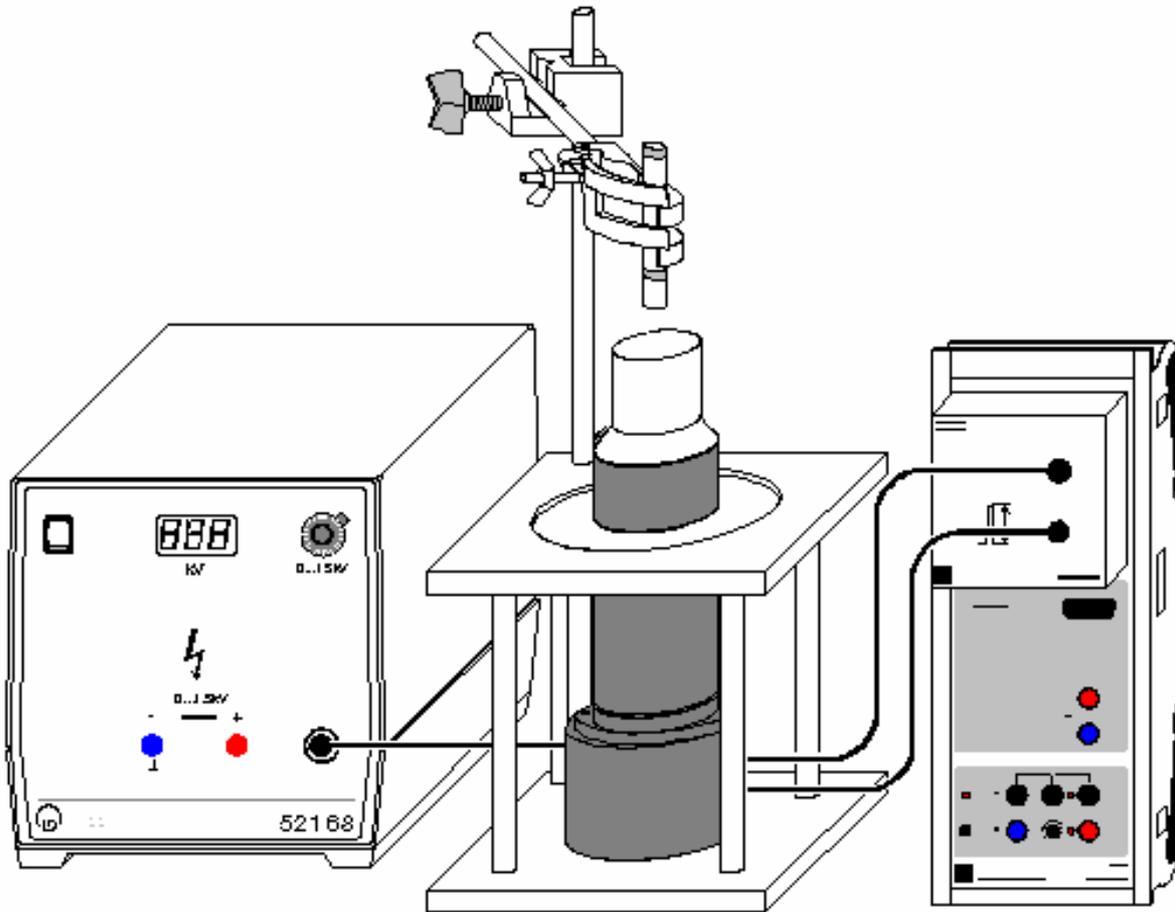
In order to show the suppression of quanta that are not correlated in time, two preparations are used at the same time. Cs-137 provides a non-correlated background, which is only visible in the coincidence measurement because of accidental coincidence, whereas it is clearly visible without coincidence measurement.

If the measurement is made in coincidence to the 1275 keV line, there is no correlation in space. Therefore the spectra look the same at different angles. Since there is only one 1275 keV quantum per decay, no 1275 keV line is observed in coincidence.

Remark

The time window for coincidences has a fixed default value of 4 μ s.

Measurements with the single-channel analyzer



can also be carried out with Pocket-CASSY

■ Load example

Safety note

When radioactive preparations are handled, country specific regulations must be observed, e.g. the Radiation Protection Regulation (StrlSchV) in Germany. The radioactive substances used in this experiment are approved for teaching purposes at schools in accordance with the StrlSchV. Since they produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the preparations by **unauthorized persons**.
- Before using the preparations make sure that they are **intact**.
- For the purpose of **shielding**, keep the preparations in their safety container.
- To ensure **minimum exposure time** and **minimum activity**, take the preparations out of the safety container only as long as is necessary for carrying out the experiment.
- To ensure **maximum distance**, hold the preparations only at the upper end of the metal holder.

Experiment description

To demonstrate the time advantage with a multichannel analyzer, a measurement in the MCA mode is carried out and then compared with a measurement in the single-channel mode.

Equipment list

1	Sensor CASSY	524 010
1	CASSY Lab	524 200
1	MCA box	524 058
1	Mixed preparation α , β , γ	559 84 or from 559 83
1	Scintillation counter	559 901
1	Detector output stage	559 912
1	High-voltage power supply 1.5 kV	521 68
1	Socket for scintillator screening	559 891
1	Stand rod, 47 cm	300 42
1	Leybold multiclamp	301 01
1	Universal clamp, 0...80 mm dia.	666 555
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The output stage of the scintillation counter is connected to the MCA box and to the high-voltage power supply. The preparation is placed a few centimetres above the scintillation counter with the stand material.

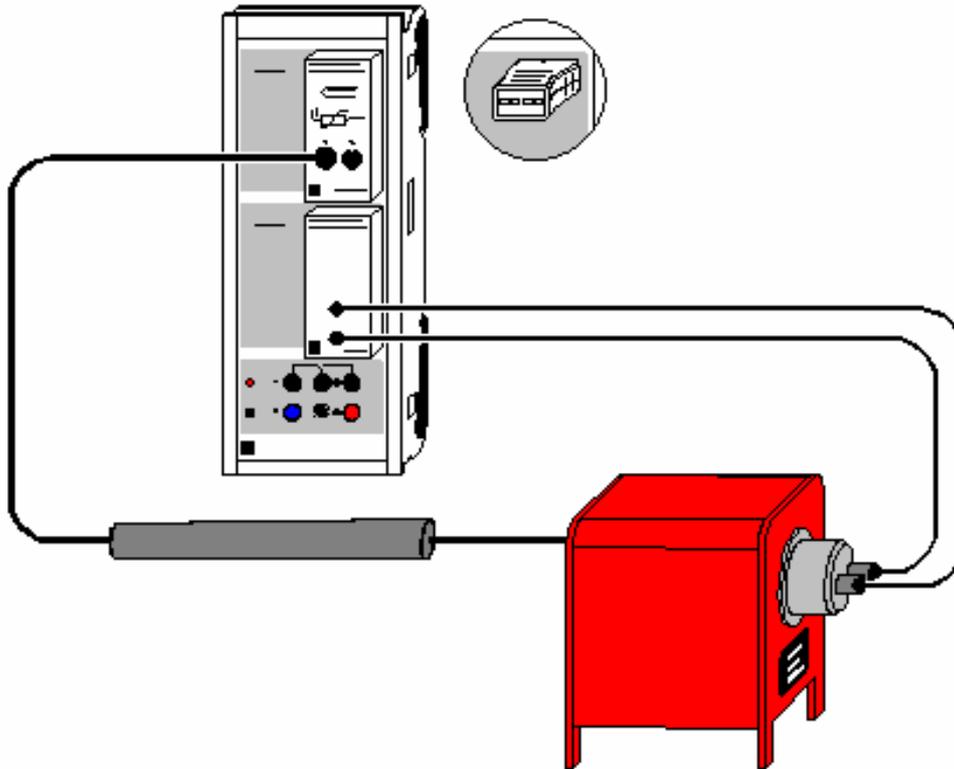
Carrying out the experiment

- Load settings
- Start the measurement in the MCA mode (**F9**).
- Start the measurement in the single-channel mode, e.g. with an equal total measuring time or with the same measuring time per point.

Evaluation

The parallel measurement of all channels has an obvious time advantage in comparison with the sequential measurement of individual channels. With equal measuring times, this time advantage is converted into a gain in resolution or in the signal-to-noise ratio.

Electrical conduction in solid bodies



can also be carried out with Pocket-CASSY and Mobile-CASSY

- Load example (Temperature box)
- Load example (NiCr-Ni adapter S)

Experiment description

The temperature-dependency of the specific resistance R is a simple test for models of electric conductivity in conductors and semiconductors. In electrical conductors, R rises with the temperature, as the collisions of the quasi-free electrons from the conduction band with the incomplete atoms of the conductor play an increasing role. In semiconductors, on the other hand, the resistance decreases as the temperature increases since more and more electrons move from the valence band to the conduction band, thus contributing to the conductivity.

This experiment measures the resistance values of a noble-metal resistor and a semiconductor resistor as a function of the temperature. For the noble metal resistor, the relationship

$$R = R_0 \cdot (1 + \alpha \cdot \vartheta) \quad (R_0: \text{resistance at } \vartheta = 0 \text{ } ^\circ\text{C})$$

is verified with sufficient accuracy in the temperature range under study. For the semiconductor resistor, the evaluation reveals a dependency with the form

$$R \propto e^{\Delta E / 2kT} \quad (k = 1.38 \cdot 10^{-23} \text{ J/K: Boltzmann constant})$$

with the energy band interval ΔE .

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Current supply box	524 031

1	Temperature box	524 045
1	Temperature sensor NiCr-Ni	666 193
or		
1	NiCr-Ni adapter S	524 0673
1	Temperature sensor NiCr-Ni, type K	529 676
1	Noble metal resistor	586 80
1	Semiconductor resistor	586 82
1	Electric oven, 230 V	555 81
1	Safety connecting box	502 061
2	Connecting leads, 100 cm, black	500 444
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The temperature box at Sensor-CASSY input A measures the temperature of the sensor in the electric oven. Insert the measuring tip into the hole on the back of the oven so that the tip is in direct proximity to the resistor element. The current supply box at input B registers the electrical resistance.

Carrying out the experiment

- Load settings (Temperature box)
- Load settings (NiCr-Ni adapter S)
- Start the measurement with **F9** (a value pair is recorded for every temperature increase of 5 K).
- Switch on the oven.
- Stop the measurement with **F9** at the latest when the temperature reaches 470 K (approx. 200 °C).
- Switch off the oven and remove the resistor.
- When the oven has cooled off repeat the measurement with a different resistor.

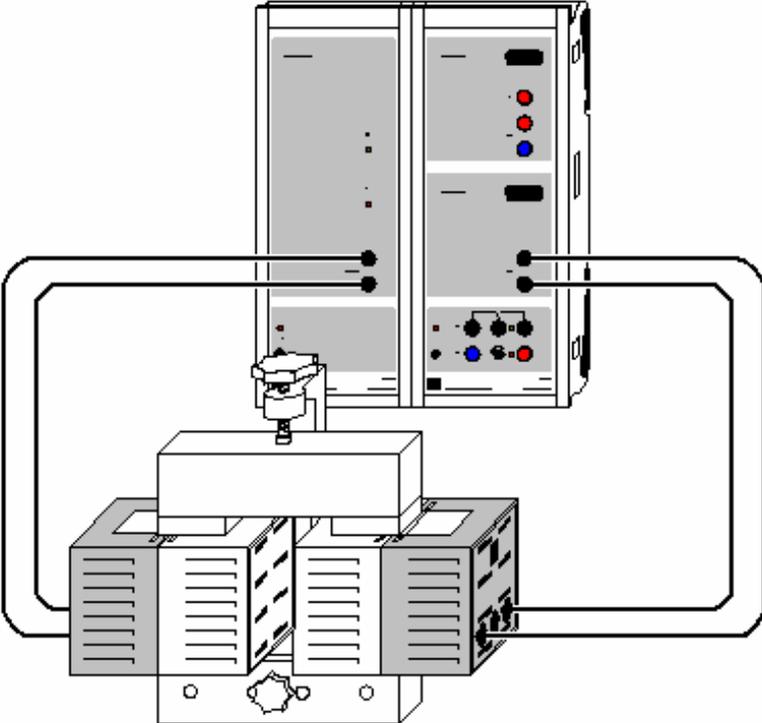
Evaluation

When a noble metal (platinum) resistor is used, we obtain a linear increase in resistance as the temperature rises. The temperature coefficient α of the resistor can be determined easily by fitting a straight line. In this example we observe an increase in resistance of 0.407 Ω /K and a resistance of 100 Ω at 0 °C, i.e. $\alpha = 0.00407$ /K. This agrees very well with the literature value $\alpha = 0.00392$ /K for platinum.

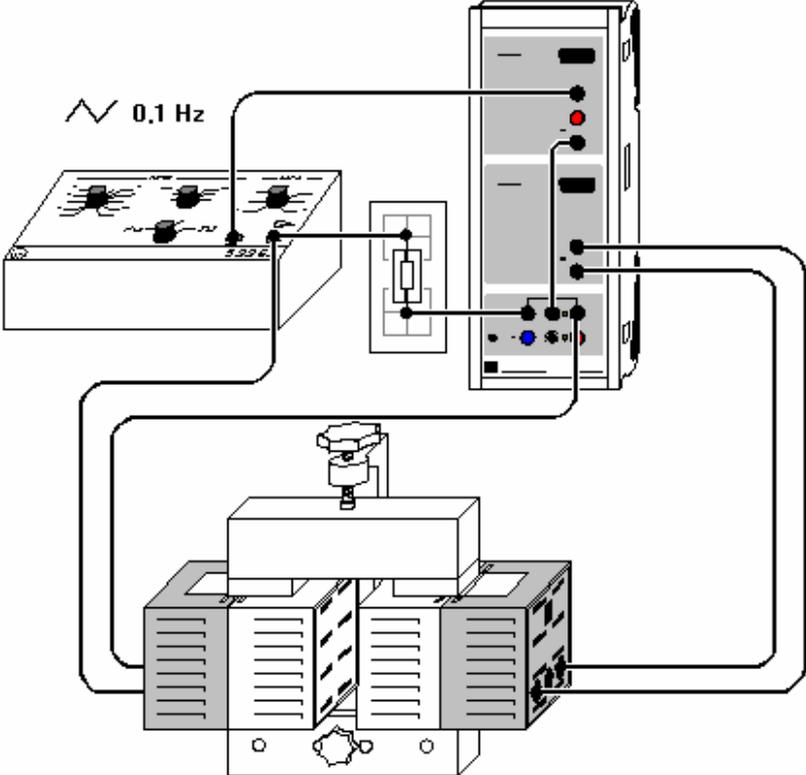
The resistance of the semiconductor resistor does not decrease linearly as the temperature rises. By fitting an exponential function to the 1/T display (click on the display tab with the mouse) we can confirm the relationship $R \propto e^{(\Delta E/2kT)}$ for higher temperatures T. In the example, this gives us $2k/\Delta E = 0.000368$ /K for the semiconductor used here, i.e. $\Delta E = 7.5 \cdot 10^{-20}$ J = 0.47 eV (1 eV = $1.602 \cdot 10^{-19}$ J).



Hysteresis of a transformer core



Alternatively (without Power-CASSY):



- Load example (with Power-CASSY)
- Load example (without Power-CASSY)

Experiment description

In a transformer core (ferromagnet) the magnetic field

$$H = N1/L \cdot I$$

is proportional to the coil current I and the effective turns density $N1/L$ of the primary coil. However, the generated magnetic flux density or magnetic induction

$$B = \mu_r \cdot \mu_0 \cdot H \quad (\text{where } \mu_0 = 4\pi \cdot 10^{-7} \text{ Vs/Am})$$

is not proportional to H . Rather, it reaches a saturation value B_s as the magnetic field H increases. The relative permeability μ_r of the ferromagnet depends on the magnetic field strength H , and also on the previous magnetic treatment of the ferromagnet. In a demagnetized ferromagnet, the magnetic field strength is $B = 0 \text{ T}$ at $H = 0 \text{ A/m}$. Normally however, a ferromagnet still retains a residual magnetic flux density B not equal to 0 T when $H = 0 \text{ A/m}$ (remanence).

Thus, it is common to represent the magnetic induction B in the form of a hysteresis curve as a function of the rising and falling field strength H . The hysteresis curve differs from the magnetization curve, which begins at the origin of the coordinate system and can only be measured for completely demagnetized material ($H = 0 \text{ A/m}$, $B = 0 \text{ T}$).

In this example H and B are not measured directly; rather, the quantities proportional to these, i.e. the primary current $I = L/N1 \cdot H$ and magnetic flux $\Phi = N2 \cdot A \cdot B$ through the secondary coil are used ($N2$: number of turns of secondary coil; A cross-section of ferromagnet). The magnetic flux Φ is calculated as the integral of the voltage U induced in the secondary coil.

Equipment list

1	Power-CASSY	524 011
1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	U-core with yoke	562 11
1	Clamping device	562 12
2	Coils with 500 turns	562 14
4	Connecting leads, 100 cm, black	500 444
1	PC with Windows 95/98/NT or higher version	

Alternatively (without Power-CASSY)

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	U-core with yoke	562 11
1	Clamping device	562 12
2	Coils with 500 turns	562 14
1	Function generator S12	522 621
1	STE resistor 1 Ω , 2 W	577 19
1	Socket board section	576 71
1	Connecting lead, 50 cm, black	500 424
7	Connecting leads, 100 cm, black	500 444
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Power-CASSY supplies the current for the primary coil of the transformer. The magnetic flux Φ is calculated from the induction voltage U of the secondary coil, which is measured at Sensor-CASSY input B.

Alternatively, you can perform the experiment without Power-CASSY, using the function generator S12. This apparatus must be set to sawtooth signal, frequency around 0.1 Hz and amplitude about 2 V. Recording of the magnetization curve is triggered at $I = 0 \text{ A}$. To hit this point exactly, the current is shunted past the transformer by the relay and flows through a 1 Ω resistor prior to recording of the curve.



Carrying out the experiment

- Load settings (with Power-CASSY)
- Load settings (without Power-CASSY)
- Correct the offset if necessary: open Settings UB, select **Correct**, set the first target value 0 V and click on **Correct Offset**.
- Demagnetize the transformer core, e.g. by striking the end face of the yoke against the end faces of the U-core several times.
- Start the measurement with **F9**.
- Stop the measurement with **F9** after one period of the hysteresis curve or at $\Phi = 0$ Vs (in this case the core does not have to be demagnetized again).
- If the hysteresis curve lies in the second and fourth quadrants, reverse the connections on one of the two coils.
- If the display instrument UB is overdriven during measurement (display flashes), extend the measuring range in Settings UB.

Evaluation

As the area of a hysteresis loop $B(H)$

$$\int B \cdot dH = \frac{E}{V}$$

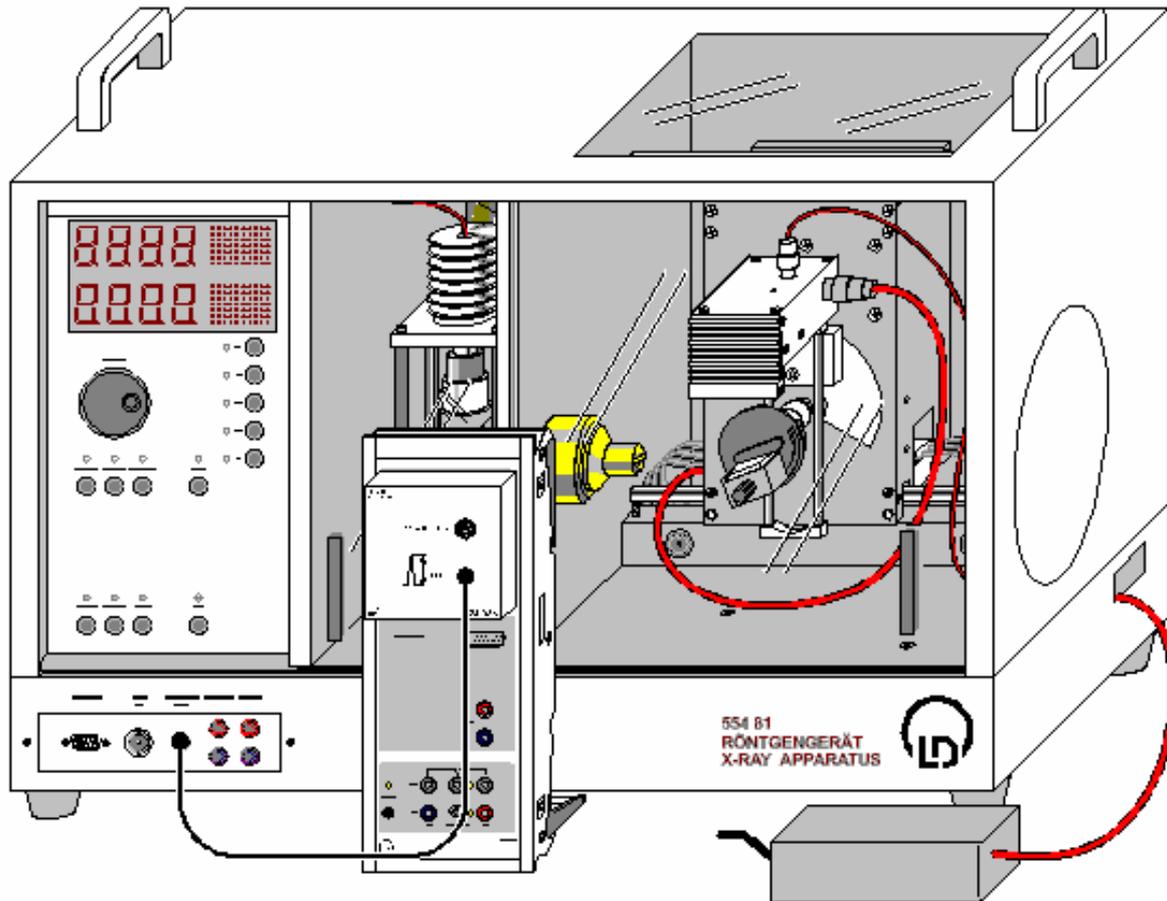
just corresponds to the energy loss in remagnetization per volume V of the demagnetized material, the enclosed area in the diagram $\Phi(I)$

$$\begin{aligned} \int \Phi \cdot dI &= \int N_2 A B \cdot \frac{L}{N_1} \cdot dH \\ &= \frac{N_2}{N_1} V \int B \cdot dH = \frac{N_2}{N_1} E \end{aligned}$$

gives us precisely the energy loss E of the remagnetization for $N_1=N_2$.

In the diagram, you can calculate this energy loss using "peak integration" of a hysteresis loop.

Non-destructive analysis of the chemical composition (x-ray fluorescence)



can also be carried out with Pocket-CASSY

■ Load example

Safety notes

The X-ray apparatus fulfils all regulations on the design of an X-ray apparatus and fully protected device for instructional use and is type approved for school use in Germany (NW 807 / 97 Rö).

The built-in protective and shielding fixtures reduce the dose rate outside the X-ray apparatus to less than 1 $\mu\text{Sv/h}$, which is of the order of magnitude of the natural background radiation.

- Before putting the X-ray apparatus into operation, inspect it for damage and check whether the voltage is switched off when the sliding doors are opened (See instruction sheet of the X-ray apparatus).
- Protect the X-ray apparatus against access by unauthorized persons.

Avoid overheating of the anode in the X-ray tube.

- When switching the X-ray apparatus on, check whether the ventilator in the tube chamber starts rotating.

The goniometer is positioned solely by means of electric stepper motors.

- Do not block the target arm and the sensor arm of the goniometer and do not use force to move them.



Experiment description

When a sample is irradiated with high energy x-ray photons it will emit characteristic x-ray lines whose energy depends on the atomic number of the element of the sample material. This dependency is the topic of the experimental examples of Moseley's law (K-line and L-line x-ray fluorescence)

If a sample consists of a chemical compound or mixture, its fluorescence spectrum will also be complex. Because the inner electron shells between which the x-ray transitions occur are not involved in the chemical bonds, the characteristic lines are largely independent of the chemical bonds in the element. This means that the x-ray fluorescence spectra of a chemical compound are, to a first approximation, a superposition of the spectra of its components.

For the qualitative analysis of the chemical composition of a sample, initially all the peaks found in the fluorescence spectrum are correlated to the elements. This is done by means of the values for the energies of the characteristic lines found in the table. For the correlation, the "pattern" of each of the spectral series is also considered: for example, together with the $K\alpha$ -line there must also be the $K\beta$ -line with a lesser (approx. one fifth to one tenth) intensity in the spectrum. The $L\alpha$ -line appears accompanied by the $L\beta$ -line of a similar intensity and the $L\gamma$ -line of a lesser intensity.

Information about the relative concentrations of individual elements in the compound can be gained from the relative intensities of their fluorescence lines.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	MCA-Box	524 058
1	X-ray apparatus with x-ray tube Mo	554 811
1	Target set of alloys	554 848
1	X-ray energy detector	559 938
1	HF cable, 1 m	501 02
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

- Guide the connection cable for the table-top power supply through the empty channel of the x-ray apparatus and connect it to the mini-DIN socket of the x-ray energy detector.
- Secure the sensor holder with the mounted x-ray energy detector in the goniometer sensor arm
- Connect the signal output of the x-ray energy detector to the BNC socket SIGNAL IN of the x-ray apparatus by means of the BNC cable included
- Feed enough connection cable through to make complete movement of the sensor arm possible
- Press the SENSOR button and set the sensor angle with the rotary adjuster ADJUST manually to 90°
- Set the distances between the slit aperture of the collimator and the axis of rotation as well as between the axis of rotation and the window of the x-ray energy detector both to 5 to 6 cm
- Press the TARGET button and adjust the target angle manually using the rotary button ADJUST to 45° .
- Connect Sensor-CASSY to the computer and connect the MCA box
- Connect the SIGNAL OUT output in the connection panel of the x-ray apparatus to the MCA box by means of the BNC cable.

Carrying out the experiment

■ Load settings

- Connect the table-top power supply to the mains (after approx. 2 min the LED will glow green and the x-ray energy detector will be ready for use).
- Place the calibration target (galvanised steel plate) from the scope of delivery for the x-ray energy detector onto the table
- Set the tube high voltage $U = 35$ kV, emission current $I = 1.00$ mA and switch the high voltage on
- Start the measurement by pressing **F9**
- Then record spectra for the four targets in the target set of alloys

Energy calibration

The energy calibration of the spectra is made using the spectrum of the calibration target (Fe+Zn).

- Open in the context menu of the diagram (right mouse button) or select with **Alt+E** the Energy calibration, select **global energy calibration** and enter on the right-hand side the energies of the Fe $K\alpha$ -line (6.40 keV) and of the Zn $K\alpha$ -line (8.64 keV). Do not yet close the **Energy calibration** window.
- In the context menu of the diagram select under other evaluations Calculate peak center, mark the Fe $K\alpha$ -line and enter the result in the left-hand side of the Energy calibration (e.g. with drag & drop from the status line)
- Then determine the centre for the Zn $K\alpha$ -line and also enter it on the left-hand side
- Close the **Energy calibration** window
- Call the **X-ray energies** for identification and labelling of the lines in the context menu of the diagram or by using **Alt+X** and click on the **Fe** element symbol, select **Adopt**, click on **Zn** and close the window by clicking on **OK**.

It becomes apparent that four of the measured peaks have been caused by the fluorescence of the main components Fe and Zn of the galvanised steel plate.

Evaluation

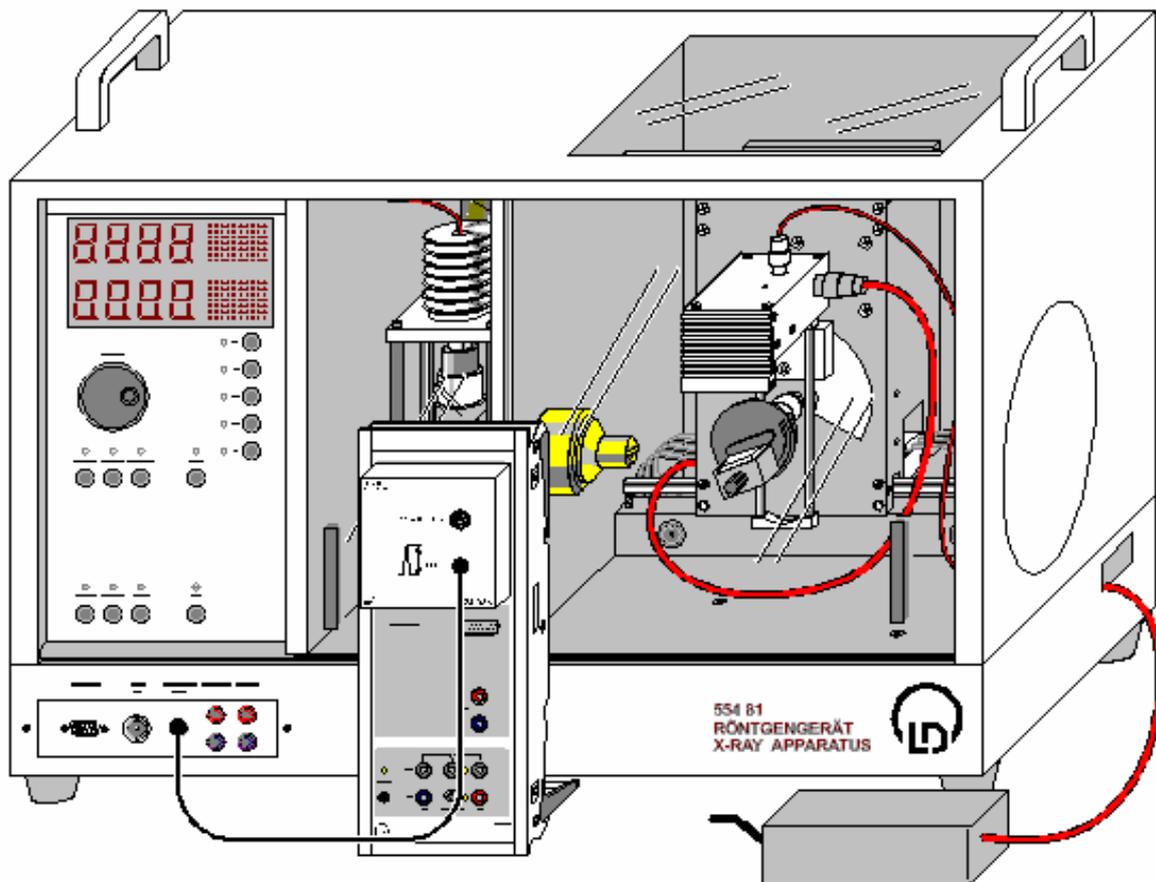
For the identification of the components of the alloys:

- Select spectrum and mark a suitable section
- In the context menu of the diagram window or by using **Alt+X** select the window **X-ray energies** and click on the element symbols and determine a suitable element by means of the displayed markers for the energies in the table.
- Place the marker by clicking **Adopt** and determine further components of the alloy

The results of the qualitative investigation of the alloys by means of their x-ray fluorescence spectra correspond to the known chemical composition:

- Target 1: Stainless steel X5CrNi18-10 – contains 72 % Fe, 18 % Cr, 10 % Ni.
- Target 2: Brass CuZn36 - contains 64 % Cu, 36 % Zn.
- Target 3: Brass CuZn39Pb3 - contains 58 % Cu, 39 % Zn, 3% Pb.
- Target 4: Praseodymium-samarium-cobalt magnet. These magnets can, in addition to Co, Sm, Pr, also contain Fe, Cu and Zr. Also the K-lines of bromium can be found, which originate from the fire-retardant in the plastic support.

Determination of the chemical composition of a brass sample (x-ray fluorescence)



can also be carried out with Pocket-CASSY

■ Load example

Safety notes

The X-ray apparatus fulfils all regulations on the design of an X-ray apparatus and fully protected device for instructional use and is type approved for school use in Germany (NW 807 / 97 Rö).

The built-in protective and shielding fixtures reduce the dose rate outside the X-ray apparatus to less than $1 \mu\text{Sv/h}$, which is of the order of magnitude of the natural background radiation.

- Before putting the X-ray apparatus into operation, inspect it for damage and check whether the voltage is switched off when the sliding doors are opened (See instruction sheet of the X-ray apparatus).
- Protect the X-ray apparatus against access by unauthorized persons.

Avoid overheating of the anode in the X-ray tube.

- When switching the X-ray apparatus on, check whether the ventilator in the tube chamber starts rotating.

The goniometer is positioned solely by means of electric stepper motors.

- Do not block the target arm and the sensor arm of the goniometer and do not use force to move them.

When handling heavy metals or allergen substances from the target set, observe their operating instructions.

Experiment description

In this experiment, the quantitative analysis of the chemical composition of a brass sample containing lead is carried out. The components in this alloy were already identified in the experiment Non-destructive analysis of the chemical composition.

For calculating the mass ratios, the fact is made use of that the height of a peak is proportional to the number n of radiating atoms. In the reference spectrum this number n_0 is determined by the density of the substance ρ , its atomic weight A , the radiated area S and the effective thickness d of the irradiated layer:

$$n_0 = S \cdot d \cdot \rho / A.$$

For the number of atoms of each type in the alloy, to first approximation the expression

$$n = n_0 \cdot H / H_0 = V \cdot \rho / A \cdot H / H_0$$

can be used. In this H and H_0 are the peak heights in the spectrum to be analysed and in the reference spectrum is $V = S \cdot d$ the irradiated volume. Using this information, the mass ratio C_i of the element number i in the alloy is

$$C_i = \frac{n_i \cdot A_i}{\sum_i n_i \cdot A_i} = \frac{\rho_i \cdot \frac{H_i}{H_{0i}}}{\sum_i \rho_i \cdot \frac{H_i}{H_{0i}}}$$

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	MCA-Box	524 058
1	X-ray apparatus with x-ray tube Mo	554 811
1	Target set of alloys	554 848
1	Target set for K-lines fluorescence	554 844
1	Target set for L-lines fluorescence	554 846
1	X-ray energy detector	559 938
1	BNC cable, 1 m	501 02
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

- Guide the connection cable for the table-top power supply through the empty channel of the x-ray apparatus and connect it to the mini-DIN socket of the x-ray energy detector.
- Secure the sensor holder with the mounted x-ray energy detector in the goniometer sensor arm
- Connect the signal output of the x-ray energy detector to the BNC socket SIGNAL IN of the x-ray apparatus by means of the BNC cable included
- Feed enough connection cable through to make complete movement of the sensor arm possible
- Press the SENSOR button and set the sensor angle with the rotary adjuster ADJUST manually to 90°
- Set the distances between the slit aperture of the collimator and the axis of rotation as well as between the axis of rotation and the window of the x-ray energy detector both to 5 to 6 cm
- Press the TARGET button and adjust the target angle manually using the rotary button ADJUST to 45°.
- Connect Sensor-CASSY to the computer and connect the MCA box
- Connect the SIGNAL OUT output in the connection panel of the x-ray apparatus to the MCA box by means of the BNC cable.

Carrying out the experiment

■ Load settings

- Connect the table-top power supply to the mains (after approx. 2 min the LED will glow green and the x-ray energy detector will be ready for use).
- Place target 3 (brass containing lead) from the target set of alloys onto the target table
- Set the tube high voltage $U = 35$ kV, emission current $I = 1.00$ mA and switch the high voltage on
- Start the measurement by pressing **F9**



- Finally, record the spectra for the targets Cu, Zn and Pb from the target sets for K-lines and L-lines fluorescence as reference spectra

Energy calibration

The energy calibration is carried out using the spectra of copper and lead (reference spectra).

- Open in the context menu of the diagram (right mouse button) or by using **Alt+E** the Energy calibration, select **global energy calibration** and enter on the right-hand side the energies of the Cu $K\alpha$ -line (8.04 keV) and of the Pb $L\alpha$ -line (10.56 keV). Do not yet close the **Energy calibration** window.
- In the context menu of the diagram select under Other evaluations Calculate peak center, mark the Cu $K\alpha$ -line and enter the result in the left-hand side of the Energy calibration (e.g. with drag & drop from the status line)
- Then determine the centre for the Pb $L\alpha$ -line and also enter it on the left-hand side.
- Close the **Energy calibration** window

Evaluation

For identifying and labelling the lines in the brass spectrum:

- In the context menu of the diagram or using **Alt+X** open the **X-ray energies** window and click on the element symbol for copper (**Cu**) and select **Adopt**
- Then enter the lines of zinc (**Zn**) and lead (**Pb**)

It becomes apparent that the second-highest peak in the spectrum consists of two lines which are not resolved: Zn $K\alpha$ and Cu $K\beta$. The Cu $K\beta$ -line is in part superimposed with the Zn $K\alpha$ -line.

The mass ratios of the alloy components are calculated by comparing the heights of the strongest lines in the fluorescence spectrum of brass and the reference spectra. These lines are: the copper $K\alpha$, the zinc $K\alpha$ and the lead $L\alpha$.

For the determination of the heights of the Cu $K\alpha$ and the Zn $K\alpha$, the brass fluorescence spectrum must be resolved in the energy range from 7.5 keV to 9.1 keV. For this the spectrum in this range is fitted with three Gaussian curves of equal width at the known energies of the Cu $K\alpha$ -line ($E = 8.04$ keV), the Cu $K\beta$ -line (8.91 keV) and the Zn $K\alpha$ -line (8.64 keV). The best way to do this is using the fit Gaussians of specified energies under Other evaluations. When selecting the area, it must be observed that all the three required energy lines are contained in the area (do not include the Pb $L\alpha$ -line).

The result is a fitted contour of the fluorescence spectrum. The determined heights H are found in the status line and are to be entered in the **Mass Proportion** diagram (e.g. by drag & drop) together with the densities ρ for Cu ($\rho = 8.96$ g/cm³), Zn ($\rho = 7.10$ g/cm³) and Pb ($\rho = 11.34$ g/cm³).

The same applies to the heights H_0 for the three reference spectra. When the three densities and the six heights have been entered, the three mass ratios are automatically calculated.

The determined mass ratios of the alloy components in the brass sample correspond well to the known chemical composition (CuZn39Pb3).

Element	Stated	Experimental
Copper	58 %	61.6 %
Zinc	39 %	35.6 %
Lead	3 %	2.9 %

Additional information

The example of the copper-zinc alloy (brass) shows how the secondary fluorescence modifies the spectrum shape. During the irradiation of such a sample with x-ray photons, the K-lines of both copper and zinc are excited. But because the $K\beta$ -line of zinc ($E = 9.57$ keV) lies above the K-edge of copper ($E = 8.99$ keV), it can also "secondarily" excite the copper L-lines.

Therefore, in the fluorescence radiation emitted, the intensity of the copper lines is higher at the cost of the Zn $K\beta$ -line, and the ratio of the Zn $K\alpha$ and the $K\beta$ -lines does not correspond to the ratio found in pure zinc. For this reason, the mass ratio of the alloy components determined from the $K\alpha$ -lines indicates a slightly too high proportion of copper.

Experiment examples chemistry

These experiment examples support you in using CASSY Lab. Where applicable, the corresponding experiment number is also given. The measurement data or settings for the examples can be loaded directly into CASSY Lab. Simply click in the  buttons in the descriptions. New examples are labelled with a red .

Inorganic Chemistry

- The Bunsen burner
- C1.3.1.6a pH measurement on foodstuffs
- C1.3.1.6b pH measurement on cleaning agents
- C1.3.1.7 Determining the pK_a value of acetic acid
- C1.3.1.8 Titration of phosphoric acid

Analytical Chemistry

- Melting and solidification point of palmitic acid
- Supercooling a sodium thiosulphate melt
- C3.1.4.5 Determining the molar mass byway of freezing-point depression
- Titration of hydrochloric acid with caustic soda solution (pH and conductivity)
- C3.3.7.2 Titration of household vinegar
- Titration of acetic acid with caustic soda solution (pH and conductivity)
- Automatic titration of NH₃ with NaH₂PO₄ (piston burette)
- Automatic titration (drop counter)
- C3.4.4.1 Gas chromatography (separation of alkanes from lighter gas)
- C3.4.4.2 Gas chromatography (separation of alcohols)
- C3.4.4.3 Gas chromatography (separation of air)
- Recording the spectrum of a solution of crude chlorophyll (with the spectrophotometer 667 3491)

Physical Chemistry

- Reaction of marble with hydrochloric acid (determining the carbonate content)
- Splitting of urea by urease (zero-order reaction)
- C4.3.2.3 Hydrolysis of tertiary butyl chloride (determining the reaction order)
- Reaction of marble with hydrochloric acid (determining the reaction order)
- C4.3.2.4 Alkaline hydrolysis of ethyl acetate (determining the reaction order)
- Alkaline hydrolysis of ethyl acetate (determining the activation parameters)
- C4.4.3.5 Differential thermal analysis of copper sulphate
- Preparing a freezing mixture
- C4.4.4.5 Determining the melting enthalpy of ice
- Gas laws
- C4.6.1.1 Determining the conductivity of different solutions
- C4.6.1.4 Determining the limiting equivalent conductivity of sodium chloride
- C4.6.1.5 Determining the dissociation constant of acetic acid

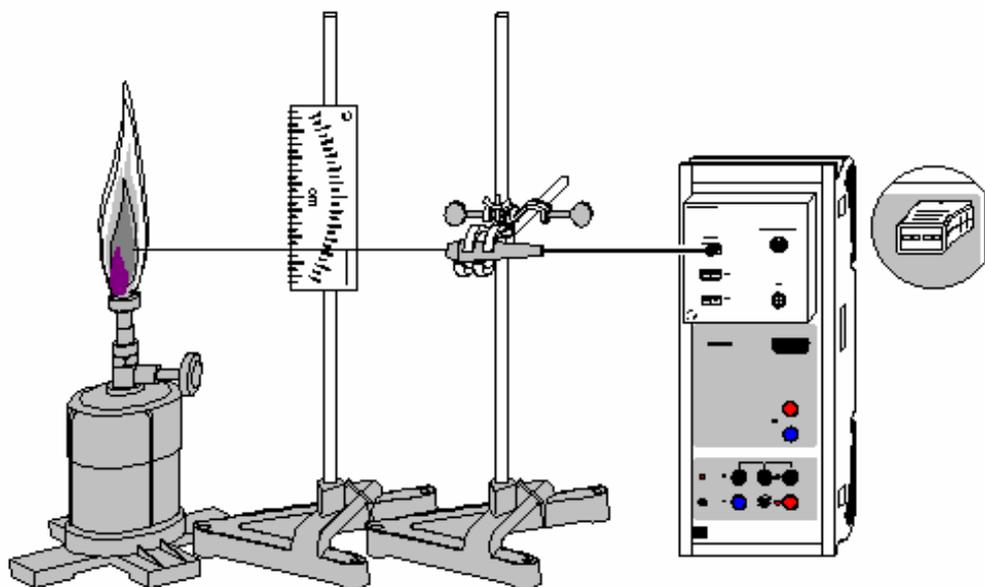
Technical Chemistry

- Separation of a two-component mixture using the rectification apparatus CE2

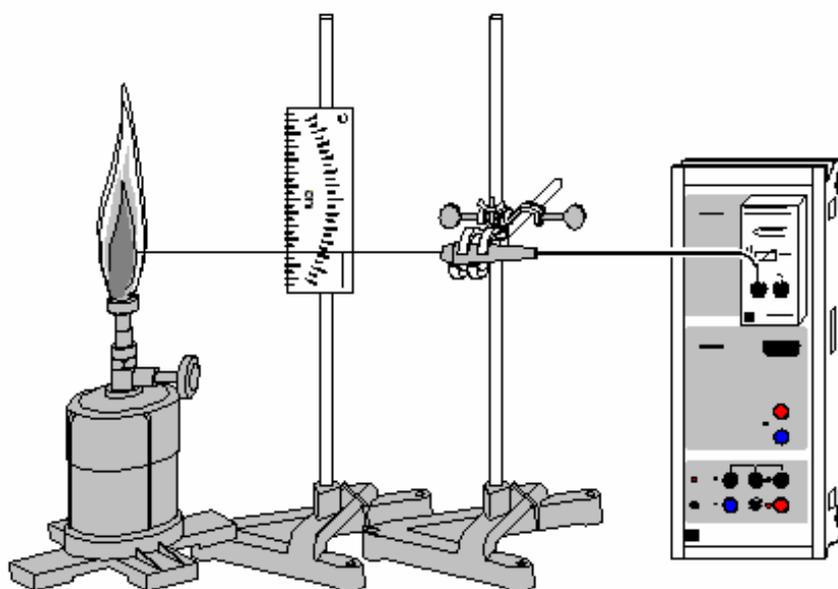
Environmental Technology

- Absorption of UV radiation
- C6.1.4.3 Simulation of the ozone hole
- C6.1.4.4 Greenhouse effect of CO₂

The Bunsen burner



Alternatively with temperature box:



can also be carried out with Pocket-CASSY and Mobile-CASSY

- Load example (chemistry box or NiCr-Ni adapter S)
- Load example (temperature box)

Safety notes

- Danger of burn. Tie back your hair and take off scarves in order to prevent them from catching fire by mistake.
- Close the gas supply immediately when the flame strikes back because of excess air supply.
- If the gas burner is not used for some time, set it to luminous flame and reduce the gas flow.
- Do not set up the gas burner near the edge of a table.

Experiment description

The gas burner is a device which is particularly often used in chemistry laboratories. It consists of a barrel with adjustable air supply. Gas can flow into the barrel through a nozzle. Depending on the design, the air supply is adjusted by means of a screw disc or another adjustable opening. If the air supply is closed, the flame obtained will luminesce in a colour between yellow and orange and reach temperatures of up to 600 °C. If the air supply is opened, the gas air mixture will burn with a rustling, bluish, non-luminous flame and produce substantially higher temperatures. The temperature regions of the flame, which depend on the height over the burner tip, can be studied very well by means of a NiCr-Ni temperature sensor.

Equipment list (with chemistry box or NiCr-Ni adapter S)

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Chemistry box or NiCr-Ni adapter S	524 067(3)
1	Temperature sensor NiCr-Ni, type K	529 676
1	Gas burner, e.g.	666 714
2	Stand bases, V-shape, 20 cm	300 02
2	Stand rods, 47 cm	300 42
1	Dual scale	340 82
1	Clamping block MF	301 25
2	Support clips, for plugging in	314 04
1	Crossed bosshead	666 543
1	Miniature clamp	666 551
	Matches or lighter	

Equipment list (alternatively with temperature box)

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Temperature box	524 045
1	Temperature sensor NiCr-Ni, DIN plug	666 193
1	Gas burner, e.g.	666 714
2	Stand bases, V-shape, 20 cm	300 02
2	Stand rods, 47 cm	300 42
1	Dual scale	340 82
1	Clamping block MF	301 25
2	Support clips, for plugging in	314 04
1	Crossed bosshead	666 543
1	Miniature clamp	666 551
	Matches or lighter	

Experiment setup (see drawing)

Connect the chemistry box (or, alternatively, the temperature box) to input A of the Sensor-CASSY, and plug the temperature sensor into input T1.

Using the stand material, set up two stands: attach the dual scale to one stand by means of the clamping block and the support clips so that the lower edge of the scale is at the same height as the tip of the gas burner. Using the miniature clamp, attach the temperature sensor to the other stand, and align it exactly horizontally.

Set up the two stands around the gas burner so that the height over the burner tip is indicated by the test rod of the temperature sensor on the centimetre scale. At the same time, the outermost tip of the temperature sensor should be located immediately over the opening of the burner. When setting up the stands, see to it that you can adjust the height of the thermocouple without getting burnt.

Carrying out the experiment

- Load settings (chemistry box or NiCr-Ni adapter S)
- Load settings (temperature box)

Remark: By means of NiCr-Ni temperature sensors, temperatures of up to 1150 °C (temperature sensor for chemistry box) or 1100 °C (temperature sensor for temperature box), respectively, can be measured. Do not exceed this measuring range.



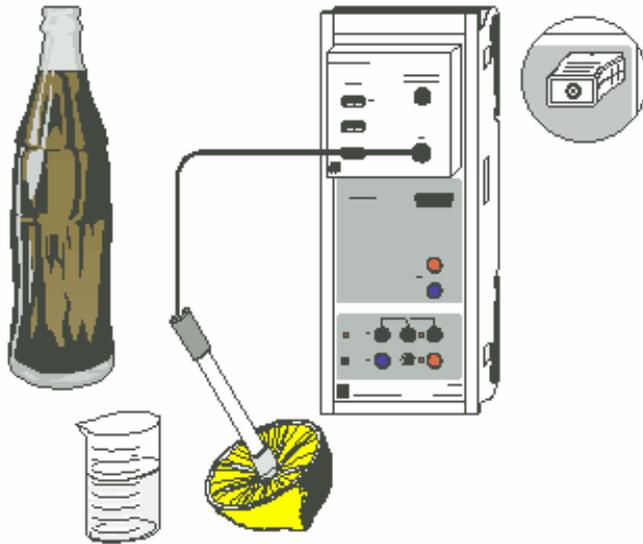
- Light the gas burner with luminous flame (air supply closed). Then open the air supply until the flame rustles.
- Fix the temperature sensor at the upper end of the measuring scale. See to it that the tip is exactly in the centre of the flame.
- Wait until the displayed measured value is almost stable (± 5 °C). Record the measured value by pressing **F9** or the  button. Via the display instrument, which is accessed via the $\varnothing A11$ button at the upper edge of the screen, the instantaneous value of the temperature can be displayed on the full screen so that persons who are sitting at a distance are able to read the temperature.
- Click the corresponding cell of the table, and enter the height over the burner tip associated with the measured value via the key board.
- Access another colour region of the flame (outer cone: weakly bluish, inner cone: light blue) in the diagram by pressing the combination **Alt+V**, and, using the mouse, mark the subsequent position by a vertical line. With **Alt+T** text related to the mark can be added.
- When reaching the light blue region of the flame, make the measurements in steps of 0.5 cm.

Evaluation

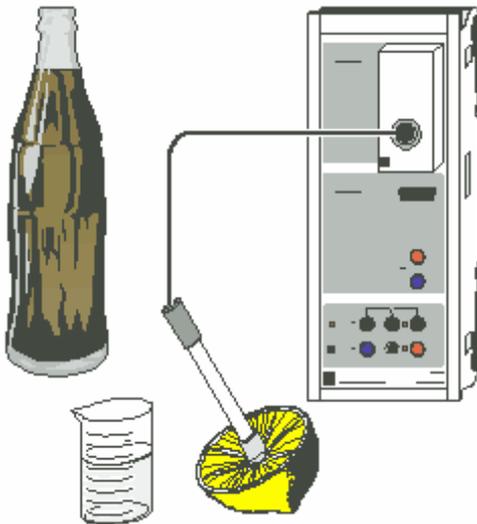
As expected, the temperature in the central region of the burner flame is higher than at a certain height above the flame. However, the temperatures generated by the light blue flame just above the outlet opening is much lower than the temperature generated by the weakly bluish flame a few centimetres above. From this it can be concluded that the gas used is only completely burnt above the light blue region of the flame.

When chemical experiments are carried out, the different temperatures of the regions of the burner flame can be taken advantage of. If particularly high temperatures are desired, the region immediately above the light blue flame is used for heating. If the heating temperature should be lower, a greater distance from the burner tip is chosen.

pH measurement on foodstuffs



Alternatively with pH box:



can also be carried out with Pocket-CASSY and Mobile-CASSY

- Load example (chemistry box or pH adapter S)
- Load example (pH box)

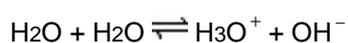
Experiment description

In this experiment, the pH values of foodstuffs, particularly of drinks, are investigated.

The pH value is a measure for the acidic strength or basic strength, respectively, of a solution. It is defined as the negative decimal logarithm of the concentration of H_3O^+ ions in an aqueous solution:

$$\text{pH} = -\lg c(\text{H}_3\text{O}^+)$$

The concentration of H_3O^+ ions depends on the autoprotolysis equilibrium of water:





In dilute solutions, the equilibrium is independent of the concentration of water molecules; at 25 °C, the equilibrium constant is:

$$K = c(\text{H}_3\text{O}^+) \cdot c(\text{OH}^-) = 10^{-14} \text{ mol}^2/\text{l}^2$$

That means, the concentration of hydronium ions and the concentration of hydroxyl ions in a solution are related via the protolysis equilibrium of water; their product always equals $10^{-14} \text{ mol}^2/\text{l}^2$. Therefore acidic solutions (hydronium ions predominate) have a pH value between 0 and 7, and basic solutions (hydroxyl ions predominate) have a pH value between 7 and 14.

Measuring the pH value is one of the most important procedures in chemical analysis. It is employed, e.g., for monitoring water quality, determining the concentrations of acidic and basic solutions, monitoring manufacturing processes (e.g. foodstuffs, body care products, paint and lacquer) and determining air pollution (acidic rain). In many biochemical processes, e.g. digestion, the pH value plays an important role.

Equipment list (with chemistry box or pH adapter S)

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Chemistry box or pH adapter S	524 067(2)
1	pH electrode with BNC plug	667 4172
1	Temperature sensor NiCr-Ni (if needed)	529 676
1	Beaker, 250 ml, squat shape	664 130
1	Laboratory knife	667 018
1	PC with Windows 95/98/NT or higher version	

Equipment list (alternatively with pH box)

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	pH-Box	524 035
1	Single-rod pH electrode	667 424
1	Beaker, 250 ml, squat shape	664 130
1	Laboratory knife	667 018
1	PC with Windows 95/98/NT or higher version	

Required substances

Tap water

Foodstuffs/drinks, e.g.:

- mineral water with and without carbonic acid
- water from a furred boiler
- fizzy drinks/cola
- fruit juice
- 1 lemon
- coffee
- various kinds of tea
- vinegar
- cooking oil
- milk

Buffer solution pH 4.00 e.g. 250 ml: 674 4640

Buffer solution pH 7.00 e.g. 250 ml: 674 4670

Experiment setup (see drawing)

Plug the chemistry box with the connected pH electrode into input A of the Sensor-CASSY.

Alternatively, connect the pH box with the single-rod pH electrode to input A of the Sensor-CASSY.

Prepare hot drinks (coffee, tea) in good time in order that they have sufficiently cooled down when you start the measurements. If the solutions are still hot and if the chemistry box is used, a temperature

sensor can be connected to input T1 for temperature compensation. In this case, the pH electrode and the temperature sensor are immersed together in the solution. CASSY Lab then automatically calculates the pH value corresponding to a temperature of 25 °C.

Cut the lemon open with the knife, and form a hollow where the juice can accumulate. The hollow has to be deep enough for the pH electrode to be immersed up to the diaphragm.

Be sure to read the Instruction Sheet for the pH electrode.

Calibration

In order to obtain accurate measuring results, you have to calibrate the pH electrode when you use it for the first time. Afterwards the calibration should be repeated from time to time:

- Load settings (chemistry box or pH adapter S)
- Load settings (pH box)
 - Select **Correct** in Settings pHA1.
 - Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 7.00, and agitate it briefly.
 - Enter 7.00 as the first target value. When the measured value is stable, press the **Correct Offset** button.
 - Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 4.00, and agitate it briefly.
 - Enter 4.00 as the second target value. When the measured value is stable, press the **Correct Factor** button.
 - For later use, store the calibrated settings with **F2** under a new name.
 - Mark the Sensor-CASSY, the pH electrode, and the chemistry or pH box in order that they can be used at the same input later on (otherwise the stored calibration will not be applicable).

Carrying out the experiment

- Use or load the calibrated settings.

In the order:

tap water, mineral waters, fizzy drinks/coke, fruit juices, lemon, teas, coffee, milk, vinegar, oil keep to the following sequence:

- Pour the liquid into the beaker (leave the lemon juice in the hollow for the measurement).
- Immerse the pH electrode so that the diaphragm is just immersed, and wait until a stable value is displayed.
- Record the measured value by pressing **F9** or the  button.
- Add a caption to the measured value in the diagram by pressing the combination **Alt+T** and entering the examined substance.
- Pour the substance away (do not drink it!), and rinse the beaker thoroughly.

Evaluation

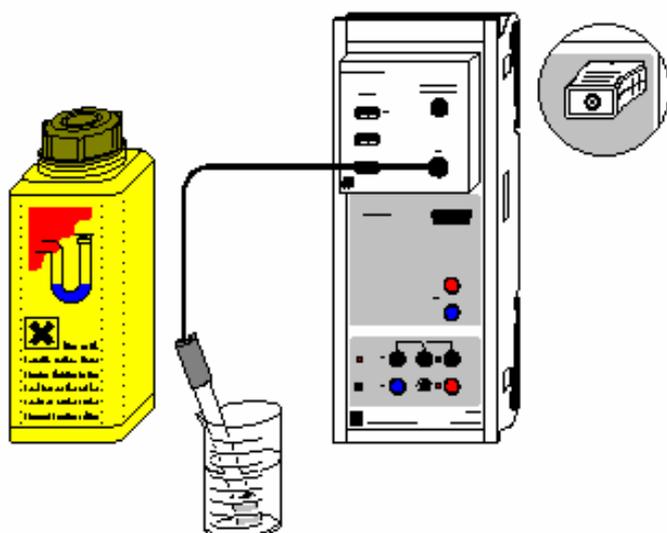
Almost all of the liquids examined in this experiment have a pH value below 8, i.e. they are acidic or neutral. Drinks such as fruit juices, fruit teas, and fizzy drinks have pH values between 2.5 and 4, which indicates that they are clearly acidic, whereas none of the substances examined exhibits a comparable degree of basic strength. The solution with a pH value of 8.9, which was the one with the strongest basicity, was obtained by warming water in a heavily furred water boiler; in this case, small amounts of dissolving calcium carbonate lead to an increase of the pH value by approx. 2 compared with tap water.

Drinks with a fruit juice content usually exhibit relatively strong acidic properties: This is particularly well seen on comparing the two kinds of tea examined in this example. The acidic character is caused by acids contained in fruit: organic acids such as citric acid, malic acid, and tartaric acid. Some of these acids also occur in human and animal metabolism (citric-acid cycle). Compared with drinks containing fruit juice, carbonic acid (H₂CO₃) in mineral water leads to a significantly weaker acidification.

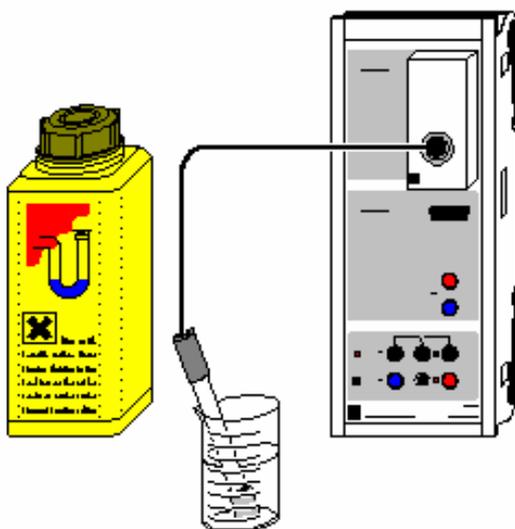
The predominantly acidic character of the examined foodstuffs stated, the process of neutralization of an acid or a base can be considered. What would happen in the stomach if strong basic liquids entered it? Maybe it is possible to examine the neutralizing function of remedies against heartburn (Maaloxan, sodium bicarbonate, salt of hartshorn).

The diagram generated can be printed via the printer symbol in the upper line on the screen.

pH measurement on cleaning agents



Alternatively with pH box:



can also be carried out with Pocket-CASSY and Mobile-CASSY

- Load example (chemistry box or pH adapter S)
- Load example (pH box)

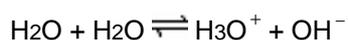
Experiment description

In this experiment, the pH values of cleaning agents are investigated. Depending on the purpose of the cleaning agents, they may have any pH value from the entire pH scale.

The pH value is a measure for the acidic strength or basic strength, respectively, of a solution. It is defined as the negative decimal logarithm of the concentration of H_3O^+ ions in an aqueous solution:

$$\text{pH} = -\lg c(\text{H}_3\text{O}^+)$$

The concentration of H_3O^+ ions depends on the autoprotolysis equilibrium of water:



In dilute solutions, the equilibrium is independent of the concentration of water molecules; at 25 °C, the equilibrium constant is:

$$K = c(\text{H}_3\text{O}^+) \cdot c(\text{OH}^-) = 10^{-14} \text{ mol}^2/\text{l}^2$$

That means, the concentration of hydronium ions and the concentration of hydroxyl ions in a solution are related via the protolysis equilibrium of water; their product always equals $10^{-14} \text{ mol}^2/\text{l}^2$. Therefore acidic solutions (hydronium ions predominate) have a pH value between 0 and 7, and basic solutions (hydroxyl ions predominate) have a pH value between 7 and 14.

Measuring the pH value is one of the most important procedures in chemical analysis. It is employed, e.g., for monitoring water quality, determining the concentrations of acidic and basic solutions, monitoring manufacturing processes (e.g. foodstuffs, body care products, paint and lacquer) and determining air pollution (acidic rain). In many biochemical processes, e.g. digestion, the pH value plays an important role.

Equipment list (with chemistry box or pH adapter S)

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Chemistry box or pH adapter S	524 067(2)
1	pH electrode with BNC plug	667 4172
1	Beaker, 100 ml, tall shape	664 137
1	Laboratory knife	667 018
1	PC with Windows 95/98/NT or higher version	

Equipment list (alternatively with pH box)

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	pH-Box	524 035
1	Single-rod pH electrode	667 424
1	Beaker, 100 ml, tall shape	664 137
1	Laboratory knife	667 018
1	PC with Windows 95/98/NT or higher version	

Required substances

Tap water

Cleaning agents, e.g.:

washing-up liquid

detergents containing acetic acid

tube cleaner

cleaning agents that are ecologically friendly

For comparison:

vinegar

1 lemon

Buffer solution pH 4.00 e.g. 250 ml: 674 4640

Buffer solution pH 7.00 e.g. 250 ml: 674 4670

Experiment setup (see drawing)

Plug the chemistry box with the connected pH electrode into input A of the Sensor-CASSY.

Alternatively, connect the pH box with the single-rod pH electrode to input A of the Sensor-CASSY.

Cut the lemon open with the knife, and form a hollow where the juice can accumulate. The hollow has to be deep enough for the pH electrode to be immersed up to the diaphragm.

Be sure to read the Instruction Sheet for the pH electrode.



Calibration

In order to obtain accurate measuring results, you have to calibrate the pH electrode when you use it for the first time. Afterwards the calibration should be repeated from time to time:

- Load settings (chemistry box or pH adapter S)
- Load settings (pH box)
- Select **Correct** in Settings pH A1.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 7.00, and agitate it briefly.
- Enter 7.00 as the first target value. When the measured value is stable, press the **Correct Offset** button.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 4.00, and agitate it briefly.
- Enter 4.00 as the second target value. When the measured value is stable, press the **Correct Factor** button.
- For later use, store the calibrated settings with **F2** under a new name.
- Mark the Sensor-CASSY, the pH electrode, and the chemistry or pH box in order that they can be used at the same input later on (otherwise the stored calibration will not be applicable).

Carrying out the experiment

- Use or load the calibrated settings.

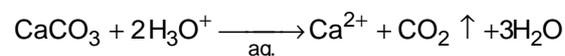
For all cleaning agents examined in the experiment keep to the following sequence:

- Keeping to safety notes and dosage instructions (calculate the dosage for the volume of the beaker, which is 100 ml) that may be written on the package, prepare the solution to be examined in the beaker. If a cleaning agent is to be used undiluted, pour as little as possible (approx. 30 ml) into the beaker.
- Leave the lemon juice in the hollow for the measurement.
- Immerse the pH electrode in the solution so that the diaphragm is just immersed, and wait until a stable value is displayed.
- Record the measured value by pressing **F9** or the  button.
- Add a caption to the measured value in the diagram by pressing the combination **Alt+T** and entering the examined substance.
- Pour the substance away, and rinse the beaker thoroughly with tap water.

Evaluation

Depending on the purpose, cleaning agents can have any pH value from strongly acidic to strongly basic.

Particularly agents for removing lime deposits and for cleaning bathrooms have relatively low pH values, which may even correspond to hydrochloric acid of approx. 0.3 mol/l concentration. This is due to the lime dissolving reaction of CaCO₃ with acids, which is used for removing lime deposits:

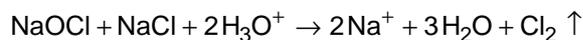


As the acidity of these cleaning agents is sometimes quite strong, the instruction saying that protective gloves should be worn is right in place on the package.

The ecologically friendly agent containing citric acid does not dissolve CaCO₃ through the acidic character of citric acid, but through formation of a water soluble complex of citric acid and calcium ions. In this way the low pH value of other cleaning agents can be avoided.

As basic soap solution also damages the skin, nowadays washing-up liquids for dissolving fat and oil mainly contain neutral surfactants instead of basic soaps. This shows up in the pH value of the examined washing-up liquid, which indicates approximate neutrality. However, as the surface of human skin is slightly acidic (around pH 5.5), this washing-up liquid will also mean stress to the skin although to a lesser extent.

Among strongly basic cleaning agents there are, above all, tube cleaners, which have to dissolve fat deposits and hair at places where mechanical cleaning is impossible. These tube cleaners contain high concentrations of sodium hydroxide (NaOH) and often, in addition, hypochlorites, e.g. NaOCl, as oxidizing agents. Tube cleaners that contain hypochlorites must not get into contact with other cleaning agents as corrosive chlorine gas is generated when acids are added to NaOCl and common salt, which is also contained in tube cleaners:



If usual pH electrodes are used, the pH value measured on the strongly basic tube cleaner is distorted by the so-called alkali error. Starting from pH values of approx. 12, glass electrodes display a value below the real one; therefore you can assume that the examined tube cleaner is even more basic.

As an alternative, economically friendly tube cleaners are supplied today, which are based on enzymes and are almost neutral. The cleaning agent examined in the example is supposed to decompose fat enzymatically. This is achieved under almost neutral conditions, which means that sewage is much less contaminated.

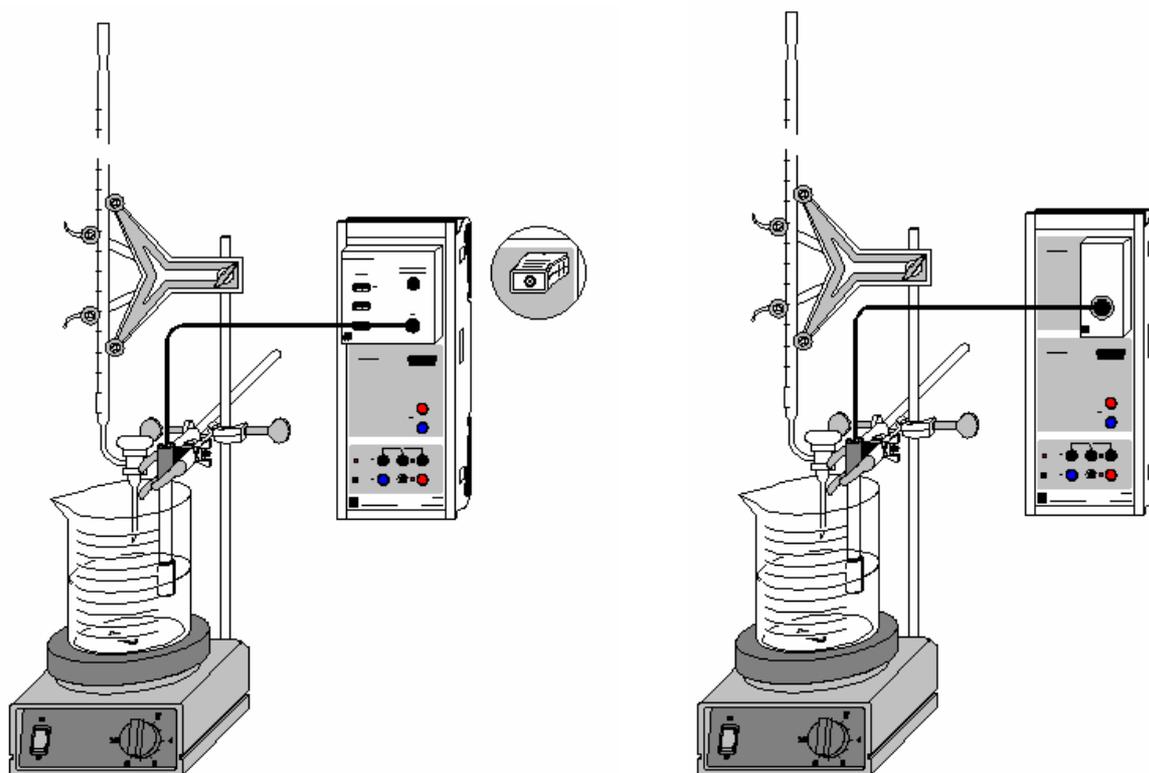
The diagram generated can be printed via the printer symbol in the upper line on the screen.

Further experiment options

The pH values of other substances that occur in everyday life can be examined as well.

- An insertion electrode with a conical diaphragm enables solid pieces of soap and creams to be examined.
- Determining the pH value of human skin by means of an electrode with flat diaphragm before and after washing the skin with soaps may be interesting with regard to the question of whether these substances are well-tolerated by the skin.

Determining the pKa value of acetic acid



can also be carried out with Pocket-CASSY and Mobile-CASSY

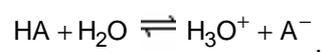
- Load example (chemistry box or pH adapter S)
- Load example (pH box)

Danger

Acids and bases are caustic. Wear protective goggles and acid-resistant gloves.

Experiment description

A measure for the strength of moderately strong or weak acids called the pKa value is determined from its titration curve with a strong base. Starting from the dissociation equation for the acid,



we obtain

$$[\text{A}^-] = [\text{HA}]$$

for the point of half equivalence (where half of the acid has reacted with the base).

From the equilibrium equation

$$K_a = \frac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}]}$$

it therefore follows that

$$\text{p}K_a = \text{pH}$$

in this case.

Thus the pK_a value can easily be read after the equivalence point and the point of half equivalence of the titration have been determined.

Equipment list (with chemistry box or pH adapter S)

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Chemistry box or pH adapter S	524 067(2)
1	pH electrode with BNC plug	667 4172
1	Magnetic stirrer	666 845
1	Beaker, 250 ml, squat shape	664 103
1	Stand rod, 450 mm, M10 thread	666 523
1	Graduated pipette, 10 ml	665 997
1	Pipetting ball	666 003
1	Burette, 25 ml	665 845
1	Burette filling funnel	665 816
1	Burette clamp simple	666 559
1	Crossed bosshead	666 543
1	Small universal clamp	666 551
1	PC with Windows 95/98/NT or higher version	

Equipment list (alternatively with pH box)

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	pH box	524 035
1	Single-rod pH electrode	667 424
1	Magnetic stirrer	666 845
1	Beaker, 250 ml, squat shape	664 103
1	Stand rod, 450 mm, M10 thread	666 523
1	Graduated pipette, 10 ml	665 997
1	Pipetting ball	666 003
1	Burette, 25 ml	665 845
1	Burette filling funnel	665 816
1	Burette clamp simple	666 559
1	Crossed bosshead	666 543
1	Small universal clamp	666 551
1	PC with Windows 95/98/NT or higher version	

Chemicals

Acetic acid, $c = 0.1 \text{ mol/l}$	e.g. 500 ml: 671 9560
Caustic soda solution, $c = 0.1 \text{ mol/l}$	e.g. 500 ml: 673 8410
Buffer solution pH 4.00	e.g. 250 ml: 674 4640
Buffer solution pH 7.00	e.g. 250 ml: 674 4670
Distilled water	

Experiment setup (see drawing)

Plug the pH box with the single rod pH electrode into input A of the Sensor-CASSY, which is connected to the PC.

Set up the titration assembly using the stand material, the magnetic stirrer, the beaker and the burette. Put about 100 ml of distilled water into the beaker and add exactly 10 ml of 0.1 M acetic acid by means of the pipette. Fill 0.1 M caustic soda solution into the burette through the funnel up to the zero mark.

Attach the pH electrode so that on the one hand the measuring diaphragm is completely immersed and on the other hand the glass membrane cannot be damaged by the rotating stirrer bar. In order to mark the equivalence point, you may add some drops of phenolphthalein solution as an indicator.

Calibration

In order to obtain accurate measuring results, you have to calibrate the pH electrode when you use it for the first time. Afterwards the calibration should be repeated from time to time:

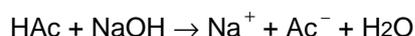
- Load settings (chemistry box or pH adapter S)
- Load settings (pH box)
- Select **Correct** in Settings pH A1.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 7.00, and agitate it briefly.
- Enter 7.00 as the first target value. When the measured value is stable, press the **Correct Offset** button.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 4.00, and agitate it briefly.
- Enter 4.00 as the second target value. When the measured value is stable, press the **Correct Factor** button.
- For later use, store the calibrated settings with **F2** under a new name.
- Mark the Sensor-CASSY, the pH electrode, and the pH box in order that they can be used at the same input later on (otherwise the stored calibration will not be applicable).
- If you want to apply other volume steps than 0.2 ml, the entry can be changed in Settings V in the field Formula, e.g. by entering "0.5*n-0.5" for steps of 0.5 ml.

Carrying out the experiment

- Use or load the calibrated settings.
- Determine the first measured value by pressing the key **F9** or the  button.
- Continuously add drops of caustic soda solution at a slow rate, and record the pH value in steps of 0.2 ml by pressing **F9**.

Evaluation

At the equivalence point ($V = V_{\text{eq}}$), all the acetic acid has reacted with the caustic soda solution:

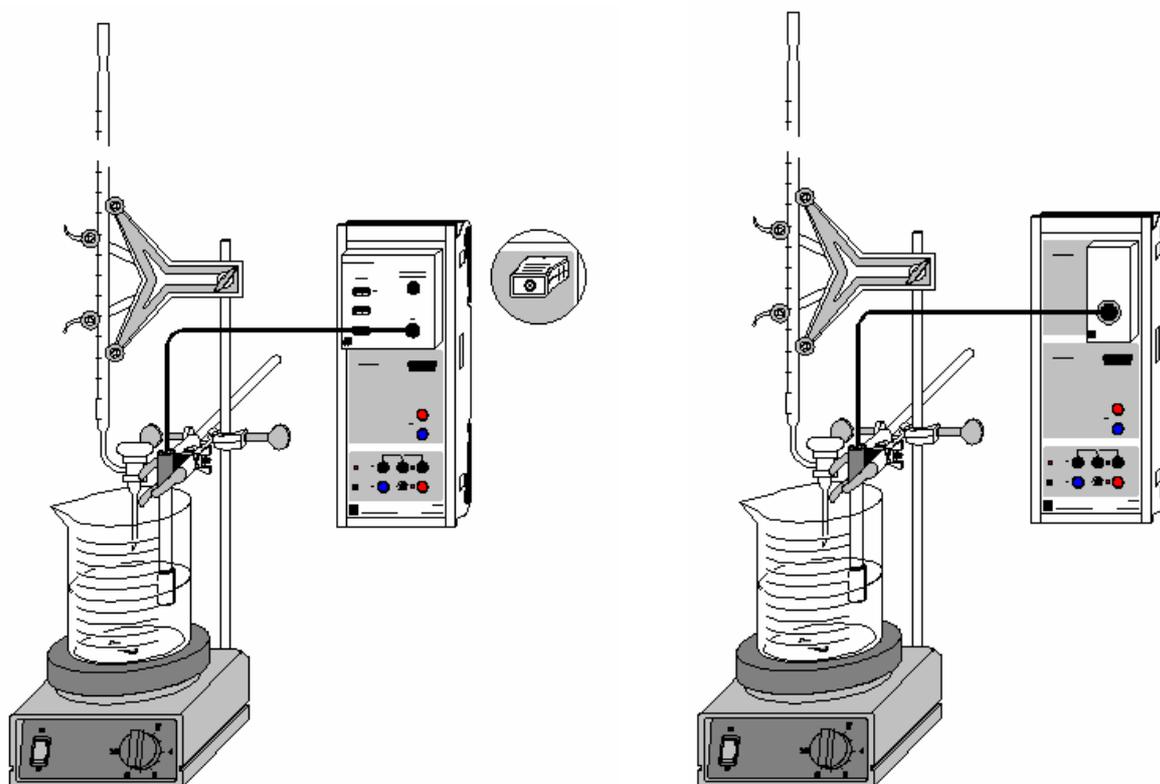


In order to exactly determine the equivalence point with CASSY-Lab, press the right mouse button in the diagram, select **Find Equivalence Point** in the menu **Other Evaluations**. After marking the curve range, you will obtain a graphical display of the equivalence point and the pK_a value as determined via the point of half equivalence ($V = V_{\text{heq}}$). The associated values are written below in the status line and can be inserted as text at an arbitrary place in the diagram.

Further experiment options

By neutralizing a hydrochloric acid solution of the same pH value as the present acetic acid solution (approx. 10 ml of 0.01 M HCl) and comparing the two titration curves, the concept of a buffer solution can be introduced. The strongly diluted hydrochloric acid is already neutralized after 1 ml of NaOH has been added, whereas for neutralizing the acetic acid of similar acidity approx. 10 ml of NaOH are required. Determining the pK_a value of the hydrochloric acid would not be meaningful.

Titration of phosphoric acid



can also be carried out with Pocket-CASSY and Mobile-CASSY

- Load example (chemistry box or pH adapter S)
- Load example (pH box)

Danger

Acids and bases are caustic. Wear protective goggles, gloves and clothing.

Experiment description

Polybasic acids exhibit characteristic titration curves, which enable the pK_a values of individual stages of protolysis to be determined following sections of the curve that have similar shapes.

In aqueous solution, phosphoric acid forms the following equilibria:

1. $\text{H}_3\text{PO}_4 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{PO}_4^- + \text{H}_3\text{O}^+$ (pK_{a1} = 2,1)
2. $\text{H}_2\text{PO}_4^- + \text{H}_2\text{O} \rightleftharpoons \text{HPO}_4^{2-} + \text{H}_3\text{O}^+$ (pK_{a2} = 7,1)
3. $\text{HPO}_4^{2-} + \text{H}_2\text{O} \rightleftharpoons \text{PO}_4^{3-} + \text{H}_3\text{O}^+$ (pK_{a3} = 12,3)

As the differences between the pK_a values amount to approx. 5 in each case, the equilibria can be considered independently of each other.

By titration with caustic potash solution, the equivalence points of the first and the second stage of protolysis can be determined. However, since KOH is not a substantially stronger base than the phosphate ion, the equilibrium 3 does not sufficiently tend to the right-hand side for the third equivalence point to be determined. In aqueous solution, the latter is only accessible in the opposite direction by titrating potassium phosphate, e.g., with hydrochloric acid.



In the pH range of the titration considered here (approx. pH 2 to pH 12), the hydrogenphosphates act as ampholytes, on the right-hand side of an equilibrium they represent the base of the respective acid-base pair, whereas on the left-hand side they have the function of the base.

Equipment list (with chemistry box or pH adapter S)

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Chemistry box or pH adapter S	524 067(2)
1	pH electrode with BNC plug	667 4172
1	Temperature sensor NiCr-Ni (if needed)	529 676
1	Magnetic stirrer	666 845
1	Beaker, 250 ml, squat shape	664 103
1	Stand rod, 450 mm, M10 thread	666 523
1	Graduated pipette, 10 ml	665 997
1	Pipetting ball	666 003
1	Burette, 50 ml	665 847
1	Burette filling funnel	665 816
1	Burette clamp simple	666 559
2	Crossed bossheads	666 543
2	Small universal clamps	666 551
1	PC with Windows 95/98/NT or higher version	

Equipment list (alternatively with pH box)

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	pH box	524 035
1	Single-rod pH electrode	667 424
1	Magnetic stirrer	666 845
1	Beaker, 250 ml, squat shape	664 103
1	Stand rod, 450 mm, M10 thread	666 523
1	Graduated pipette, 10 ml	665 997
1	Pipetting ball	666 003
1	Burette, 50 ml	665 847
1	Burette filling funnel	665 816
1	Burette clamp simple	666 559
1	Crossed bosshead	666 543
1	Small universal clamp	666 551
1	PC with Windows 95/98/NT or higher version	

Chemicals

Phosphoric acid, 10 %, 100 ml	674 3440
Caustic potash solution, c = 1 mol/l, 1 l	672 4460
Buffer solution pH 4.00, 250 ml	674 4640
Buffer solution pH 7.00, 250 ml	674 4670
Distilled water	

Experiment setup (see drawing)

Plug the chemistry box with the pH electrode into input A of the Sensor-CASSY, which is connected to the PC. If the temperature differs from 25 °C significantly, use of a temperature sensor at input T1 is recommendable. The measured temperature of the solution is automatically used to compensate the voltage determined at the pH electrode.

As an alternative to the chemistry box, plug the pH box with the single rod pH electrode into input A of the Sensor-CASSY.

Set up the titration assembly using the stand material, the magnetic stirrer, the beaker and the burette.

Put just 100 ml of distilled water into the beaker, and add 10 ml of a 10 % solution of phosphoric acid (c(H₃PO₄) approx. 1.1 mol/l) using the pipette. Fill 1 M caustic potash solution into the burette through the funnel up to the zero mark.

Attach the pH electrode so that on the one hand the measuring diaphragm is completely immersed and on the other hand the glass membrane cannot be damaged by the rotating stirrer bar. In order to mark the equivalence point, you may add some drops of a mixture of methyl red and phenolphthalein to the solution as an indicator.

Calibration

In order to obtain accurate measuring results, you have to calibrate the pH electrode when you use it for the first time. Afterwards the calibration should be repeated from time to time:

- Load settings (chemistry box or pH adapter S)
- Load settings (pH box)
 - Select **Correct** in Settings pH A1.
 - Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 7.00, and agitate it briefly.
 - Enter 7.00 as the first target value. When the measured value is stable, press the **Correct Offset** button.
 - Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 4.00, and agitate it briefly.
 - Enter 4.00 as the second target value. When the measured value is stable, press the **Correct Factor** button.
 - For later use, store the calibrated settings with **F2** under a new name.
 - Mark the Sensor-CASSY, the pH electrode, and the chemistry or pH box in order that they can be used at the same input later on (otherwise the stored calibration will not be applicable).
 - If you want to apply other volume steps than 0.5 ml, the entry can be changed in Settings V in the field Formula, e.g. by entering "0.2*n-0.2" for steps of 0.2 ml.

Carrying out the experiment

- Use or load the calibrated settings.
- Determine the first measured value by pressing the key **F9** or the  button.
- Continuously add 40 ml of caustic potash solution drop by drop at a slow rate, and record the pH value in steps of 0.5 ml by pressing **F9**.

Evaluation

The curve obtained exhibits several characteristic ranges, which correspond to the three protolysis equilibria. The equivalence points ($V = V_{\text{eq}}$) are easily determined in CASSY Lab: after pressing the right mouse button in the diagram **Standard** and selecting **Other Evaluations** and **Find Equivalence Point**, you can mark the curve range in which the equivalence point is to be determined. After the range has been marked, the calculated equivalence point and the pK_a value are displayed automatically; the associated values are written below in the status line and can be inserted as text at an arbitrary place in the diagram.

Further evaluation

The parallel shape of the buffer ranges can be made clearer. There are several possibilities of doing this:

1. In the representation **Straight Line Evaluation**: after clicking the right mouse button in the diagram, select the menu points **Fit Function** and **Best-fit straight line** and mark a narrow curve range in one of the buffer regions symmetrically around the point of half-equivalence V_{eq} as determined in the **Standard** diagram. As a result you obtain a straight line with the average slope of the marked range. Repeat this procedure in the two remaining buffer regions. In addition, calculate the third equivalence point from the first and the second one. The three straight lines that you obtain should be almost parallel according to the general formula for buffer regions

$$[\text{H}_3\text{O}^+] = \frac{K_a \cdot [\text{HA}]}{[\text{A}^-]}$$

(a slight inaccuracy occurs because of changes in volume due to the addition of KOH and because the limits of the measuring range of the pH electrode are exceeded).

2. In the representation **Straight Line Evaluation**: via the combination **Alt+F** the menu point **Free fit** enables you to define a fit function. Enter the general equation for a straight line, "A*x+B", into the appropriate line. After **Continue with marking a range**, click a narrow curve range which is sym-



metrical around the second point of half-equivalence. As a result you obtain a straight line whose slope A appears in the status line. Now set A **constant** in the menu point **Free fit (Alt+F)**, mark the corresponding ranges around the other two points of half-equivalence.

If the series of measurements is all right, the buffer regions near the points of half-equivalence should have almost equal slopes and should be well described by the fitted straight lines.

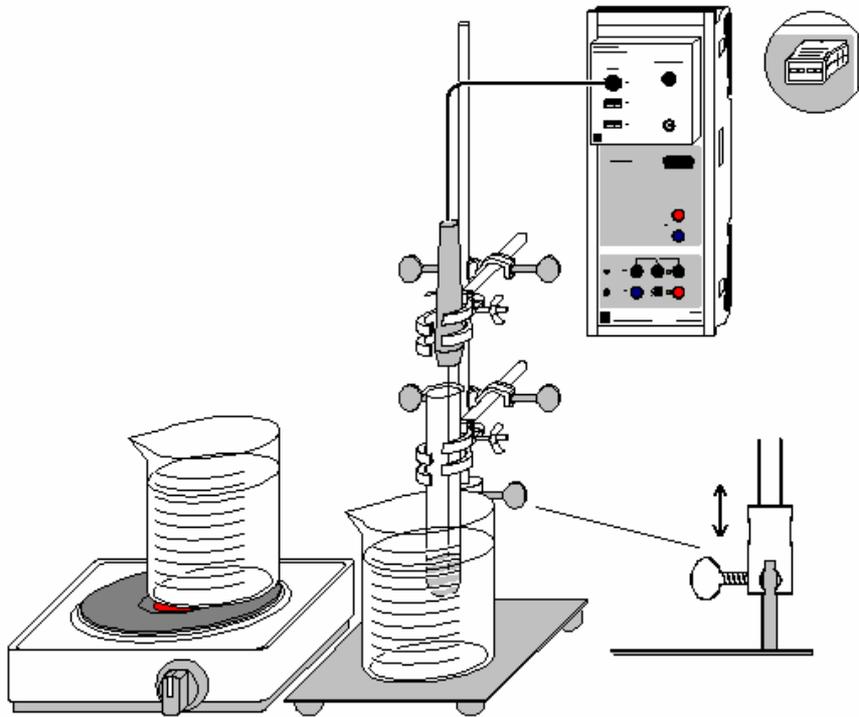
3. In the representation **Buffering Curves**: in order to plot the pH value against the degree of neutralization N of the respective protolysis stage in percent, enter the volumes associated with the three equivalence points in Settings V_{eq1} , V_{eq2} and V_{eq3} instead of the entries of the experiment example. The degree of neutralization is defined by

$$N = 100 \cdot \left[\frac{V}{V_{eq1}} \cdot (V \leq V_{eq1}) + \frac{V - V_{eq1}}{V_{eq2} - V_{eq1}} \cdot ((V > V_{eq1}) \text{ and } (V < V_{eq2})) + \frac{V - V_{eq2}}{V_{eq3} - V_{eq2}} \cdot (V \geq V_{eq2}) \right]$$

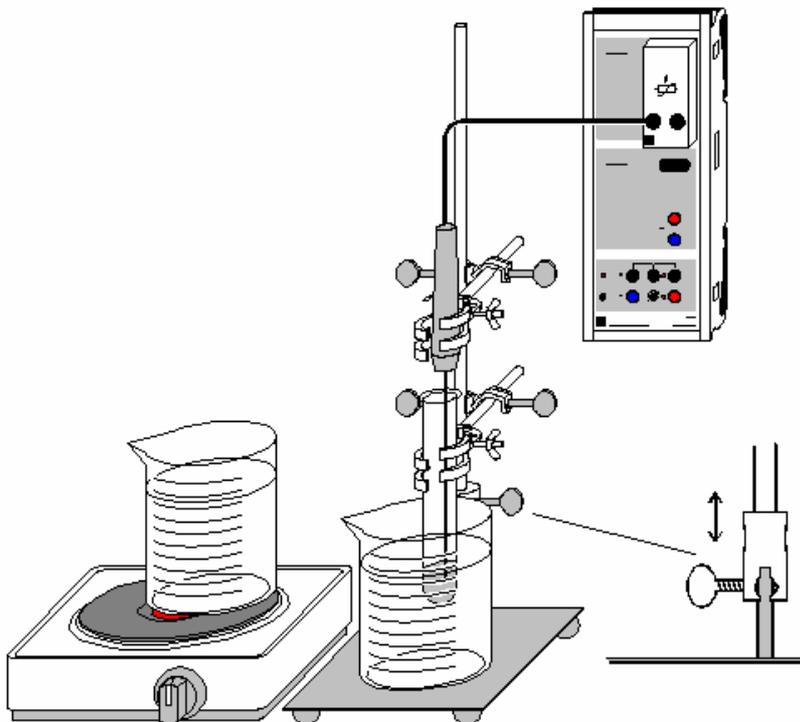
and describes the progress of the neutralization of the respective protolysis stage in percent. The first expression of each term in the square brackets is the volume ratio for each protolysis stage and the second expression represents the limits within which this ratio is to be calculated.

In the representation **Buffering Curves** ($\text{pH}_{A1} = f(N)$), three sections of the titration curve are plotted one over the other in a diagram. Here the similarity of the buffering curves are clearly seen. For further evaluation, you can add straight lines in the diagram as explained above in order to check the slope of the buffer curves.

Melting and solidification point of palmitic acid



Alternatively with temperature box:



can also be carried out with Pocket-CASSY and Mobile-CASSY

- Load example (chemistry box or NiCr-Ni adapter S)
- Load example (temperature box)



Experiment description

It is possible to find the melting and solidification point of a substance by recording its temperature curve.

Equipment list (with chemistry box or NiCr-Ni adapter S)

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Chemistry box or NiCr-Ni adapter S	524 067(3)
1	Temperature sensor NiCr-Ni, type K	529 676
2	Beakers, 250 ml, ts	664 113
1	Bunsen stand	666 504
1	Stand tube, 13 mm dia.	666 607
1	Universal bosshead	666 615
2	Double bossheads	301 09
2	Universal clamps	666 555
1	Test tube, from	664 043
1	Double-bladed spatula	666 962
1	Hot plate, e.g.	666 767
1	PC with Windows 95/98/NT or higher version	

Equipment list (alternatively with temperature box)

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Temperature box	524 045
1	Temperature sensor NTC	666 212
2	Beakers, 250 ml, ts	664 113
1	Bunsen stand	666 504
1	Stand tube, 13 mm dia.	666 607
1	Universal bosshead	666 615
2	Double bossheads	301 09
2	Universal clamps	666 555
1	Test tube, from	664 043
1	Double-bladed spatula	666 962
1	Hot plate, e.g.	666 767
1	PC with Windows 95/98/NT or higher version	

Chemicals

1	Palmitic acid, 50 g	674 0500
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Experiment setup (see drawing)

- Fill a beaker around 3/4 full with water and heat it to 80 to 90 °C on the hot plate.
- Fill the test tube with about 3 to 4 cm of palmitic acid and melt it in the water bath.
- Slide the 13 mm tube above the 10 mm tube using the universal bosshead so that the two parts can "telescope". Clamp the test tube with the palmitic acid and the NTC temperature sensor to the 13 mm tube so that the sensor is approx. 1 cm above the bottom of the test tube and in the middle (not touching the wall).
- Connect the temperature sensor with input T1 of the temperature box. Connect the box at input A of Sensor-CASSY.
- Cool the sample to at least 40 °C. Use the second beaker with cold water.

Carrying out the experiment

- Load settings (chemistry box or NiCr-Ni adapter S)
- Load settings (temperature box)

Notes on calibration

The connected temperature sensor can be calibrated as necessary. To do this, open the Settings ⌘A11 (right mouse button) and, after correction, enter the two set values 0 °C and 100 °C, and click on **Correct Offset** (temperature sensor immersed in ice/water mixture) and **Correct Factor** (temperature sensor immersed in boiling water).

- Using your telescopic stand, place the test tube with the solidified palmitic acid and the embedded temperature sensor in the water bath at approx. 80 °C.
- In the program, start the measurement by clicking on the clock button (or press **F9**).
- When the temperature starts to climb steadily again above about 60 °C, lift the sample with the sensor out of the hot water bath using the stand and place in a beaker of cold water to cool it down more quickly (you can also let the sample cool in air, but this takes longer).
- When the temperature has fallen significantly below the solidification point (approx. 60 °C), stop the measurement by pressing **F9** or clicking the clock button.

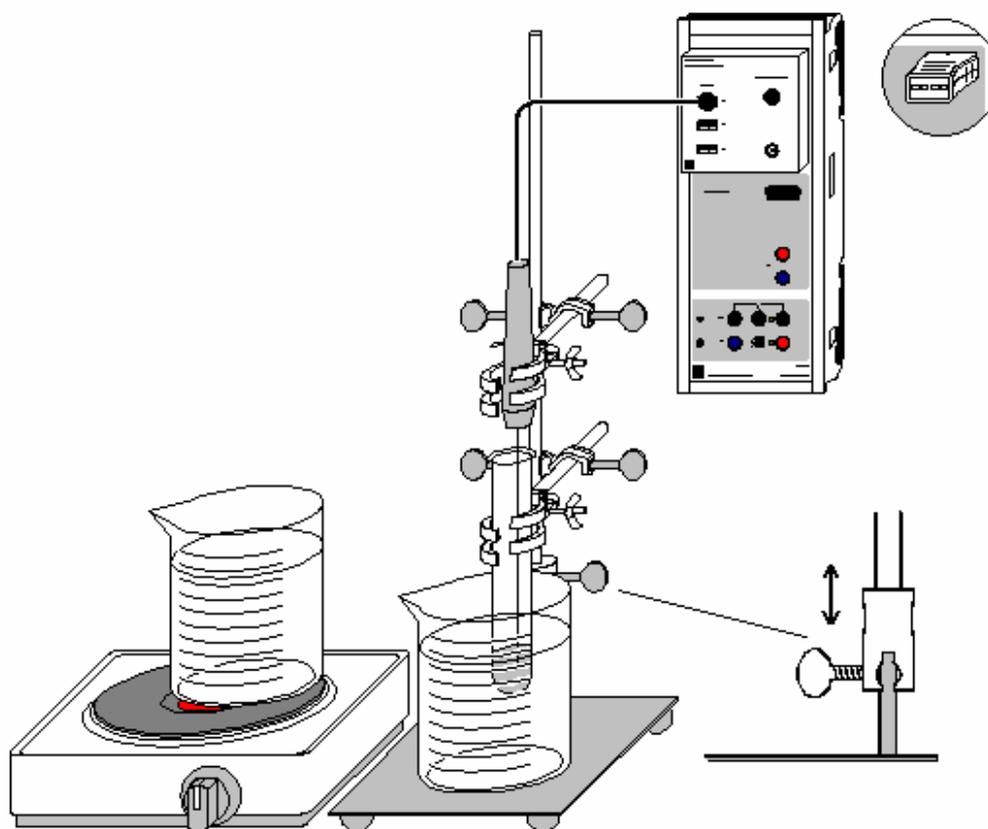
Evaluation

- You can vary areas of the windows for optimum diagram display. To do this, click on the respective axis with the right mouse button or zoom the graph.
- To determine and mark the melting and solidification point, draw a horizontal line (click on the graph with the right mouse button and set a horizontal line as a marker) and position this line so that it runs through the constant solidification range.
- You can insert the value shown in the status line (bottom left) in the diagram as text (click on the graphic with the right mouse button, set the marker and select text). You can also edit this text if desired.

Further experiment options

- Recording the temperature curve of other substances, e.g. sodium thiosulfate-5-hydrate
- Comparing the temperature curves of different substances by superimposing
- Comparing the temperature curves for a single substance in differing purities
- Investigating the melting and solidification behavior of mixtures with different compositions, determining the eutectic mixture, preparing a phase diagram

Supercooling a sodium thiosulphate melt



can also be carried out with Pocket-CASSY and Mobile-CASSY

■ Load example

Experiment description

The melting and crystallisation curve of sodium thiosulphate pentahydrate exhibits some peculiarities. The substance melts at approx. 48 °C. However, given a sufficient purity and vibration-free storage, it crystallizes only when it is strongly supercooled under 30 °C. During solidification, the temperature of sodium thiosulphate increases again reaching almost the melting point.

The corresponding regions (melting, supercooling, crystallization) are very well seen when the melting and crystallization curve is recorded.

Supercooling of a melt occurs when, due to the lack of crystal nuclei, the establishment of the equilibrium between solid and melt is delayed. States, such as a supercooled melt, which are thermodynamically unstable, but inhibited kinematically are called metastable.

The property of sodium thiosulphate which consists in forming a relatively stable supercooled melt which warms up during solidification is used for the chemical generation of heat. Hand warmers and packages of single servings of food or drinks (e.g. for travellers) can be warmed this way.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Chemistry box or NiCr-Ni adapter S	524 067(3)
1	Temperature sensor NiCr-Ni, type K	529 676
2	Beakers, 250 ml, squat shape	664 103
1	Bunsen burner stand	666 504

1	Stand tube, 13 mm Ø	666 607
1	Universal bosshead	666 615
2	Bossheads S	301 09
2	Small universal clamps	666 551
1	Test tube, e.g. from	664 043
1	Double ended spatula	666 962
1	Hot plate, e. g.	666 767
1	PC with Windows 95/98/NT or higher version	

Chemicals

1	sodium thiosulphate pentahydrate, e.g. 100 g	673 8000
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Preparing the experiment (see drawing)

- Plug the chemistry box with the temperature sensor being connected to T1 into input A of the Sensor-CASSY.
- Fill the two beakers to about $\frac{3}{4}$ of their height with water. Put one beaker on the hot plate and the other beside it.
- Fill the test tube to a height of 2 or 3 cm with sodium thiosulphate.
- Slide the 13 mm tube over the 10 mm rod and fix it with the universal bosshead so that it can be moved in a telescope-like manner.
- Using the small universal clamps, attach the test tube and the temperature sensor to the 13 mm tube so that the tip of the sensor is positioned some mm over the bottom and in the centre of the test tube embedded in the substance (it must not touch the wall of the test tube).

Calibration

In order to obtain accurate measuring results, calibrate the temperature sensor before carrying out the experiment for the first time:

■ Load settings

- Immerse the temperature sensor in a mixture of water and ice, enter the target value "0 °C" in the upper line in Settings ϑ_{A11} under **Correct**, and click **Correct Offset**.
- Then immerse the temperature sensor in boiling water, enter the target value "100 °C" in the upper line in Settings ϑ_{A11} under **Correct**, and click **Correct Factor**. If necessary, take into account the influence of the air pressure on the boiling point.
- Store the calibrated settings with **F2** under a new name.
- Mark the Sensor-CASSY, the chemistry box, and the temperature sensor in order that they can be used again in the same combination. Otherwise the stored calibration will not be applicable.

Carrying out the experiment

- Use or load the calibrated settings.
- Switch the hot plate on.
- Put the test tube with the temperature sensor into the beaker on the hot plate with the aid of the telescope-like stand.
- Start the measurement by pressing the key **F9** or the  button.
- When the sodium thiosulphate has completely melted and reached a temperature of approx. 65 °C, take the test tube out of the hot water bath by means of the stand, and put it into the beaker with cold water in order that it cools down more quickly (alternatively the sample can be cooled down more slowly in the air).
- In order to reach low supercooling temperatures, see to it that the assembly is not subject to vibrations or shocks. On the other hand, crystallisation can be initiated and enhanced by knocking slightly at the test tube.
- Maximum crystallisation temperature is reached if the test tube is taken out of the water bath on the onset of crystallization (ϑ_{A11} rises again) and by continuing knocking at the test tube.
- When the crystallisation of the sodium thiosulphate is accomplished, stop the measurement by pressing the key **F9** or the  button.



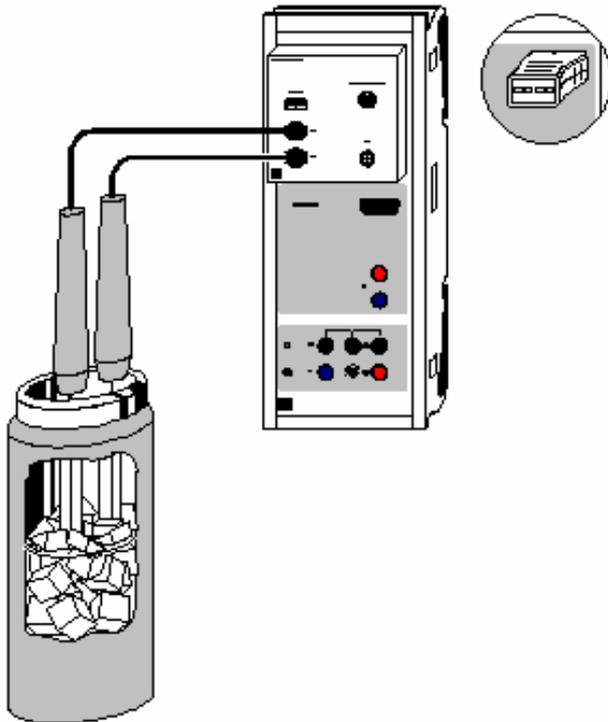
Evaluation

Several regions are discernible in the curve:

- a) Warming of the solid substance.
- b) Melting range of sodium thiosulphate pentahydrate. As the warming takes place more quickly than the establishment of the thermodynamic equilibrium, only a melting range, but not an exact melting point is seen.
- c) Warming of the melt.
- d) Cooling of the melt. It is clearly seen that the temperature falls below the melting range without a plateau showing up, which would be typical of a phase transition.
- e) The minimum of the temperature curve marks the onset of the crystallization of sodium thiosulphate pentahydrate, which, in turn, leads to a rise in temperature up to the crystallization temperature. The latter can be determined by clicking the diagram with the right mouse button, selecting **Draw Mean Value** and marking the approximately horizontal range in the temperature maximum of the crystallization region. The average crystallization temperature is displayed in the status line and can be dragged into the diagram by means of the mouse pointer or via **Alt+T**.
- f) Cooling of the completely solidified substance.

The different regions of the measured curve can be marked by vertical lines for better separation.

Determining the molar mass by way of freezing-point depression



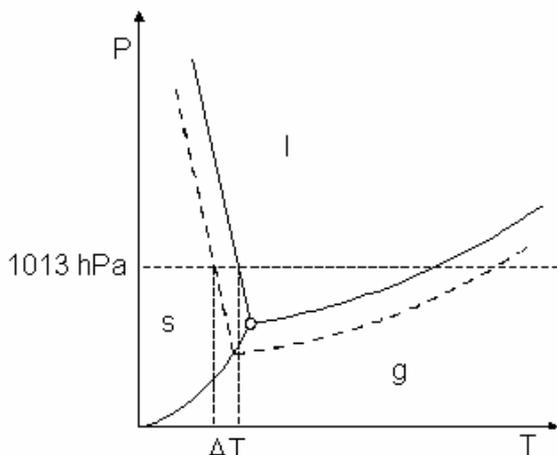
can also be carried out with Pocket-CASSY and Mobile-CASSY

■ Load example

Experiment description

A relatively simple method of determining the molar mass of a substance is given by measuring the freezing-point depression of dilute solutions of this substance in a solvent. Being a colligative property of dilute solutions, the freezing-point depression only depends on the amount of substance of the dissolved particles, but not on the kind of these particles.

If a substance is dissolved in a solvent, this leads to a shift of the boundaries between the phases solid (s), liquid (l), and gaseous (g) in the phase diagram (solid lines: pure solvent, dashed lines: solution). This shift leads to an elevation of the boiling point and a depression of the freezing point (ΔT) of the solution as compared with the pure solvent.





For the freezing-point depression, the equation

$$\Delta T = \left(\frac{R \cdot T^{*2} \cdot M_2}{\Delta H_f} \right) \cdot \frac{n_1}{m_2}$$

can be derived, where R is the general gas constant, T* and M₂ are the freezing point and molar mass of the pure solvent, and ΔH_f is its molar enthalpy of fusion. The term in brackets is defined as the cryoscopic constant K_k, which is characteristic of every solvent. For water K_k is 1853 K²g/mol; in chemical analysis, however, often camphor is preferred as a solvent because of its high constant K_k = 40000 K²g/mol. The second fraction in the above equation is called the molality (amount of substance n₁ / mass m₂ of solvent) of the dissolved substance.

From the freezing-point depression the molar mass of the dissolved substance is easily determined:

$$\Delta T = K_k \cdot \frac{n_1}{m_2} = K_k \cdot \frac{m_1}{M_1 \cdot m_2}$$

(m₁: mass of the dissolved substance in g, m₂: mass of the solvent in g, M₁: molar mass of the dissolved substance in g/mol)

Solving for M₁ gives:

$$M_1 = \frac{K_k \cdot m_1}{\Delta T \cdot m_2}$$

This equation does not only apply to dissociating substances. In the case of salts, acids, and bases, the number of dissolved particles and the degree of dissociation α have to be taken into account.

In the experiment example, an approximately 1.0-M solution of ethylene glycol (HO-CH₂-CH₂-OH) in water is examined. Ethylene glycol is found, e.g., in cars as an antifreeze agent for the cooling water and the windscreen wiper system.

For the purpose of cooling, a freezing mixture of common salt and water in a Dewar flask is used (see Preparing a freezing mixture).

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Chemistry box or NiCr-Ni adapter S	524 067(3)
2	Temperature sensor NiCr-Ni, type K	529 676
1	Dewar flask, 0.5 l	667 320
2	Test tubes, 16x160 mm, e.g. from	664 043
1	Pasteur pipette, e.g. from	665 950
1	Bulb for the Pasteur pipette, e.g. from	665 954
1	Rubber stopper, Ø 14-18 mm	667 253
1	Beaker, 250 ml, tall shape	664 138
1	Laboratory balance, resolution ≤ 0.01 g, Range ≥ 300 g	
1	PC with Windows 95/98/NT or higher version	

Required substances

Sodium chloride, e.g. 250 g	673 5700
Ethylene glycol, e.g. 250 ml	671 9800
Ice, approx. 200 g	
Distilled water	

Calibration

In order to obtain accurate measuring results, calibrate the temperature sensors when using it for the first time. Afterwards the calibration should be repeated from time to time.

■ Load settings

- Immerse the two temperature sensors in ice water (mixture of ice and water), stir with the temperature sensors, and wait until the displays show measured values that are stable up to ± 0.1 °C.
- For each of the sensors, enter the target value "0" in the first line in Settings ϑA_{12} , ϑA_{13} and ΔTA_1 under **Correct**, and press the **Correct Offset** button.
- Store the calibrated settings with **F2** under a new name.
- Mark the Sensor-CASSY, the chemistry box, and the temperature sensors in order that they can be used again in the same combination (otherwise the stored calibration will not be applicable).

Experiment setup (see drawing)

- Plug the chemistry box with the temperature sensors being connected to T2 and T3 into input A of the Sensor-CASSY.
- For preparing the freezing mixture, crush the ice as fine as possible, and put it into the Dewar flask.
- Using the balance, weigh in approx. 40-50 g of NaCl into the beaker.
- Step by step add the salt to the ice in the Dewar flask and stir with a temperature sensor. If the ice is difficult to stir, add some distilled water.
- Stir until a uniform temperature distribution is achieved in the Dewar flask. A temperature of approx. -18 to -20 °C is to be expected. This can be checked by means of the display instrument associated with the temperature sensor.
- Put two dry test tubes into the beaker on the balance, and set the balance to 0.
- Use the Pasteur pipette to put approx. 0.5-0.7 g of ethylene glycol into one of the test tubes and determine the exact mass. Set the balance to 0, add 10-12 g of distilled water to the ethylene glycol, and determine the exact mass. In Settings Comment (accessible via **F5**), the values can be entered and stored along with the measurement.
- Close the test tube with the rubber stopper, and dissolve the ethylene glycol by shaking.
- Put approx. 9-10 g of distilled water into the second test tube.
- Immerse the clean temperature sensor which is connected to T2 in the ethylene glycol solution and the other sensor, which should be clean as well, in the distilled water.

Carrying out the experiment

- Use or load the calibrated settings.
- The temperature sensors being immersed, put the two test tubes into the freezing mixture at the same time and to the same depth. The liquid levels in the test tubes should be below the level of the freezing mixture. See to it that no salt solution from the freezing mixture comes into the test tubes.
- Start the measurement by pressing the key **F9** or the  button.
- Permanently stir the content of the test tubes with the two temperature sensors until the liquids are completely frozen.
- Continue the measurement until ΔTA_1 is almost back to 0 and the temperatures are virtually constant.
- Stop the measurement by pressing the key **F9** or the  button.

Evaluation

During the measurement, three curves were recorded at the same time: the two freezing curves (ϑA_{12} and ϑA_{13}) - one for the sample and a reference curve of distilled water - and the difference curve (ΔTA_1).

The freezing curves exhibit several regions:

- At the beginning of the measurement, the temperatures ϑA_{12} and ϑA_{13} drop sharply as long as the two liquids are cooled quickly.
- The steep drop in temperature ends - above all in the case of ϑA_{12} - in a local minimum, the so-called supercooling of the liquids.



c) This temperature minimum is followed by the solidification region of the curve, which is the relevant part for determining the freezing-point depression. In the case of pure solvents, the temperature remains exactly constant during solidification giving rise to a plateau region in the freezing curve (see the curve ϑ_{A13} in the example).

In the case of solutions, the solidification region has another shape: as here almost pure solvent crystallizes and the dissolved substance remains in the liquid phase, the concentration of the dissolved substance increases steadily. For this reason, the freezing point of the solution drops even more (see the curve ϑ_{A12} in the example). That means, the looked-for freezing point of the original solution lies in the maximum at the beginning of the solidification process.

d) When the solidification process is accomplished, the substances quickly cool down to the ambient temperature following an exponential course. As the pure ice crystal has no phase boundaries, in contrast to the frozen solution, it cools down at a much quicker rate.

For evaluating the measuring data, first determine the freezing point of the ethylene glycol solution from the freezing curve. This point shows up as a maximum at the beginning of the solidification region of the curve. The coordinates of this narrow range can be read from the table of measured values (to do this click the maximum with the left mouse button - thereby the associated value in the table is marked). The temperature difference between the two freezing curves in this range determines the freezing-point depression ΔT of the solution as compared with pure water. As the measurement of the temperature difference ΔT_{A1} can be performed at a higher resolution with the chemistry box, this curve is used for determining the freezing-point depression.

For this press **Alt+Z** and select the range of the freezing and difference curve which is relevant for the evaluation with the left mouse button to obtain a magnified representation of this range. Then click the diagram with the right mouse button, select **Draw Mean Value**, and mark those measured values on the difference curve ΔT_{A1} with the mouse which belong to the solidification region of ϑ_{A12} . While setting the marks, you can check the position of the mouse pointer in the status line. The mean value of ΔT_{A1} is marked by a horizontal line in the diagram; the associated numerical value is found in the status line and can be inserted in the diagram via **Alt+T** as Text.

From the freezing-point depression found in this way, the molar mass of the substance under consideration can be determined according to the equation

$$M_1 = \frac{K_k \cdot m_1}{\Delta T \cdot m_2}$$

With the values from the experiment example ($m_1 = 0.63$ g; $m_2 = 11.56$ g; $\Delta T = |\Delta T_{A1}| = 1.59$ K; $K_k = 1853$ K \cdot g/mol) the molar mass of ethylene glycol turns out to be

$$M_1 = 63.51 \text{ g/mol.}$$

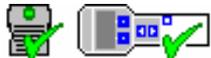
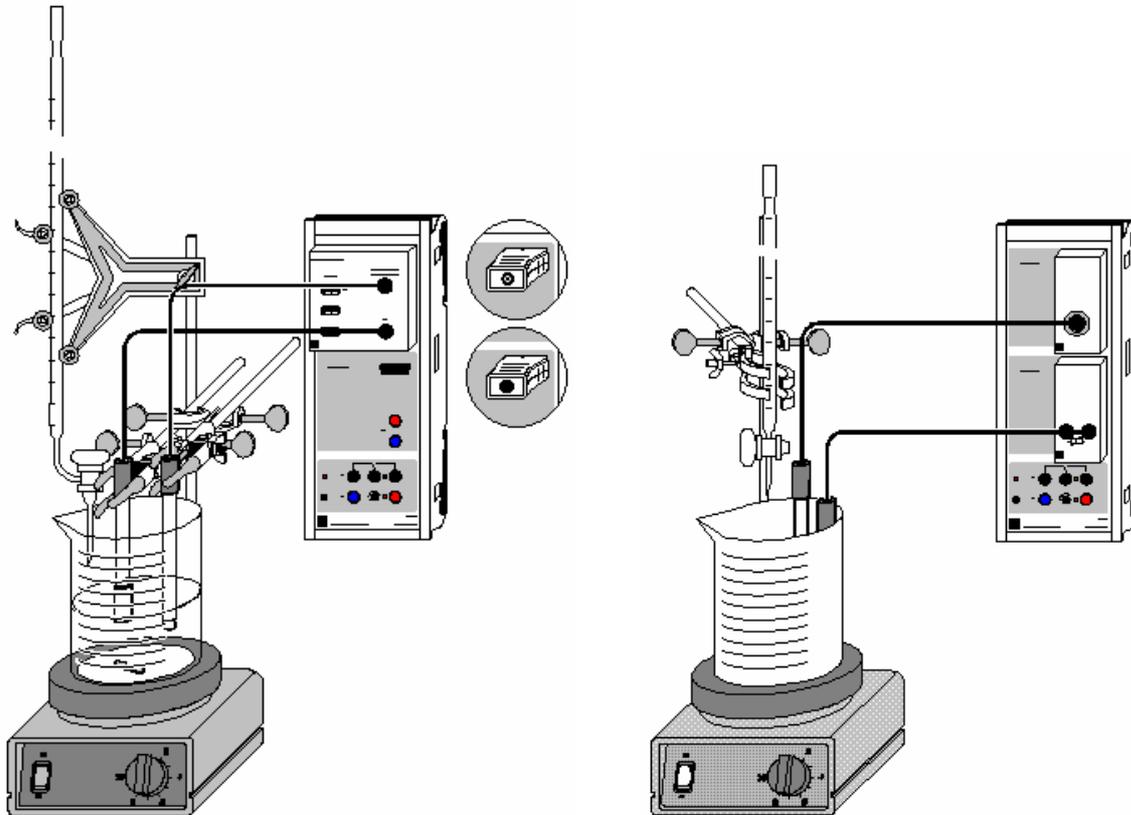
Compared with the literature value of 62.07 g/mol, this corresponds to an error of 2.3 %.

Further experiment options

This experiment setup is well suited to record the freezing curves of many other substances.

Provided the composition is known, the degree of dissociation at a certain concentration can be obtained from the freezing curves of salts, acids, and bases. For this the freezing-point depression of a certain amount of salt is measured, from which the total amount of dissolved particles is derived. From the result the degree of dissociation can be calculated.

Titration of hydrochloric acid with caustic soda solution (pH and conductivity)



can also be carried out with Pocket-CASSY and Mobile-CASSY

- Load example (chemistry box)
- Load example (pH adapter S and conductivity adapter S)
- Load example (pH box and conductivity box)

Danger

Acids and bases are caustic. Wear protective goggles.

Experiment description

During titration the pH value and the conductivity are measured simultaneously, and the equivalence point and the pKa value of the titration are determined in the evaluation.

Equipment list (with chemistry box or pH/conductivity adapter S)

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Chemistry box or pH/conductivity adapter S	524 067(2+1)
1	Conductivity sensor	529 670
1	pH electrode with BNC plug	667 4172
1	Magnetic stirrer	666 845
1	Beaker, 250 ml, ts	664 113
1	Stand rod, 450 mm, M10 thread	666 523
3	Crossed bossheads	666 543
3	Universal clamps	666 555
1	Burette, 50 ml	665 847
1	Burette funnel	665 816



1	Pipette, 10 ml	665 975
1	Pipetting ball	666 003
1	PC with Windows 95/98/NT or higher version	

Equipment list (alternatively with pH box and conductivity box)

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	pH box	524 035
1	pH single-rod electrode	667 424
1	Conductivity box	524 037
1	Conductivity measuring cell	667 426
1	Magnetic stirrer	666 845
1	Beaker, 250 ml, ts	664 113
1	Stand rod, 450 mm, M10 thread	666 523
3	Crossed bossheads	666 543
3	Universal clamps	666 555
1	Burette, 50 ml	665 847
1	Burette funnel	665 816
1	Pipette, 10 ml	665 975
1	Pipetting ball	666 003
1	PC with Windows 95/98/NT or higher version	

Chemicals

Hydrochloric acid, c = 0.1 mol/l, 500 ml	674 6950
Caustic soda solution, c = 0.1 mol/l, 500 ml	673 8410
Distilled water	

Experiment setup (see drawing)

The pH and conductivity are measured by Sensor-CASSY via the pH box at input A and the conductivity box at input B.

Set up the titration assembly using the magnetic stirrer, the beaker, the stand material and the burette. Put approx. 100 ml water in the beaker and add 10 ml hydrochloric acid with the pipette.

Attach the electrodes so that they are immersed to a sufficient depth but cannot be struck by the rotating stirrer bars.

Calibration

For precise measurements, you should calibrate the electrodes before first use as well as later at longer intervals.

- Load settings (chemistry box)
- Load settings (pH adapter S and conductivity adapter S)
- Load settings (pH box and conductivity box)
 - In Settings pH pHA1 select **Correct**.
 - Rinse the electrode with distilled water, immerse it in a pH 7.00 buffer solution and agitate it briefly.
 - Enter 7.00 as the first target value and click **Correct Offset**.
 - Rinse the electrode with distilled water, immerse it in a pH 4.00 buffer solution and agitate it briefly.
 - Enter 4.00 as the second target value and click **Correct Factor**.
 - In Settings Conductivity CB1 select **Correct**.
 - Enter the factor engraved on the electrode shaft in place of the factor 1.00 and click on **Correct Factor**.
 - You can save your calibrated settings under a new name for later use with **F2**.
 - Mark Sensor-CASSY, the electrodes and sensor boxes so that they can be used subsequently in the same configuration (this is the only way that the stored calibration will remain applicable).

Carrying out the experiment

- Use or load the appropriate calibrated settings.
- Record the initial values with **F9**.
- Allow the caustic soda solution to drip continuously and register the corresponding pH and conductivity values every 0.5 ml with **F9**.

Evaluation

There are two ways to determine the equivalence point:

pH

Click on the diagram with the right mouse button, select in the other evaluations **Find Equivalence Point** and mark the desired curve range. The value (if desired with pK value) appears in the status line at the bottom left and can be inserted anywhere in the diagram as text.

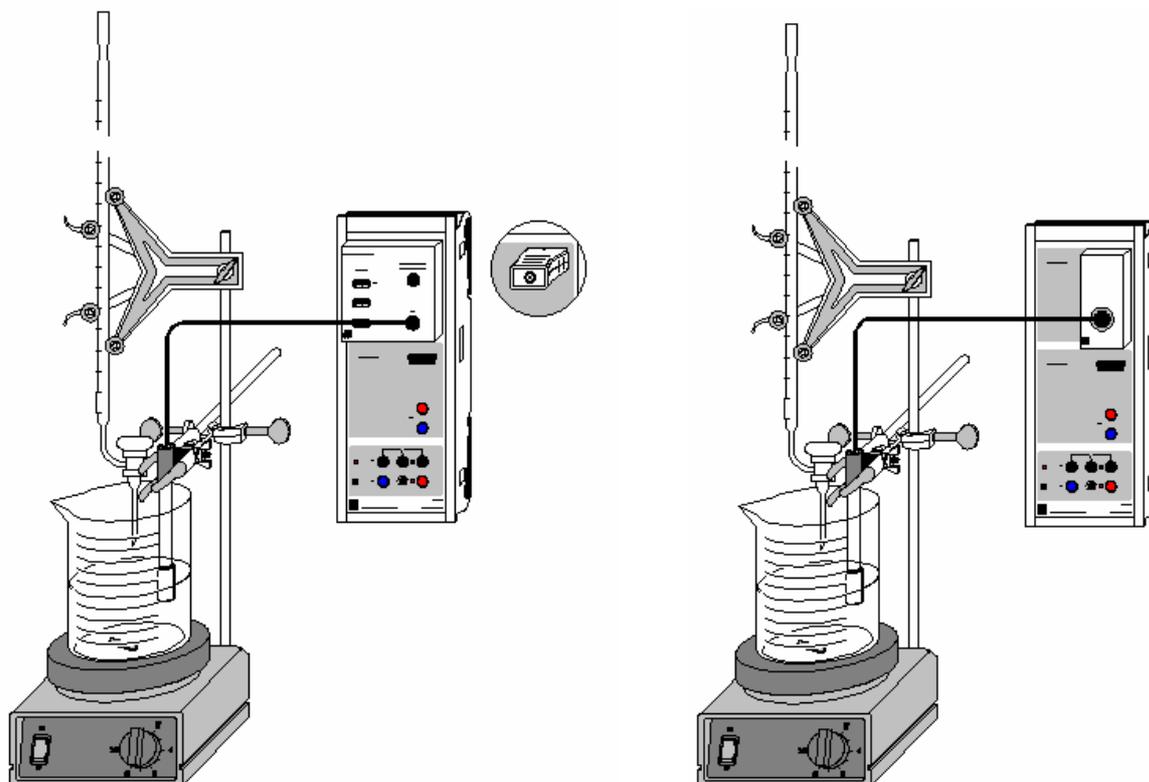
Conductivity

Click on the diagram with the right mouse button, fit a straight line and mark the left branch of the conductivity curve. Do the same with the right branch. You can place a vertical line to mark the intersection of the two lines. It is also possible to display the coordinates.

Further experiment options

- Recording of a single measurement quantity (e.g. pH)
Click on the conductivity window with the right mouse button and select **Delete**. The display window disappears, along with all other data relating to conductivity. The experiment now only measures pH.
- Using a synchronous burette or motor piston burette (automatic titration)
In the measuring parameter window (press **F5** twice) select **Automatic Recording** and set an interval of e.g. 1 s.
In the Settings V for the volume, enter the formula $t/20$ (this assumes that 1 ml is metered every 20 s. You may need to match this value as well as the maximum volume).
- Registering volume using a balance (automatic titration)
In the CASSY General Settings (press **F5**), select the option **Balance** for the serial interface to which the balance is connected (e.g. set COM2 to **Balance** if the balance is connected to this port). Match the settings of the balance (transmission rate, mode, etc.) to the balance program (refer to the manual for that balance if necessary).
In the Settings V for the volume, enter the formula $m/1.05$ (this assumes a density of the titrant of 1.05 g/ml. You may need to match this value as well as the maximum volume).

Titration of household vinegar



can also be carried out with Pocket-CASSY and Mobile-CASSY

- Load example (chemistry box or pH adapter S)
- Load example (pH box)

Danger

Acids and bases are caustic. Wear protective goggles and acid-resistant gloves.

Experiment description

The concentration of acids (and bases) can be determined via titration with a standard solution. For this purpose, the equivalence point of a volume V of the acid, which has been measured exactly, is obtained by way of titration. If the valence n of the acid is known, its concentration c can be determined by means of the equation

$$n_1 \cdot c_1 \cdot V_1 = n_2 \cdot c_2 \cdot V_2$$

With household vinegar as an example, the determination can be easily performed using 1 M NaOH as standard solution.

Equipment list (with chemistry box or pH adapter S)

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Chemistry box or pH adapter S	524 067(2)
1	pH electrode with BNC plug	667 4172
1	Temperature sensor NiCr-Ni (if needed)	529 676
1	Magnetic stirrer	666 845
1	Beaker, 250 ml, squat shape	664 103
1	Stand rod, 450 mm, M10 thread	666 523

1	Graduated pipette, 10 ml	665 997
1	Pipetting ball	666 003
1	Burette, 25 ml	665 845
1	Burette filling funnel	665 816
1	Burette clamp simple	666 559
1	Crossed bosshead	666 543
1	Small universal clamp	666 551
1	PC with Windows 95/98/NT or higher version	

Equipment list (alternatively with pH box)

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	pH box	524 035
1	Single-rod pH electrode	667 424
1	Magnetic stirrer	666 845
1	Beaker, 250 ml, squat shape	664 103
1	Stand rod, 450 mm, M10 thread	666 523
1	Graduated pipette, 10 ml	665 997
1	Pipetting ball	666 003
1	Burette, 25 ml	665 845
1	Burette filling funnel	665 816
1	Burette clamp simple	666 559
1	Crossed bosshead	666 543
1	Small universal clamp	666 551
1	PC with Windows 95/98/NT or higher version	

Chemicals

Household vinegar

Distilled water

Caustic soda solution, $c = 1 \text{ mol/l}$ e.g. 500 ml: 673 8420

Buffer solution pH 4.00 e.g. 250 ml: 674 4640

Buffer solution pH 7.00 e.g. 250 ml: 674 4670

Experiment setup (see drawing)

Plug the chemistry box with the pH electrode into input A of the Sensor-CASSY, which is connected to the PC. If the temperature differs from 25 °C significantly, use of a temperature sensor at input T1 is recommendable. The measured temperature of the solution is automatically used to compensate the voltage determined at the pH electrode.

As an alternative to the chemistry box, plug the pH box with the single rod pH electrode into input A of the Sensor-CASSY.

Set up the titration assembly using the stand material, the magnetic stirrer, the beaker and the burette. Put about 100 ml of distilled water into the beaker, and add exactly 10 ml of household vinegar using the pipette. Fill 1 M caustic soda solution into the burette through the funnel up to the zero mark.

Attach the pH electrode so that on the one hand the measuring diaphragm is completely immersed and on the other hand the glass membrane cannot be damaged by the rotating stirrer bar. In order to mark the equivalence point, you may add some drops of a phenolphthalein solution as an indicator.

Calibration

In order to obtain accurate measuring results, you have to calibrate the pH electrode when you use it for the first time. Afterwards the calibration should be repeated from time to time:

- Load settings (chemistry box or pH adapter S)
- Load settings (pH box)
- Select **Correct** in Settings pH A1.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 7.00, and agitate it briefly.



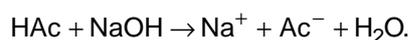
- Enter 7.00 as the first target value. When the measured value is stable, press the **Correct Offset** button.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 4.00, and agitate it briefly.
- Enter 4.00 as the second target value. When the measured value is stable, press the **Correct Factor** button.
- For later use, store the calibrated settings with **F2** under a new name.
- Mark the Sensor-CASSY, the pH electrode, and the chemistry or pH box in order that they can be used at the same input later on (otherwise the stored calibration will not be applicable).
- If you want to apply other volume steps than 0.2 ml, the entry can be changed in Settings V in the field Formula, e.g. by entering "0.5*n-0.5" for steps of 0.5 ml.

Carrying out the experiment

- Use or load the calibrated settings.
- Determine the first measured value by pressing the key **F9** or the  button.
- Continuously add drops of caustic soda solution at a slow rate, and record the pH value in steps of 0.2 ml by pressing **F9**.

Evaluation

At the equivalence point ($V = V_{eq}$), the acetic acid has entirely reacted with the caustic soda solution:



As the two substances react with one another in a ratio of 1:1, the concentration of the acetic acid is calculated according to the formula

$$c_{\text{HAc}} \cdot V_{\text{HAc}} = c_{\text{NaOH}} \cdot V_{\text{eq}}$$

For the determination of the required volume of NaOH, the equivalence point is determined by CASSY-Lab. This is simply achieved by clicking the diagram with the right mouse button, selecting the item **Other Evaluations** and clicking **Find Equivalence Point**. Just mark the desired curve range. The equivalence point and the pKa value of the curve will immediately be displayed graphically. The associated values below on the left in the status line and can be inserted as text at an arbitrary place in the diagram.

Further evaluation

More advanced calculations can be performed to discuss the measured concentration in mol/l and the indication on the label of the vinegar in Vol.-%.

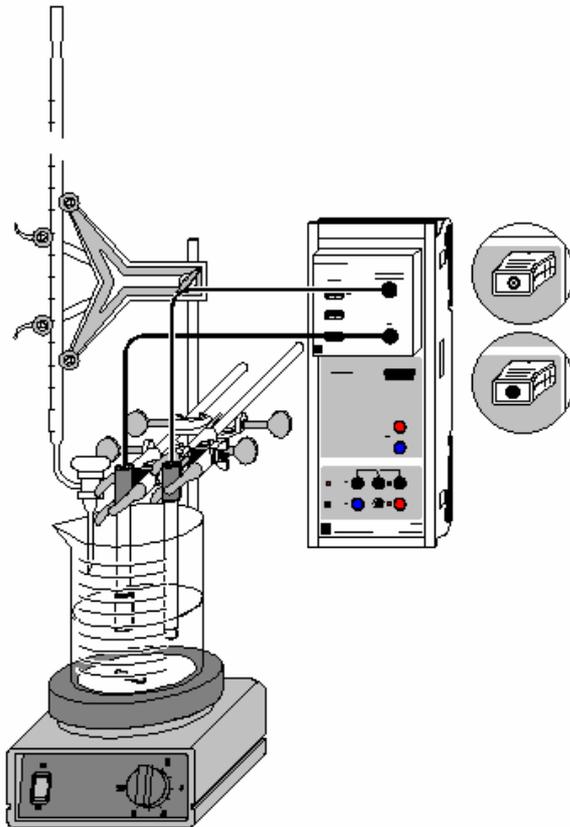
First calculate the mass of pure acetic acid in the vinegar solution by multiplying its concentration by the molar mass ($M_{\text{HAc}} = 60.05\text{g/mol}$):

$$c_{\text{HAc}} \cdot M_{\text{HAc}} = \frac{m_{\text{HAc}}}{1\text{l}}$$

Divide the value obtained by the density of pure acetic acid ($\rho_{\text{HAc}} = 1050\text{g/l}$) to obtain the proportion per volume of pure acetic acid in the titrated household vinegar. The percentage is then calculated by multiplying by a factor of 100:

$$\frac{m_{\text{HAc}} \cdot 100}{1\text{l} \cdot \rho_{\text{HAc}}} = \text{Vol.}\%_{\text{HAc}}$$

Titration of acetic acid with caustic soda solution (pH and conductivity)



can also be carried out with Pocket-CASSY and Mobile-CASSY

- Load example (chemistry box)
- Load example (pH adapter S and conductivity adapter S)

Danger

Acids and bases are caustic. Wear protective goggles and acid-resistant gloves.

Experiment description

With the chemistry box several experiments can be carried out simultaneously. This enables several aspects of a single experiment to be considered at the same time. Therefore it is possible to obtain information on the course of the reaction from both the pH measurement and the conductivity during the titration of acetic acid with caustic soda solution.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Chemistry box or pH/conductivity adapter S	524 067(2+1)
1	Conductivity sensor	529 670
1	pH electrode with BNC plug	667 4172
1	Magnetic stirrer	666 845
1	Beaker, 250 ml, squat shape	664 103
1	Stand rod, 450 mm, M10 thread	666 523
1	Graduated pipette, 10 ml	665 997
1	Pipetting ball	666 003
1	Burette, 25 ml	665 845



1	Burette filling funnel	665 816
1	Burette clamp simple	666 559
2	Crossed bossheads	666 543
2	Small universal clamps	666 551
1	PC with Windows 95/98/NT or higher version	

Chemicals

Acetic acid, $c = 0.1 \text{ mol/l}$	e.g. 500 ml: 671 9560
Caustic soda solution, $c = 0.1 \text{ mol/l}$	e.g. 500 ml: 673 8410
Distilled water	
Buffer solution pH 4.00	e.g. 250 ml: 674 4640
Buffer solution pH 7.00	e.g. 250 ml: 674 4670

Experiment setup (see drawing)

Plug the chemistry box with the conductivity sensor and the pH electrode into input A of the Sensor-CASSY, which is connected to the PC.

Set up the titration assembly using the stand material, the magnetic stirrer, the beaker and the burette.

Put about 120 ml of distilled water into the beaker, and add exactly 10 ml of acetic acid using the pipette; fill caustic soda solution into the burette through the funnel up to the zero mark.

In order to prevent distortion of the conductivity measurement by contamination of reference electrolyte from the pH electrode, rinse the pH electrode thoroughly with distilled water before using it in the experiment. In addition, the upper opening of the electrode should be laid open for the purpose of pressure compensation. When attaching the pH electrode, see to it that on the one hand the measuring diaphragm is completely immersed and on the other hand the glass membrane cannot be damaged by the rotating stirrer bar.

Because of its stray field, the conductivity sensor has to be immersed to a depth of at least 2 cm in way that its distance from the wall of the vessel and from other material in the liquid (pH sensor, stirrer bar) is at least 1 cm.

Calibration

In order to obtain accurate measuring results, you have to calibrate the pH electrode when you use it for the first time. Afterwards the calibration should be repeated from time to time:

- Load settings (chemistry box)
- Load settings (pH adapter S and conductivity adapter S)
- Select **Correct** in Settings pH A1.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 7.00, and agitate it briefly.
- Enter 7.00 as the first target value. When the measured value is stable, press the **Correct Offset** button.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 4.00, and agitate it briefly.
- Enter 4.00 as the second target value. When the measured value is stable, press the **Correct Factor** button.
- The cell constant of the conductivity sensor for the chemistry box has already been set to 0.58 in CASSY Lab. If another conductivity sensor is used, its cell constant has to be entered as a factor in Settings CA1 under **Correct**. Then the **Correct Factor** button has to be pressed.
- For a more precise determination of the cell constant, calibration solutions can be used: rinse the beaker and the conductivity sensor first with distilled water and then with approx. 30-40 ml of calibration solution. Immerse the conductivity sensor in another 50 ml of calibration solution as if it was for a conductivity measurement (pay attention to the distances from the walls of the beaker), enter the target value in the second line in Settings CA1 under **Correct**, and press the **Correct Factor** button when a stable measured value is reached.
- Mark the Sensor-CASSY, the electrodes, and the chemistry box in order that they can be used at the same input later on (otherwise the stored calibration will not be applicable).
- For later use, store the calibrated settings with **F2** under a new name.
- If you want to apply other volume steps than 0.2 ml, the entry can be changed in Settings V in the field Formula, e.g. by entering "0.5*n-0.5" for steps of 0.5 ml.

Carrying out the experiment

- Use or load the calibrated settings.
- Determine the first measured value by pressing the key **F9** or the  button.
- Continuously add 20 ml of caustic soda solution drop by drop at a slow rate, and record the pH value in steps of 0.2 ml by pressing **F9**.
- If you are interested in the use of a piston burette and a light barrier for automatic titration, see the corresponding experiment examples.

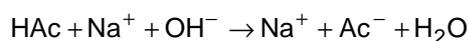
Evaluation

The determination of the equivalence point via the conductivity is done graphically. First click the coordinate system with the right mouse button, and select **Fit Function** and **Best-fit straight line**. Then mark one of the two curve sections to which the straight line is to be fitted. The appropriate sections are those to the right and to the left of the cusp of the conductivity curve. The intersection of the two fitted straight lines marks the neutralization volume for the titrated acetic acid on the x axis. It can be marked by a vertical line via the combination **Alt+V**.

For determining the equivalence point via the pH measurement, click the diagram with the right mouse button, and select **Other Evaluations** and **Find Equivalence Point**. When you have marked the curve, the equivalence point and the point of half-equivalence are calculated and displayed automatically. The pH value at the point of half equivalence also gives you the pKa value of acetic acid. The corresponding numerical values are found in the status line and can be dragged into the diagram with the left mouse button as labels.

Remarks

At the equivalence point t ($V = V_{eq}$), almost exclusively sodium and acetate ions are found in the solution:



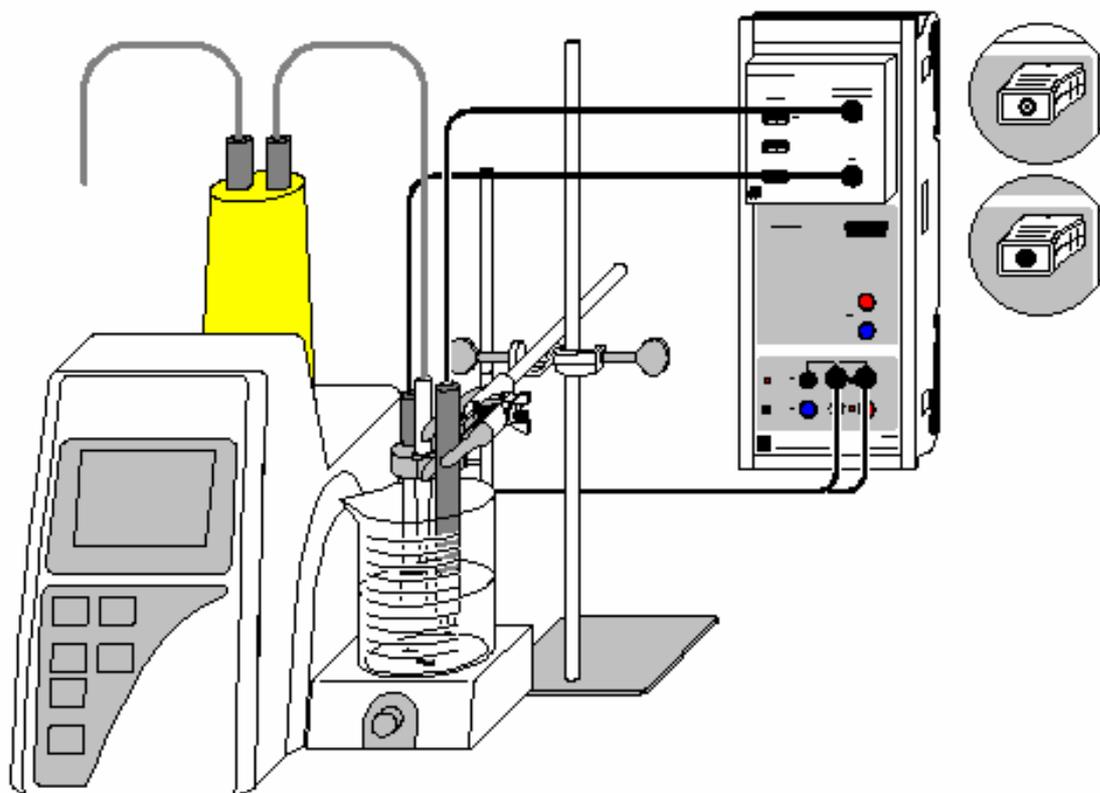
The concentrations of H_3O^+ and OH^- ions are very low (pH approx. 8). As the ion mobility of hydroxide ions is much greater than that of acetate ions, the conductivity curve exhibits a clear cusp at the equivalence point: Before the neutralization, the hydroxide ions react completely with the acetic acid so that the increase in conductivity can only be attributed to the produced acetate and sodium ions (slight rise of the conductivity curve).

The short drop in conductivity at the beginning of the titration corresponds to the somewhat steeper rise of the pH value in the same range: due to the buffer equation that applies for weak acids,

$$[\text{H}_3\text{O}^+] = K_a \frac{[\text{HA}]}{[\text{A}^-]}$$

the concentration of H_3O^+ ions is determined by the ratio $[\text{HA}]/[\text{A}^-]$, which decreases at a particularly high rate at the beginning of the titration because $[\text{A}^-]$ is almost zero in the initial acetic acid and increases quickly when caustic soda solution is added. As the ion mobility of H_3O^+ ions is particularly high, the conductivity drops correspondingly.

Automatic titration of NH_3 with NaH_2PO_4 (piston burette)



- Load example (chemistry box)
- Load example (pH adapter S and conductivity adapter S)

Experiment description

If a piston burette is used in conjunction with CASSY, a titration can be performed totally automatically including the acquisition of measured values.

The titration of a weak base such as ammonia with a weak acid such as sodium dihydrogenphosphate results in a very weak slope of the pH curve. In this case, measuring the conductivity leads to data that is easier to evaluate. By recording both curves simultaneously with CASSY, you can compare the two methods directly and assess the accuracy of the determination of the equivalence point for each case.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Chemistry box or pH/conductivity adapter S	524 067(2+1)
1	Conductivity sensor	529 670
1	pH electrode with BNC plug	667 4172
1	Piston burette	665 825
1	Connecting cable for piston burette	665 8251
1	Beaker, 250 ml, squat shape	664 103
2	Volumetric flasks, 100 ml	665 793
1	Bulb pipette, 5 ml	665 974
1	Pipetting ball	666 003
1	Bunsen burner stand, 450 mm	666 502
1	Crossed bosshead	666 543
1	Small universal clamp	666 551
1	Spatula	666 962
1	Watch glass dish, e.g. 80 mm	664 154

- | | |
|--|---------|
| 1 Powder funnel, e.g. 60 mm | 602 681 |
| 1 Balance (at least up to 100 g,
Resolution 0.01 g) | |
| 1 PC with Windows 95/98/NT
or higher version | |

Chemicals

Distilled water

Ammonia solution, dilute	e.g. 500 ml:	670 3650
NaH ₂ PO ₄ * 2 H ₂ O,	e.g. 50 g:	673 6000
Buffer solution pH 4.00	e.g. 250 ml:	674 4640
Buffer solution pH 7.00	e.g. 250 ml:	674 4670

Preparing the solutions

Weigh in exactly 1.56 g of sodium dihydrogenphosphate (0.01 mol) on a watch glass dish on the balance, rinse it via a funnel into a 100 ml volumetric flask with distilled water and fill up to 100 ml. Using the bulb pipette, put 5 ml of ammonia into the other volumetric flask and fill up to the mark with distilled water. As a result you have a 0.1 M solution of each of the two substances.

Experiment setup (see drawing)

Plug the chemistry box with the pH electrode into input A of the Sensor-CASSY, which is connected to the PC.

Rinse and fill the piston burette (read the instruction sheet) with the NaH₂PO₄ solution just prepared, and put the beaker with 10 ml of ammonia solution, 100 ml of distilled water, and a stirrer bar on the magnetic stirrer of the piston burette. In the menu "Dosing" of the burette, set the target volume to 20 ml and the feed rate to 2.0 ml/min.

Plug one end of the connecting cable into the two inputs on the right of the relay R of the Sensor CASSY and the other end into the push-button input of the piston burette.

In order to prevent distortion of the conductivity measurement by contamination of reference electrolyte from the pH electrode, rinse the pH electrode thoroughly with distilled water before using it in the experiment. In addition, the upper opening of the electrode should be laid open for the purpose of pressure compensation. When attaching the pH electrode (to the stand of the piston burette), see to it that on the one hand the measuring diaphragm is completely immersed and on the other hand the glass membrane cannot be damaged by the rotating stirrer bar.

Because of its stray field, the conductivity sensor has to be immersed to a depth of at least 2 cm so that its distance from the wall of the vessel and from other material in the liquid (pH sensor, stirrer bar) is at least 1 cm. Therefore it is recommendable to attach the conductivity sensor to a separate Bunsen burner stand.

Calibration

In order to obtain accurate measuring results, you have to calibrate the pH electrode when you use it for the first time. Afterwards the calibration should be repeated from time to time:

- Load settings (chemistry box)
- Load settings (pH adapter S and conductivity adapter S)
- Select **Correct** in Settings pHA1.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 7.00, and agitate it briefly.
- Enter 7.00 as the first target value. When the measured value is stable, press the **Correct Offset** button.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 4.00, and agitate it briefly.
- Enter 4.00 as the second target value. When the measured value is stable, press the **Correct Factor** button.
- The cell constant of the conductivity sensor for the chemistry box has already been set to 0.58 in CASSY Lab. If another conductivity sensor is used, its cell constant has to be entered as a factor in Settings CA1 under **Correct**. Then the **Correct Factor** button has to be pressed.



- For a more precise determination of the cell constant, calibration solutions can be used: rinse the beaker and the conductivity sensor first with distilled water and then with approx. 30-40 ml of calibration solution. Immerse the conductivity sensor in another 50 ml of calibration solution as if it was for a conductivity measurement (pay attention to the distances from the walls of the beaker), enter the target value in the second line in Settings CA1 under **Correct**, and press the **Correct Factor** button when a stable measured value is reached.
- Mark the Sensor-CASSY, the pH electrode, and the chemistry box in order that they can be used at the same input later on (otherwise the stored calibration will not be applicable).
- For later use, store the calibrated settings with **F2** under a new name.

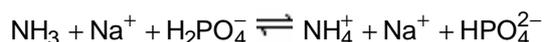
If you wish another dosage than the target volume of 20 ml and the feed rate of 2.0 ml/min at the piston burette, the default values in CASSY Lab have to be changed, namely the quantity n (table index) in the Measuring parameters and in Settings Relay/Voltage Source and the formula in Settings Volume V.

Carrying out the experiment

- Use or load the calibrated settings.
- Start the titration by pressing the key **F9** or the  button. The measured values and the dosage of the titrator from 0 to 20 ml are recorded automatically.

Evaluation

NH₃ and NaH₂PO₄ react according to the following equation:



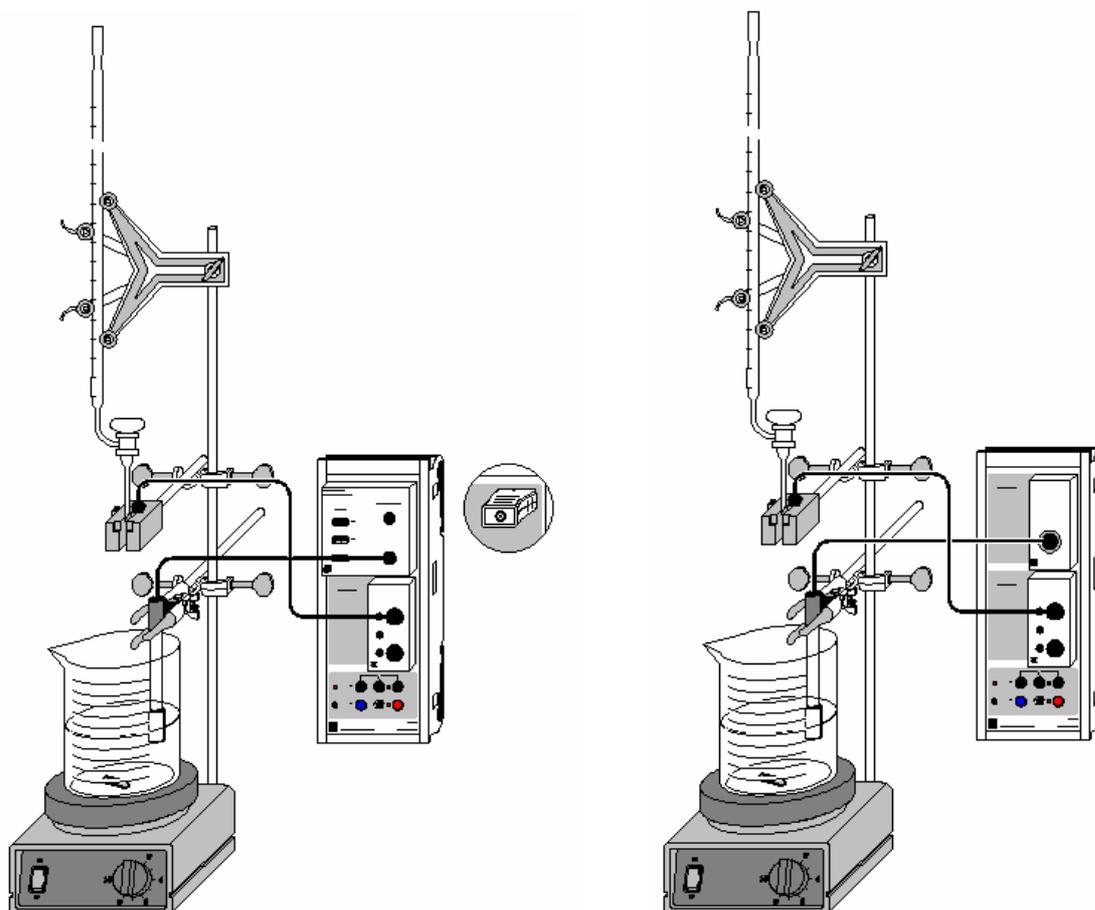
As ammonia is only a weak base, very few OH⁻ ions are in the solution at the beginning of the reaction. For this reason, the initial conductivity is very small and increases in the course of the titration due to the formation of the reaction products. When the equivalence point has been reached, i.e., when the ammonia has entirely reacted, the conductivity only increases by the amount of sodium and dihydrogenphosphate ions, which leads to a marked cusp of the conductivity curve at the equivalence point.

In order to determine the equivalence point from the conductivity graphically, first click the coordinate system with the right mouse button, and select **Fit Function** and **Best-fit straight line**. Then mark one of the two curve sections to which the straight line is to be fitted. The appropriate sections are those to the right and to the left of the cusp of the conductivity curve. The intersection of the two fitted straight lines marks the neutralization volume for the titrated acetic acid on the x axis. It can be marked by a vertical line via the combination **Alt+V**.

For determining the equivalence point via the pH measurement, click the diagram with the right mouse button, and select **Other Evaluations** and **Find Equivalence Point**. When you have marked the curve, the equivalence point and the point of half-equivalence are usually calculated and displayed automatically. The corresponding numerical values are found in the status line and can be dragged into the diagram with the left mouse button as labels.

In this example, however, the slope of the pH curve is so weak that no meaningful results are obtained when the equivalence point is determined. The determination of the equivalence point via the conductivity turns out to be more reliable in this case.

Automatic titration (drop counter)



can also be carried out with Pocket-CASSY

- Load example (chemistry box or pH adapter S)
- Load example (pH box)

Danger

Acids and bases are caustic. Wear protective goggles, gloves and clothing.

Experiment description

A titration experiment can be simplified significantly by using a light barrier as a drop counter. From the number of drops CASSY Lab calculates the dosage automatically. As the pH measurement and the plot in the pH (V) diagram are done automatically as well, you only need to read the exact total volume of the added titrator in order to be able to evaluate the measuring results.

Here the procedure of employing a drop counter is described with the titration of phosphoric acid with caustic potash solution as an example.

In aqueous solution, phosphoric acid forms the following equilibria:

1. $\text{H}_3\text{PO}_4 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{PO}_4^- + \text{H}_3\text{O}^+$ ($\text{pK}_{\text{a}1} = 2,1$)
2. $\text{H}_2\text{PO}_4^- + \text{H}_2\text{O} \rightleftharpoons \text{HPO}_4^{2-} + \text{H}_3\text{O}^+$ ($\text{pK}_{\text{a}2} = 7,1$)
3. $\text{HPO}_4^{2-} + \text{H}_2\text{O} \rightleftharpoons \text{PO}_4^{3-} + \text{H}_3\text{O}^+$ ($\text{pK}_{\text{a}3} = 12,3$)



As the differences between the pK_a values amount to approx. 5, the three equilibria can be considered independently of each other.

By titration with caustic potash solution, the equivalence points of the first and the second stage of protolysis can be determined. However, since KOH is not a substantially stronger base than the phosphate ion, the equilibrium 3 does not sufficiently tend to the right-hand side for the third equivalence point to be determined.

Equipment list (with chemistry box or pH adapter S)

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Chemistry box or pH adapter S	524 067(2)
1	pH electrode with BNC plug	667 4172
1	Temperature sensor NiCr-Ni (if needed)	529 676
1	Timer box	524 034
1	Combination light barrier	337 462
1	Multi-core cable, 6-pole, 1.5 m	501 16
1	Magnetic stirrer	666 845
2	Beakers, 250 ml, squat shape	664 103
1	Stand rod, 450 mm, M10 thread	666 523
1	Graduated pipette, 10 ml	665 997
1	Pipetting ball	666 003
1	Burette, 50 ml	665 847
1	Burette filling funnel	665 816
1	Burette clamp simple	666 559
2	Crossed bossheads	666 543
1	Small universal clamp	666 551
1	PC with Windows 95/98/NT or higher version	

Equipment list (alternatively with pH box)

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	pH box	524 035
1	Single-rod pH electrode	667 424
1	Timer box	524 034
1	Combination light barrier	337 462
1	Multi-core cable, 6-pole, 1.5 m	501 16
1	Magnetic stirrer	666 845
2	Beakers, 250 ml, squat shape	664 103
1	Stand rod, 450 mm, M10 thread	666 523
1	Graduated pipette, 10 ml	665 997
1	Pipetting ball	666 003
1	Burette, 50 ml	665 847
1	Burette filling funnel	665 816
1	Burette clamp simple	666 559
2	Crossed bossheads	666 543
1	Small universal clamp	666 551
1	PC with Windows 95/98/NT or higher version	

Chemicals

Phosphoric acid, 10 %, 100 ml	674 3440
Caustic potash solution, c = 1 mol/l, 1 l	672 4460
Buffer solution pH 4.00, 250 ml	674 4640
Buffer solution pH 7.00, 250 ml	674 4670
Distilled water	

Experiment setup (see drawing)

Plug the chemistry box with the pH electrode into input A of the Sensor-CASSY, which is connected to the PC. If the temperature differs from 25 °C significantly, use of a temperature sensor at input T1 is recommendable. The measured temperature of the solution is automatically used to compensate the voltage determined at the pH electrode.

As an alternative to the chemistry box, plug the pH box with the single rod pH electrode into input A of the Sensor-CASSY.

Plug the timer box into input B with the light barrier being connected to connector E via the 6-pole cable.

Set up the titration assembly using the stand material, the magnetic stirrer, the beaker and the burette.

Put just 100 ml of distilled water into the beaker, and add 10 ml of a 10 % solution of phosphoric acid ($c(\text{H}_3\text{PO}_4)$ approx. 1.1 mol/l) using the pipette; fill 1 M caustic potash solution into the burette through the funnel up to the zero mark.

Attach the pH electrode so that on the one hand the measuring diaphragm is completely immersed and on the other hand the glass membrane cannot be damaged by the rotating stirrer bar.

With the aid of the enclosed stand rod, mount the combination light barrier below the outlet of the burette so that the drops escaping from the burette fall through the slit of the light barrier into the beaker and trigger a signal in the sensor of the light barrier. The sensor is located by approx. 1 cm behind the opening of the light barrier. Triggering of a signal is indicated by the display instrument NB1 and by the red LED at the light barrier. To check the function, allow some drops to fall through the light barrier into an empty beaker. Then reset the counter to zero in Settings Events NB1.

Calibration

In order to obtain accurate measuring results, you have to calibrate the pH electrode when you use it for the first time. Afterwards the calibration should be repeated from time to time:

- Load settings (chemistry box or pH adapter S)
- Load settings (pH box)
- Select **Correct** in Settings pHA1.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 7.00, and agitate it briefly.
- Enter 7.00 as the first target value. When the measured value is stable, press the **Correct Offset** button.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 4.00, and agitate it briefly.
- Enter 4.00 as the second target value. When the measured value is stable, press the **Correct Factor** button.
- For later use, store the calibrated settings with **F2** under a new name.
- Mark the Sensor-CASSY, the pH electrode, and the chemistry or pH box in order that they can be used at the same input later on (otherwise the stored calibration will not be applicable).

Carrying out the experiment

- Use or load the calibrated settings.
- Start the measurement series by pressing the key **F9** or the  button.
- Carefully open the cock of the burette, and add drops of caustic potash solution at a slow rate.
- Every five seconds a measured value (volume and pH value) is recorded automatically. See to it that the drops are added at a constant rate.
- When approx. 40 ml of KOH have been added, close the cock, stop the measurement (**F9** or ) , and read the total number of drops (N_0) and the exact volume of added KOH (V_0).

Evaluation

At first the average volume of a drop of KOH is calculated. The general formula to be applied reads " $\text{NB1} * V_0 / N_0$ ", where NB1 is the number of drops, V_0 the total volume added, and N_0 the total number of drops at the end of the titration. Enter the read values for N_0 and V_0 in the field Formula of the Settings Volume V instead of "754" and "40".

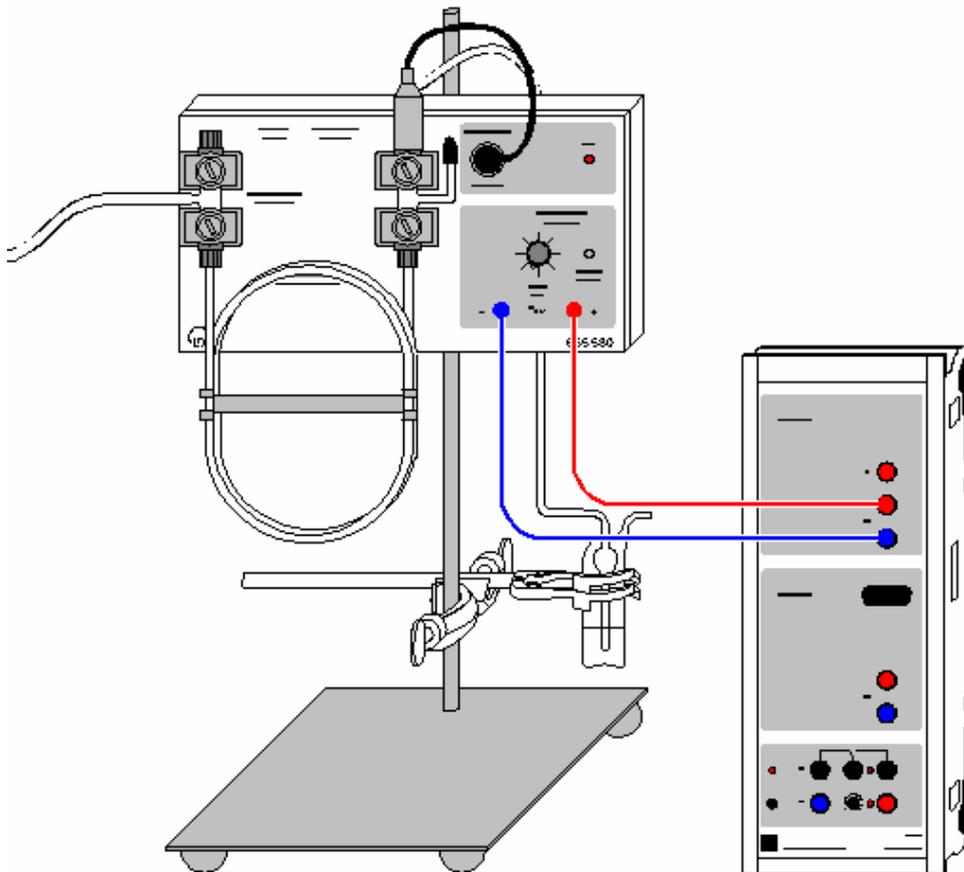


The titration curve, which is determined automatically, exhibits several characteristic ranges, which can be assigned to the three protolysis equilibria of phosphoric acid.

The equivalence points ($V = V_{eq}$) are easily determined in CASSY Lab: after pressing the right mouse button in the diagram and selecting **Other Evaluations** and **Find equivalence point**, you can mark the curve range in which the equivalence point is to be determined. After the range has been marked, the calculated equivalence point and the pK_a value are displayed automatically; the associated values are written below in the status line and can be inserted as text at an arbitrary place in the diagram using the mouse.

For further evaluation options in CASSY Lab see experiment example Titration of phosphoric acid.

Gas chromatography (separation of alkanes from lighter gas)



can also be carried out with Pocket-CASSY and Mobile-CASSY

■ Load example

Experiment description

In this experiment, in which alkanes are separated from lighter gas, the voltage from the detector is measured at the recorder output of the gas chromatograph as a function of time.

For qualitative analysis, the retention times of the individual peaks can be determined and compared with those of the reference substances.

Be sure to read the Instruction Sheet for your gas chromatograph.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Gas chromatograph LD1	665 580
1	Separation column (dinonylphthalate)	665 583
1	Hydrocarbon sensor (detector)	665 582
1	Air pump	662 286
1	Bubble counter	309 064 75
1	Syringe, 1 ml	665 957
1	Disposable needles, 10 pieces	665 960
1	Pair of cables, 50 cm, red and blue	501 45
1	PC with Windows 95/98/NT or higher version	



Chemicals

Lighter gas (sample)	
n butane, Minican gas can (reference)	660 989
Fine regulating valve	660 980

Experiment setup (see drawing)

- Set up the gas chromatograph (GC) with the separation column (dinonylphthalate) and the hydrocarbon sensor (detector).
- Connect the input of the GC to the air pump and the output to the bubble counter.
- Switch the air pump on.
- Connect the GC to the plug-in unit. The LED at the GC lights up.

Carrying out the experiment

■ Load settings

- Use the zero point controllers on the GC to set the zero line at approx. $U_{A1}=0.05$ V.
- Start the test measurement with **F9**.
- As soon as a stable zero line is recorded, stop the test measurement, again with **F9**.
- Draw approx. 1 ml of gas from the lighter into the syringe without needle. Do this several times. Then put a needle on the syringe and push the gas out except 0.05 ml. Inject the remaining 0.05 ml of gas into the injection head of the GC.
- Restart the recording of the voltage with **F9**, and continue measuring until all peaks to be expected have appeared; then stop the measurement with **F9**. Store the measurement series.
- For identifying individual components, repeat the experiment with a reference substance, e. g. n butane. Store this measurement series, too.

Evaluation

You can zoom in on the relevant curve section so that it covers the diagram (open the Evaluations menu by clicking on the diagram with the right mouse button).

To determine the retention times you can insert a vertical line through the maximum value of a peak or calculate the peak center. You can also insert the retention time in the diagram as text. By comparing the retention time of the reference peak (n butane) with the retention times of the sample, it turns out that the fourth substance is n butane.

Alternatively the curves of the sample and the reference substance can be superimposed. For this load the curves one after another and answer yes to the question "Do you want to load the new measurement series in addition to the present one?".

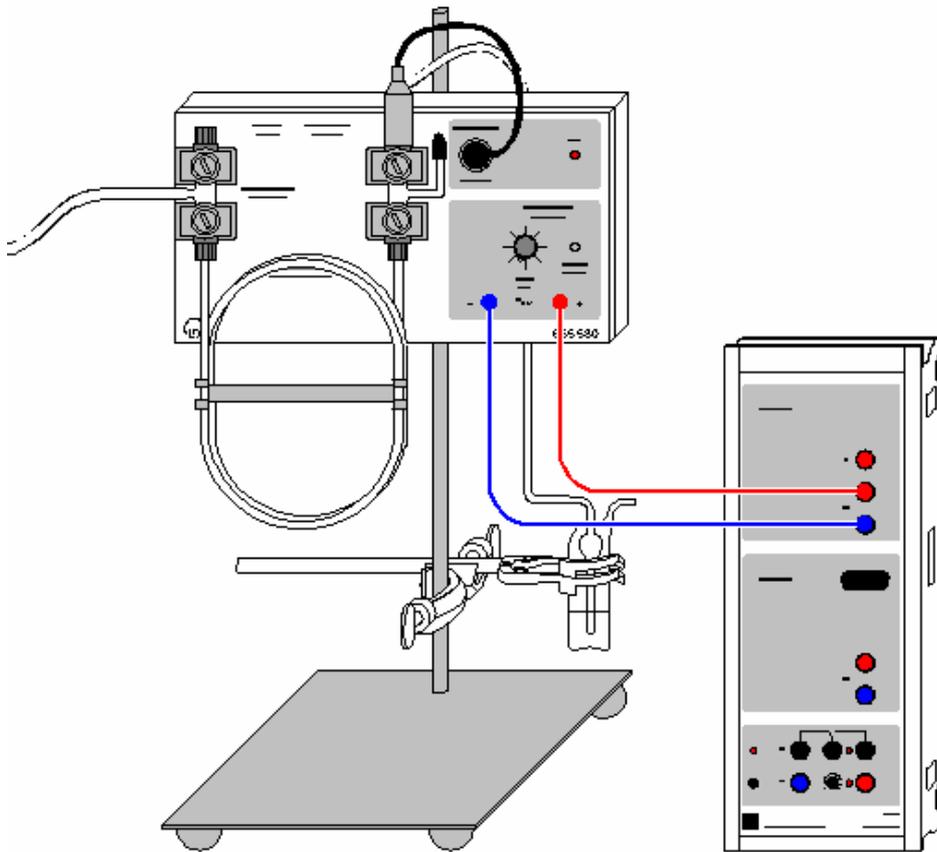
Remark: discrepancies between the retention times can arise because of changes in the room temperature.

Further experiment options

As described for the example of n butane, other components of the lighter gas can be identified with the corresponding reference substances (ethane, propane, i butane).

By recording the chromatograms of the gases from different lighters, differences in composition can be detected.

Gas chromatography (separation of alcohols)



can also be carried out with Pocket-CASSY and Mobile-CASSY

■ Load example

Experiment description

In this experiment, in which different alcohols are separated, the voltage from the detector at the recorder output of the gas chromatograph is measured as a function of time.

For qualitative analysis, the retention times of the individual peaks can be determined. A determination of the peak areas by integration enables quantitative investigation of the sample.

Be sure to read the Instruction Sheet for your gas chromatograph.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Gas chromatograph LD1	665 580
1	Separation column (Porapak P)	665 584
1	Hydrocarbon sensor (detector)	665 582
1	Air pump	662 286
1	Bubble counter	309 064 75
1	Microliter syringe, 1 μ l	665 617
1	Replacement cannulas, set of 3	665 616
1	Pair of cables, 50 cm, red and blue	501 45
1	PC with Windows 95/98/NT or higher version	



Chemicals

Methanol, 250 ml	673 2700
Ethanol, abs., 250 ml	671 9700
Propanol-1, 250 ml	674 4310
Propanol-2, 250 ml	674 4400

Experiment setup (see drawing)

- Prepare the sample, e. g. a mixture of different alcohols such as: methanol, ethanol and propanol.
- Set up the gas chromatograph with the separation column (Porapak P) and the hydrocarbon sensor (detector).
- Connect the input of the gas chromatograph to the air pump and the output to the bubble counter.
- Switch the air pump on.
- Connect the gas chromatograph to the plug-in unit. The LED at the gas chromatograph lights up.

Carrying out the experiment

■ Load settings

- Use the zero point controller on the gas chromatograph to set the zero line at approx. $U_{A1}=0.05$ V.
- Start the test measurement with **F9**
- As soon as a stable zero line is recorded, stop the test measurement, again with **F9**.
- Using the microliter syringe, inject $0.5 \mu\text{l}$ of the alcohol mixture into the injection head of the gas chromatograph.
- Restart recording of the voltage with **F9**, and continue measuring until all peaks to be expected have appeared; then stop the measurement with **F9**

Evaluation

You can zoom in on the relevant curve section so that it covers the diagram (open the Evaluations menu by clicking on the diagram with the right mouse button).

To determine the retention times you can insert a vertical line through the maximum value of a peak or calculate the peak center. You can also insert the retention time in the diagram as text.

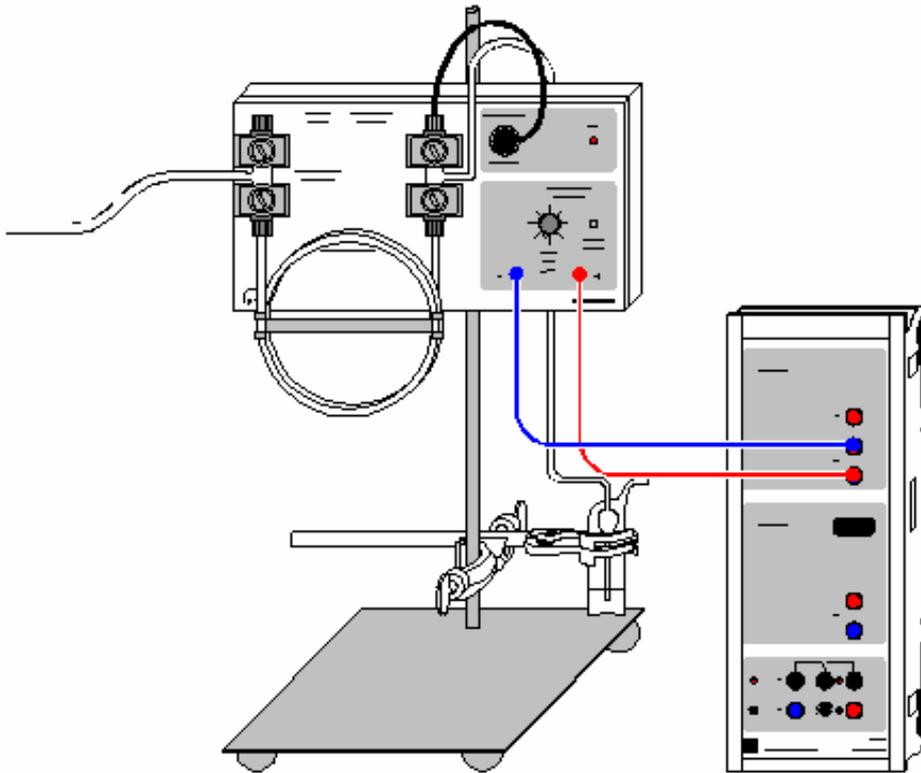
For quantitative analysis of the mixture, the peak areas are determined by integration. Then the fraction of the peak area relative to the total area of all peaks is determined. In this example, the total area of all peaks is 950 Vs. The fractional area of ethanol is thus $206 \text{ Vs} / 950 \text{ Vs} = 22 \%$. The concentration can be determined precisely through calibration with the individual substances or by using the addition method.

Further experiment options

After recording a calibration series with known alcohol concentrations, you can determine the alcohol content of several alcoholic drinks.

By heating the column in a water bath, you can also separate alcohols of greater chain length.

Gas chromatography (separation of air)



can also be carried out with Pocket-CASSY and Mobile-CASSY

■ Load example

Experiment description

In this experiment, in which the gases present in air are separated, the voltage at the recorder output of the gas chromatograph, which is supplied by the thermal conductivity detector, is measured as a function of time. The carrier gas is hydrogen, which is taken from a hydride reservoir.

Determination of the peak areas by integration enables quantitative investigation of the sample. For a qualitative analysis, the retention times of the individual peaks can be determined and compared with those of the reference substances.

Be sure to read the Instruction Sheet for your gas chromatograph.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Gas chromatograph LD1	665 580
1	Separation column with molecular sieve	665 585
1	Thermal conductivity detector	665 581
1	Metal hydride reservoir	661 005
1	Regulating valve	666 4792
1	Bubble counter	309 06 475
1	Syringe, 5 ml	665 955
1	Disposable needles, 10 pieces	665 960
1	Pair of cables, 50 cm, red and blue	501 45
1	PC with Windows 95/98/NT or higher version	



Experiment setup (see drawing)

- Set up the gas chromatograph (GC) with the separation column (molecular sieve) and the thermal conductivity detector (HCD).
- Connect the input of the GC to the metal hydride reservoir and the regulating valve and the output to the bubble counter.
- Open the regulating valve to allow hydrogen to flow through the GC.
- Connect the GC to the plug-in unit. The LED at the GC lights up.
- In order to get a positive signal, change the polarity of the connecting leads to the CASSY (the thermal conductivity of the substances to be separated is lower than that of hydrogen).

Carrying out the experiment

■ Load settings

- Use the zero point controllers on the GC to set the zero line at approx. $U_{A1}=0.05$ V.
- Start the test measurement with **F9**.
- As soon as a stable zero line is recorded, stop the test measurement, again with **F9**.
- With the syringe inject 2 ml of air into the injection head of the GC.
- Restart the recording of the voltage with **F9**, and continue measuring until all peaks to be expected have appeared; then stop the measurement with **F9**.

Evaluation

You can zoom in on the relevant curve section so that it covers the diagram (open the Evaluations menu by clicking on the diagram with the right mouse button).

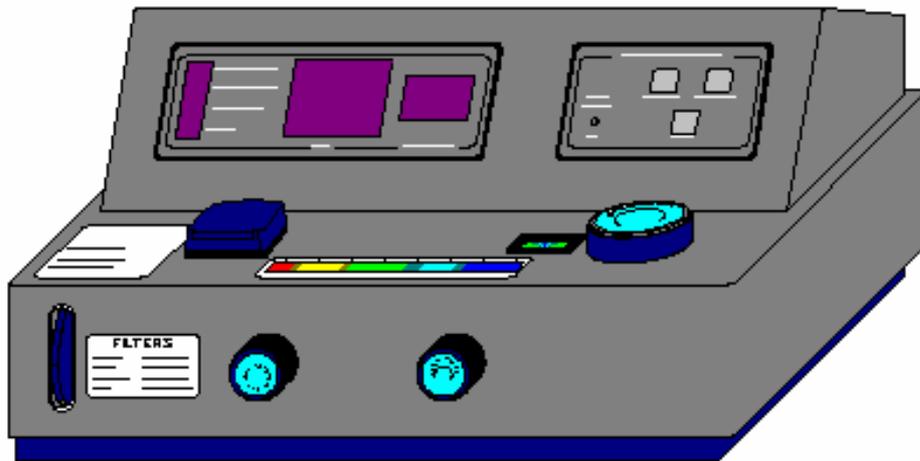
For quantitative analysis of the mixture, the peak areas are determined by integration. Then the percentage of a peak with regard to the total area of all peaks is determined. In the example, the total area of all peaks is 37.85 Vs. The percentage of the first component (oxygen) is therefore $8.12 \text{ Vs} / 37.85 \text{ Vs} = 21 \%$. The percentage of the second substance (nitrogen) is $29.73 \text{ Vs} / 37.85 \text{ Vs} = 79 \%$. As the specific heat of the two gases is similar, it is not necessary to perform a calibration with the individual substances or according to the addition method, which is usually required for an exact determination of the concentrations.

Remark: the rise of the zero line (drift) from the second peak onwards is caused by a change in the room temperature during the measurement.

Further experiment options

As this setup also enables carbon monoxide and methane to be separated, other gas mixtures, such as biogas, can be examined.

Recording the spectrum of a solution of crude chlorophyll (with the spectrophotometer 667 3491)



- Load settings

Experiment description

The spectrum is recorded by measuring the transmission of the chlorophyll solution in the wavelength range from 360 to 800 nm. Then the absorption maxima of the leaf-dyes (the spectrum of activity of photosynthesis) can be determined from the spectrum.

Equipment list

- | | |
|-----------------------------|----------|
| 1 Digital spectrophotometer | 667 3491 |
|-----------------------------|----------|

Required for preparing the chlorophyll solution:

- | | |
|-------------------------------------|----------|
| 1 Mortar | 667 094 |
| 1 Pestle | 667 095 |
| 1 Erlenmeyer, 100 ml, SB 19 | 664 241 |
| 1 Rubber stopper, SB 19 | 667 255 |
| 1 Funnel | 602 670 |
| 1 Round filters, d=110 mm, 100 pcs. | 661 034 |
| 1 Sea-shore sand, cleaned, 250 g | 674 8200 |
| 1 Acetone, 250 ml | 670 0400 |

Danger



Acetone is readily flammable. Keep it away from ignition sources.

Preparing the experiment

- Cut dried nettle leaves (tea) - alternatively fresh grass or other leaves - into small pieces, and put them into the mortar.
- Add some sea-shore sand and first only a small quantity of acetone so that the mixture can be grinded until it is a kind of pulp.
- After grinding 1 to 2 minutes, add about 10 to 20 ml of acetone and stir.
- Filter the solution, which now has a clearly green colour, into the Erlenmeyer flask with the funnel and a folded round filter.
If the experiment is not carried out immediately, keep the Erlenmeyer flask with the solution of crude chlorophyll in a dark place.
- For the experiment, part of the solution has to be diluted so that the transmission at 605 nm is larger than 0 %.



- Connect the Digital spectrophotometer to the computer with the serial cable, and switch it on. Mind the instruction sheet of the device.
- Get the program CASSY Lab started on the computer. Select the serial interface used and the **Digital spectrophotometer (667 3491)** as the connected device.

Carrying out the experiment

■ Load settings

- Fill one round cell with the solution of crude chlorophyll (sample solution) and another one with the reference solution (the pure solvent, here: acetone) each to approximately 3/4 height.
- Set the starting wavelength to 340 nm at the spectrophotometer.
(For general explanations on using the device see instruction sheet.)
- Make the 100 %T calibration with the reference cell, then insert the sample cell.
- Take over the displayed measured value and the associated wavelength by pressing **F9** (or by clicking the clock button). This value is now displayed in the table and in the plot.
- Increase the measuring wavelength by 5 nm, and repeat the calibration and the measurement.
- The measurement is finished when the measuring wavelength 800 nm has been reached.

Remark

Recording the measured values as described here takes about one hour. A shorter measuring time can be achieved by measuring in steps of 10 nm and/or by stopping the measurement already at 730 nm.

Evaluation

The spectrum can be displayed as transmission T , absorption $A = 100 - T$ or as extinction $E = -\log(T/100)$.

The strong absorption (lower transmission) around 405 nm (blue light) and 660 nm (red-orange) is clearly discernible. The evaluation menu (click Graphics with the right mouse key) enables individual wavelengths to be marked with a vertical line. With Text the marked wavelength is written near the line or curve.

Due to absorption in these parts of the visible light spectrum the rest of the spectrum stands out more conspicuously when light is reflected (leaf surface) or passes through (solution). This latter part around 550 nm corresponds to the green component of light, and this is the reason why a solution of chlorophyll and leaves appear to be green.

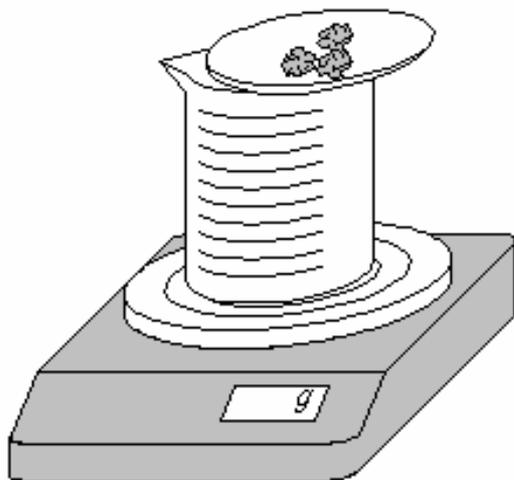
By irradiating with light at wavelengths around the absorption maxima, maximum photosynthetic performance is obtained, i. e. the absorption or extinction curve represents the spectrum of activity of photosynthesis.

If considered more precisely, this spectrum turns out to be the superposition of three individual spectra, namely those of chlorophyll a, chlorophyll b, and β -carotene. The individual leaf-dyes can be separated, e. g. by thin-layer chromatography.

Further experiment proposals

- Apart from chlorophyll, the spectra of arbitrary other coloured solutions can be studied.
- For carrying out the experiment in a shorter time a rougher resolution (e. g. in steps of 10 nm) and another wavelength range may be chosen.
- The Diode-array Photometer (667 347) makes recording spectra considerably quicker and more comfortable (667 347).
- The dependence of the transmission and the extinction on the concentration can be demonstrated by measuring a series of concentrations, e. g. of a copper-sulphate solution, at the absorption maximum.
- For kinetic investigations (e. g. decolorization of crystal violet) the absorption maximum is measured as a function of time. The opportunities provided by specifying a formula and the corresponding displays and evaluations enable the reaction order and the rate constant of the reaction to be determined.

Reaction of marble with hydrochloric acid (determining the carbonate content)



■ Load example

Danger

Hydrochloric acid is corrosive. Wear protective goggles.

Experiment description

Due to the development of CO₂ during the reaction of marble with hydrochloric acid, a loss of mass occurs which is registered using a balance (CASSY interface device not required).

Equipment list

1 CASSY Lab	524 200
1 Electronic balance with data output and connecting cable	667 795 729 769
or	
1 Electronic balance with retrofitting kit and interface cable	667 7780 667 7791 667 7796
1 Beaker, 250 ml, ss	664 130
1 Watch glass, Ø = 80 mm	664 154
1 PC with Windows 95/98/NT or higher version	

Chemicals

Marble, chips, 250 g	673 2500
Hydrochloric acid, c = 2 mol/l, 500 ml (approx. 6-7 %)	674 6920

Experiment setup (see drawing)

The software supports the Sartorius, Mettler and Ohaus balances with serial data output available from LD Didactic.

Connect the balance to a serial port of the computer (e. g. COM2) via the connecting cable. As the cables of different manufacturers differ from each other, use the interface cable provided by the respective manufacturer to ensure that the computer connection works correctly.

Fill the beaker with about 100 ml 6 % hydrochloric acid and place it on the balance. Place the watch glass on the beaker. Zero the balance by pressing the tare button. Then weigh 5 g marble chips into the watch glass.



Carrying out the experiment

■ Load settings

- Assign the balance as the measuring device to the desired serial interface (e.g. COM2) in the General tab of the Settings dialog (accessible with **F5**).
- Adjust the baud rate and the mode of the balance in Settings mass m:
Factory settings of Sartorius balances:
Mode: 7O1
Baud rate: 1200
Factory settings of Mettler balances:
Mode: 8N1
Baud rate: 9600
- In one respect the factory settings of the balance have to be changed. Read the instruction sheet of the balance:
Sartorius: data transfer as "Auto print regardless of stability" instead of "Print on request after stability"
Mettler: continuous data transfer ("S.Cont")
- All transferred measured values are displayed (Troubleshooting)
- Enter the mass of the marble chips in the calculation of the mass component. In Settings w change the example value 4.96 to the currently displayed value.
- Start the measurement with **F9**.
- Start the reaction immediately by tilting the watch glass to dump the marble chips into the beaker. Leave the watch glass tilted on the beaker.
- Record and observe the reaction until the marble is completely dissolved.
- Stop the measurement with **F9**.

Evaluation

You can correct the irritating weight fluctuations which occur when "dumping" the marble by clicking on the "fliers" in the table and setting them to the initial value (in this example 4.96 g).

In the shape of the curve of mass m (in g) respectively mass component w (in %), we can initially observe a high reaction speed, which decreases progressively (exponentially) as the concentration of the reactants (resp. the number or reacting molecules and ions) becomes less.

From the final mass values (best seen in the table), we can determine the amount of escaped CO_2 in marble (CaCO_3).



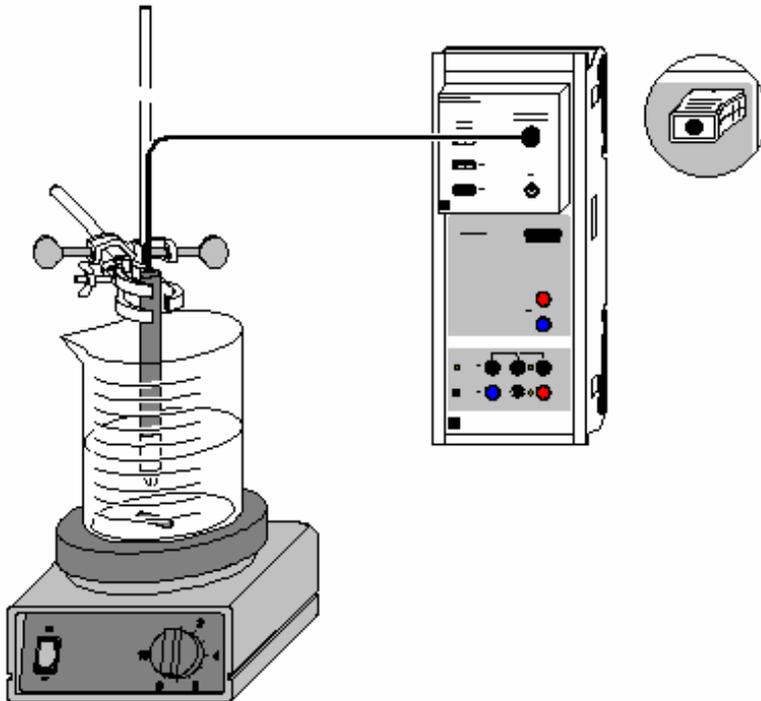
In the example measurement series, the experimentally determined CO_2 component is

$$m_{\text{CaO}} = 2.85 \text{ g} / 4.96 \text{ g} = 57.5 \% \quad m_{\text{CO}_2} = 100 \% - 57.5 \% = 42.5 \%$$

The theoretical value is

$$m_{\text{CO}_2} = \text{CO}_2 / \text{CaCO}_3 = 44.0 \text{ g} / 100.0 \text{ g} = 44.0 \%$$

Splitting of urea by urease (zero-order reaction)



can also be carried out with Pocket-CASSY and Mobile-CASSY

■ Load example

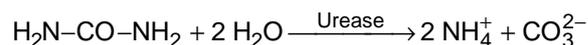
Experiment description

Enzymatic splitting of urea by urease can be considered from several points of view. At first this reaction can serve as an example of a zero-order reaction. This reaction order is recognized from the linear increase of the product concentration.

Besides, the kinetics of the catalysis can be considered: first there is an equilibrium between the substrate and the enzyme on the one hand and an enzyme-substrate complex on the other hand. This equilibrium can already be compared with the diffusion-controlled addition of a substrate to a catalytically active surface. The enzyme-substrate complex is then quickly converted into the products in a second step.

Moreover, the reaction can be used as an introduction into enzyme kinetics: by carrying out several measurements, the maximum reaction rate, the Michaelis constant, and the enzyme concentration can be determined.

As in the course of the hydrolysis of urea



ammonium carbonate is produced, which dissociates into several ions, the reaction can be followed by measuring the conductivity. The concentration of the products and the reaction rate are calculated from the gathered data.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Chemistry box or conductivity adapter S	524 067(1)
1	Conductivity sensor	529 670



1	Magnetic stirrer	666 845
1	Stand rod, 450 mm, M10 thread	666 523
1	Crossed bosshead	666 543
1	Beaker, 100 ml, tall shape	664 137
1	Beaker, 150 ml, tall shape	602 010
2	Weighing scoops	602 763
1	Graduated pipette, 10 ml	665 997
1	Pipetting ball	666 003
1	Volumetric flask, 100 ml	665 793
1	Watch glass dish, e.g. 80 mm	664 154
1	Powder funnel, e.g. 60 mm	602 681
2	Test tubes from	664 043
2	Rubber stoppers, \varnothing 14...18 mm	667 253
1	Spatula	666 961
1	Balance, resolution 0.01 g	
1	PC with Windows 95/98/NT or higher version	

Chemicals

Ammonium carbonate, e.g. 100 g	670 3900
Urea, e.g. 100 g	672 1700
Urease (1 U/mg), e.g. 5 g	675 2810
Copper(II) sulphate pentahydrate, e.g. 100 g	672 9600
Distilled water	

Note concerning the chemicals

At room temperature, urease degenerates within a few hours. Therefore urease may only stay outside the refrigeration for a few minutes.

In air, ammonium carbonate slowly reacts to ammonium bicarbonate. As this would distort the conductivity measurement, do not use old stocks.

Preparing the solutions

Weigh in 0.96 g of ammonium carbonate on the watch glass dish, and rinse it via the funnel into the 100 ml volumetric flask. Fill the volumetric flask up to the mark, and dissolve the ammonium carbonate completely.

Weigh in 0.10 g of urease and 0.60 g of urea each in a weighing scoop. Put the substances into the two test tubes, and rinse residues that may have remained in the weighing scoops into the test tubes with the aid of the pipette, in each case using exactly 10 ml of distilled water.

Close the test tubes with the rubber stoppers, and dissolve the substances by shaking. As a result you obtain 10 ml of a 1 M urea solution and 10 ml of a urease solution with an enzyme activity of 10000 U/l - i.e., given the activity of the urease of 1U/mg, 10 mmol of the substrate can be converted per minute and litre.

Calibration

■ Load settings

The cell constant of the conductivity sensor for the chemistry box has already been set to 0.58 in CASSY Lab.

If another conductivity sensor is used, its cell constant has to be entered as a factor in Settings CA1 under **Correct**. Then the **Correct Factor** button has to be pressed.

For a more precise determination of the cell constant, calibration solutions can be used:

- Rinse the 100 ml beaker and the conductivity sensor first with distilled water and then with approx. 30-40 ml of calibration solution.
- Immerse the conductivity sensor in another 50 ml of calibration solution as if it was for a conductivity measurement (pay attention to the distances from the walls of the beaker), enter the target value in the second line in Settings CA1 under **Correct**, and press the **Correct Factor** button when a stable measured value is reached.

Preparing the experiment (see drawing)

Plug the chemistry box with the conductivity sensor into input A of the Sensor-CASSY.

Rinse the 100 ml beaker and the conductivity sensor with approx. 30 ml of ammonium carbonate solution. Dispose of the rinsing solution, fill the remainder of the ammonium carbonate solution into the beaker, and measure the conductivity of this solution. See to it that the conductivity sensor is immersed to a depth of at least 2 cm and that its distance from the walls of the vessel is at least 1 cm (see instruction sheet).

Enter the measured value in Settings κ_1 in the field Formula instead of the default value. This value is required for calculating the concentration of urea since it is assumed that after complete hydrolysis of the urea a 0.1 M solution of ammonium carbonate is obtained.

Setup an assembly for measuring the conductivity using the magnetic stirrer, the stand material, the conductivity sensor, and the second beaker. Again see to it that the distance of the conductivity sensor from the walls of the vessel and from the stirrer bar is sufficient.

Fill exactly 80 ml of distilled water into the beaker (use the graduated pipette), add the urea solution, and switch the magnetic stirrer on. The conductivity indicated in the display instrument CA1 should not exceed 0.02 mS/cm in the case of pure chemicals.

Carrying out the experiment

- Use or load the calibrated settings.
- Start the measurement by pressing the key **F9** or the  button.
- Pour the urease solution into the beaker with the urea solution.
- After 2 to 3 minutes, add some crystals of copper sulphate to the solution using the spatula. Mark the moment when you add the copper sulphate by a vertical line via the combination **Alt+V**.
- Wait until the shape of the conductivity curve becomes linear again. Then stop the measurement by pressing the key **F9** or the  button.

Evaluation

For the purpose of evaluation, several diagrams have been prepared:

1. In the diagram **Specific Conductivity**, the measured values of the conductivity are plotted against the time. It is clearly seen that the conductivity increases almost linearly before the addition of copper sulphate, whereas the curve is almost horizontal after the copper sulphate has completely dissolved. This demonstrates the toxic action of the heavy metal on the enzyme.

2. The diagram **Urea Concentration** shows the course of the urea concentration as calculated from the specific conductivity. The applied formula reads:

$$[\text{NH}_2\text{CONH}_2] = \frac{\kappa_1 - C_{A1}}{\kappa_1 - \kappa_0} \cdot 100 \text{ mmol/l}$$

Here κ_1 is the conductivity of the ammonium carbonate solution measured before the experiment (conductivity at the end of the reaction), C_{A1} the conductivity measured at the time t , κ_0 the conductivity of the solution at the beginning of the reaction, and 100 mmol/l the concentration of urea at the beginning of the reaction. In order to calculate the urea concentration, the first value of the conductivity has to be entered in Settings κ_0 in the field Formula instead of the default value.

This calculation is correct until copper sulphate is added (range A in the diagram); afterwards C_{A1} is also influenced by the copper and sulphate ions present in the solution (ranges B and C). However, after the copper sulphate has completely dissolved, the relative change of the conductivity only depends on the proceeding hydrolysis of the urea (C). Therefore the reaction rate after the poisoning of the urease can also be determined.

The slope of the resulting straight line in the plot of the urea concentration against the time gives the value of $k_2 \cdot [\text{ES}]$. As $[\text{ES}]$ is almost constant in the steady state (see theoretical background), the curve obtained for the reaction rate r is approximately a straight line. In order to calculate the initial reaction rate, fit a straight line to the curve range up to $t \approx 60$ s. Click the diagram with the right mouse button, select **Fit function** and **Best-fit straight line**, and mark the corresponding curve range. The slope of



the straight line is displayed as parameter A below on the left in the status line, and can be inserted in the diagram with the left mouse button or with **Alt+T**. The slope of the second linear curve range after the addition of copper sulphate is determined in the same way. From a comparison of the two slopes it becomes obvious that the reaction has almost been stopped.

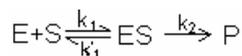
3. In the diagram **Reaction Rate**, the derivative of the urea concentration with respect to the time is plotted. It is clearly seen that the reaction rate is constant before the addition of CuSO_4 and approximately 0 afterwards. By inserting a vertical line at the value for $k_2 \cdot [\text{ES}]$ obtained via the diagram **Urea Concentration**, this difference can be emphasized. A comparison with the diagram **Reaction Rate** of the experiment Reaction of marble with hydrochloric acid (determining the reaction order) reveals the differences between a first-order reaction and the zero-order reaction observed in this experiment.

Theoretical background

The reaction rate r is defined as the change of the concentration of one of the parent substances or one of the products per unit time, i.e. it always refers to one of the substances that participate in the reaction. The change of the concentration of the reactants enters the calculation with a negative sign and that of the products with a positive sign. In the enzymatic splitting of urea, the reaction rate with reference to the urea concentration thus is:

$$r_{\text{H}_2\text{NCONH}_2} = - \frac{d[\text{H}_2\text{NCONH}_2]}{dt}$$

The reaction takes place through catalysis by the enzyme urease. The mechanism can be described as follows (E: enzyme urease, S: substrate urea, ES: enzyme-substrate complex, P: products):



The reaction rate of the splitting of urea is also given by the rate equation

$$r_{\text{H}_2\text{NCONH}_2} = - \frac{d[\text{H}_2\text{NCONH}_2]}{dt} = k_2 \cdot \frac{k_1}{k_1} \cdot [\text{E}] \cdot [\text{S}] = k_2 \cdot [\text{ES}]$$

That means, with reference to $[\text{ES}]$ it is a first-order reaction.

As the enzyme E acts as a catalyst, its total concentration remains constant in the course of the reaction. If the substrate concentration is sufficient, a stationary state arises, where the rates of formation and decomposition of the enzyme-substrate complex are equal:

$$k_1 \cdot [\text{E}] \cdot [\text{S}] = (k_1 + k_2) \cdot [\text{ES}]$$

For this reason, the concentration $[\text{ES}]$ is constant during the reaction, its magnitude being controlled by the magnitude of the rate coefficient. Such a case is called a steady state. For the formation of the reaction products P this results in a constant reaction rate, and therefore the curve of the urea concentration has a linear shape. All together this leads to a zero-order rate equation for the splitting of urea by urease:

$$r_{\text{H}_2\text{NCONH}_2} = k_2 \cdot [\text{ES}] = k_3$$

As the reaction rate actually depends on $[\text{ES}]$, this dependence being hidden by the constancy of $[\text{ES}]$, this case is also called a pseudo-zero-order reaction.

For determining the rate coefficient of a reaction of this type, you only have to determine the slope of the straight line in the concentration-time diagram of the urea.

The fact that urease is not stable at room temperature is also obvious from the drop of the reaction rate when the experiment is continued for a long time. Only in the beginning of the reaction is the curve for the urea concentration linear.

Further experiment options

The enzymatic reaction kinetics can be studied more thoroughly if an experiment series with different initial concentrations of urea (e.g. 0.005 mol/l, 0.01 mol/l, 0.025 mol/l, 0.05 mol/l, 0.075 mol/l, 0.1 mol/l, 0.2 mol/l) is carried out. Plot the reaction rate as a function of the initial concentration in a new diagram.

From the maximum reaction rate r_{\max} obtained in the experiment series, the Michaelis constant K_m can be determined. K_m is defined as

$$K_m = \frac{k_1' + k_2}{k_1} = \frac{[E] \cdot [S]}{[ES]} \quad (1)$$

and is related with the reaction rate via

$$r = k_2 \cdot ([E] + [ES]) \cdot \frac{[S]}{K_m + [S]} \quad (2)$$

Given that r_{\max} is reached when the enzyme is saturated with substrate, half the enzyme has to be complexed in the enzyme-substrate complex at $\frac{1}{2} r_{\max}$. Then $[E] = [ES]$, and from (1) it follows that

$$K_m = [S] \quad \text{at } \frac{1}{2} r_{\max}.$$

As, in addition, for high concentrations

$$r_{\max} = k_2 \cdot ([E] + [ES]) \quad (3)$$

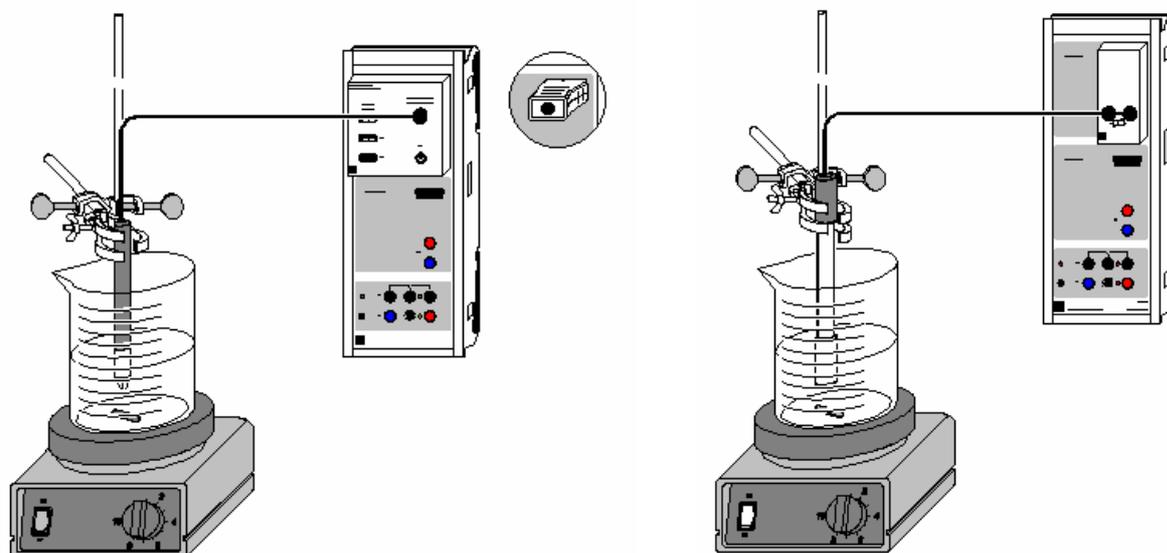
the reaction rate of an enzyme-substrate mixture can easily be calculated according to (2) and (3) with the Michaelis constant and the maximum reaction rate.

The Michaelis constant is to be determined from the substrate concentration at $\frac{1}{2} r_{\max}$. K_m is determined more precisely if $1/r$ is plotted against $1/[S]$ following Lineweaver-Burk. The plot is based on a transformation of (2) and (3):

$$\frac{1}{r} = \frac{K_m}{r_{\max} \cdot [S]} + \frac{1}{r_{\max}}$$

The slope of the straight line gives just the term K_m/r_{\max} , and the cut off from the $1/r$ axis is $1/r_{\max}$.

Hydrolysis of tertiary butyl chloride (determining the reaction order)

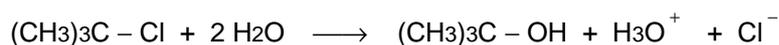


can also be carried out with Pocket-CASSY and Mobile-CASSY

- Load example (chemistry box or conductivity adapter S)
- Load example (conductivity box)

Experiment description

Hydrolysis of tertiary butyl chloride (2-chloro-2-methylpropane) results in the formation of tertiary butanol and hydrogen chloride (through protolysis of oxonium and chloride ions), which lead to a sharp increase in conductivity:



Equipment list (with chemistry box or conductivity adapter S)

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Chemistry box or conductivity adapter S	524 067(1)
1	Conductivity sensor	529 670
1	Magnetic stirrer	666 845
1	Beaker, 250 ml, ts	664 113
1	Stand tube	666 607
1	Double bosshead	301 09
1	Small clamp	666 551
1	Graduated cylinder, 100 ml	665 754
1	Measuring pipette, 1 ml	665 994
1	Pipetting ball	666 003
1	PC with Windows 95/98/NT or higher version	

Equipment list (alternatively with conductivity box)

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Conductivity box	524 037
1	Conductivity measuring cell	667 426
1	Magnetic stirrer	666 845
1	Beaker, 250 ml, ts	664 113

1	Stand tube	666 607
1	Double bosshead	301 09
1	Small clamp	666 551
1	Graduated cylinder, 100 ml	665 754
1	Measuring pipette, 1 ml	665 994
1	Pipetting ball	666 003
1	PC with Windows 95/98/NT or higher version	

Chemicals

0.8 ml solution of tertiary butyl chloride ($c=0.1$ mol/l) in acetone

Danger



Acetone is highly flammable. Keep away from ignition sources.

Experiment setup (see drawing)

- Set up the magnetic stirrer on the stand.
- In the graduated cylinder, measure off 90 ml distilled water and 10 ml acetone and pour these into the beaker.
- Add a magnetic stirrer bar and place the beaker on the magnetic stirrer. Mount the conductivity measuring cell on the stand so that it is immersed to a level just below the air opening. Switch on the magnetic stirrer.
- Plug in the conductivity box at input A of Sensor-CASSY and connect the conductivity measuring cell to the conductivity box using the banana plug.

Carrying out the experiment

- Load settings (chemistry box or conductivity adapter S)
- Load settings (conductivity box)

Notes on the displayed conductivity value

The initial conductivity value should not exceed $10 \mu\text{S}/\text{cm}$ for this experiment. If this occurs, clean the measuring cell thoroughly with distilled water.

Alternatively, you can **Correct** the offset in Settings Conductivity (click on the display with the right mouse button) to set the initial value to zero.

- Calibrate the measuring cell. To do this, open Settings Conductivity (click on the display with the right mouse button), enter the factor stamped on the cell and select **Correct Factor**.
- Measure off 0.8 ml of the tertiary butyl chloride solution ($c = 0.1$ mol/l) with the measuring pipette.
- In the program, start the measurement by clicking on the clock button (or press **F9**).
- Quickly dissolve the measured quantity of tertiary butyl chloride in the beaker. Mark the time of injection by a vertical line in the diagram by pressing the combination **Alt+V**.
- After about 8 minutes, terminate the measurement by clicking the clock button again (or with **F9**); at this point the conductivity should scarcely change. If necessary, you can increase the measuring range in Settings CA1.

Evaluation

This experiment is provided with four evaluation procedures already prepared:

Display of change in concentration

Click the **Concentration** tab. You can now follow the change in the concentration c of tertiary butyl chloride. The calculation of the concentration in mmol/l is performed using the amount of the substance (0.8 ml 0.1 mol solution), the present conductivity CA1 and the final conductivity (here: $198.9 \mu\text{S}/\text{cm}$; this value can be changed in accordance with the conductivity value read from the table).

You can view the conversion formula **$(1-CA1/198.9)*0.8$** , and alter it if desired, in the Settings c ; the same is true for the display range.



Test for 1st-order reaction

Select the tab **Test for 1st Order**. This shows $\ln(c_A/c)$ as a function of t (c_A = initial concentration, c quantity of tertiary butyl chloride used). To determine the velocity constant k of the reaction, apply a best-fit straight line to the beginning linear section of the curve (click the right mouse button to fit the line in the diagram) and determine the slope. Using Set Marker, you can label the line with the value for the slope (A).

Test for 2nd-order reaction

Select the tab **Test for 2nd Order**. This shows $1/c - 1/c_A$ as a function of t (c_A = initial concentration, c quantity of tertiary butyl chloride used). This diagram does not show a linear relationship. Thus, no second-order reaction occurs here.

Method of half-times

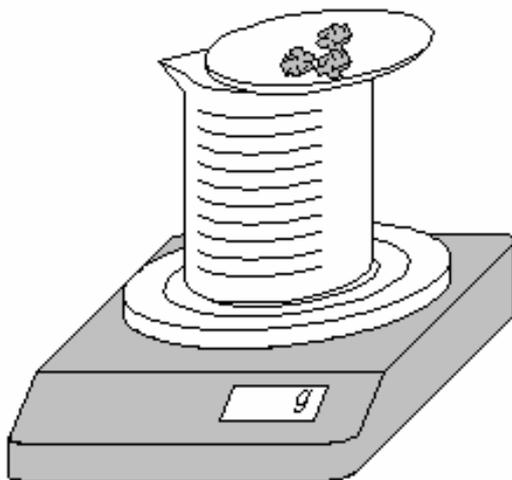
In the diagram **Half-time**: as this is a first-order reaction, the rate constant can also be determined via the method of half-times. Insert horizontal lines with **Alt+H** at 0.4 mmol, 0.2 mmol, and 0,1 mmol; mark the points of intersection of these lines with the concentration curve by vertical lines (**Alt+V**). The average time difference between all vertical lines is the half-time $t_{1/2}$, which in this example is 63 s.

Enter the half-time determined in the experiment in Settings k in the formula **In 2/63** as denominator. The result is displayed in the display instrument k.

Further experiment options

- Performance and recording of hydrolysis at different temperatures. The curves are superimposed for comparison when the measurement is repeated. The effect on the progress and speed of the reaction can be clearly seen. The activation energy of the reaction can be calculated from the different velocity constants and the corresponding temperatures.
- Use of different solvents to investigate how the solvent affects the order and speed of the reaction.
- Investigation of enzymatic reactions, e.g. breakdown of urea by urease.

Reaction of marble with hydrochloric acid (determining the reaction order)



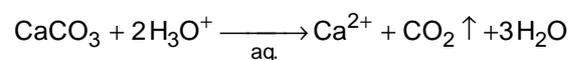
■ Load example

Danger

Hydrochloric acid is caustic. Wear protective goggles, gloves and clothing.

Experiment description

If an excess amount of marble (lime, CaCO_3) reacts with a defined amount of hydrochloric acid, the reaction order can be determined from the mass balance. The reaction takes place according to the following equation:



As carbon dioxide escapes, the mass of the reaction mixture decreases continuously. This decrease can be measured by means of a balance and enables the evolution of the concentration of hydrochloric acid to be determined.

Equipment list

1 CASSY Lab	524 200
1 Electronic balance with data output and connecting cable	667 795 729 769
or	
1 Electronic balance with retrofitting kit and interface cable	667 7780 667 7791 667 7796
1 Beaker, squat shape, 250 ml	664 130
1 Watch glass dish, 80 mm	664 154
1 Bulb pipette, 25 ml	665 976
1 Pipetting ball	666 003
1 PC with Windows 95/98/NT or higher version	

Chemicals

Marble, chips, 250 g	673 2500
Hydrochloric acid, $c = 2 \text{ mol/l}$, 500 ml	674 6920

Preparing the experiment (see drawing)

The program supports the Sartorius, Mettler and Ohaus balances with a serial data output available from LD Didactic.

Connect the balance to a serial port of the computer (e. g. COM2) via the connecting cable. As the cables of different manufacturers differ from each other, use the interface cable provided by the respective manufacturer to ensure that the computer connection works correctly.

Use the pipette to put exactly 75 ml of hydrochloric acid into the beaker. Put the watch glass dish on the beaker, set the balance to 0, and weigh in exactly 30 g of marble chips on the watch glass dish. Reset the balance to 0.

Carrying out the experiment

■ Load settings

- Assign the balance as a measuring device to the desired interface in the General settings (accessible, e. g., via **F5**).
- Adjust the baud rate and the mode of the balance in Settings mass m:
Factory settings of Sartorius balances:
Mode: 7O1
Baud rate: 1200
Factory settings of Mettler balances:
Mode: 8N1
Baud rate: 9600
- In one respect the factory settings of the balance have to be changed. Read the instruction sheet of the balance:
Sartorius: data transfer as "Auto print regardless of stability" instead of "Print on request after stability"
Mettler: continuous data transfer ("S.Cont")
- All transferred measured values are displayed (Troubleshooting)
- Start the measurement by pressing the key **F9** or the  button.
- Initiate the reaction by pouring the marble chips from the watch glass dish into the beaker. Leave the watch glass dish on the beaker.
- When the reaction has almost come to a standstill (approx. 10 minutes), stop the data logging by pressing the key **F9** or the  button.

Evaluation

The fluctuations at the beginning of the measurement, which are caused by moving the watch glass dish, can be corrected by clicking the respective value with the mouse and entering "0".

1. In the diagram **Standard**: the measuring data give the mass m of the carbon dioxide that has escaped during the reaction (see reaction equation). Calculate the amount $n(\text{CO}_2)$ that has escaped from these data points and from this the concentration of the remaining acid $[\text{H}_3\text{O}^+]$:

$$n(\text{CO}_2) = -\frac{m}{44 \text{ g/mol}}$$

$$[\text{H}_3\text{O}^+] = \frac{2 \text{ mol/l} \cdot 0,075 \text{ l} - 2 \cdot n(\text{CO}_2)}{0,075 \text{ l} + 3 \cdot n(\text{CO}_2) \cdot 0,018 \text{ l}}$$

In the second equation, the numerator corresponds to the overall balance with respect to the amount of acid and the denominator to the overall volume balance.

2. In the diagram **1st order**: as a test for a first-order reaction with respect to the hydrochloric acid, the natural logarithm of the concentration of hydrochloric acid is plotted against the time t . In the case of a first order reaction, this plot leads to a straight line with the slope $-k$.

In order to determine the rate coefficient k , click the diagram with the right mouse button, select **Fit function** and **Best-fit straight line**, and mark the linear curve range, where a linear fit is reasonable.

The slope of the straight line obtained in the fit is displayed in the status line below on the left and can be dragged into the diagram using the mouse. In the present experiment example, a rate coefficient of 0.01541/s is obtained.

In the experiment example, the plot for the first-order rate equation does not result in a straight line over the whole range because, after part of the hydrochloric acid has reacted, the rate is governed by diffusion: when the concentration of hydrochloric acid decreases, the acid reacts at a faster rate than new H_3O^+ ions are transported to the surface of the marble. Therefore the rate coefficient drops, and a deviation from the rate equation is observed. However, the reaction is well described by the first-order rate equation until 80 % of the acid are consumed in the reaction.

3. In the diagram **2nd order**: as a test for a second-order reaction with respect to the hydrochloric acid, the term $1/[\text{H}_3\text{O}^+]$ is plotted against the time t . If the reaction was of second order, this plot would result in a straight line with the slope k .

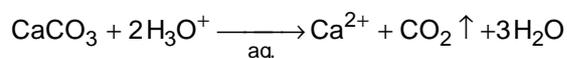
In the experiment example, the H_3O^+ concentration used for the calculations is averaged over 10 seconds in order to smooth the jumps that occur after 95 % of the acid have been consumed. These jumps are due to the finite resolution of the balance.

As there is no clearly linear region in this plot, you can assume that at no time a second-order reaction occurs in the experiment.

4. The evolution of the reaction rate r following from the reaction order is illustrated in the diagram **Reaction rate**. As the resolution of the measured values output by the balance would have to be greater by one order of magnitude - which would make the demonstration experiment much more difficult- in order to obtain optimum results in this diagram, the reaction rate r_m , which is averaged over 10 seconds, is plotted instead of r .

Theoretical background

The reaction rate r is defined as the change of the concentration of one of the parent substances or one of the products per unit time, i.e. it always refers to one of the substances that participate in the reaction. The change of the concentration of the reactants enters the calculation with a negative sign and that of the products with a positive sign. For the reaction



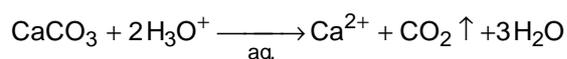
the reaction rate r with respect to the concentration of H_3O^+ ions thus is

$$r_{\text{H}_3\text{O}^+} = -\frac{d[\text{H}_3\text{O}^+]}{dt}$$

It is double the reaction rate with respect to the concentration of calcium ions because two H_3O^+ ions are required to create one calcium ion:

$$r_{\text{Ca}^{2+}} = \frac{1}{2} r_{\text{H}_3\text{O}^+} = \frac{d[\text{Ca}^{2+}]}{dt}$$

In order to find the dependence of the reaction rate on the concentration of the participating substances, the rate equation that governs the reaction is determined experimentally. The reaction order with respect to a particular substance is given by the exponent carried by this substance in the rate equation. The overall reaction order is formed from the sum of the exponents. In the reaction



the reaction order can only be determined easily for the ions in the solution. For a first-order reaction the rate equation would read:

$$r_{\text{H}_3\text{O}^+} = 2 \cdot \frac{d[\text{Ca}^{2+}]}{dt} = -\frac{d[\text{H}_3\text{O}^+]}{dt} = k \cdot [\text{H}_3\text{O}^+]$$



After integration, the straight-line equation

$$\ln [\text{H}_3\text{O}^+] = -k \cdot t + \ln [\text{H}_3\text{O}^+]_0$$

with the slope $-k$ and the cut off $\ln[\text{H}_3\text{O}^+]_0$ is obtained. $[\text{H}_3\text{O}^+]_0$ is the initial concentration of the acid.

For a second-order reaction with respect to the H_3O^+ concentration, the rate equation would read:

$$r = -\frac{d[\text{H}_3\text{O}^+]}{dt} = k \cdot [\text{H}_3\text{O}^+]^2$$

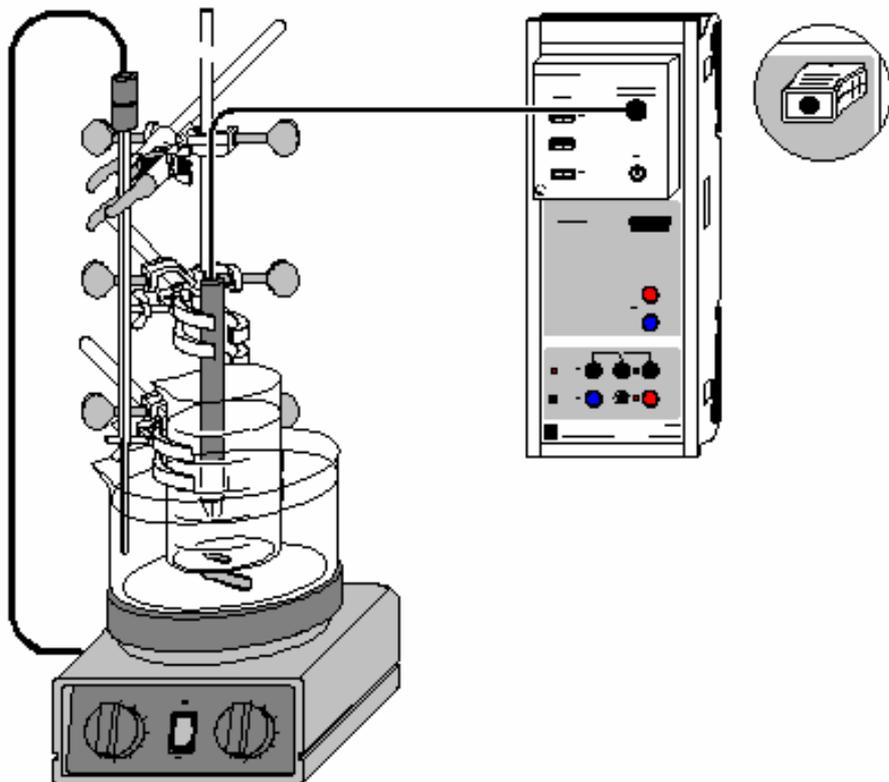
After integration, the straight-line equation

$$\frac{1}{[\text{H}_3\text{O}^+]} = k \cdot t + \frac{1}{[\text{H}_3\text{O}^+]_0}$$

with the slope k and the cut off $1/[\text{H}_3\text{O}^+]_0$ is obtained.

By plotting these two straight lines, it can be examined to what extent a reaction obeys the rate equations of first order or second order, respectively.

Alkaline hydrolysis of ethyl acetate (determining the reaction order)



can also be carried out with Pocket-CASSY and Mobile-CASSY

■ Load example

Safety notes

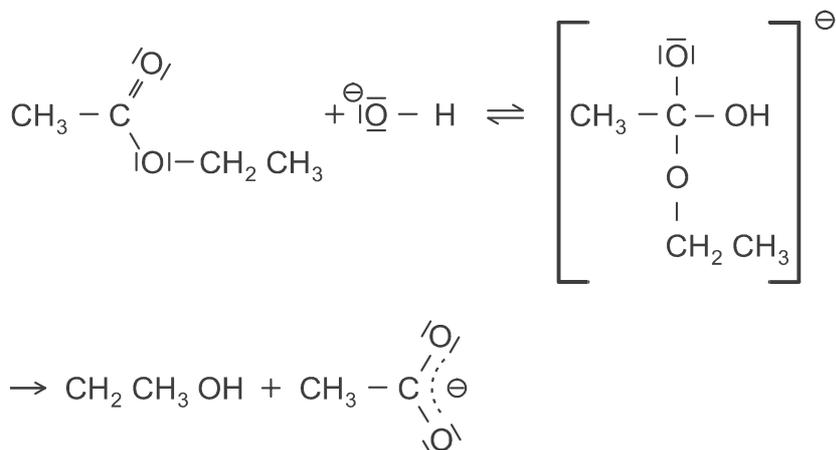
Ethyl acetate is highly flammable. Keep away from ignition sources.

Ethyl acetate irritates the eyes. Wear protective goggles while working with ethyl acetate. When it gets into contact with your eyes, immediately rinse your eyes with water, and consult a doctor.

The vapour of the ester can cause a dazed feeling; do not breathe in the vapour.

Experiment description

Alkaline hydrolysis of esters proceeds in two steps:





As in the course of the reaction acetate ions go into solution instead of the hydroxide ions, the reaction can be followed via measurements of the conductivity. From the time dependence of the hydroxide ion concentration obtained from these measurements the reaction order and the rate coefficient of the alkaline ester hydrolysis can be determined. As the rate coefficient depends on the temperature, it is recommendable to carry out the experiment in a thermostated water bath.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Chemistry box or conductivity adapter S	524 067(1)
1	Conductivity sensor	529 670
1	Magnetic stirrer with hot plate	666 839
1	KT4 contact rod thermometer	666 8401
1	Stirrer bar, 50 mm	666 854
1	Stirrer bar, 15 mm	666 850
1	Stand rod, 500 mm, $\varnothing = 10$ mm	301 27
3	Crossed bossheads	666 543
2	Small universal clamps	666 551
1	Universal clamp	666 555
1	Beaker 100 ml, tall shape	664 137
1	Crystallization dish, 900 ml	664 177
1	Syringe, 2 ml	665 963
1	Disposable needle, 40 mm	665 960
1	Bulb pipette, 25 ml	665 976
1	Pipetting ball	666 003
1	Balance, resolution 0.01 g	

Chemicals

Ethyl acetate, e.g. 250 ml	671 9630
Caustic soda solution, $c = 0.1$ mol/l, e.g. 500 ml	673 8410
If necessary: calibration solution, 12.88 mS/cm	667 4640

Calibration

■ Load settings.

- The cell constant of the conductivity sensor for the chemistry box has already been set to 0.58 in CASSY Lab. If another conductivity sensor is used, its cell constant has to be entered as a factor in Settings CA1 under **Correct**. Then the **Correct Factor** button has to be pressed.
- For a more precise determination of the cell constant, calibration solutions can be used: rinse the beaker and the conductivity sensor first with distilled water and then with approx. 30-40 ml of calibration solution. Immerse the conductivity sensor in another 50 ml of calibration solution as if it was for a conductivity measurement (see to it that the distance from the walls of the beaker is at least 1 cm), enter the target value in the second line in Settings CA1 under **Correct**, and press the **Correct Factor** button when a stable measured value is reached.
- For later use, store the calibrated settings with **F2** under a new name. Mark the sensor used, the chemistry box, and the Sensor-CASSY as the calibration is only valid for this combination.

Experiment setup (see drawing)

Fill tap water into the crystallization dish almost up to the brim, and put the dish with the bigger stirrer bar onto the magnetic stirrer. Attach the beaker with the other stirrer bar to the stand rod with the aid of the universal clamp so that the beaker hangs in the crystallization dish. The beaker should be immersed as deeply as possible in the centre of the water bath over the stirring magnet. Use the pipette to put exactly 75 ml of caustic soda solution (0.0075 mol) into the beaker.

Immerse the contact thermometer in the water bath and the conductivity sensor in the beaker, each with one of the small universal clamps. See to it that the distance between the conductivity sensor and both the glass wall and the stirrer bar is at least 1 cm. Set the heat controller of the magnetic stirrer to 80 °C at maximum. Set the contact thermometer, which has to be connected to the magnetic stirrer, to approx. 40 to 45 °C. Set the speed of the stirrer so that vortex formation is just avoided.

Wait until the temperature of the caustic soda solution has reached a constant value. This can be checked at the display instrument for the temperature ϑ_{A1} (access via the corresponding button in the upper line on the screen) or, even more comfortable, starting a measurement by pressing **F9**.

Put the empty syringe with the needle on the balance, and set the balance to 0. Weigh in exactly 1.32 g of ethyl acetate (0,015 mol) into the syringe.

Carrying out the experiment

- If you have checked the constancy of the temperature by means of a measurement, stop this measurement series by pressing **F9** and delete it by pressing **F4**.
- Start a new measurement by pressing **F9** or the  button.
- Firmly inject the ethyl acetate in order to achieve a good distribution. Mark the time of injection by a vertical line in the diagram by pressing the combination **Alt+V**.
- Depending on the reaction temperature, allow the reaction to proceed for approx. 8 to 12 minutes until the value of the conductivity has become constant.
- Stop the measurement by pressing **F9** or the  button. Switch the hot plate off.

Evaluation

1. In the diagram **Specific Conductivity**, the measured values of the specific conductivity and the temperature are plotted against the reaction time. In order to determine the reaction temperature exactly, click the diagram with the right mouse button, select **Draw Mean Value**, and obtain the average temperature at which the experiment has been carried out by marking the curve section between the initial and the final temperature. The mean value is drawn in the diagram automatically and can be read in the status line below on the left. The numerical value can be inserted in the diagram with **Alt+T**.

2. The diagram **Hydroxide Concentration** shows the course of the concentration of hydroxide ions as calculated from the specific conductivity. The $[\text{OH}^-]$ concentration is calculated according to the formula

$$[\text{OH}^-] = \frac{C_{A1} - \kappa_1}{\kappa_0 - \kappa_1} \cdot 0,1 \text{ mol/l}$$

Here C_{A1} is the measured conductivity, κ_0 the conductivity before the ester has been added, κ_1 the conductivity at the end of the reaction, and 0.1 mol/l the concentration of the caustic soda solution at the beginning of the reaction. In order that the concentration of hydroxide ions is calculated correctly, enter the respective measured values in Settings κ_1 and κ_0 in the field formula instead of the default values.

3. The diagrams **1st Order** and **2nd Order** have been prepared for determining the reaction order: for fitting a straight line to the curve in each case, click the diagram with the right mouse button, select **Fit function** and **Best-fit straight line**, and, starting from the beginning of the reaction, mark the curve range where a fit to a straight line is reasonable. The great deviation from a straight line in the **1st Order** diagram and the fair agreement with a straight line up to a consumption of approx. 90 % of the reactants in the **2nd Order** diagram indicate that this is a second-order reaction. The slope of the straight line in the **2nd Order** plot is the rate coefficient k of the reaction. It is found as parameter A of the straight-line equation $A \cdot x + B$ in the status line and can be dragged from there into the diagram using the mouse.

4. The diagrams **Arrhenius / Eyring 1** and **2** have been prepared for determining the activation parameters. For details see the experiment Alkaline hydrolysis of ethyl acetate - determining the activation parameters.

Theoretical background

The reaction rate r is defined as the change of the concentration of one of the parent substances or one of the products per unit time, i.e. it always refers to one of the substances that participate in the reaction. The change of the concentration of the reactants enters the calculation with a negative sign and that of the products with a positive sign. For the alkaline ester hydrolysis, the reaction rate with respect to the ester concentration equals that with respect to the hydroxide concentration as the two substances react with each other in the ratio 1:1:

$$r_{\text{OH}^-} = r_{\text{CH}_3\text{COOAc}} = -\frac{d[\text{OH}^-]}{dt} = -\frac{d[\text{CH}_3\text{COOAc}]}{dt}$$



In order to find the dependence of the reaction rate on the concentration of the participating substances, the rate equation that governs the reaction is determined experimentally. The reaction order with respect to a particular substance is given by the exponent carried by this substance in the rate equation. The overall reaction order is formed from the sum of the exponents.

In the experiment example, the reaction is tested for two reaction orders: if the reaction was of first order with respect to the hydroxide concentration and independent of the ester concentration, the overall rate equation would be of first order:

$$r_{\text{OH}^-} = -\frac{d[\text{OH}^-]}{dt} = k \cdot [\text{OH}^-]$$

The same rate equation would result if the reaction exhibited a first order dependence on the ester concentration and independence of the hydroxide concentration because

$$\frac{d[\text{OH}^-]}{dt} = \frac{d[\text{CH}_3\text{COOAc}]}{dt}$$

In order to check the validity of this rate equation, its integrated form is used:

$$\ln[\text{OH}^-] = -k \cdot t + \ln[\text{OH}^-]_0$$

if $\ln[\text{OH}^-]$ is plotted against the time t , the result is a straight line with slope $-k$ and cut off $\ln[\text{OH}^-]_0$ in the case of a first-order reaction. $[\text{OH}^-]_0$ is the initial concentration on hydroxide ions.

In the case of a first-order reaction with respect to both components, the result is a second-order rate equation:

$$-\frac{d[\text{OH}^-]}{dt} = -\frac{d[\text{CH}_3\text{COOAc}]}{dt} = k \cdot [\text{OH}^-] \cdot [\text{CH}_3\text{COOAc}]$$

The integrated form of the rate equation reads:

$$\ln \frac{[\text{OH}^-]_0 \cdot ([\text{CH}_3\text{COOAc}]_0 - ([\text{OH}^-]_0 - [\text{OH}^-]))}{[\text{CH}_3\text{COOAc}]_0 \cdot [\text{OH}^-]} \cdot \frac{1}{[\text{CH}_3\text{COOAc}]_0 - [\text{OH}^-]_0} = k \cdot t$$

A plot of the expression on the left hand side against t is already arranged in the **2nd Order** diagram. The slope of the function, which is a straight line until approx. 90 % of the reactants have been consumed, is the rate coefficient of the reaction.

If the initial concentrations of the two substances are equal, the rate equation takes the simpler form

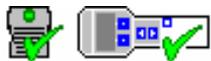
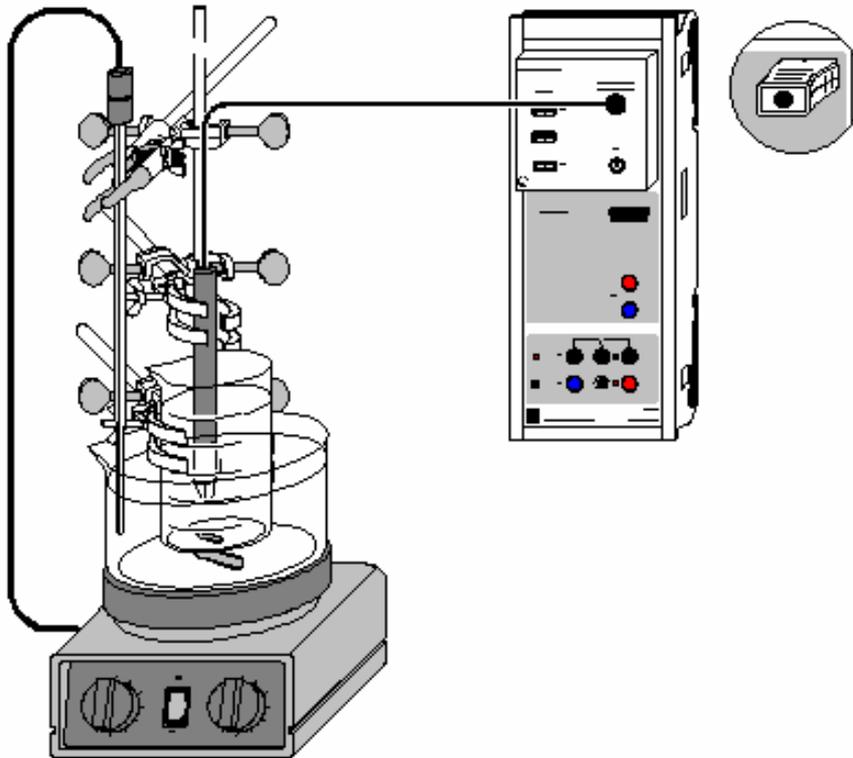
$$-\frac{d[\text{OH}^-]}{dt} = -\frac{d[\text{CH}_3\text{COOAc}]}{dt} = k \cdot [\text{OH}^-]^2$$

Its integrated form

$$\frac{1}{[\text{OH}^-]} = k \cdot t + \frac{1}{[\text{OH}^-]_0}$$

leads to a plot of $1/[\text{OH}^-]$ against t , which, in the case of a second-order reaction, is a straight line with slope k and cut off $1/[\text{OH}^-]_0$. However, as equimolar use of ester and caustic soda solution leads to a much longer duration of the reaction, double the amount of ester was used in this experiment example, and the determination of the rate equation via more complicated expressions was accepted.

Alkaline hydrolysis of ethyl acetate (determining the activation parameters)



can also be carried out with Pocket-CASSY and Mobile-CASSY

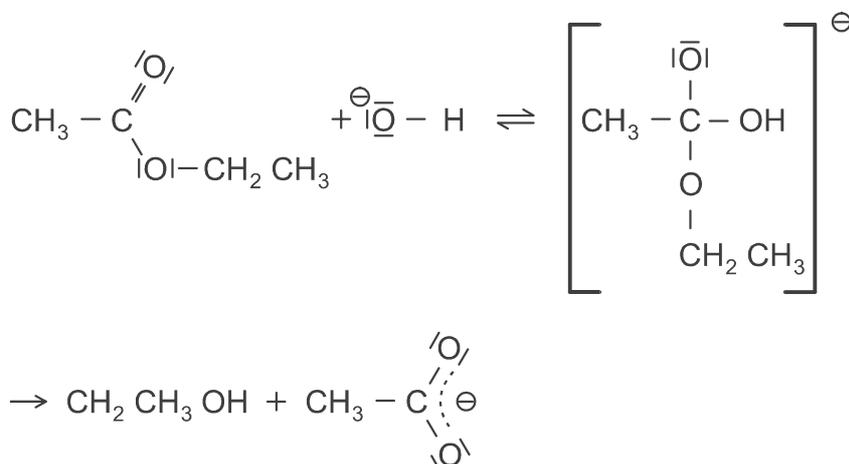
■ Load example

Safety notes

Ethyl acetate is highly flammable. Keep away from ignition sources.
 Ethyl acetate irritates the eyes. Wear protective goggles while working with ethyl acetate. When it gets into contact with your eyes, immediately rinse your eyes with water, and consult a doctor.
 The vapour of the ester can cause a dazed feeling; do not breathe in the vapour.

Experiment description

Alkaline hydrolysis of esters proceeds in two steps:





As in the course of the reaction acetate ions go into solution instead of the hydroxide ions, the reaction can be followed via measurements of the conductivity. From the time dependence of the hydroxide ion concentration obtained from these measurements the reaction order and the rate coefficient k of the alkaline ester hydrolysis can be determined.

The temperature dependence of the rate coefficient can be determined by carrying out the ester hydrolysis several times at different temperatures in a water bath. From the temperature dependence of k , the activation parameters can be calculated: the activation energy E_a according to Arrhenius and the free energy of activation ΔG^\ddagger after Eyring, respectively, which is a function of the activation enthalpy ΔH^\ddagger and the activation entropy ΔS^\ddagger .

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Chemistry box or conductivity adapter S	524 067(1)
1	Conductivity sensor	529 670
1	Magnetic stirrer with hot plate	666 839
1	KT4 contact rod thermometer	666 8401
1	Stirrer bar, 50 mm	666 854
1	Stirrer bar, 15 mm	666 850
1	Stand rod, 500 mm, $\varnothing = 10$ mm	301 27
3	Crossed bossheads	666 543
2	Small universal clamps	666 551
1	Universal clamp	666 555
1	Beaker, 100 ml, tall shape	664 137
1	Crystallization dish, 900 ml	664 177
1	Syringe, 2 ml	665 963
1	Disposable needle, 40 mm	665 960
1	Bulb pipette, 25 ml	665 976
1	Pipetting ball	666 003
1	Balance, resolution 0,01 g	

Chemicals

Ethyl acetate, e.g. 250 ml	671 9630
Caustic soda solution, $c = 0.1$ mol/l, e.g. 500 ml	673 8410
If necessary: calibration solution, 12.88 mS/cm	667 4640

Calibration

■ Load settings.

- The cell constant of the conductivity sensor for the chemistry box has already been set to 0.58 in CASSY Lab. If another conductivity sensor is used, its cell constant has to be entered as a factor in Settings CA1 under **Correct**. Then the **Correct Factor** button has to be pressed.
- For a more precise determination of the cell constant, calibration solutions can be used: rinse the beaker and the conductivity sensor first with distilled water and then with approx. 30-40 ml of calibration solution. Immerse the conductivity sensor in another 50 ml of calibration solution as if it was for a conductivity measurement (see to it that the distance from the walls of the beaker is at least 1 cm), enter the target value in the second line in Settings CA1 under **Correct**, and press the **Correct Factor** button when a stable measured value is reached.
- For later use, store the calibrated settings with **F2** under a new name. Mark the sensor used, the chemistry box, and the Sensor-CASSY as the calibration is only valid for this combination.

Experiment setup (see drawing)

Fill tap water into the crystallization dish almost up to the brim, and put the dish with the bigger stirrer bar onto the magnetic stirrer. Attach the beaker with the other stirrer bar to the stand rod with the aid of the universal clamp so that the beaker hangs in the crystallization dish. The beaker should be immersed as deeply as possible in the centre of the water bath over the stirring magnet.

Immerse the contact thermometer in the water bath and the conductivity sensor in the beaker, each with one of the small universal clamps. See to it that the distance between the conductivity sensor and both the glass wall and the stirrer bar is at least 1 cm. Set the heat controller of the magnetic stirrer to 80 °C at

maximum. Set the contact thermometer, which has to be connected to the magnetic stirrer, to approx. 35 °C for the first measurement series, to 45 °C for the second, and to approx. 55 °C for the third measurement series. If desired, further measurement series can be recorded, e.g., at 50 or 60 °C. Set the speed of the stirrer so that vortex formation is just avoided.

Carrying out the experiment

- Use the pipette to put exactly 75 ml of 0.1 M caustic soda solution (0.0075 mol) into the beaker.
- Wait until the temperature of the caustic soda solution has reached a constant value. This can be checked at the display instrument for the temperature ϑ_{A1} (access via the corresponding button in the upper line on the screen) or, even more comfortable, starting a measurement by pressing **F9**.
- In the meantime, put the empty syringe with the needle on the balance, and set the balance to 0. Weigh in exactly 1.32 g of ethyl acetate (0,015 mol) into the syringe.
- If you have checked the constancy of the temperature by means of a measurement, stop this measurement series by pressing **F9** and delete it by pressing **F4**.
- Start a new measurement by pressing **F9** or the  button.
- Firmly inject the ethyl acetate in order to achieve a good distribution. Mark the time of injection by a vertical line in the diagram by pressing the combination **Alt+V**.
- Depending on the reaction temperature, allow the reaction to proceed for approx. 7 to 15 minutes until the value of the conductivity has become constant.
- Stop the measurement by pressing **F9** or the  button, and store the measured values by pressing **F2**, adding a note on the reaction temperature.
- Having stored the measurement series, delete it with **F4** to make way for recording the next measurement series.
- Set the contact thermometer to the new reaction temperature, put the reaction mixture into a container, and rinse the beaker.
- Repeat the experiment at the next temperature.
- Record and store at least three measurement series.

Evaluation

1. In the diagram **Specific Conductivity**, the measured values of the specific conductivity C_{A1} and the temperature ϑ_{A1} are plotted against the reaction time.
2. From C_{A1} the concentration of hydroxide ions is calculated according to the formula

$$[\text{OH}^-] = \frac{C_{A1} - \kappa_1}{\kappa_0 - \kappa_1} \cdot 0,1 \text{ mol/l}$$

In this equation, κ_0 is the conductivity before the ester has been added, κ_1 the conductivity at the end of the reaction, and 0.1 mol/l the concentration of the caustic soda solution at the beginning of the reaction. In order that the concentration of hydroxide ions is calculated correctly, enter the respective measured values in Settings κ_1 and κ_0 in the field formula instead of the default values for each measurement series. The evolution of the concentration of hydroxide ions calculated from the above equation is shown in the diagram **Hydroxide concentration**.

3. Next the measurement series are united into a single file by loading the other recorded measurement series with **F3** in addition to the measurement series which is just open. Answer **Yes** to the question whether the new measurement series shall be loaded in addition to the current one.
4. In order to determine the reaction temperatures exactly, click the diagram **Specific Conductivity** with the right mouse button, select **Draw Mean Value**, and obtain the average temperature ϑ_m at which the respective measurement has been carried out by marking one of the temperature curves between the initial and the final temperature. The mean value is drawn in the diagram automatically and can be read in the status line below on the left. The numerical value can be inserted in the diagram with **Alt+T**.
5. The rate coefficients k associated with the different temperatures are determined in the diagram **2nd Order**. Click the diagram with the right mouse button, select **Fit function** and **Best-fit straight line**, and, starting from the beginning of the reaction, mark for each of the curves the curve range where a fit to a straight line is reasonable. The slope of the resulting straight line is the rate coefficient k of the reaction at the average temperature ϑ_m just determined. This slope is found as parameter A of the straight-line equation $A \cdot x + B$ in the status line. It can be dragged from there into the diagram using the mouse and is entered in the diagram via the combination **Alt+T**.



6. Now enter the previously obtained rate coefficients and the associated absolute temperatures T in K ($T = \vartheta_m + 273.15$) into the table **Arrhenius / Eyring 1** by clicking the corresponding line of the table with the left mouse button and typing the values. In the diagram **Arrhenius / Eyring 2**, the plots according to Arrhenius and Eyring are calculated automatically.

7. In order to determine the activation energy E_a according to Arrhenius, apply a Best-fit straight line to the data points of $\ln k$ in the diagram **Arrhenius / Eyring 2**. The resulting slope of this straight line is equal to $-E_a/R$. The Best-fit straight line applied to the data points of $\ln(k/T)$ has the slope $-\Delta H^\ddagger/R$ and the cut off $\ln(k_b/h) + \Delta S^\ddagger/R$ (see Theoretical background). The slopes of the straight lines can again be read below in the status line as parameters A. The cut offs are given by the parameters B. These parameters, too, can be transferred into the diagram.

Theoretical background

Arrhenius gave an explanation of the exponential relation between the temperature and the reaction rate, which had already known for some time, by identifying the two parameters a and b in the empirical formula

$$k = a \cdot e^{-b/T}$$

as the frequency factor A and the activation energy in units of the general gas constant E_a/R , whereby the activation energy E_a is the energy required by two colliding molecules in order to be able to react; the factor A contains the number of molecule collisions per second and a steric factor, which takes into account the fact that colliding molecules must have a certain mutual orientation in order to react with each other.

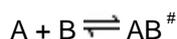
According to Arrhenius, the temperature dependence of the rate coefficient can also be written in the following form:

$$k = A \cdot e^{-E_a/RT}$$

A plot of $\ln k$ against $1/T$ leads to a straight line with the slope $-E_a/R$ and the cut off $\ln A$.

A more precise form was given to Arrhenius' equation by the "Theory of the transition state" of Eyring, which gives a more accurate definition of the parameters A and E_a .

Eyring's starting point was the consideration that for all elementary reactions to occur between two substances A and B an activated complex has to be reached as a transition state; this state is in chemical equilibrium with the initial substances:



$$K^\ddagger = \frac{[AB^\ddagger]}{[A] \cdot [B]}$$

Eyring's decisive achievement was to prove that the activated complexes of any elementary chemical reaction are converted into the products with the same rate coefficient:

$$\frac{d[C]}{dt} = \frac{k_b \cdot T}{h} \cdot [AB^\ddagger]$$

Here C is the product of the elementary reaction, k_b the Boltzmann constant, h the Planck constant, and T the absolute temperature. The rate of the entire reaction is therefore

$$\frac{d[C]}{dt} = \frac{k_b \cdot T}{h} \cdot K^\ddagger \cdot [A] \cdot [B]$$

with the rate coefficient:

$$k = \frac{k_b \cdot T}{h} \cdot K^\ddagger$$

From thermodynamics it is known that any equilibrium constant K can be determined from the differences between the free enthalpies of the products and the parent substances. Thus:

$$\Delta G^\ddagger = -RT \cdot \ln K^\ddagger; \quad \Delta G^\ddagger = \Delta H^\ddagger - T\Delta S^\ddagger$$

If these two expressions are inserted in the equation of the rate coefficient, Eyring's equation is obtained:

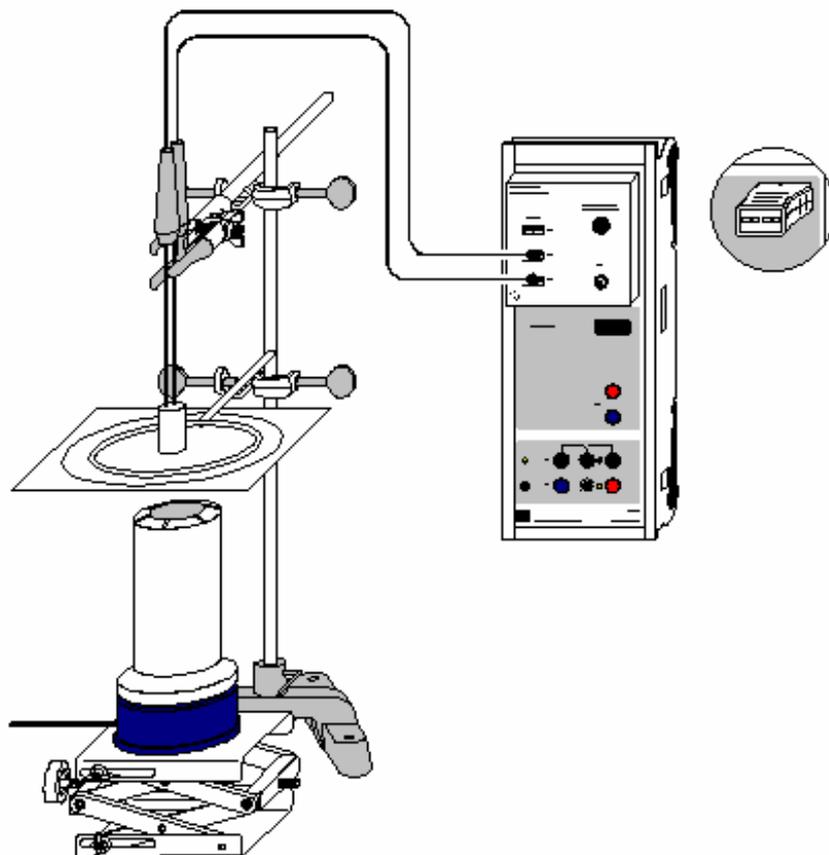
$$k = \frac{k_b \cdot T}{h} \cdot e^{\Delta S^\ddagger / R} \cdot e^{-\Delta H^\ddagger / RT}$$

ΔS^\ddagger is called the activation entropy and ΔH^\ddagger the activation enthalpy. From these two parameters conclusions can be drawn regarding the transition state of a reaction: a negative activation entropy such as in this experiment example indicates a higher-order transition state with respect to the initial state, i.e., in order that the activated complex can form, bonds have to form or the particles must have a certain position relative to each other. If ΔS^\ddagger is negative, the entry has a retarding effect on the reaction as the temperature rises. A positive activation entropy, on the other hand, indicates the breakage of bonds in the activated complex or an increase in rotational degrees of freedom around one or more bonds. This leads to an enhancing effect on the reaction when the temperature rises.

The free energy of activation ΔG^\ddagger of a reaction, which results from the activation entropy and the activation enthalpy, is always positive. Its temperature dependent magnitude determines the magnitude of the rate coefficient and is thus related to the reaction rate. In the experiment example, the averaged values of ΔS^\ddagger and ΔH^\ddagger at 298 K (25 °C) lead to a free energy of activation of

$$\Delta G^\ddagger = 68200 \text{ J/mol} + 50 \text{ J/(mol} \cdot \text{K)} \cdot 298 \text{ K} = 83,1 \text{ kJ/mol}$$

Differential thermal analysis of copper sulphate



can also be carried out with Pocket-CASSY and Mobile-CASSY

■ Load example

Danger

Copper sulphate is dangerous to health and environmentally hazardous. Do not allow copper sulphate to get into the environment.

Danger of burn. Before touching the apparatus, allow it to cool down to room temperature.

Experiment description

On the one hand, differential thermal analysis (DTA) enables important quantities of physical chemistry to be measured, e.g., latent heats or enthalpies of transition. On the other hand, DTA is well suited as an introduction into analytical chemistry because it is quite easy to grasp.

In DTA, two substances are heated in an adjustable oven: a chemically inert reference substance (e.g. aluminium oxide, Al_2O_3) and the sample substance, which is examined for phase transitions and/or chemical reactions in the entire temperature range. The substances are in symmetric places in the oven, each provided with a temperature sensor.

If an endothermic (e.g. evaporation) or an exothermic (e.g. combustion reaction) process takes place in the sample, a temperature difference ΔT arises between the reference substance and the sample. In the case of endothermic reactions, the sample substance warms up at a slower rate than the reference substance, in the case of exothermic reactions at a faster rate. By plotting ΔT against the reference temperature ϑ , a characteristic DTA curve is obtained for every substance. From this curve the transition temperatures and enthalpies of transition of the occurring processes can be determined.

In order to make the experiment easier to understand, an open measuring assembly, which gives a good illustration of the principle of measurement, is used in the present experiment example. However, for an accurate determination of enthalpies of transition, a closed oven is required.

In this example, the temperatures at which water of crystallization bonded in copper sulphate is split off are determined up to 150 °C. For this the opportunity of directly measuring the differential temperature provided by the chemistry box is taken advantage of as it is more precise than computing the difference between two individual temperatures.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Chemistry box or NiCr-Ni adapter S	524 067(3)
2	Temperature sensor NiCr-Ni, type K, Ø 1.5 mm	529 676
1	Heating block with two holes	666 202
1	Set of 20 glass tubes	666 203
1	Electric burner	666 776
1	Stand base, V-shape, 20 cm	300 02
1	Stand rod, 47 cm	300 42
2	Crossed bossheads	666 543
1	Miniature clamp	666 551
1	Stand ring with stem, Ø 100 mm	666 573
1	Wire gauze, 160*160 mm	666 685
1	Laboratory stand 3	666 583
2	Mortars, 50 ml	608 350
2	Pestles	608 360

Chemicals

Aluminium oxide (Al ₂ O ₃), e.g. 250 g	670 2900
Copper(II) sulphate pentahydrate, e.g. 100 g	672 9600

Experiment setup (see drawing)

Connect the chemistry box to input A of the Sensor-CASSY with the temperature sensors being connected to inputs T2 and T3.

Set up an assembly for heating the heating block using the stand material, the wire gauze, the electric burner, and the laboratory stand 3. Put the heating block onto the wire gauze exactly over the heating aperture of the electric burner. At the beginning of the measurement, the distance between the heating aperture of the burner and the wire gauze should be approx. 5 cm.

Triturate a spatula-tipfull of copper sulphate in one of the mortars, and fill it into one of the glass tubes up to approx. two-thirds of its height. Do the same with another glass tube and a spatula-tipfull of aluminium oxide.

Turn the temperature sensor connected to T2 as deeply as possible into the aluminium oxide and that connected to T3 into the copper sulphate.

Fix both temperature sensors together with a miniature clamp below the handle so that the glass tubes rest on the bottom of the two holes of the heating block. See to it that the entire base of the heating block has contact with the wire gauze.

Carrying out the experiment

■ Load settings

- Switch the electric burner on.
- Wait about one minute. Then start the measurement by pressing **F9** or the  button.
- When the temperature curve becomes horizontal, enhance the height of the laboratory stand 3 somewhat to reduce the distance between the burner and the wire gauze.
- Stop the measurement by pressing **F9** or the  button when the temperature is approx. 150°C. Switch the electric burner off.



Evaluation

1. In the diagram **Standard**, the temperature value and the temperature difference ΔT are plotted against the time.
2. In the diagram **dT(T)**, the temperature difference is plotted against the reference temperature (temperature of the aluminium oxide).

In order to determine the transition temperature, apply inflectional tangents to the left edges of each peak. To do this, click the diagram with the right mouse button, select the items **Fit function** and **Best-fit straight line**, and then mark a narrow curve range around the inflection point of the left edge of the peak. After that the associated base line is determined for each peak. The base lines are also constructed as **Best-fit straight lines**, whereby the curve range to be marked is the range just before the respective peak. In the experiment example, the peaks are very close to each other so that the first base line can be used for the second peak as well. The base line of the third peak has to be constructed as a horizontal line through the preceding minimum. However, the resulting errors remain small (± 0.3 °C).

In differential thermal analysis, the point of intersection of the inflectional tangent of every peak and the associated base line is given as the temperature value for the phase transition or the start of a reaction. As DTA is a dynamic method of analysis, these temperatures can slightly deviate from the thermodynamic equilibrium temperatures depending on the ambient conditions.

In order to determine the point of intersection, switch the coordinate display on by pressing **Alt+K**, position the mouse pointer on the point of intersection, and enter the indicated temperature in the diagram with **Alt+T**. In addition, you can mark the transitions by a vertical line (combination **Alt+V**) and insert an explanatory text (**Alt+T**).

Up to 150 °C, the DTA of copper sulphate exhibits three peaks. The first one (approx. 96 °C) is associated with the spitting-off of the first two bonded water molecules, the second corresponds to the evaporation of these water molecules and the third one to the splitting-off and evaporization of two more water molecules:

1. $\text{CuSO}_4 \cdot 5\text{H}_2\text{O} \xrightarrow{96^\circ\text{C}} \text{CuSO}_4 \cdot 3\text{H}_2\text{O} + 2\text{H}_2\text{O}(\text{l})$
2. $2\text{H}_2\text{O}(\text{l}) \xrightarrow{103^\circ\text{C}} 2\text{H}_2\text{O}(\text{g})$
3. $\text{CuSO}_4 \cdot 3\text{H}_2\text{O} \xrightarrow{118^\circ\text{C}} \text{CuSO}_4 \cdot \text{H}_2\text{O} + 2\text{H}_2\text{O}(\text{g})$

The last bonded water molecule is only split off at 250 °C; recording this peak was renounced in favour of a shorter duration of the experiment.

Further experiment options

In order to obtain a clearer separation of the peaks, you can slow down the rate of heating or reduce the amount of substance significantly. Regarding the practicability of the experiment as a demonstration experiment, these possibilities were renounced in the example measurement.

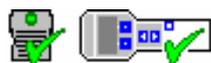
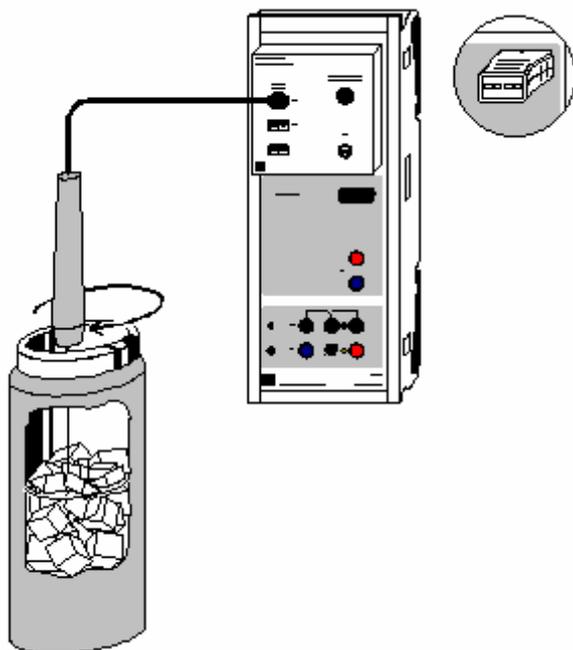
If you weigh the copper sulphate exactly before and after each peak, you can determine the amount of evaporated crystallization water. To do this, first stop heating at approx. 100 °C, then at approx. 115 °C and at 150 °C. When the substance has cooled down, you can determine the mass difference relative to the initial mass.

In the described experiment setup, many other determinations can be carried out. It is suitable for, e.g.:

- a consideration of the phase transitions of sulphur (transition between the α and β modification at approx. 100 °C, melting point at 119 °C, transition between the λ and μ melt starting from 159 °C),
- the determination of the triggering temperature of strongly exothermic reactions (e.g. ignition of black powder), which is relatively harmless due to the small amount of substance,
- setting up state diagrams of mixtures (e.g. tin and lead).

A more precise adjustment for a continuous rise in temperature is possible by means of a power controller that is suitable for use in conjunction with the burner (catalogue number 667 823).

Preparing a freezing mixture



can also be carried out with Pocket-CASSY and Mobile-CASSY

■ Load example

Experiment description

If ice is mixed with a salt, part of the ice melts, and the salt dissolves in the water from the melted ice. The energy required for melting the water and dissolving the salt is taken from the environment so that the entire mixture cools down. Depending on the kind of salt, temperatures of down to -60 °C are reached. Water soluble liquids (e.g. ethanol) can also create such effects.

The melting of ice when a salt is added is due to the freezing-point depression of a solution as compared with the pure solvent. Thereby the water-ice equilibrium is shifted towards the liquid state, and heat is taken from the environment until a new equilibrium is established at a lower temperature.

In this experiment, a simple freezing mixture is prepared from common salt and ice in a Dewar flask. Even with this cheap mixture temperatures of below -20 °C can be reached.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Chemistry box or NiCr-Ni adapter S	524 067(3)
1	Temperature sensor NiCr-Ni, type K	529 676
1	Dewar flask, 0.5 l	667 320
8	watch glass dishes, $\varnothing = 8\text{ cm}$	664 154
1	Laboratory balance	
1	PC with Windows 95/98/NT or higher version	

Required substances

Sodium chloride, e.g. 250 g	673 5700
Ice, approx. 200 g	
Distilled water	



Preparing the experiment

- Plug the chemistry box with the temperature sensor being connected to T1 into input A of the Sensor-CASSY.
- Weigh in 10 g of sodium chloride on each of the watch glass dishes.
- Crush the ice as fine as possible in order that it can well be mixed with the salt.

Calibration

In order to ensure a sufficient accuracy, calibrate the temperature sensor when using it for the first time. Afterwards the calibration should be repeated from time to time.

■ Load settings

- Immerse the temperature sensor in ice water (mixture of ice and a small amount of water), stir with the temperature sensor, and wait until the display instrument shows a measured value that is stable up to ± 0.1 °C.
- Enter the target value "0" in the first line in Settings ϑ_{A11} under **Correct**, and press the **Correct Offset** button.
- Store the calibrated settings with **F2** under a new name.
- Mark the Sensor-CASSY, the chemistry box, and the temperature sensor in order that they can be used again in the same combination (otherwise the stored calibration will not be applicable).

Carrying out the experiment

- Use or load the calibrated settings.
- Fill crushed ice into the Dewar flask, and add a small amount of water.
- Immerse the temperature sensor in the ice and stir.
- Record the first measured value by pressing the key **F9** or the  button, and enter "0" as the first value in the table column mNaCl, by clicking the table line with the left mouse button and typing the number.

Keep to the following procedure until all of the salt has been added to the ice:

- Put 10 g of common salt into the Dewar flask.
- Thoroughly stir with the temperature sensor until a uniform temperature is measured everywhere in the freezing mixture (check with the aid of the display instrument ϑ_{A11}).
- Record the measured value by pressing the key **F9** or the  button.
- Enter the total mass of common salt added up to that moment into the appropriate table cell for mNaCl.

Evaluation

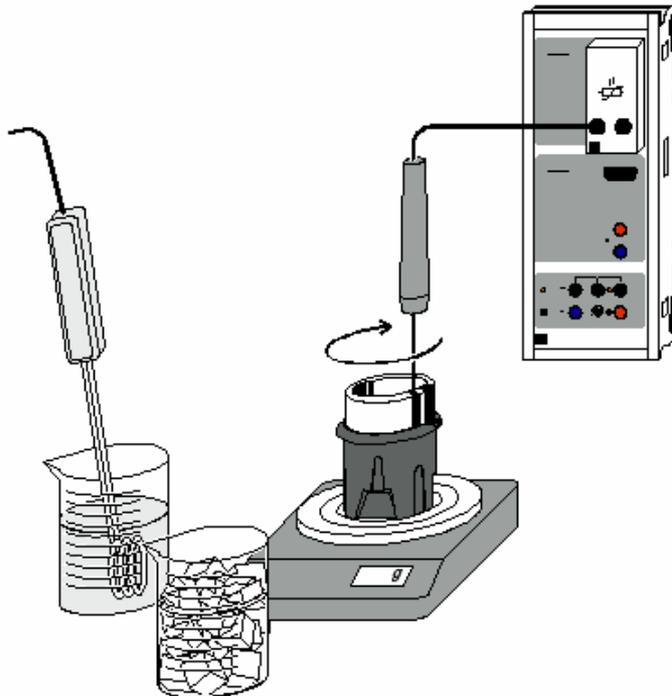
The measuring curve shows the temperature in the freezing mixture as a function of the mass of sodium chloride added. It is clearly seen that addition of 10 g of NaCl to pure ice leads to a significantly stronger decrease in temperature than addition to a freezing mixture that already contains a great amount of salt. After 60 g of NaCl has been added, saturation is reached. Further addition of common salt does not lower the temperature of the mixture as the limit of the solubility of common salt in water is reached.

The saturation temperature can be marked by a horizontal line through the temperature minimum by pressing **Alt+H**. The temperature value is displayed in the status line and can be inserted in the diagram with the mouse or by pressing **Alt+T**.

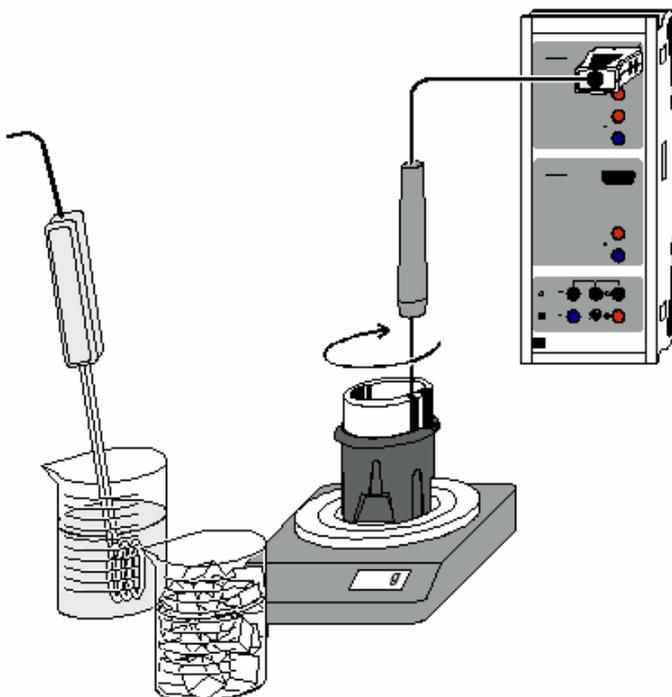
If desired, the temperatures can be displayed as a bar chart by clicking the diagram with the right mouse button and selecting **Select Value Display** and **Show bars**.

The diagram generated can be printed via the printer symbol in the upper line on the screen.

Determining the melting enthalpy of ice



Alternatively with temperature sensor S:



can also be carried out with Pocket-CASSY and Mobile-CASSY

- Load example (temperature box)
- Load example (temperature sensor S)



Experiment description

If a certain amount of ice is put into the warm water contained in a calorimeter, a mixing temperature ϑ_m can be determined after the ice has melted and completely mixed with the water. The mixing temperature depends on the masses of the water (m_1) and the ice (m_2) as well as on the corresponding temperatures ϑ_1 and ϑ_2 . In order to simplify the evaluation, ice of $\vartheta_2 = 0\text{ °C}$ is used for the measurement.

Quick recording of the measured values with CASSY Lab enables a temperature curve to be determined, which can be used to calculate the melting enthalpy of ice. With the same setup other calorimetric measurements can be carried out as well, e.g., mixing experiments or the determination of heat capacities.

Equipment list (temperature box)

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Temperature box	524 045
1	Temperature sensor NTC	666 212
1	Dewar flask	386 48
1	Safety immersion heater	303 25
1	Beaker, squat shape, 250 ml	664 130
1	Beaker, squat shape, 600 ml	664 132
1	Balance, measuring range up to 500 g, resolution 0.01 g	
1	Absorbent cloth	

Equipment list (temperature sensor S)

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Temperature sensor S	524 044
1	Dewar flask	386 48
1	Safety immersion heater	303 25
1	Beaker, squat shape, 250 ml	664 130
1	Beaker, squat shape, 600 ml	664 132
1	Balance, measuring range up to 500 g, resolution 0.01 g	
1	Absorbent cloth	

Required substances

Ice, approx. 100 g
Distilled water

Experiment setup (see drawing)

Plug the temperature box with the temperature sensor being connected into input A of the Sensor-CASSY. Alternatively, connect the temperature sensor S to input A.

Heat distilled water in the bigger beaker up to a temperature of about 80 °C. Put the dry Dewar flask on the balance and set the display of the balance to 0.

Calibration

Calibrate the temperature sensor while the water is heated:

- Load settings (temperature box)
- Load settings (temperature sensor S)
- Crush the ice, and put it into the other beaker.
- Add a small amount of water. After a short time, the ice-water equilibrium with a temperature of 0 °C should be established.
- Immerse the temperature sensor in the ice water mixture and stir.
- Enter the target value "0" in the first line in Settings ϑ_{A11} under **Correct**, and press the **Correct Offset** button.

Carrying out the experiment

- Pour about 120 g of hot water into the Dewar flask.
- Pour the water from the ice water mixture away, pour the ice on the cloth, and dry it thoroughly.
- Read the mass of the hot water, and take it down.
- Immerse the temperature sensor in the flask.
- Start the measurement by pressing the key **F9** or the  button.
- Having waited for approx. 30 to 60 seconds, pour the ice from the cloth into the Dewar flask. While doing so, permanently stir with the temperature sensor.
- After another 30 to 60 seconds, stop the measurement by pressing the key **F9** or the  button.
- Remove the temperature sensor from the Dewar flask, and drain it well over the flask. Read the total mass at the balance, and take it down.

Evaluation

In the diagram, the measured values of the temperature ϑ are plotted against the time t .

1. In order to determine the calorimeter and the mixing temperature, first fit straight lines to the linear curve ranges at the beginning and at the end of the measurement (click the diagram with the right mouse button, select, **Fit function** and **Best-fit straight line**, and mark the respective curve section).

2. Next generate a vertical line with **Alt+V**, and position it so that the two (almost triangular) areas each formed by one of the fitted straight lines, the vertical line and the measuring curve have equal sizes. The point of intersection of the vertical line with the upper best-fit straight line corresponds to the initial temperature ϑ_1 of the calorimeter, whereas the lower point of intersection corresponds to the mixing temperature ϑ_m . As the straight lines are almost horizontal, only a small error has to be expected (± 0.1 °C).

3. For a precise determination of the coordinates, press **Alt+C**, and position the mouse pointer exactly in the points of intersection. The coordinates are displayed in the status line below on the left and can be inserted as text in the diagram via **Alt+T**.

The calculation of the melting enthalpy ΔH_f can be derived in the following way:

I) Quantity of heat given off by the calorimeter and the hot water:

$$\Delta Q_1 = c_w \cdot (m_1 + m_0) \cdot (\vartheta_1 - \vartheta_m)$$

II) Quantity of heat taken up by the ice ($\vartheta_2 = 0$ °C) from the calorimeter:

$$\Delta Q_2 = m_2 \cdot \Delta H_f + m_2 \cdot c_w \cdot (\vartheta_m - 0)$$

Here c_w is the heat capacity of water, m_1 the mass of the hot water, m_2 the mass of the ice and m_0 the water equivalent of the calorimeter. As there is almost no heat exchanged with the environment, we have

$$\Delta Q_1 = \Delta Q_2$$

Consequently the melting enthalpy ΔH_f is calculated according to

$$\Delta H_f = \left(\frac{m_1 + m_0}{m_2} \cdot (\vartheta_1 - \vartheta_m) - \vartheta_m \right) \cdot c_w$$

With the water equivalent $m_0 = 24$ g of the Dewar flask used, the measured values of the experiment example lead to the following calculation:

$$\Delta H_f = \left(\frac{121 + 24}{75,6} \cdot (73,5 - 21,5 \text{ °C}) - 21,5 \text{ °C} \right) \cdot 4,19 \text{ J / °C} \cdot \text{g} = 327,8 \text{ J / g}$$

This result is very close to the value of 334 J/g quoted in the literature.

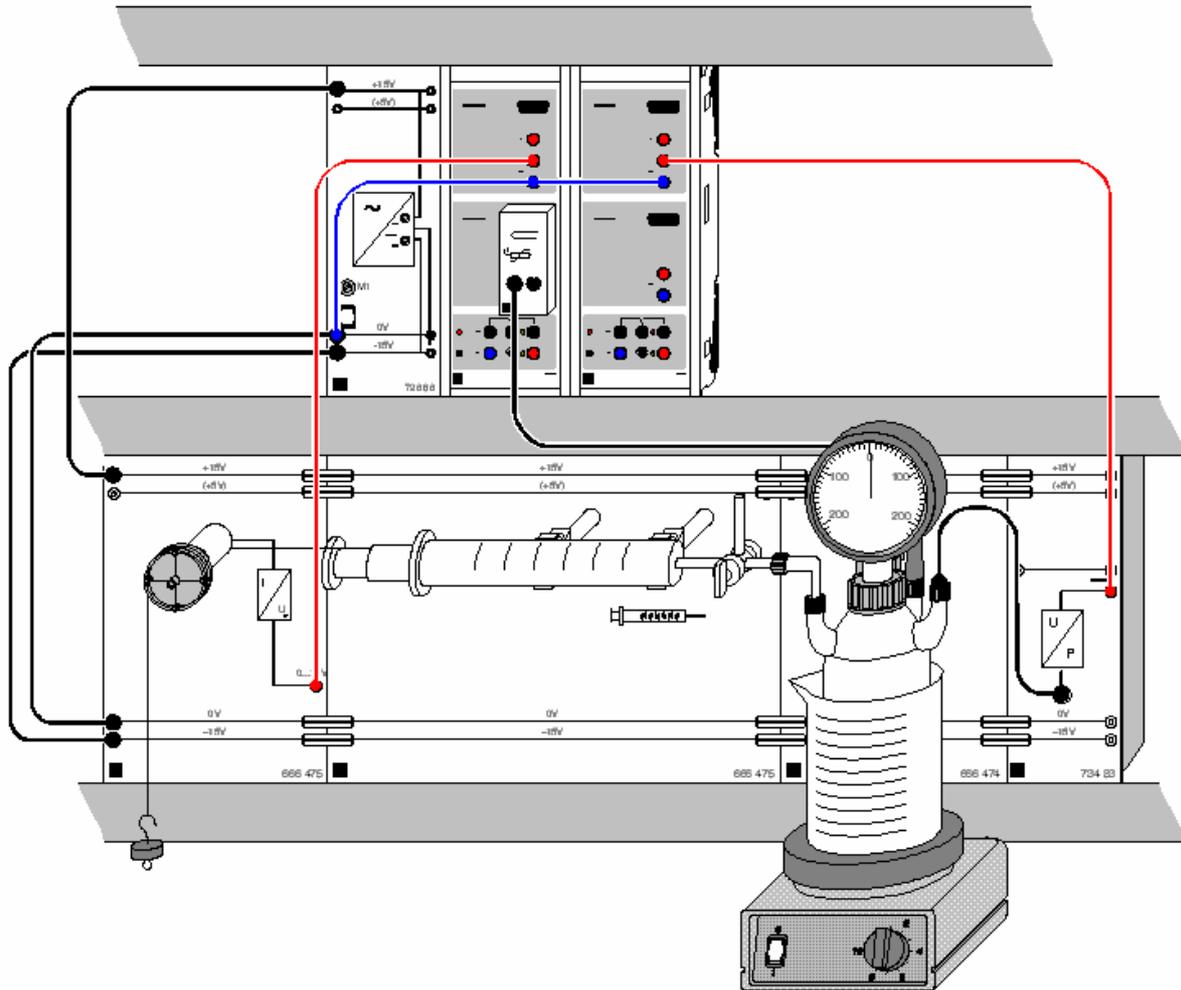


ΔH_f is significantly greater than the heat capacity of 1 g of water:

$$\frac{\Delta H_f}{c_w \cdot 1 \text{ g}} = \frac{334}{4,19} = 79,7$$

That means: with the energy required to melt 1 g of ice having a temperature of 0 °C, 1 g of water can be heated from 0 °C to approx. 80 °C.

Gas laws



can also be carried out with Pocket-CASSY and Mobile-CASSY

- Load example for Boyle-Mariotte's law (isothermic)
- Load example for Amontons' law (isochoric)
- Load example for Gay-Lussac's law (isobaric)

Experiment description

This experiment records the three quantities pressure p , temperature T and volume V simultaneously. Assuming ideal behavior of the respective gas, the ideal law of gases applies

$$p \cdot V = n \cdot R \cdot T,$$

whereby n is the quantity of matter in mol and $R = 8.315 \text{ J/K/mol}$ is the general gas constant. To verify the gas laws in the experiment, one of the three variables (p , V and T) is maintained constant each time. We thus obtain the three derived gas laws:

Boyle-Mariotte's law ($T = \text{const.}$, isothermic)	$p \propto 1/V$
Amontons' law ($V = \text{const.}$, isochoric):	$p \propto T$
Gay Lussac's law ($p = \text{const.}$, isobaric):	$V \propto T$



Equipment list

2	Sensor-CASSYs	524 010
1	CASSY Lab	524 200
1	Temperature box	524 045
1	Temperature sensor NiCr-Ni	666 216
1	CPS electronic displacement transducer	666 475
1	CPS-P/U converter	734 83
1	CPS-basic unit for gas laws	666 474
1	Gas syringe for gas laws	666 473
1	Stabilized power supply ± 15 V	726 86
1	Magnetic stirrer, heatable	666 847
1	Stirrer bar	666 854
1	Laboratory stand	300 76
1	Beaker, 1000 ml, ss	664 107
1	GL-18 screw cap	667 305
1	Set of 10 silicone seals	667 306
1	Set of 10 bridging plugs	501 511
1	Panel frame C100, two-level	666 428
3	Connecting leads, 100 cm, black	500 444
2	Pairs of cables, 1 m, red and blue	501 46
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Place the displacement transducer, the gas syringe for gas laws, the basic unit for gas laws and the power supply in the bottom level of the panel frame and connect the individual panels together using the bridging plugs. Attach the gas syringe, the thermocouple and the pressure sensor to the basic unit using the GL 18 screw connectors. Seal the GL 45 connector with the enclosed screw cap. Attach the weight to the clamp for the gas syringe using a thread. Push the clamp onto the end of the plunger and wind the thread two times around the pulley of the displacement transducer. When the plunger is pushed in, the weight should be around 30 to 40 cm above the benchtop. Shorten the thread as necessary.

Place the two Sensor-CASSY units in the top level of the CPS panel frame and cascade them (connect them together). Allocate the Sensor-CASSY analog outputs as follows:

- Connect sensor input A1 to the voltage output of the CPS displacement transducer using connecting leads.
- Connect sensor output B1 to the NiCr-Ni temperature sensor via the temperature box.
- Connect sensor output A2 to the voltage output of the CPS-P/U converter using connecting leads.

Carrying out the experiment

a) Boyle-Mariotte's law ($T = \text{const.}$, $p \propto 1/V$)

■ Load settings

- Open the three-way stopcock.
- Pull out the plunger of the gas syringe to the 100 ml mark and turn the deflection pulley to the left until just before full stop.
- Check the volume $V = 725$ ml, if necessary adjust the adjusting screw on the CPS displacement transducer.
- Close the stopcock so that there is only one connection between the syringe and the bottle, and no more air can enter the system.
- Record the first measured values with **F9**.
- Carefully depress the plunger in increments of 10 ml and wait until the previously measured temperature (ambient temperature) is restored.
- Record additional measured values each time with **F9**.

b) Amontons' law ($V = \text{const.}, p \propto T$)

■ Load settings

- Open the three-way stopcock to vent the Woulff's bottle.
- Close the stopcock so that there is no connection to the bottle.
- Switch on the hot plate and the magnetic stirrer.
- Start automatic measurement with **F9**.
- Switch off the hot plate before the water in the beaker begins to boil and stop the measurement with **F9**.

c) Gay Lussac's law ($p = \text{const.}, V \propto T$)

■ Load settings

- Switch on the hot plate and the magnetic stirrer.
- Switch off the hot plate before the water in the beaker begins to boil.
- Open the three-way stopcock.
- Pull out the plunger of the gas syringe to the 100 ml mark and turn the deflection pulley to the left until just before full stop.
- Check the volume $V = 725$ ml, if necessary adjust the adjusting screw on the CPS displacement transducer.
- Close the stopcock so that there is only one connection between the syringe and the bottle, and no more air can enter the system.
- Record the first measured values with **F9**.
- Carefully depress the plunger in increments of 5 ml and wait until the previously measured pressure (ambient pressure) is restored.
- Record additional measured values each time with **F9**.
- Stop the measurement as soon as the temperatures approach the ambient temperature.

Evaluation

The following diagrams are used to evaluate the respective experiment parts:

- | | |
|--|----------------|
| a) Isothermic experiment part ($T = \text{const.}$): | $p(V)$ diagram |
| b) Isochoric experiment part ($V = \text{const.}$): | $p(T)$ diagram |
| c) Isobaric experiment part ($p = \text{const.}$): | $T(V)$ diagram |

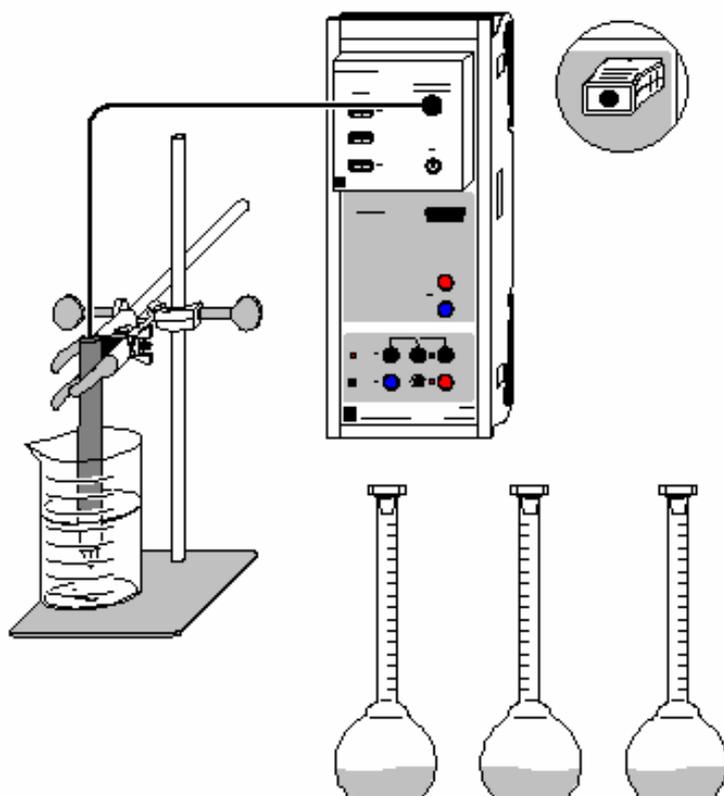
In the display **Regression** (click on this tab) these diagrams are already pre-scaled so that the zero point of the coordinate system is visible; you can fit the following functions in the diagram:

- | | |
|--|--------------------------------------|
| a) Isothermic experiment part ($p \propto 1/V$): | hyperbola $1/x$ |
| b) Isochoric experiment part ($p \propto T$): | best-fit line or line through origin |
| c) Isobaric experiment part ($T \propto V$): | best-fit line or line through origin |

Remark

The scaling in **Regression** begins with the zero point and covers a broad range. This enables significant curve sections and intersections to be recognized and explained better.

Determining the conductivity of different solutions



can also be carried out with Pocket-CASSY and Mobile-CASSY

■ Load example

Experiment description

The electric conductivity of aqueous solutions depends on several parameters:

a) concentration of the solution, b) degree of dissociation of the substance, c) mobility of the ions, and d) charge of the ions.

From a comparison of conductivities measured on different solutions, conclusions can be drawn regarding these parameters.

The values obtained are displayed by CASSY-Lab in easy to read large characters and in clearly arranged diagrams.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Chemistry box or conductivity adapter S	524 067(1)
1	Conductivity sensor	529 670
1	Bunsen burner stand, 450 mm	666 502
1	Crossed bosshead	666 543
1	Miniature clamp	666 551
1	Beaker, 100 ml, tall shape	664 137
15	volumetric flasks, 100 ml	665 793
1	Bulb pipette, 50 ml	665 977
1	Bulb pipette, 10 ml	665 975

2	Pipetting balls	666 003
1	Spatula	666 962
1	Watch glass dish, e.g. 80 mm	664 154
1	Powder funnel, e.g. 60 mm	602 681
1	Balance (at least up to 100 g, resolution 0.01 g)	
1	PC with Windows 95/98/NT or higher version	

Chemicals

D(+)-glucose, e.g. 100 g	672 1100
Acetic acid, c = 1 mol/l, e.g. 1000 ml:	671 9590
Magnesium sulphate 7-hydrate, e.g. 100 g	673 1600
Sodium chloride, e.g. 250 g	673 5700
Hydrochloric acid, c = 1 mol/l, 500 ml	674 6900
Distilled water	
If necessary:	
Calibration solution, 111.8 mS/cm	667 4644
Calibration solution, 12.88 mS/cm	667 4640

Preparing the solutions

For preparing the solutions, the balance, the pipettes, the volumetric flasks, the spatula, the watch glass dish, and the funnel are required. From each substance three solutions of different concentrations are prepared. Of course, other concentrations can be used in addition or some of the measuring values can be omitted.

1) Glucose solutions (1 mol/l, 0.5 mol/l, 0.1 mol/l)

One after another weigh in exactly 19.82 g (1 mol/l), 9.91 g (0.5 mol/l) and 1.98 g (0.1 mol/l) of glucose on the watch glass dish, which is lying on the balance, and rinse it with distilled water through the funnel into a 100 ml flask. Then clean the watch glass dish, the spatula and the funnel.

2) Acetic acid solutions (0.5 mol/l, 0.1 mol/l, 0.01 mol/l)

Using the pipette, put 50 ml (0.5 mol/l) and 10 ml (0.1 mol/l) of 1 M acetic acid in a 100 ml volumetric flask each, and fill the flasks with distilled water up to the calibration mark. Prepare the 0.01 M acetic acid from 10 ml of 0.1 M solution in a new flask.

3) Magnesium sulphate solutions (0.5 mol/l, 0.1 mol/l, 0.01 mol/l)

One after another weigh in exactly 12.32 g (0.5 mol/l) and 2.46 g (0.1 mol/l) of magnesium sulphate on the watch glass dish, which is lying on the balance, and rinse it with distilled water through the funnel into a 100 ml flask. Using the cleaned pipette, prepare the 0.01 M solution from 10 ml of 0.1 M magnesium sulphate solution in a new flask. Then clean the watch glass dish, the spatula, the funnel and the pipette.

4) NaCl solutions (0.5 mol/l, 0.1 mol/l, 0.01 mol/l)

Weigh in exactly 2.92 g (0.5 mol/l) of sodium chloride on the watch glass dish, which is lying on the balance, and rinse it with distilled water through the funnel into a 100 ml flask. Using the pipette, prepare the 0.1 M solution from 20 ml of 0.5 M solution in a new volumetric flask and the 0.01 M solution from 10 ml of the 0.1 M solution.

5) Hydrochloric acid solution (0.5 mol/l, 0.1 mol/l, 0.01 mol/l)

Using cleaned pipettes, put 50 ml (0.5 mol/l) and 10 ml (0.1 mol/l) of 1 M hydrochloric acid into a 100 ml volumetric flask each, and fill the flask with distilled water up to the calibration mark. Prepare the 0.01 M acetic acid from 10 ml of 0.1 M solution in a new flask.

Experiment setup (see drawing)

Plug the chemistry box with the conductivity sensor being connected into input A of the Sensor-CASSY. After thoroughly rinsing the conductivity sensor with distilled water, fix it in the clamp, so that its height can be adjusted with the crossed bosshead according to the requirements.

Calibration

■ Load settings

The cell constant of the conductivity sensor for the chemistry box has already been set to 0.58 in CASSY Lab. If another conductivity sensor is used, its cell constant has to be entered as a factor in Settings Conductivity CA1 under **Correct**. Then the **Correct Factor** button has to be pressed.

For a more precise determination of the cell constant, calibration solutions can be used: rinse the beaker and the conductivity sensor first with distilled water and then with approx. 30-40 ml of calibration solution. Immerse the conductivity sensor in another 50 ml of calibration solution as if it was for a conductivity measurement (pay attention to the distances from the walls of the beaker), enter the target value in the second line in Settings CA1 under **Correct**, and press the **Correct Factor** button when a stable measured value is reached.

Carrying out the experiment

One after another measure the conductivity of distilled water, the solutions of glucose, acetic acid, magnesium sulphate, sodium chloride, and hydrochloric acid, starting with the lowest concentration and keeping to the following order:

- Rinse the electrode and the beaker thoroughly with 30-40 ml of the solution.
- Fill another 60 ml of the solution into the beaker.
- Adjust the height of the conductivity sensor so that its immersion depth in the liquid is 2 cm and its distance from every wall at least 1 cm.
- If necessary, change the measuring range in Settings Conductivity CA1. Always select the lowest possible measuring range.
- When the displayed value is stable, record the measured value by pressing **F9** or the  button.
- Enter the concentration and the substance associated with the measured value in the diagram. To do this, press **Alt+T**, type the substance and the value of the concentration and position the text at the desired place in the diagram with the mouse.
- In order to simplify the evaluation, select **Append New Meas. Series** in Measuring Parameters before measuring the conductivity of a new substance.
- Before measuring the conductivity of a new substance, thoroughly rinse the beaker and the conductivity sensor with distilled water.

Evaluation

When the large representation of the display instrument is selected, the measured values can also be read by persons who are at some distance from the screen. The values are automatically entered in the diagrams as bars so that the differences between the conductivities are visualized.

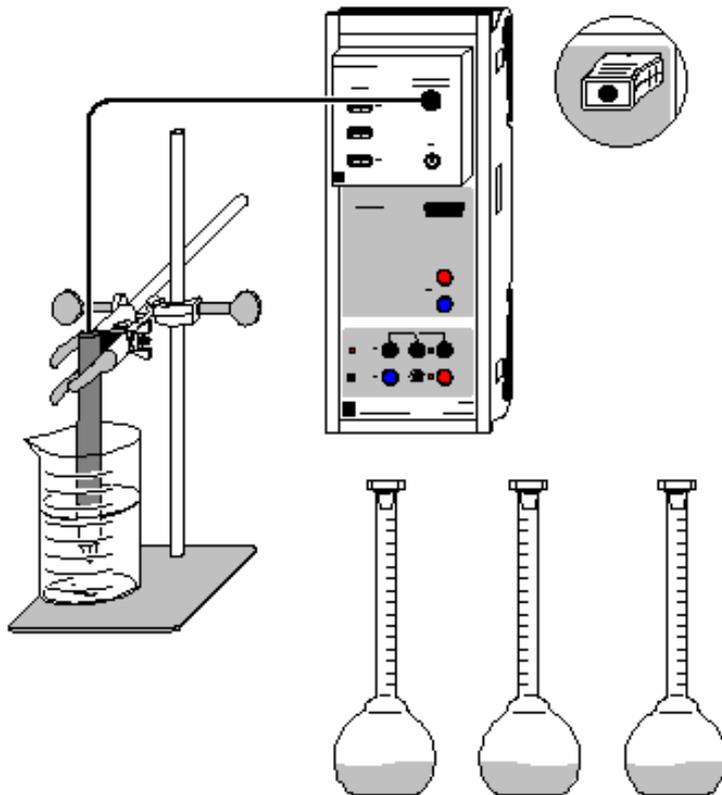
The diagram **Specific Conductivity** has been prepared as an overview for this purpose. The other diagrams allow direct comparison of two particular substances with each other. In order to get a clear separation between the different substances, vertical lines can be inserted in the diagram between the measurement series.

This experiment demonstrates clearly that the conductivity depends strongly on the concentration. Moreover it can be seen from the measuring results that strong electrolytes having a high degree of dissociation conduct much better than substances that do not or only to a small proportion dissociate. From the higher conductivity of hydrochloric acid as compared with the common salt solutions it can be concluded that the mobility of hydronium ions is greater than that of sodium ions.

Despite the higher ion charge, the magnesium sulphate solutions of higher concentration do not exhibit a greater conductivity than the corresponding NaCl solutions because the ions exert strong electrostatic forces on each other due to their charges, which are twice the charges of the ions of sodium and chloride ions. However, at lower concentrations (great distances between the ions), e.g. 0.01 mol/l, the conductivity is higher as compared with NaCl.

The diagrams generated can be printed via the printer symbol in the upper line on the screen.

Determining the limiting equivalent conductivity of sodium chloride



can also be carried out with Pocket-CASSY and Mobile-CASSY

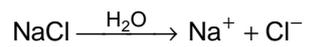
■ Load example

Experiment description

Measurement of the conductivities of the same electrolyte at different concentrations enables several important characteristic data of the substance to be determined. In this experiment, the measured specific conductivity κ_{A1} of sodium chloride is used to calculate its equivalent conductivity Λ_{eq} , which is defined as the ratio of the specific conductivity and the equivalent concentration:

$$\Lambda_{eq} = \frac{\kappa_{A1}}{c_0 \cdot n}$$

Here c_0 is the concentration of the solution and n the number of released positive and negative charges. In the case of NaCl, n is 1 as NaCl dissociates according to the equation



As dissolved ions are subject to mutual electrostatic interactions, the equivalent conductivity depends on the concentration. Only at infinite dilution are the interactions equal to zero as the distances between the ions become too large. Therefore the equivalent conductivity at infinite dilution Λ_0 (limiting equivalent conductivity) gives the equivalent conductivity of the completely dissociated substance without interionic interactions. Λ_0 can be determined graphically according to Kohlrausch's square-root law

$$\Lambda_{eq} = \Lambda_0 - k\sqrt{c_0}$$

The ratio of the equivalent conductivity and the limiting equivalent conductivity Λ_{eq}/Λ_0 corresponds to the degree of dissociation α of sodium chloride. In strong electrolytes such as NaCl, α is almost 1 in solutions of low concentration.



Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Chemistry box or conductivity adapter S	524 067(1)
1	Conductivity sensor	529 670
1	Bunsen burner stand, 450 mm	666 502
1	Crossed bosshead	666 543
1	Miniature clamp	666 551
1	Beaker, 100 ml, tall shape	664 137
1	Volumetric flask, 250 ml	665 794
6	Volumetric flask, 100 ml	665 793
1	Bulb pipette, 10 ml	665 975
1	Bulb pipette, 25 ml	665 976
2	Pipetting balls	666 003
1	Spatula	666 962
1	Watch glass dish, e.g. 80 mm	664 154
1	Powder funnel, e.g. 60 mm	602 681
1	Balance (at least up to 100 g, resolution 0.01 g)	
1	PC with Windows 95/98/NT or higher version	

Chemicals

Sodium chloride, e.g. 250 g	673 5700
Distilled water	
If necessary:	
Calibration solution, 111.8 mS/cm	667 4644
Calibration solution, 12.88 mS/cm	667 4640

Preparing the solutions

For preparing the solutions, the balance, the pipettes, the volumetric flasks, the spatula, the watch glass dish, and the funnel are required.

Weigh in exactly 29.22 g of sodium chloride (0.5 mol) on the watch glass dish, which is lying on the balance, and rinse the salt through the funnel into the 250 ml flask with distilled water. After dissolving the salt completely and filling the flask up to the calibration mark, use the 2 M NaCl solution for preparing the other solutions. For 100 ml of the respective solution you need:

for 1 mol/l:	50 ml
for 0.8 mol/l:	40 ml
for 0.5 mol/l:	25 ml
for 0.2 mol/l:	10 ml
for 0.1 mol/l:	of the solution with $c = 1$ mol/l: 10 ml
for 0.01 mol/l:	of the solution with $c = 0.1$ mol/l: 10 ml

If you intend to investigate the specific conductivity of NaCl over the total range of concentrations, it is recommendable to prepare some additional solutions of higher concentration, e.g. 1.5 mol/l, 3 mol/l, 4 mol/l, 5 mol/l, and 6 mol/l.

Experiment setup (see drawing)

Plug the chemistry box with the conductivity sensor being connected into input A of the Sensor-CASSY. After thoroughly rinsing the conductivity sensor with distilled water, fix it in the clamp, so that its height can be adjusted with the crossed bosshead according to the requirements.

Calibration

■ Load settings

The cell constant of the conductivity sensor for the chemistry box has already been set to 0.58 in CASSY Lab. If another conductivity sensor is used, its cell constant has to be entered as a factor in Settings Conductivity CA1 under **Correct**. Then the **Correct Factor** button has to be pressed.

For a more precise determination of the cell constant, calibration solutions can be used: rinse the beaker and the conductivity sensor first with distilled water and then with approx. 30-40 ml of calibration solution. Immerse the conductivity sensor in another 50 ml of calibration solution as if it was for a conductivity measurement (pay attention to the distances from the walls of the beaker), enter the target value in the second line in Settings CA1 under **Correct**, and press the **Correct Factor** button when a stable measured value is reached.

Such a correction with calibration solutions is also necessary for the conductivity sensor used in this experiment if you intend measurements on highly concentrated NaCl solutions whose specific conductivity exceeds 100 mS/cm. This is the case for concentrations over 1.5 mol/l.

Carrying out the experiment

Starting with the solution of the lowest concentration (0.01 mol/l) and following the order up to the 2 M solution, keep to the following procedure:

- Rinse the electrode and the beaker thoroughly with 30-40 ml of the solution.
- Pour this portion of the solution away.
- Fill the remaining solution (approx. 60 ml) into the beaker.
- Adjust the height of the conductivity sensor so that its immersion depth in the liquid is 2 cm and its distance from every wall at least 1 cm.
- If necessary, change the measuring range in Settings Conductivity CA1. Always select the lowest possible measuring range.
- When the displayed value is stable, record the measured value by pressing **F9** or the  button.
- Enter the concentration associated with the measured value into the table. To do this, click the corresponding line of the table with the left mouse button, and type the value of the concentration.
- Pour the solution away.

Evaluation

The values obtained for CA1 give the specific conductivity of the solution. This quantity is not substance specific, but depends on the concentration and the temperature. The temperature compensation for the sensor programmed in CASSY-Lab determines the data automatically with respect to the standard temperature of 25 °C.

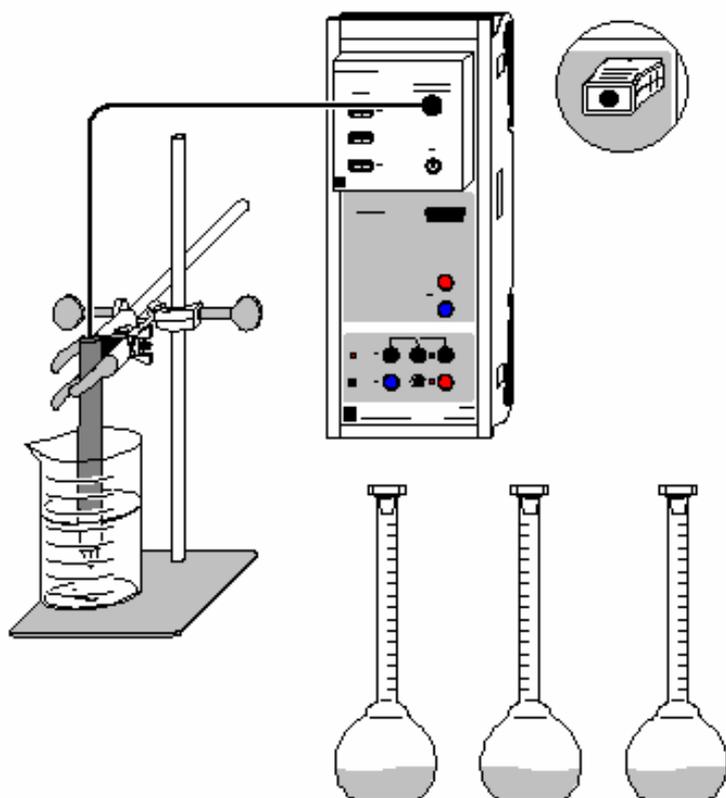
For the evaluation of the data, 4 diagrams have been prepared in CASSY-Lab:

1. In the first diagram, the **specific conductivity** CA1 is plotted against the concentration c_0 .
2. The second diagram displays the concentration dependence of **the equivalent conductivity** Λ_{eq} .
3. According to Kohlrausch's square-root law, the plot of the equivalent conductivity against the square root of the molar concentration is approximately a straight line in the range of low concentrations, the cut off being the limiting equivalent conductivity. This behaviour can be seen in the diagram **Kohlrausch plot**. The slope k depends on the number of ions that result from dissociation (i.e., this slope is smaller in the case of NaCl than, e.g., in the case of H₂SO₄).

For fitting a straight line, click the diagram with the right mouse button, select **Fit function**, and Best-fit straight line. After marking the curve range between 0 and 0.5 mol/l you obtain a straight line whose slope A and cut off B are displayed in the status line below on the left. These values can be dragged in to the diagram with the mouse or inserted as text via **Alt+T**. The parameter A corresponds to $-k$ in the Kohlrausch law, and B is the value of the limiting equivalent conductivity Λ_0 . Enter this value in Settings Λ_0 in the field Formula to calculate α .

4. Finally, the diagram **Degree of dissociation** shows the calculated data for α . It is clearly seen that even in the case of strong electrolytes the degree of dissociation is only approximately 1 for very low concentrations. This deviation from the ideal behaviour of a strong electrolyte can be explained by the interactions between the ions (ionic association due to Coulomb forces, impediment to the migration of ions in the solution).

Determining the dissociation constant of acetic acid



can also be carried out with Pocket-CASSY and Mobile-CASSY

■ Load example

Danger

Highly concentrated acetic acid is caustic. Wear protective goggles, gloves and clothing. Do not breathe in the vapour of concentrated acetic acid.

Concentrated acetic acid is flammable. Avoid free flames, and do not smoke.

Experiment description

The specific conductivity of acetic acid in various concentrations is measured. From the data acquired, the equivalent conductivity Λ_{eq} is calculated. The values obtained show that Kohlrausch's square-root law for determining the limiting equivalent conductivity does not apply to weak electrolytes. With the aid of the limiting equivalent conductivity determined via the individual ionic limiting equivalent conductivities and by applying Ostwald's dilution law, the degree of dissociation α and the equilibrium constant K_{Diss} of the dissociation equilibrium of acetic acid can be calculated.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Chemistry box or conductivity adapter S	524 067(1)
1	Conductivity sensor	529 670
1	Bunsen burner stand, 450 mm	666 502
1	Crossed bosshead	666 543
1	Miniature clamp	666 551
1	Beaker, 100 ml, tall shape	664 137

9	Volumetric flasks, 100 ml	665 793
1	Bulb pipette, 10 ml	665 975
1	Bulb pipette, 50 ml	665 977
2	pipetting balls	666 003
1	Collection container, approx. 1.5 l capacity	
1	PC with Windows 95/98/NT or higher version	

Chemicals

Acetic acid, 99-100 % (approx. 17.5 mol/l), 500 ml	671 9510
Acetic acid, c = 1 mol/l, 1000 ml	671 9590
Distilled water	

Preparing the solutions

For preparing the acetic acid solutions, the pipettes and the volumetric flasks are required.

Quantities of pure acetic acid required for 100 ml of solution:

- for HAc 50 % (8.75 mol/l): 50 ml
- for HAc 20 % (3.5 mol/l) and 10 % (1.75 mol/l), respectively: 20 ml and 10 ml, respectively

For preparing other solutions, use 1 M acetic acid:

- for HAc, c = 0.5 mol/l: 50 ml
- for HAc, c = 0.1 mol/l: 10 ml

Fill distilled water into the volumetric flasks containing the above mentioned amounts of acetic acid up to the calibration mark. Now use the acetic acid solutions just prepared to prepare further solutions. For this purpose put 10 ml of the HAc solution that has ten times the concentration of the solution to be prepared into a new flask, and add distilled water up to the calibration mark. In this way you obtain the following concentrations:

c = 0.05 mol/l, c = 0.01 mol/l, c = 0.005 mol/l, c = 0.001 mol/l

Now you have eleven acetic acid solutions available for measuring the conductivity at different concentrations. If you intend to perform detailed investigations of the total range of the specific conductivity, it is recommendable to prepare additional solutions of higher concentration (e.g. 30 %, 40 %, 60 %, 70 %, 80 %, 90 %).

Experiment setup (see drawing)

Plug the chemistry box with the conductivity sensor being connected into input A of the Sensor-CASSY. After thoroughly rinsing the conductivity sensor with distilled water, fix it in the clamp, so that its height can be adjusted by loosening and fastening the screw of the crossed bosshead at the stand.

Calibration

■ Load settings

The cell constant of the conductivity sensor for the chemistry box has already been set to 0.58 in CASSY Lab. If another conductivity sensor is used, its cell constant has to be entered as a factor in Settings Conductivity CA1 under **Correct**. Then the **Correct Factor** button has to be pressed.

For a more precise determination of the cell constant, calibration solutions can be used: rinse the beaker and the conductivity sensor first with distilled water and then with approx. 30-40 ml of calibration solution. Immerse the conductivity sensor in another 50 ml of calibration solution as if it was for a conductivity measurement (pay attention to the distances from the walls of the beaker), enter the target value in the second line in Settings CA1 under **Correct**, and press the **Correct Factor** button when a stable measured value is reached.



Carrying out the experiment

Starting with the solution of the lowest concentration (0.001 mol/l) and following the order up to concentrated acetic acid, keep to the following procedure:

- Rinse the electrode and the 100 ml beaker thoroughly with 30-40 ml of the solution.
- Pour this portion of the solution into a collection container.
- Fill the remaining solution (approx. 60 ml) into the 100 ml beaker.
- Fix the conductivity sensor at the stand so that its immersion depth in the liquid is 2 cm and its distance from every wall at least 1 cm.
- When the displayed value is stable, record the measured value by pressing **F9** or the  button.
- Enter the concentration associated with the measured value into the table by clicking the corresponding place of the table with the left mouse button and typing the value of the concentration.
- Pour the solution into the collection container.

Evaluation

The values determined for CA1 give the specific conductivity of the respective solution. This quantity is not substance specific, but depends on the concentration and the temperature. The temperature compensation for the sensor integrated in CASSY-Lab determines the data automatically with respect to the standard temperature of 25 °C.

For the evaluation of the data, several diagrams have been prepared in CASSY-Lab:

1+2) In the first two diagrams, the specific conductivity CA1 is plotted against the molar concentration and the percentage by volume, respectively, of the acetic acid.

3) The third diagram shows the **equivalent conductivity** Λ_{eq} as a function of the concentration.

4) If acetic acid was a strong electrolyte, a plot of the equivalent conductivity against the square root of the molar concentration would yield a straight line (see below: Kohlrausch's square-root law). The strong deviation from this law is seen in the diagram **Kohlrausch**.

5) In the diagram **Dissociation**, the values of the negative decimal logarithm of the dissociation constant pK_{Diss} and the degree of dissociation α as calculated from the measuring data are plotted. One reason for the decrease of K_{Diss} towards higher concentrations is the fact that in this region the concentration of water can no longer be considered to be constant; a further reason is given by the formation of ion agglomerates which occurs when the distances between ions become small.

6) In the diagram **Ostwald**, you can check the agreement between the measured values and the values quoted in the literature. For this purpose, plot the reciprocal of the equivalent conductivity (in $\text{mol}/(\text{S} \cdot \text{cm}^2)$) against the specific conductivity up to concentrations of 1 mol/l. From the cut off and the slope of the resulting straight line, K_{Diss} and Λ_0 can be calculated (see last equation in the section Theoretical background). As small errors in the measured values lead to big errors in this plot, this calculation has been renounced. Instead, the literature values for K_{Diss} and Λ_0 are used to check the measured values:

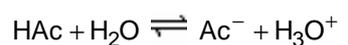
Calculate the corresponding straight line with the parameters A for pK_{Diss} and B for Λ_0 in the menu item Free fit (**Alt+F**). Enter " $1/B + x/(B^2 \cdot 10^{-A})$ " in the field intended for the formula; enter the literature values "4.76" for pK_{Diss} (parameter A) and "390.6" for Λ_0 (parameter B) and set the associated switch to **constant**. After clicking **Continue with Range Marking**, select an arbitrary range of the plotted measured values to obtain the calculated straight line.

Theoretical background

The equivalent conductivity Λ_{eq} is a substance specific quantity. It is given by the ratio of the specific conductivity CA1 and the equivalent concentration:

$$\Lambda_{eq} = \frac{C_{A1}}{c_0 \cdot n}$$

where c_0 is the molar concentration of the dissolved substance and n the number of positive or negative charges arising from the dissociation of one molecule. In the case of acetic acid we have $n = 1$:



The equilibrium is described by two characteristic parameters: the degree of dissociation α and the equilibrium constant (acidity constant) K_{Diss} .

α is defined as

$$\alpha = \frac{[\text{Ac}^-]}{c_0}$$

with the initial concentration c_0 of acetic acid and the concentration of acetate ions $[\text{Ac}^-]$ in the solution.

K_{Diss} and the acidity constant of acetic acid are identical:

$$K_{\text{Diss}} = \frac{[\text{Ac}^-] \cdot [\text{H}_3\text{O}^+]}{[\text{HAc}]}$$

By inserting

$$[\text{Ac}^-] = [\text{H}_3\text{O}^+] = \alpha \cdot c_0$$

and

$$[\text{HAc}] = (1 - \alpha) \cdot c_0$$

in the equation for K_{Diss} , "Oswald's dilution law" can be derived. For monovalent electrolytes it reads:

$$K_{\text{Diss}} = \frac{\alpha^2 \cdot c_0}{1 - \alpha}$$

For weak electrolytes with a small value of K_{Diss} , it follows that α increases as the concentration c_0 decreases until $\alpha = 1$ in the case of infinite dilution. Even weak electrolytes dissociate completely when infinitely dilute because recombination does not take place due to the infinite distances between cations and anions.

That means, for the limiting equivalent conductivity, i.e., the equivalent conductivity for infinite dilution Λ_0 , we have $\alpha = 1$. As the equivalent conductivity is proportional to the proportion of dissociated molecules, the degree of dissociation can also be determined via

$$\alpha = \frac{\Lambda_{\text{eq}}}{\Lambda_0}$$

For strong electrolytes, Kohlrausch's "square-root law" holds:

$$\Lambda_{\text{eq}} = \Lambda_0 - k\sqrt{c_0}$$

From this, Λ_0 can be determined graphically. For weak electrolytes, Λ_0 has to be determined in a roundabout way via the "law of independent migration of ions", which states that ions of opposite charges move independently from each other in the case of infinite dilution. For monovalent compounds it reads:

$$\Lambda_0 = \lambda_+ + \lambda_-$$

λ_+ and λ_- are the equivalent conductivities of the individual kinds of cations and anions at infinite dilution. However, as they cannot be measured individually, sums are formed of known limiting equivalent conductivities of strong electrolytes. The equivalent conductivity of acetic acid at infinite dilution is calculated in the following way:

$$\begin{aligned} \Lambda_0(\text{HAc}) &= \Lambda_0(\text{HCl}) + \Lambda_0(\text{NaAc}) - \Lambda_0(\text{NaCl}) \\ &= \lambda(\text{H}^+) + \lambda(\text{Cl}^-) + \lambda(\text{Na}^+) + \lambda(\text{Ac}^-) - \lambda(\text{Na}^+) - \lambda(\text{Cl}^-) = \lambda(\text{H}^+) + \lambda(\text{Ac}^-) \end{aligned}$$

Inserting the literature values, you obtain $\Lambda_0(\text{HAc}) = 390.6 \text{ S} \cdot \text{cm}^2 / \text{mol}$.

This value is used in the experiment example for calculating α , which eventually is needed for determining the dissociation constant K_{Diss} according to "Ostwald's dilution law".



Another possibility of determining the limiting equivalent conductivity is given by inserting

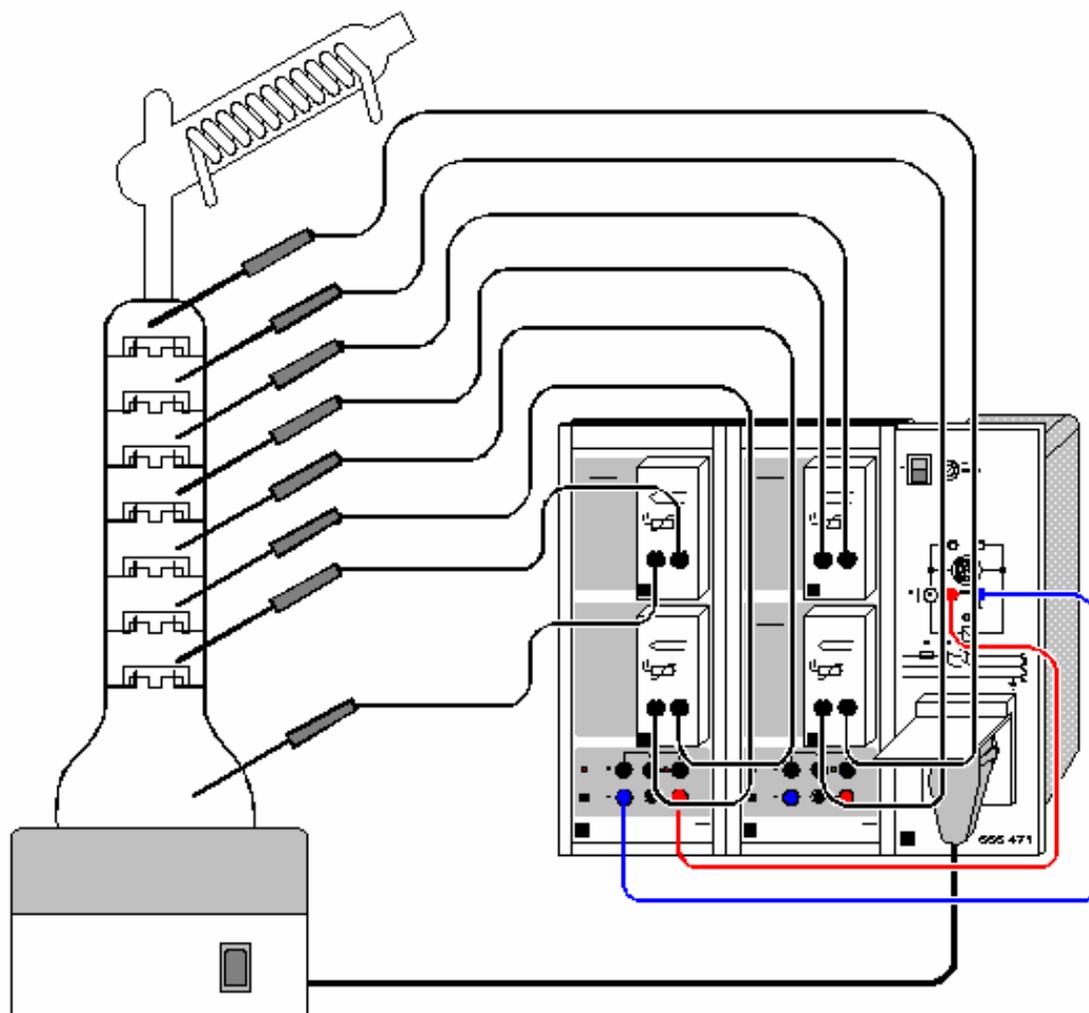
$$\alpha = \frac{\Lambda_{\text{eq}}}{\Lambda_0}$$

in Ostwald's dilution law. A transformation leads to the equation

$$\frac{1}{\Lambda_{\text{eq}}} = \frac{1}{\Lambda_0} + \frac{\Lambda_{\text{eq}} \cdot c_0}{K_{\text{Diss}} \cdot \Lambda_0^2}$$

If you plot $1/\Lambda_{\text{eq}}$ against $\Lambda_{\text{eq}} \cdot c_0$, you obtain a straight line with the cut off $1/\Lambda_0$ and the slope $1/(K_{\text{Diss}} \cdot \Lambda_0)$, whereby $\Lambda_{\text{eq}} \cdot c_0 = CA_1$ for acetic acid. However, as even very small inaccuracies of the measurement lead to big errors, this method is only suited for high-precision measurements. Here the equation is used to check the accuracy of the measurement in the low concentration range.

Separation of a two-component mixture using the rectification apparatus CE2



■ Load example

Experiment description

The rectification apparatus CE2 enables separation of organic material systems, e.g. a 1:1 mixture of methanol and ethanol, and determination of the theoretical separation stages with total material reflux.

In this experiment, up to eight temperatures can be measured and recorded by the computer, with simultaneous heating control.

Equipment list

2	Sensor-CASSYs	524 010
1	CASSY Lab	524 200
4	Temperature boxes	524 045
8	Temperature sensors NiCr-Ni	666 193
1	CPS-voltage supply, switchable	666 471
1	Rectification apparatus CE2	661 311
1	Stand system CE2	661 301
1	CPS mains distributor	665 497
1	Panel frame	666 425
1	Pair of cables, 50 cm, red and blue	501 45
1	PC with Windows 95/98/NT or higher version	



Experiment setup (see drawing)

For information on setting up the apparatus for experiments (see drawing), refer to the experiment manual (668 922) and the Instruction Sheet of the rectification apparatus. **Observe all safety notes given in the Instruction Sheet!**

Place the two Sensor-CASSY units in the top level of the CPS panel frame and cascade them.

Attach temperature boxes at **analog inputs A1, B1, A2 and B2**. Connect two NiCr-Ni temperature sensors to each temperature box. The temperature sensors have the following order in the rectification apparatus, beginning from the sump of the column:

ϑ_{A11} (sump); ϑ_{A12} ; ϑ_{B11} ; ϑ_{B12} ; ϑ_{A21} ; ϑ_{A22} ; ϑ_{B21} ; ϑ_{B22} (column head)

The **Voltage Output S1** is connected to the CPS voltage supply and the knob on CASSY set to about the middle. The CPS-voltage supply is used to connect the heating device. This should be controlled so that it switches off at a specific temperature ϑ_{A11} in the column sump and after a specified time t . You can set these parameters by defining a formula. Open the formula dialog in Settings Relay/Voltage Source (click the right mouse button over S1).

The default activation condition is **&JA11 < 120 and t > 0 and t < 2:00:00**. This means that the heating device is on when the temperature ϑ_{A11} (&JA11) is less than 120 °C, the measurement has been started and the time of two hours has not yet elapsed. You can change the defaults to match your application. Note that this formula increases the experimenter's safety.

Relay output R1 is still available. This can be used for vacuum rectification CE 4/1 (661 332) to increase the controlling accuracy.

Calibration

For precise measurements, you should calibrate the temperature sensors before first use as well as later at longer intervals.

■ Load settings

- In Settings ϑ_{A11} select **Correct**.
- Immerse temperature sensor ϑ_{A11} in ice water (0 °C).
- Enter 0 as the first target and click **Correct Offset**.
- Immerse the temperature sensor in boiling water (100 °C).
- Enter 100 as the second target value and click **Correct Factor**.
- Calibrate the other seven temperature sensors in the same way.
- You can save your calibrated settings under a new name for later use with **F2**.
- Mark the Sensor-CASSY units, the temperature sensors and temperature boxes so that they can be used subsequently in the same configuration (this is the only way that the stored calibration will remain applicable).

Carrying out the experiment

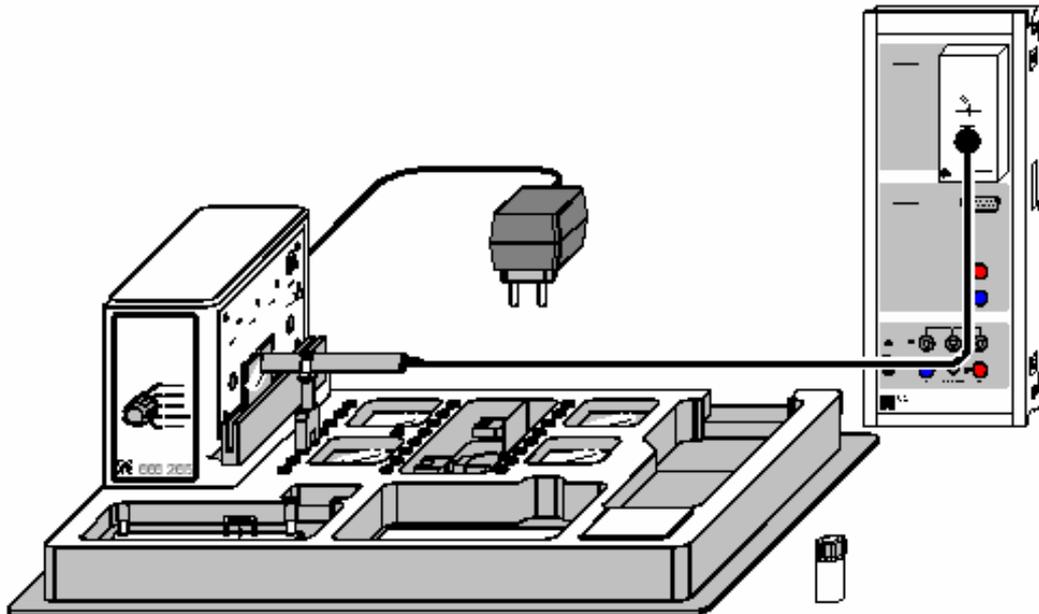
- Switch on the cooling water (cryostat or other).
- Switch on the heating apparatus with the switch on the device.
- Check the system for tightness.
- Start automatic measurement with **F9** (the heating device is started automatically).
- Wait until a constant temperature is reached.
- Stop automatic measurement with **F9**.
- Turn the switch on the heating device off and lower the heater.
- Switch off the cooling water after the column sump has cooled down.

Sampling and evaluation are described in the manual: Thermal Separation Methods, Part 2: Rectification (668 922).

Experiment results

It is important that a constant temperature is reached over the entire column. Once this is achieved, the apparatus is in equilibrium and sampling can begin. We can observe that different temperatures are measured in the individual trays due to the different composition of the phase mixtures. As we can see in the example, the temperature decreases in the bottom tray with respect to the higher ones. As the vapor phase is measured in the top tray, this temperature is naturally greater than in the next lower tray.

Absorption of UV radiation



can also be carried out with Pocket-CASSY and Mobile-CASSY

- Load example (UV-A)
- Load example (UV-B)
- Load example (UV-C)

Safety note

Do not look directly into the ray.

Experiment description

The transmission of several materials for UV-A, UV-B, and UV-C radiation is determined and the effect of sunscreens is tested by measuring the transmitted illuminance.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Lux box	524 051
1	UV-A sensor	666 244
	and/or	
1	UV-B sensor	666 245
	and/or	
1	UV-C sensor	666 246
1	UV-IR-VIS experiment kit	666 265
1	PC with Windows 95/98/NT	
	or higher version	

Experiment setup (see drawing)

Connect the lux box together with the selected UV sensor (A, B, or C) to the Sensor-CASSY. Using a clamp, fix the UV sensor as close as possible to the appropriate exit aperture of the UV-IR-VIS experiment kit. However, see to it that the holding rail remains free for material samples to be inserted. Connect the experiment kit via the plug-in power supply.

Read the instruction sheets of the UV-IR-VIS experiment kit and the sensors carefully.



Calibration

Before using a UV sensor for the first time, you have to calibrate it.

- Load settings (UV-A).
- Load settings (UV-B).
- Load settings (UV-C).
- Select the **Correct** button in Settings Illuminance EA1, enter the factor printed on the sensor, and click **Correct Factor**. Store the calibrated settings with **F2** under another name so that the calibration can be used again. This calibration is only valid for the particular corrected sensor.

Carrying out the experiment

- Use or load the calibrated settings.
- Switch the desired UV lamp on, and wait approx. 5 minutes until a stable final value has been reached in the display window for the **Illuminance EA1**. You may have to select another measuring range in Settings Illuminance EA1, if the preset range is exceeded.
- Record the first measured value (without absorber) by pressing the key **F9** or the  button.
- One after another insert the following absorbers in the holding rail between the UV lamp and the sensor:
 - quartz glass,
 - window glass,
 - plexiglass,
 - PVC,
 - quartz glass with a thin film of sunscreen filter (Parsol),
 - optionally: quartz glass with a thin film of cooking oil, spectacle lensRecord a further measured value for each of the optional items.

Evaluation

The values are displayed in two diagrams: in the bar chart **Illuminance**, the absolute measured values are shown. With **Alt+T** explanatory text can be assigned to the bars.

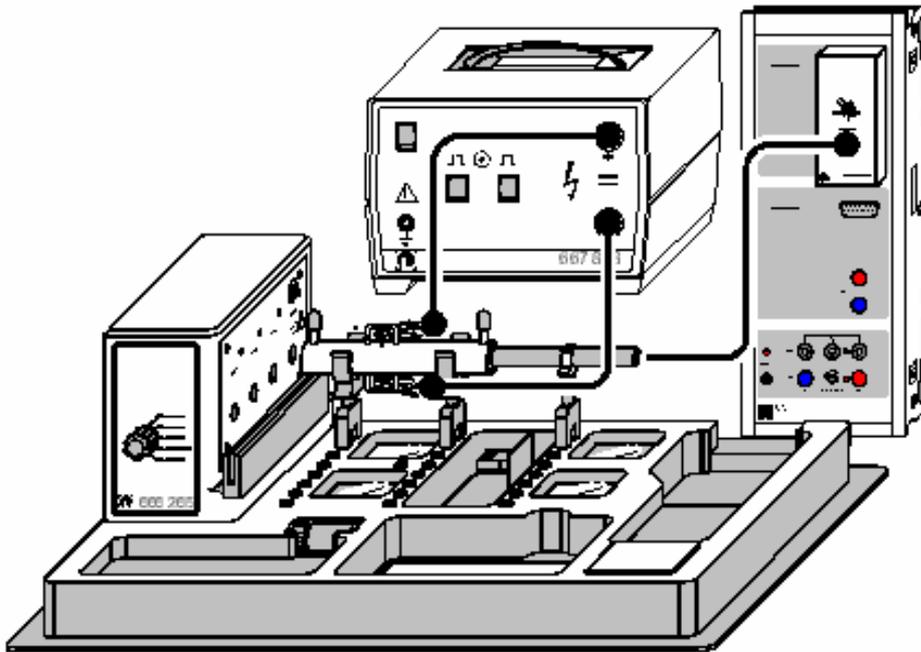
The second diagram, **Transmission**, shows the percentage of the examined radiation that has passed through the respective material.

The specific filtering effect of some materials on UV-B and UV-C radiation and their transmission of UV-A radiation is of particular interest with regard to danger to humans:

In the case of the quartz glass which has been covered with sunscreen filter, the transmission of UV-A radiation, which gives rise to the suntan, is significantly higher than the transmission of the dangerous UV-B and UV-C radiation. In the past decades, the UV-B irradiation on the surface of the earth has increased because the ozone layer has continuously become thinner and thinner. This effect is considered to be the cause of damage of hereditary substance, skin cancer, and blindness. The agent Parsol protects the skin with its UV-B and UV-C filtering effect and passes a great proportion of the tanning UV-A radiation.

As UV-C radiation is even more aggressive than UV-B radiation, the UV-C filtering effect of many materials and particularly of the atmosphere is a prerequisite for life on earth to be possible.

Simulation of the ozone hole



can also be carried out with Pocket-CASSY and Mobile-CASSY

■ Load example

Safety notes

Never look directly into the UV-C ray.

Use only non-hazardous contact high-voltage power supplies with direct currents $I < 2 \text{ mA}$.

Keep to the current regulations concerning the handling of chemicals.

Do not breathe in the vapour of dichloromethane.

Experiment description

By means of silent discharge initiated by a high voltage, ozone is produced in a closed cuvette. The absorption of UV-C radiation by the ozone formed in the cuvette is determined as a function of time via a measurement of the illuminance E with a UV-C sensor.

After addition of a small amount of dichloromethane (CH_2Cl_2 , as a surrogate of CFC), a marked increase of the illuminance (i.e. decrease of the absorption) is observed, from which it can be concluded that the ozone in the cuvette is degraded by dichloromethane.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Lux box	524 051
1	UV-C sensor	666 246
1	UV-IR-VIS experiment kit	666 265
1	Rubber bulb	667 241
1	Syringe, 1 ml	665 957
1	Spark-gap supply unit	667 818
1	PC with Windows 95/98/NT or higher version	

Chemical

Dichloromethane

e.g. 250 ml: 671 6600

Experiment setup (see drawing)

Connect the lux box together with the UV-C sensor to the Sensor-CASSY.

Set up the UV-IR-VIS experiment kit so that nobody can be blinded by the UV-C radiation. Mount the round cuvette from the UV-IR-VIS experiment kit with two holders immediately in front of the exit aperture of the UV-C radiation, and connect the metal contacts to the spark-gap supply unit via two tapping clamps and the connecting leads. As the electric field is very strong, see to it that the connecting leads do not lie one on top of the other or too close to the sensor, the Sensor-CASSY or their cabling. Using a holder, insert the UV sensor immediately in front of the cuvette window. Connect the UV-IR-VIS experiment kit via the plug-in power supply.

Read the instruction sheets of the UV-IR-VIS experiment kit and of the spark-gap supply unit carefully.

Calibration

Before using the UV sensor, you have to calibrate it.

■ Load settings.

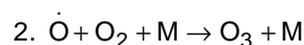
- Select the **Correct** button in Settings Illuminance EA1, enter the factor printed on the sensor, and click **Correct Factor**.
- Store the calibrated settings with **F2** under another name so that the calibration can be used again. This calibration is only valid for the particular corrected sensor.

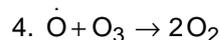
Carrying out the experiment

- Use or load the calibrated settings.
- Using the rubber bulb, remove residual gas that may be left in the round cuvette, and close the openings of the cuvette with the two black caps.
- Switch the UV-C lamp on, and wait approx. 5 minutes until a stable final value has been reached in the display window for the Illuminance **EA1**.
- You may have to select another measuring range in Settings Illuminance EA1, if the preset range is exceeded.
- Switch the spark-gap supply unit on, and set it to the mode "continuous operation" (red LED shines).
- Immediately start recording the measuring data by pressing the key **F9** or the  button.
- During the entire measurement do not move the cuvette and the sensor as this would distort the measurement.
- Switch the spark-gap supply unit off after 5 to 10 minutes and mark this moment in the diagram by a vertical line with **Alt+V**.
- Switch the supply unit on again after approx. 3 to 5 minutes, and set another mark with **Alt+V** at the corresponding position in the diagram.
- After another 3 to 5 minutes, shake the closed bottle containing dichloromethane briefly, and, using the syringe, take 1 ml of the vapour from the gas space over the liquid. Close the bottle. Do not breathe in the vapour.
- Open one of the caps of the round cuvette, inject the content of the syringe, and, having closed the cuvette, set another mark with **Alt+V** at the moment of injection.
- Stop the data logging by pressing the key **F9** or the  button after another 3 to 5 minutes has elapsed, and switch the high voltage off.

Remarks

The formation and degradation of ozone in the stratosphere (10 to 35 km altitude) is governed by several reactions:



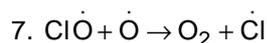
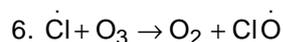
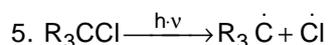


These reactions keep the ozone concentration in a stationary equilibrium.

If UV-C radiation with wavelengths below 240 nm acts on oxygen, this leads to ozone formation (reactions 1 and 2) because the oxygen radicals formed in this process react with other oxygen molecules to ozone giving off their kinetic energy to a third inert reactant M (e.g. a nitrogen molecule). As the mercury lamp used in the UV-IR-VIS experiment kit generates UV-C radiation of 254 nm wavelength, which is not able to split oxygen molecules, the reaction 1 is initiated by a high voltage of 10 kV in this experiment.

The degradation of ozone, too, takes place with the aid of UV radiation: however, for the splitting (reaction 3), radiation with wavelengths below 310 nm is sufficient. This UV dependence of the ozone formation and degradation leads to a complete absorption of UV-C radiation (220-280 nm, initiation of the reactions 1 and 3) and to a partial absorption of UV-B radiation (280-320 nm, initiation of the reaction 3) by the ozone layer in the stratosphere.

The degradation of ozone by CFC is also initiated by UV-C radiation:



The chlorine radical created in reaction 5 by absorption of UV-C radiation is set free again and again in a continuous repetition of the reactions 6 and 7, whereby the oxygen radical in reaction 7 comes from the natural degeneration of ozone (reaction 3) or from the natural splitting of oxygen (reaction 1). Therefore a few chlorine radicals suffice to initiate a ozone degenerating chain reaction.

In contrast to completely halogenated CFC, dichloromethane, which is used in this experiment, is already degenerated in the troposphere and does not damage the ozone layer.

Evaluation

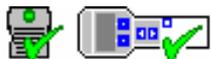
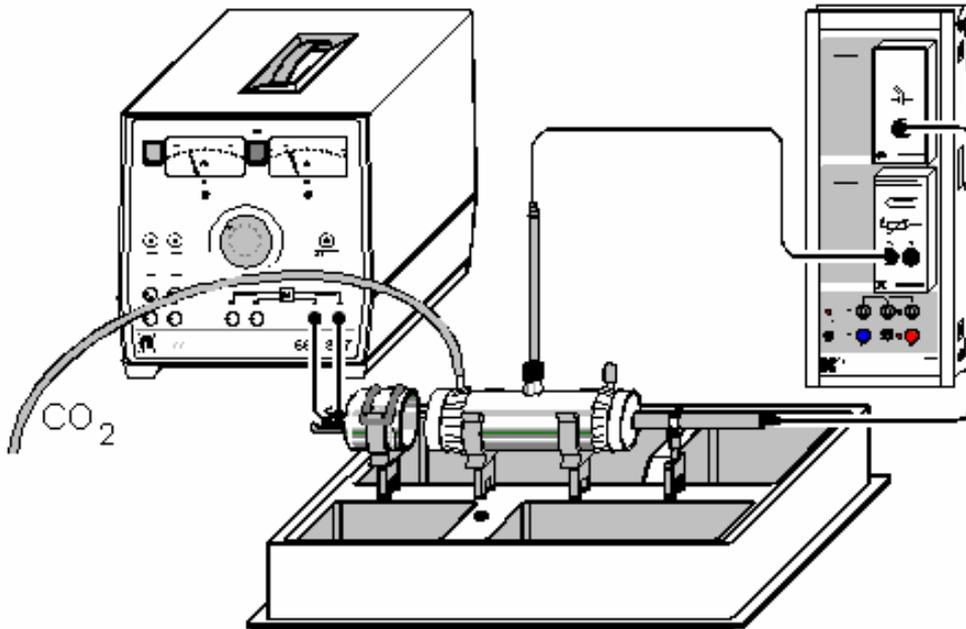
In order to get a clearer display, you can remove the values corresponding to short-term fluctuations in the illuminance caused by switching on and off the high voltage by double-clicking these values in the table and pressing the blank key.

To start the evaluation, enter the first value of the measurements series for the illuminance EA1 instead of the default value of "0.290" in the field Formula of Settings Absorption A. An explanatory text can be inserted with **Alt+T** to label the sections separated by the vertical lines.

After switching the high voltage on, the reactions 1 and 2 (ozone formation) predominate over the degeneration reactions 3 and 4. This is seen from the decrease in illuminance or from the increasing absorption of UV-C radiation (range **A** in the diagrams), respectively. When the high voltage is switched off, the ozone concentration is reduced as oxygen radicals from reaction 1 are no longer available for ozone formation, and therefore the degeneration reactions 3 and 4 predominate. As a consequence, the illuminance rises quickly and the absorption of UV-C radiation is reduced (range **B**) indicating a drop of the ozone concentration.

In range **C**, the illuminance decreases again due to another production of ozone by the high voltage. Addition of a small amount of dichloromethane again results in an increasing illuminance despite the high voltage, which is still applied (range **D** in the diagrams). Even a very small amount of CH₂Cl₂ vapour leads to a strong decrease in ozone concentration accompanied by a reduction of the UV-C absorption.

Greenhouse effect of CO₂



can also be carried out with Pocket-CASSY and Mobile-CASSY

■ Load example

Safety notes

The IR radiator becomes very hot. Do not touch the filament. Do not operate the IR radiator with currents over 6 A.

Keep to the current regulations concerning the handling of gases.

Experiment description

In general, the warming of the atmosphere known as "greenhouse effect" is, among other things, attributed to the rising concentration of carbon dioxide in the air. The experiment described in this example with the IR-CO₂ experiment kit clearly shows the effect of CO₂: if the CO₂ concentration is enhanced, an absorption of infrared radiation and an increase in temperature are measured.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Lux box	524 051
1	IR-CO ₂ sensor	666 248
1	Temperature box	524 045
1	Temperature sensor NiCr-Ni	666 216
1	IR-CO ₂ experiment kit	666 2651
1	Variable extra low voltage transformer D	667 827
1	Silicone tubing, internal diameter 5 mm	604 431
1	Connecting lead, 50 cm, red	501 25
1	Connecting lead, 50 cm, blue	501 26
2	Crocodile-clips	501 83
1	Rubber bulb	667 241
1	PC with Windows 95/98/NT or higher version	

Chemicals

Carbon dioxide, compressed gas bottle 661 0082
 with pressure reducing valve according to DIN 661 017

Experiment setup (see drawing)

Read the instruction sheets of the IR-CO₂ experiment kit, the variable extra low voltage transformer and the IR-CO₂ sensor carefully.

Connect the lux box with the IR-CO₂ sensor to input A and the temperature box with the temperature sensor being plugged in T1 to input B of the Sensor-CASSY.

Insert the IR radiator in the holding clamp on the tray, clamp the measuring cuvette which is covered with two plastic foils in the holders on the tray so that its distance from the radiator is at least 5 mm, and insert the temperature sensor in the GL14 thread so that the tip of the sensing element is positioned in the centre of the cuvette.

Using the holding clamp, mount the IR-CO₂ sensor immediately behind the measuring cuvette, and connect the direct current output of the variable extra low voltage transformer (0...20 V) to the contacts of the radiator via the connecting leads.

Connect one of the inlets of the cuvette to the compressed gas bottle via the tubing. Close the other inlet with a black plastic cap.

Calibration

Before using the IR-CO₂ sensor, you have to calibrate it.

■ Load settings.

- Select the **Correct** button in Settings Illuminance EA1, enter the factor printed on the sensor, and click **Correct Factor**.
- Store the calibrated settings with **F2** under another name so that the calibration can be used again. This calibration is only valid for the particular corrected sensor.

Carrying out the experiment

- Use or load the calibrated settings.
- Adjust a current of at most 6 A so that the filament only glows very weakly. The measured temperature should not exceed 80 °C.
- When the temperature and the illuminance are virtually constant (observe the display windows in

CASSY Lab), start the measurement by pressing the key **F9** or the  button.

- After approx. one minute, remove the black cover cap and allow carbon dioxide to flow through the cuvette for about one minute. Mark the moment when you switch the carbon dioxide flow on by a vertical line by pressing **Alt+V** and positioning the line with the mouse.
- Set another vertical line (**Alt+V**) when you switch the carbon dioxide current off, and close the cuvette with the black cap.
- Wait another 3 to 5 minutes until the temperature is constant again. Then stop the measurement by pressing the key **F9** or the  button, and switch the variable extra low voltage transformer off.

Evaluation

In the two diagrams, the relation between the temperature (first diagram) / illuminance (second diagram) and the absorption by carbon dioxide is illustrated.

For the evaluation, the stationary states before and after the introduction of carbon dioxide are relevant.

1. A comparison of the temperatures and the illuminances before and after the cuvette was filled with carbon dioxide shows a marked rise in temperature accompanied by a reduction of the illuminance.

For comparing the initial values with the values at the end of the measurement, first enter the mean values in the diagram. To do this, click the diagram with the right mouse button, select **Draw Mean Value**, and mark the respective stationary curve range at the beginning and at the end of the measurement series. The mean value calculated by CASSY Lab is displayed by a horizontal line. The corresponding value can be dragged with the mouse from the status line into the diagram.



Hint: if the scale of the Y axis relevant for the respective measured values is activated via the diagram buttons **EA1** and **B11**, the mean values and labels are displayed in the same colour as the corresponding curve.

The exact difference between the two mean values of the temperature and the illuminance is output in the status line when **Alt+D** is pressed and subsequently the two mean value straight lines are clicked. This value, too, can be dragged into the diagram with the mouse.

2. For determining the absorption, enter the first mean value E_0 (initial value) in Settings illuminance E_1 in the field formula. For the calculation of the absorption A , the formula

$$A = 100 - \left(\frac{E_{A1}}{E_0} \cdot 100 \right)$$

is preset. Mean values and differences are entered in the same way as in the case of the first diagram.

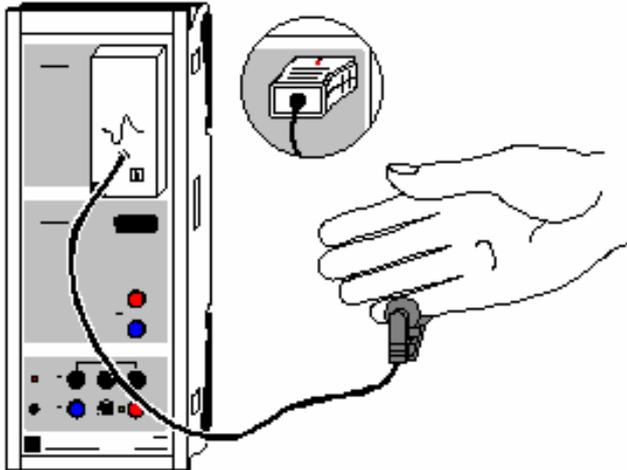
The results make it clear that carbon dioxide absorbs a great proportion of the infrared radiation. The rise of the temperature in the cuvette can be attributed to this absorption.

Experiment examples biology

These experiment examples support you in using CASSY Lab. The measurement data or settings for the examples can be loaded directly into CASSY Lab. Simply click in the  buttons in the descriptions. New examples are labelled with a red .

- Pulse
- Skin resistance
- Electrocardiogram
- Electromyogram
- Blood pressure
- Reaction time
- Lung volume (spirometry)
- Long-term measurement of climate data

Pulse



can also be carried out with Pocket-CASSY

■ Load example

Safety notes

The values and curves measured in this experiment have no medical significance and are not suitable for monitoring human health.

Use the pulse box only as described in the Instruction Sheet.

Experiment description

The pulsing flow of blood changes the optical properties of the human body. CASSY determines the pulse frequency via the pulse box. The software records the change in the pulse frequency (e.g. during physical exertion) or the resting pulse frequency of athletic and nonathletic test subjects.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Pulse box or Pulse sensor S	524 047(1)
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The pulse sensor of the pulse box at Sensor-CASSY input A is placed at a point on the body with a strong flow of blood, e.g. at the root of the nail on the little finger. Make sure that the sensor is not moved during the measurement, as this can falsify the results.

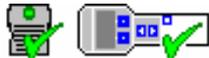
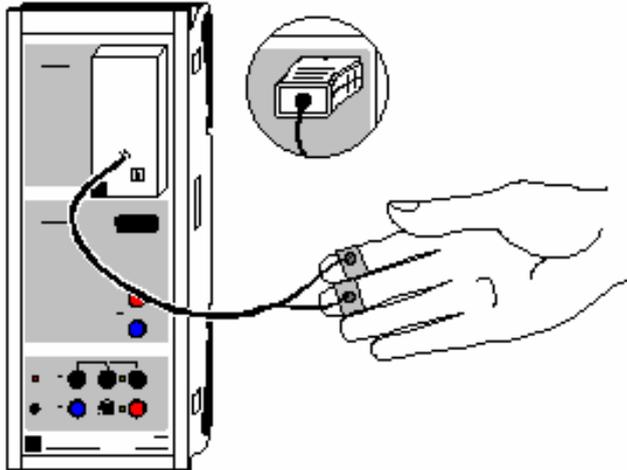
Carrying out the experiment

- Load settings
 - Wait until instrument PA1 shows stable pulse values (box adapts to the signal strength).
 - Start the measurement with **F9**.
 - If desired, investigate how the pulse curve depends on physical exertion (knee bends).
 - Stop the measurement with **F9**.
 - You can repeat the measurement with altered factors or different test subjects. Once again, wait for the pulse values to stabilize before pressing **F9**.

**Evaluation**

You can find the average pulse frequency by finding the mean value from the measuring curve. Simply click the right mouse button over the diagram, select **Draw Mean Value** and mark the desired curve range. The value appears in the status line at the bottom left and can be inserted anywhere in the diagram as text.

Skin resistance



can also be carried out with Pocket-CASSY and Mobile-CASSY

■ Load example

Safety notes

The values and curves measured in this experiment have no medical significance and are not suitable for monitoring human health.

Use the skin resistance box only as described in the Instruction Sheet.

Experiment description

The resistance of the skin R changes in response to external factors. This setup can be used e.g. to investigate the effects of autogenous training or a startling event. The measurement always shows the conductance of the skin $G=1/R$ (greater values mean lower resistance).

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Skin resistance box or Skin resistance sensor S	524 048(1)
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Plug in the skin resistance box at Sensor-CASSY input A and attach the electrodes securely to the tips of the test subject's index and middle fingers using the Velcro strips. The hand should rest on a support.

Carrying out the experiment

■ Load settings

- Adjust the measuring range in Settings Skin Conductance GA1 or drag the y-axis of the diagram so that the displayed skin conductance value GA1 is about in the middle (if necessary, enter the values via the keyboard after clicking on the y-axis).
- Start the measurement with **F9**.
- If desired, investigate the effects of autogenous training or a startling event (e.g. a loud hand clap) followed by conscious relaxation.
- Stop the measurement with **F9**.

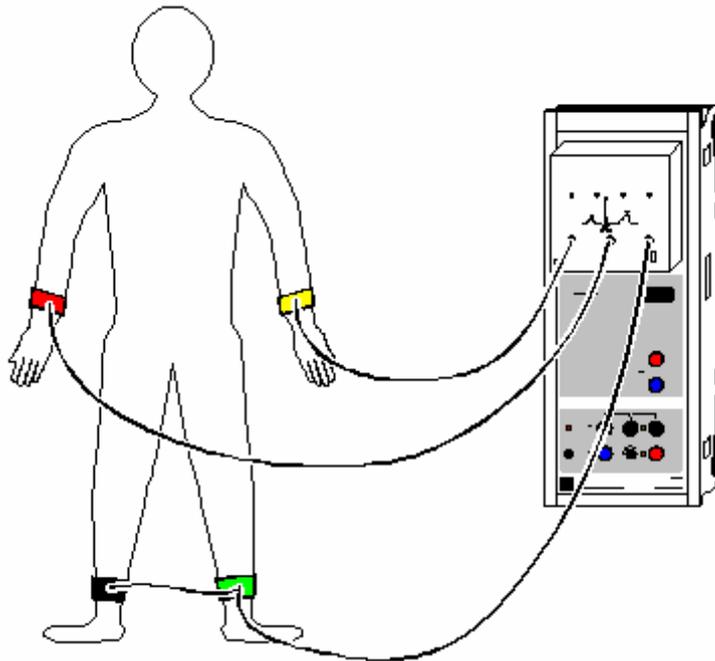
- You can repeat the measurement with altered factors or different test subjects. Once again, adjust the y-axis before pressing **F9** to restart the measurement.

Evaluation

The diagram reveals how the skin conductance changes in response to external factors.

You can determine the average skin conductance by finding the mean value from the measuring curve. Simply click the right mouse button over the diagram, select **Draw Mean Value** and mark the desired curve range. The value appears in the status line at the bottom left and can be inserted anywhere in the diagram as text.

Electrocardiogram (ECG)



can also be carried out with Pocket-CASSY

■ Load example

Safety notes

The values and diagrams obtained in this experiment have no medical significance and are not suitable for monitoring human health.

Use the ECG/EMG box only as described in the Instruction Sheet.

Experiment description

Every stimulation of the cardiac muscle is accompanied by electric voltage changes, which propagate from one cardiac muscle cell to the other. Due to the large number of cells, the generated voltages can be tapped with electrodes attached to the body and, after amplification, made visible in the form of diagrams. For the electrocardiogram the Einthoven limb leads are used (I, II, III).

The electrodes measure potential changes (voltage changes) when the different heart chambers contract. At rest the cardiac muscle cells are polarized, i. e. there is a slight potential difference between the inside of the cell membrane and the outside. The cardiac muscle cells can depolarize without any influence from outside, i. e. spontaneously. The group of cells which are the first to depolarize constitute the so-called "pacemaker" (sinoatrial node). This node is located in the right atrium of the heart. The two atria contract almost at the same time due to the high-speed conduction of stimulus between the cells.

The ventricles of the heart are electrically insulated from the atria. Only at one place there is a group of cells (atrioventricular node) which transmit the electric signal of the atrium contraction to the ventricles. A slight delay of the transmission of excitation ensures that the ventricles do not contract simultaneously with the atria so that the blood has enough time to flow from the atria into the ventricles.

The atrioventricular node transmits the depolarization over special fibres (His bundles) to the ventricles. In the muscular wall of the ventricles there are other fibres (Purkinje fibres) that provide quick conduction of stimulus. So simultaneous and complete contraction of the ventricles is ensured.

The depolarization, contraction and subsequent repolarization is a continuously repeated process which make small currents flow due to the close neighbourhood of polarized and unpolarized cells. The changes of the currents can be measured from outside, amplified and plotted as a function of time. The ECG is the graphic representation of the measured electric currents.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	ECG/EMG box	524 049
1	Electrode gel	662 112
1	Disinfectant spray	662 113
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The test subject should be relaxed and in a resting posture, as otherwise the ECG signal can be overlaid by the electrical potentials of the skeletal musculature, falsifying the measurement. To reduce the skin resistance, spread electrode gel (662 112) on the electrodes and attach them to the appropriate points in the body using the rubber straps. Then attach the leads to the electrodes as follows:

red	right arm
yellow	left arm
green	left calf
black	right calf

Important

Clean the electrodes after each use with a paper towel or similar to prevent a salt layer from forming when the gel dries. Then spray the electrodes and the corresponding skin sites with disinfectant (662 113) to ensure maximum hygiene.

Carrying out the experiment

- Load settings
 - Start the measurement with **F9**.
 - The three leads according to Einthoven are recorded simultaneously.
 - Stop the measurement with **F9**.

Evaluation

For the sake of clarity, part of the display should be enlarged with the Zoom function before evaluation

A typical part of an ECG is given by a flat line, the isoelectric line. Deviations from this line are due to the electric activity of the cardiac muscle.

In a typical ECG, the first deviation from this line is a small upward deflection. The P-wave last approx. 0.05 seconds. For the evaluation a vertical line can be set at the beginning and the end of the P-wave. The duration can be determined by a differential measurement between the two lines. The P-wave is based on the depolarization and contraction of the atria.

Next the ECG returns to the isoelectric line. During this time, the atrioventricular node transmits the excitation via the His bundle and the Purkinje fibres to the ventricles. The depolarization of the AV node leads to a slight downward pulse, the Q-wave. Immediately afterwards a quick rise (R-wave) and a subsequent drop below the isoelectric line (S-wave) occur. Then the ECG returns to the initial value. These three waves are called the QRS complex, which is brought about by the depolarization and contraction of the ventricles.

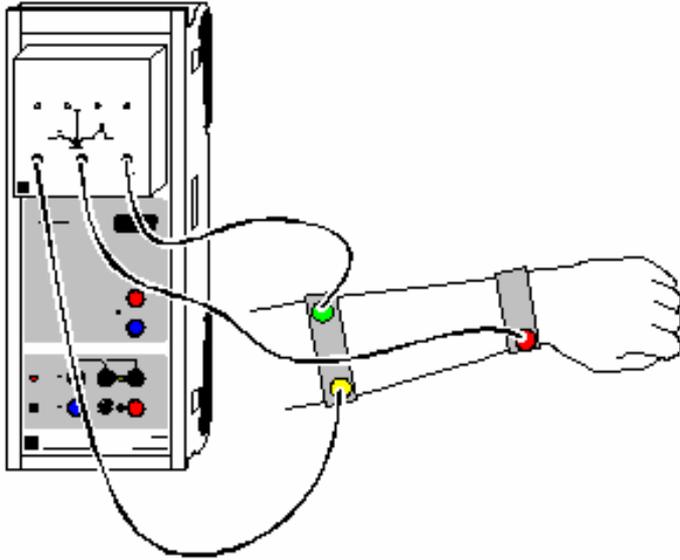
After a further break the cell repolarize. The corresponding current causes an upward wave, the T-wave.

The sequence from P over QRS to T is one cycle of the heart. The number of cycles per minute corresponds to the pulse beat.

Further experiment proposals

- Recording an ECG before and after exertion (e. g. knee-bends)
- Statistics of the duration of the individual sections for all students in the class
- Differences between women and men

Electromyogram (EMG)



can also be carried out with Pocket-CASSY

■ Load example

Safety notes

The values and diagrams obtained in this experiment have no medical significance and are not suitable for monitoring human health.

Use the ECG/EMG box only as described in the Instruction Sheet.

Experiment description

This experiment measures the electrical potentials of activated muscles by attaching surface electrodes in the area of the muscles.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	ECG/EMG box	524 049
1	Electrode gel	662 112
1	Disinfectant spray	662 113
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

To record an EMG curve of the finger musculature, attach the electrodes at the beginning and end of the muscle on the underside of the forearm and the reference electrode on the opposite side of the muscle group, i.e. on the outside of the forearm. Connect the electrodes as follows:

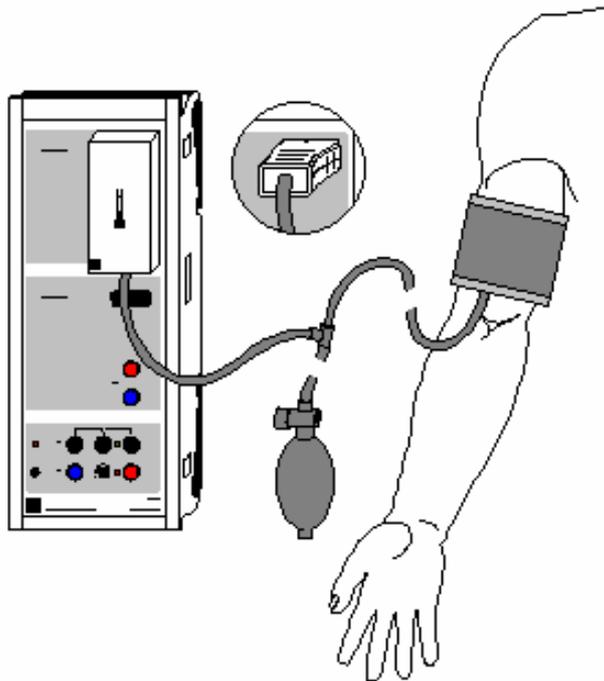
red start of muscle on underside of forearm
 yellow end of muscle on underside of forearm
 green reference electrode on outside of forearm

Carrying out the experiment

■ Load settings

- Start the measurement with **F9**.
- When recording the EMG curve, the test subject makes a fist and then opens it. This should be repeated several times.
- Stop the measurement with **F9**.

Blood pressure



can also be carried out with Pocket-CASSY

■ Load example

Safety notes

The values and curves measured in this experiment have no medical significance and are not suitable for monitoring human health.

Use the blood pressure box only as described in the Instruction Sheet.

Experiment description

The blood pressure box is used to measure the pressure at the cuff as pressure variations in the cuff (oscillometric blood pressure measurement). These can be used to calculate the diastole and systole.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Blood pressure box or Blood pressure sensor S	524 050(1)
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Connect the cuff with valve and pumping bulb to the blood pressure box at Sensor-CASSY input A. The valve on the pumping bulb should be about halfway open (in the middle between the two stops of the valve screw). The release rate of the valve should be set to 2-3 mm Hg per pulse beat. Higher release rates make for less accurate evaluations as fewer significant maxima are recorded. A measurement with the valve all the way open will serve to demonstrate this error.

Slide the cuff over the test subject's uncovered left upper arm until the lower edge of the cuff is approx. 2-3 cm above the elbow. Make sure that the cuff hose emerges from the cuff on the inside of the upper arm in the area of the artery (in the direction of the hand). The metal support must not lie against the

artery, as this will falsify the blood pressure curve. After wrapping the free end of the cuff around the arm, secure the cuff using the Velcro strips. The cuff should lie snugly on the upper arm, but should not exert any pressure on the artery before it is pumped up. During the measurement the arm should be relaxed and rest on the table slightly bent.

Carrying out the experiment

■ Load settings

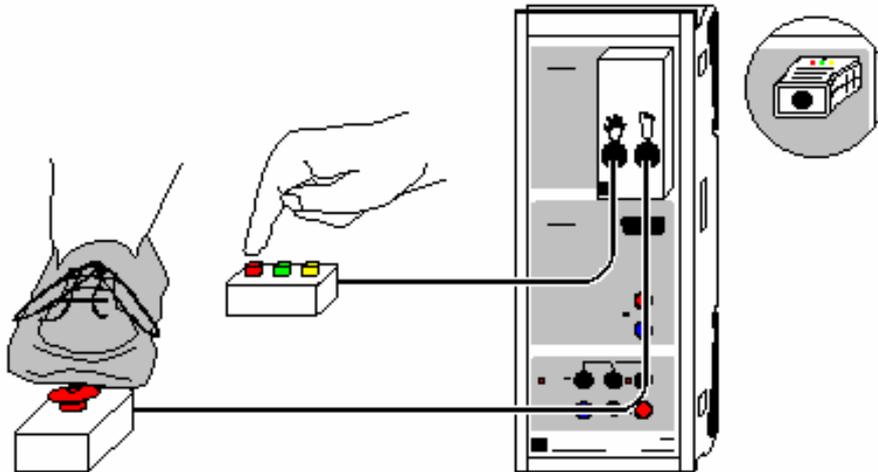
- Correct the zero point of the pressure display if necessary. To do this, open Settings Blood Pressure pA1 and select → 0 ←.
- Using the bulb, pump up the cuff to about 180 mmHg (depending on the expected systolic pressure). The display shows how the cuff pressure increases.
- Start the measurement with **F9**.
- The arm must not move during the experiment. The amplitude of the oscillations increases during the measurement (once the pressure drops below the systolic threshold) and then decreases (once the pressure drops below the diastolic threshold).
- When the amplitude of the oscillations remains constant several times in a row, stop the measurement with **F9**.
- Vent the cuff completely by pressing the red button on the hand valve.
- Wait at least two minutes before repeating measurements on the same test subject.

Evaluation

The pressure varies only slightly at supersystolic cuff pressures, due to pulse beats in the compressed arterial section. At the moment in which the cuff pressure falls below the systolic pressure and a brief systolic opening occurs in the artery, the oscillations increase and reach a maximum at the mean arterial blood pressure (which corresponds to the arithmetic mean of the pressure). The diastolic blood pressure corresponds to the point at which the oscillations stop decreasing, i.e. when the blood vessels are open during the entire diastole. The remaining pressure variations are caused by pulse beats transmitted to the cuff.

To calculate the systole and diastole, press the right mouse button in the diagram, select in the other evaluations **Determine Systole and Diastole** and mark the entire curve range. The systole and diastole values appear in the status line at the bottom left and can be inserted anywhere in the diagram as text.

Reaction time



can also be carried out with Pocket-CASSY

■ Load example

Experiment description

The reaction time is determined using the reaction test box and the pushbutton and/or foot switch. The measured times can be used to calculate the conduction velocity of nerve pulses.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Reaction test box or Reaction test adapter S	524 046(1)
1	Pushbutton and/or	662 148
1	Foot switch	662 149
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Connect the pushbutton or foot switch to the reaction test box at Sensor-CASSY input A. The test subject should be relaxed and at rest. To determine the reaction time with the hand, the subject's hand should rest on the table next to the pushbutton. When determining the reaction time with the foot, the foot should be next to the foot switch on the floor.

Carrying out the experiment

- Load settings
- Start the measurement with **F9**.
- After a random interval following pressing of any element of the pushbutton or foot switch, the pointer appears in the color red, green or yellow (foot switch is always red). The test subject must now react by pressing the same color button as the pointer as quickly as possible. The measured reaction time appears in the display instrument, the table and the diagram.
- Record the desired number of reaction times (10 to 20) in the same way.
- Stop the measurement series with **F9**.
- You can record additional measurement series with other subjects or reactions (e.g. with hand on foot switch instead of foot to determine the nerve conduction speed) with **F9**.

Evaluation

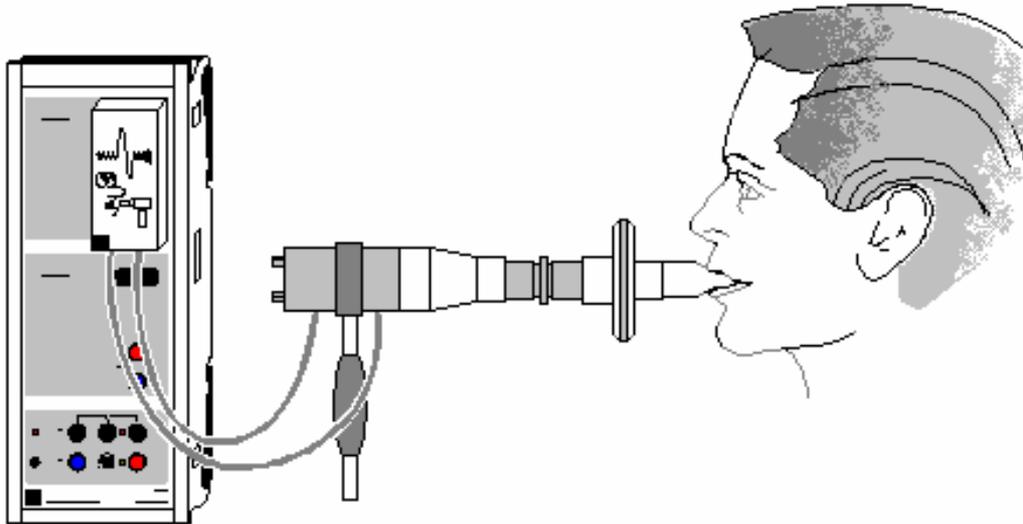
You can find the average reaction time by determining the mean value from the measuring curve. Simply click the right mouse button over the diagram, select **Draw Mean Value** and mark the desired curve range. The value appears in the status line at the bottom left and can be inserted anywhere in the diagram as text.

To determine the nerve conduction velocity you need to determine the difference in the lengths of the conducting nerve paths by first measuring the length from the spine at the level of the shoulder joint to the middle of the upper arm. Then measure from the same point to the middle of the thigh.

The mean nerve conduction velocity v is calculated as the quotient of the length difference (foot – hand) and the time difference (reaction time foot – reaction time hand) as

$$v = (l(\text{foot}) - l(\text{hand})) / (t(\text{foot}) - t(\text{hand})).$$

Lung volume (spirometry)



can also be carried out with Pocket-CASSY

■ Load example

Safety notes

Never use the spirometer without a bacteria filter.

The values and curves measured in this experiment have no medical significance and are not suitable for monitoring human health.

Use the spirometer box only as described in the Instruction Sheet.

Experiment description

The spirometer is used to determine the respiratory volume. The device operates according to the pneumotachographic principle and measures the volume flux. CASSY Lab then determines the respiratory volume through integration.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Spirometer box	524 056
1	Mouthpiece for the spirometer, 30 items	662 3812
1	Bacteria filter for spirometer, 30 items	662 3813
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Connect the spirometer box to Sensor-CASSY input A about 10 seconds before the measurement (warm-up phase). Use a new mouthpiece and a new bacteria filter for every test person, and disinfect the sieves regularly with a disinfectant.

Carrying out the experiment

■ Load settings

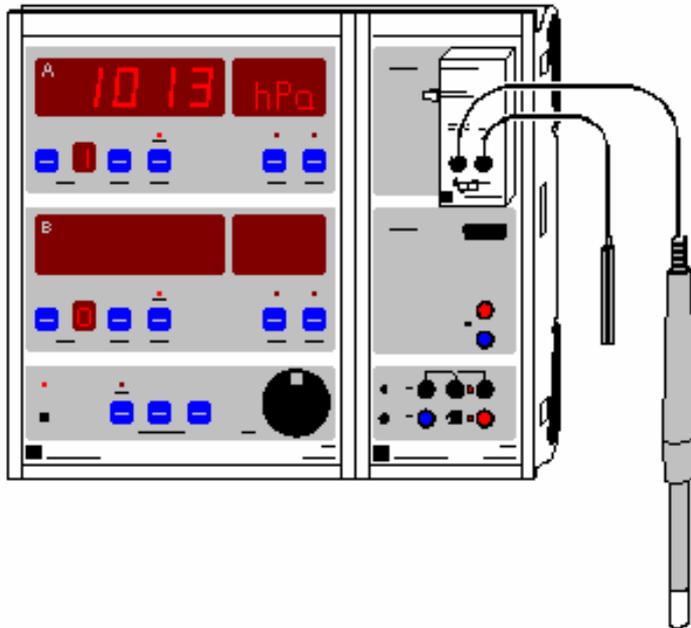
- Compensate the zero point off the displayed volume flux dVA_1 . Open the window Settings Volume Flux dVA_1 , select $\rightarrow 0 \leftarrow$ and make sure that no air is flowing through the spirometer during this procedure.
- Start the measurement as soon as possible afterwards with **F9** (as long as the thermal error in volume flux dVA_1 is still negligible).
- Breathe evenly through the spirometer three or four times. Then inhale and exhale as much air as possible through the spirometer. Then breathe evenly again.
- Stop the measurement with **F9**.

Evaluation

The tidal volume V_1 is the difference between the maximum and minimum for normal breathing. You can determine this e.g. by setting horizontal lines or directly by measuring the difference. You can insert this value at any point in the diagram as text.

The vital capacity V_2 is calculated as the sum of the inspiratory and expiratory reserve volume and the tidal volume. It can be determined from the minimum and maximum at maximum inspiration and expiration analogously to the tidal volume.

Long-term measurement of climate data



■ Load example

Experiment description

Measuring values related to climate, namely the humidity $rHA1$, the temperature of the air $TA11$ (integrated in the humidity sensor), the air pressure $pA1$ (integrated in the climate box) and the illuminance $EA1$ (light intensity) are measured over a long time interval with CASSY-Display and Sensor-CASSY (i.e. without computer). The table with measured values can be read and evaluated during the measurement or at the end of it with a computer and the CASSY Lab program.

Equipment list

1	CASSY-Display	524 020
1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Climate box	524 057
1	Humidity sensor	529 057
1	Lux sensor	666 243
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

The apparatus is set up at a protected location where there is a power supply. Alternatively, a 12 V accumulator with a sufficient capacity (> 6 Ah) may be used as a power supply.

Carrying out the experiment

- **Calibrate the humidity sensor** (only required for the first measurement).
For this connect the Sensor-CASSY with the climate box directly to the PC, activate the climate box in CASSY Lab, select **Correct**, enter the four imprinted numbers C1 to C4 and confirm with **OK**. Then connect the Sensor-CASSY again to the CASSY-Display.
- **Setting and starting the data logger**
If the key **START/STOP** is pressed, "CLR?" (new values can be appended) or "CLR!" (new values cannot be appended) appears in the upper display and the default "NO" appears in the lower display. By rotating **ADJUST** you can change from "NO" to "YES" and vice-versa and confirm by pressing **START/STOP**. Afterwards you can set the time interval of data logging with **ADJUST** and confirm

again with **START/STOP**. Then the data logger starts running (the LED over **START/STOP** now shines continuously).

- **Looking at the measured values in the data logger**

If **SHOW** is selected, all stored measured values can be looked at in the display with **ADJUST**. While this is done, data logger operation is temporarily switched off (the LED over **START/STOP** blinks). The measurement is continued by pressing **SHOW** once more.

- **Activating economy operation of the CASSY-Display**

It is possible to activate economy operation during the measurement by switching off the display of the CASSY-Display for long measuring times. For this the CASSY with number 0 is selected in both displays with the key **NEXT**. The displays go out and the Sensor-CASSY is switched off. For every new measurement the instruments are switched on for a short time interval.

Evaluation

For the data readout connect the CASSY-Display to a computer with CASSY Lab. The CASSY-Display can be transported to the computer without power supply (the measured values remain stored). The start of the measurement is entered in the comment field automatically.

In the example, a measurement series of the climate at Hanover from December 15, 2000 to February 23, 2001 is shown. The measuring interval was half an hour.

The maximum number of measured values depends on the number of measured quantities. In this example a total of approx. 5000 lines of measured values is possible. This corresponds to a maximum measuring period of 100 days.

Remark

In order that faultless operation of the CASSY-Display is ensured, the version of its firmware should be 1.08 or higher. If necessary, the CASSY-Display can be updated by CASSY Lab. When this is done, all measured data that might be stored in the CASSY-Display are deleted.

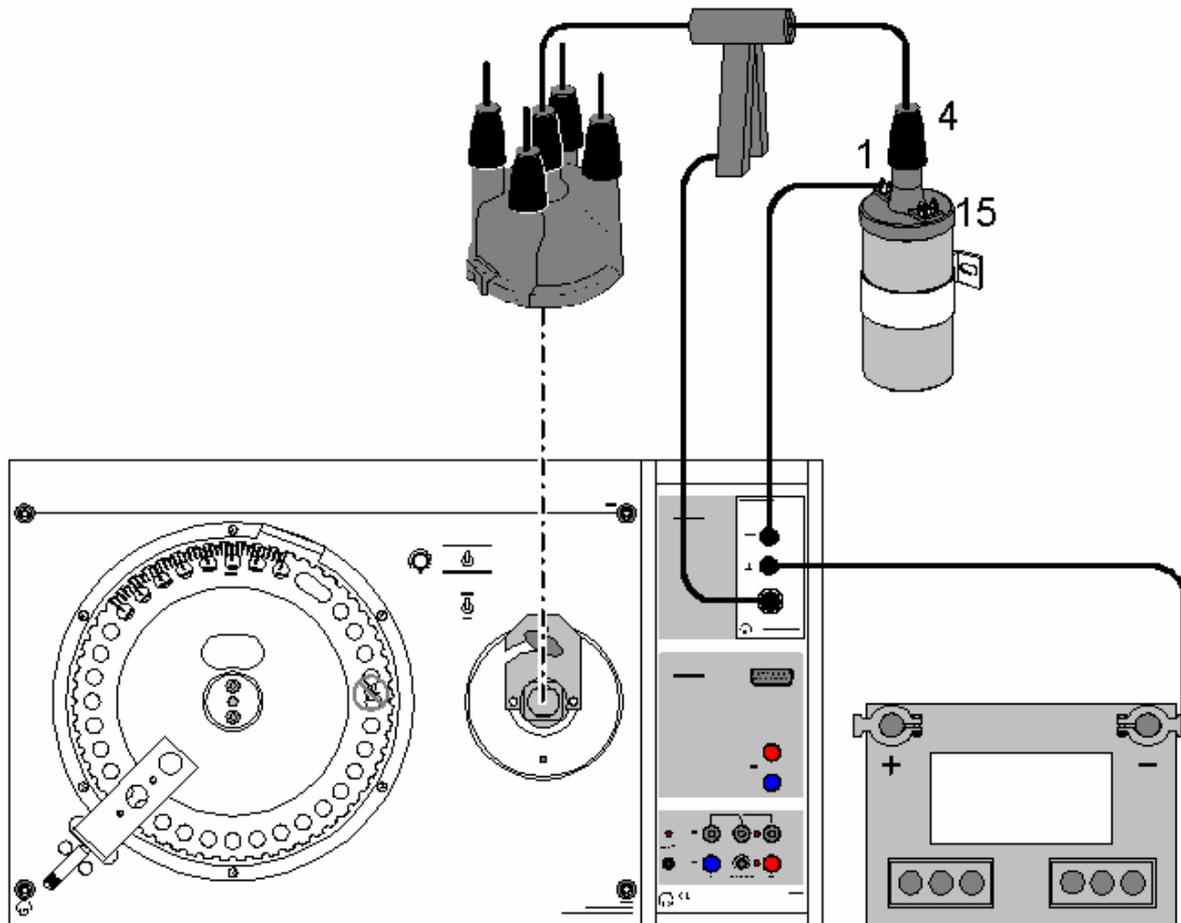


Experiment examples technology

These experiment examples support you in using CASSY Lab. If available, the corresponding label is given. The measurement data or settings for the examples can be loaded directly into CASSY Lab. Simply click the  buttons in the descriptions. New examples are labelled with a red •.

- T 3.2.4 Motor vehicle – ignition systems
- T 3.2.5 Motor vehicle – mixture formation systems
- T 3.2.7.1 Motor vehicle – on-board computer with radio
- T 3.2.7.5 Motor vehicle – comfort system with CAN bus
- T 3.2.7.5 Motor vehicle – investigating CAN databus signals
- T 7.2.2.1 Pulse code modulation (quantization)
- T 7.4.2 Physical principles of microwave technology (characteristics of the Gunn oscillator)
- T 7.4.3 Parallel plate line (TEM and TE modes)
- T 7.4.4 Microwave propagation in waveguides (measurement of the standing wave ratio)
- T 7.6 Antenna technology
- T 12.5.3 Drive engineering

Motor vehicle – ignition systems



- Load example (primary oscillogram)
- Load example (secondary oscillogram)
- Load example (contact closed interval measurement)

Safety notes

Ignition systems reach power ranges where in the entire system, i.e. not only at individual units such as the ignition coil or the ignition distributor, but also at cables, plug-in connectors, connectors of test equipment etc. dangerous voltages may be present both on the secondary and on the primary side.

- Therefore the ignition has always to be switched off before manual operations on the ignition system!
- When the ignition is switched on, no voltage-carrying parts must be touched!
- Pay particular attention to ground connections between the individual training panels!

Experiment description

In this experiment, the ignition oscillograms and the dwell angle adjustment of mechanical distributors are recorded.

The task of the ignition coil is to generate the ignition voltage of 15000 - 30000 volts required for the flashover. In the interior of the ignition coil, a soft-iron core is cast together with many turns of thin wire and a few turns of thick wire. The voltage transformation is determined by the ratio of the numbers of turns.

The primary coil (terminal 15) of the ignition coil is connected to the positive pole of the battery via the ignition lock. Apart from that, the common connection of the primary and the secondary coil (terminal 1) is connected to the ground when the switch is closed so that the primary circuit is closed. In the subsequent dwell period the magnetic field is built up. It breaks down when the switch is opened and induces a high voltage in the secondary coil. This high voltage reaches the spark plug from terminal 4 via the high-voltage cable and the high-voltage distributor.



The primary oscillogram shows the evolution of the voltage at the primary winding. It enables the contact open interval and the contact closed interval of the contact breaker to be determined. From typical changes in the normal oscillogram, certain faults in ignition systems can be identified.

The secondary oscillogram of an ignition system shows the evolution of the voltage at the ignition plug(s). For fault detection the ignition voltage with the ignition pin as well as the firing voltage are of particular importance. From typical changes in the normal oscillogram, certain faults in the ignition system can be identified.

In the dwell angle measurement, the angle at which the breaker contact is closed is measured electronically and displayed in %. The displayed values can be converted into angular degrees. The dwell angle change of a breaker-triggered ignition must not change by more than 2-3 % in an increase of the speed up to approx. 4500 1/min. In breakerless electronic ignition systems, the dwell angle cannot be adjusted and may depend strongly on the speed.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Car box i	524 076
1	Car box Z	524 077
1	Inductive-type pulse pick-up	738 986
1	Capacitive-type pick-up	738 987
1	PC with Windows 95/98/NT or higher version	

and one of the following equipments:

- T 3.2.4.2 Contact-controlled coil ignition system
- T 3.2.4.3 Breakerless-controlled coil ignition system
- T 3.2.4.4 Electronic spark advance (characteristic)
- T 3.2.4.5 Distributorless ignition system (DIS)

Experiment setup (see drawing)

You may use any of the above-mentioned ignition systems, including an original ignition system from a motor vehicle. Please refer to the corresponding experiment literature for further experiments!

In the case of a breaker-triggered ignition system, the capacitive clamp enables all four secondary pulses to be recorded via the feed line for the ignition distributor. In a DIS, only one secondary signal can be recorded.

The primary side is connected to the terminal 1 and to the ground. See to it that the ground is connected as close as possible to the terminal 1!

Remark

If the signals are to be assigned to the corresponding signals in distributor-triggered ignition systems, you need the trigger clamp connected to the CASSY car box i (524 076). Connect this clamp to the ignition cable of the first cylinder. If you use this signal (E) as trigger signal, the recording always starts with cylinder 1.

Carrying out the experiment

- a) Recording the primary oscillogram
 - Load settings
 - Start the measurement with **F9**
 - Change to the **Angular Representation** to be able to relate the oscillogram to the crankshaft angle.
- b) Recording the secondary oscillogram
 - Load settings
 - Start the measurement with **F9**
 - Change to the **Angular Representation** to be able to relate the oscillogram to the crankshaft angle.

Please keep in mind that the ignition voltages of ignition plugs that ignite in the unpressurized state are always lower than in an engine at approx. 10 bar! In air, the breakdown voltage of standard ignition plugs is only approx. 3.5 kV. For this reason, the height of the ignition pin can vary from cycle to cycle.

- c) Recording the contact closed interval
- Load settings
 - Start the measurement with **F9**
 - Increase the speed from 800 to 5000 1/min

Evaluation

In the example files, the measurements have been evaluated by way of example. Load the example files, and change to the **Evaluation** display. The contact closed interval was measured for a distributor with centrifugal advance. Up to approx. 4500 1/min, the contact closed interval does not change. Only at higher values of the speed does it decrease.

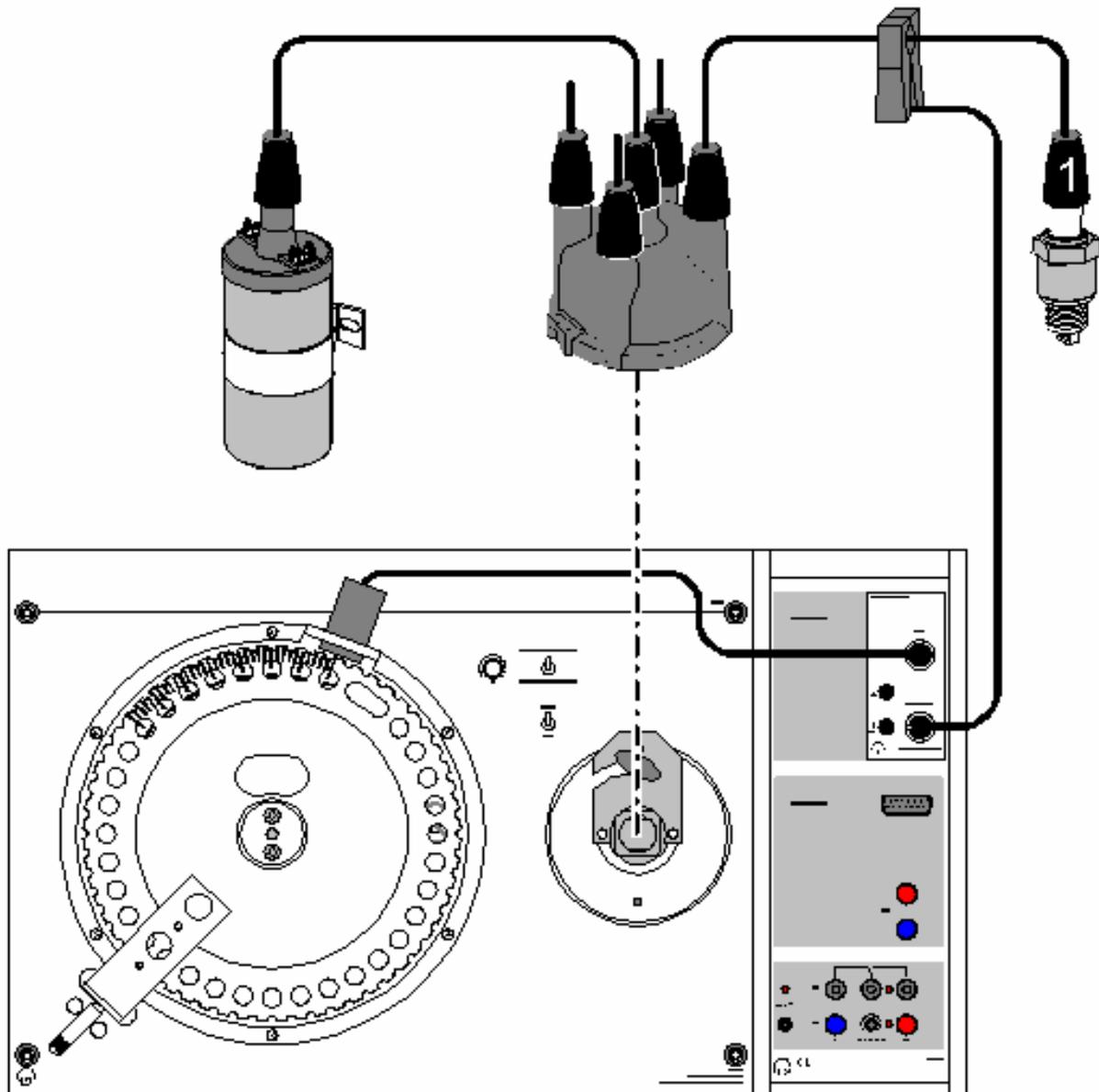
Remark

Please refer to the corresponding experiment literature for further experiments!

Further example files

- Load example (Measurement of the contact closed interval on a breakerless ignition system at rest)

Motor vehicle – mixture formation systems



- Load example (centrifugal advance)
- Load example (vacuum advance, advance unit)
- Load example (vacuum retard, retard unit)
- Load example (injection time)
- Load example (lambda closed-loop control)
- Load example (rotary idle actuator trigger)
- Load example (knock control)

Safety notes

Ignition systems reach power ranges where in the entire system, i.e. not only at individual units such as the ignition coil or the ignition distributor, but also at cables, plug-in connectors, connectors of test equipment etc. dangerous voltages may be present both on the secondary and on the primary side.

- Therefore the ignition has always to be switched off before manual operations on the ignition system!
- When the ignition is switched on, no voltage-carrying parts must be touched!
- Pay particular attention to ground connections between the individual training panels!

Experiment description

In this example, the basic possibilities of signal acquisition of relevant quantities in mixture formation systems are demonstrated. These include the speed, the moment of ignition, the injection duration and the frequency and on/off ratio of rectangular signals.

Equipment list

2	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Auto-Box i	524 076
1	Inductive-type pulse pick-up	738 986
1	Stand. workshop TDC generator	738 989
1	PC with Windows 95/98/NT or higher version	

optionally for adjusting the vacuum:

1	Pressure sensor S, ± 2000 hPa	524 064
1	Vacuum pump	738 996

and one of the following equipments:

T 3.2.5.6	LU-Jetronic
T 3.2.5.7	Motronic
T 3.2.5.10	LH-Motronic M 1.5.4 or 1.5.2
T 3.2.5.11	MONO-Motronic

Experiment setup (see drawing)

You can use one of the above-mentioned systems or a mixture formation system in a motor vehicle.

The ignition signal of cylinder 1 is detected by means of the trigger clamp. The TDC generator detects the upper dead centre of the cylinder. Apart from the speed, the moment of ignition is determined from these signals.

At the two 4 mm sockets, an arbitrary rectangular signal can be applied. The quantities that can be evaluated are the frequency, the on/off ratio and the operating time or shut-off time. If the signal of an injection valve is applied, the injection duration t_i is displayed in ms.

For the measurement of the ignition angle, the crankshaft mark of the TDC and the ignition signal of cylinder 1 are recorded. The time between the ignition pulse and the TDC generator pulse is related to the time required by the flywheel for one revolution. The result is displayed as advance angle in degrees crankshaft angle. The mark for the TDC generator is not located in the upper dead centre of cylinder 1, but 20 degrees crankshaft angle later! This angle is taken into account automatically.

Carrying out the experiment

a) Centrifugal advance

The centrifugal advance mechanism of a rotating distributor adjusts the moment of ignition depending on the speed of the engine. With increasing speed, the **cam** is moved in the direction of rotation of the ignition-distributor shaft, whereby the breaker contact is opened earlier. This leads to an earlier ignition. The centrifugal advance can only be determined, if the vacuum tubings are removed!

■ Load settings

- Start the measurement with **F9**
- Pass through the speed range from 600 to 6000 1/min

The centrifugal advance causes an adjustment of the ignition angle towards earlier ignition, which increases linearly up to approx. 3000 1/min. At higher speeds, there is no further advance as the centrifugal advance is limited mechanically. If vacuum advance is to be investigated subsequently, the corresponding centrifugal components can be determined from the diagram, which have to be subtracted from the vacuum advance.



b) Vacuum advance, advance unit

The vacuum advance mechanism adjusts the moment of ignition depending on the load of the engine. The vacuum unit is connected to the intake manifold above the throttle valve and adjusts the moment of ignition in the part-load range by turning the **breaker contact** in the direction opposite to the rotation of the ignition distributor shaft. This leads to an earlier ignition. This type of vacuum unit is called "advance unit".

The contribution of the vacuum advance to the total advance can be determined by first determining the pure centrifugal component and then subtracting it from the value measured in the vacuum experiment!

■ Load settings

- Start the measurement with **F9**
- Generate a vacuum of 0 to –600 hPa (-600 mbar) at 1000 1/min
- Repeat the measurement for 2000 and 4000 1/min

Regardless of the speed, the adjustment of the advance unit causes an advance of approx. 13 degrees crankshaft angle. For 1000 and 2000 1/min, the advance ranges are equal after subtraction of the centrifugal component!

c) Vacuum retard, retard unit

The vacuum unit for ignition retard is connected to the intake manifold below the throttle valve because in this position there is a high vacuum during idle and overrun. The retard unit adjusts the moment of ignition by turning the **breaker contact** in the direction of rotation of the ignition distributor shaft. This leads to a later ignition. This type of vacuum unit is called "retard unit".

The ignition retard is subordinate to ignition advance.

The contribution of the vacuum retard to the total advance can be determined by first determining the pure centrifugal component and then subtracting it from the value measured in the vacuum experiment!

■ Load settings

- Start the measurement with **F9**
- Generate a vacuum of 0 to –600 hPa (-600 mbar) at 1000 1/min
- Repeat the measurement for 2000 and 4000 1/min

Regardless of the speed, the adjustment of the retard unit causes an ignition retard of approx. -8 degrees crankshaft angle in the pressure range from –200 to –400 hPa. For 1000 and 2000 1/min, the retard ranges are equal after subtraction of the centrifugal component!

d) Injection valve

The function of the injection valves is to supply all cylinders (single-point injection) or individual cylinders (multipoint injection) with gasoline depending on the signal from the control unit. Usually they are triggered with 12 V via the ground cable. The injected fuel quantity depends solely on the injection duration as the opening cross-section and the pressure difference between the fuel-injection tubing and the intake manifold are kept constant. A typical effect of DC solenoid valves (injection valves) is the high induction voltage in the opposite direction when the voltage is switched off.

■ Load settings

- Start the measurement with **F9**
- Increase the speed of the engine at operating temperature and 50 % load from idle to approx. 5000 1/min
- Repeat the measurement for several load conditions (17 %, 33 %, 67 %, 83 %)

As the speed of the engine increases at constant air throughput, the absolute pressure behind the throttle valve decreases, and the cylinders can induce less mixture per lift. Therefore less fuel is required, which is achieved by a shorter injection duration. If the engine power increases at constant speed, the cylinder charge is greater. This leads to a greater fuel quantity and thus to longer injection times.

e) Lambda closed-loop control

If the exhaust-gas oxygen content is 3 % (lean mixture), the difference relative to the oxygen content of the ambient air leads to a voltage of 0.1 V. If the exhaust-gas oxygen content is less than 3% (rich mixture), the voltage of the lambda sensor increases relative to the increased difference to 0.9 V. Hence there is a control loop for each cylinder bank, which enables the mixture composition to be controlled. Depending on the sensor voltage, the injection duration is changed

■ Load settings

- Activate the periodic change of the lambda voltage
- Start the measurement with **F9** at 2000 1/min with the engine at operating temperature
- Repeat the measurement for a very cold engine and for full load, respectively

The lambda closed-loop control works such that the injection duration rises in the case of a lean mixture, which leads to a richer mixture. In the case of a rich mixture, the injection duration drops, which leads to a leaner mixture. The control does not work if the engine is cold because the fuel-air mixture has to be enriched to compensate for condensation losses at cold components. The mixture cannot be operated with $\lambda = 1$.

At full load, the control is also shut off as the engine has to be operated with a rich mixture to achieve maximum engine power.

f) Rotary idle actuator

During the fuel injection, the function of the rotary idle actuator is to open a bypass air channel around the throttle valve more or less thus controlling the idle operation. The percentage of the time within an interval of 100 ms, during which the electric motor receives a current pulse for opening, is called on/off ratio. It is, e. g., 50 % if the motor receives 12 V for 50 ms and then 0 V for another 50 ms. In this case, the inertia of the armature should lead to the bypass channel being opened for about 50 % of the time.

■ Load settings

- Start the measurement with **F9**
Reduce the speed of the engine at operating temperature from 850 to 400 1/min
Repeat the measurement for a cold engine and with the air conditioner being switched on

When the speed is decreased, the on/off ratio increases, as the engine tries to increase the speed. If the engine is cold, the on/off ratio is increased as well, as the higher engine friction has to be overcome. If the air conditioner is switched on, the engine also tries to increase the air throughput of the rotary idle actuator by increasing the on/off ratio in order to compensate for the drop in speed caused by the increased load.

g) Knocking sensor

"Knocking", an uncontrolled form of combustion, can lead to damage in the engine. However, as knock limits depend on many variable quantities such as fuel quality, engine condition and ambient conditions, a sufficient distance from the knock limit has to be kept in ignition systems with electronic adjustment, which leads to a deterioration of the fuel consumption. The distance of the program map from the knock limit, which has been indispensable up to now, may be cancelled if a knock during operation, e. g. caused by poor fuel quality, is detected and if the ignition angle is reduced accordingly. The knock control enables the engine to be operated in the limit range without damage.

■ Load settings

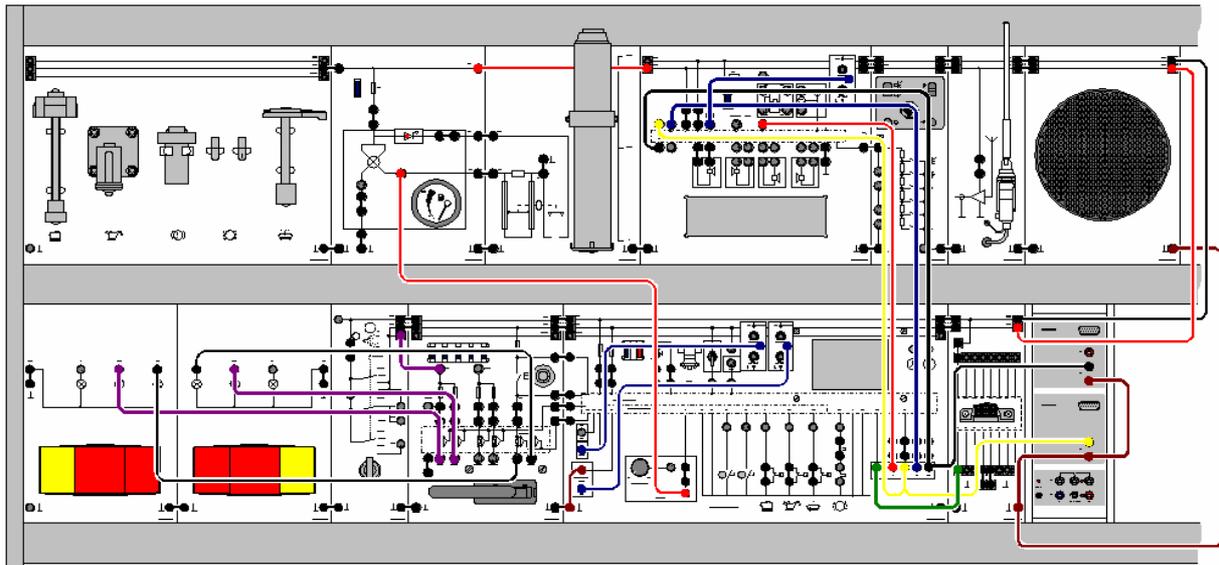
- Start the measurement with **F9**
- With the engine at operating temperature and running at a speed of 2500 1/min almost at full load, slightly hit the knock sensor against a metal block

In the case of combustion knock, the control circuit delays the moment of ignition of the knocking cylinder. Subsequently the moment of ignition is taken back to its original value slowly according to a particular scheme.

Remark

Please refer to the corresponding experiment literature for further experiments!

Motor vehicle – on-board computer with radio



■ Load example

Experiment description

The present system is the multi-info display (MID) from the Opel Omega B, model year >1994. The info display is a central information system comprising the following individual systems:

- Clock
- On-board computer
- Check control
- **Radio display part**
- Date display part

The info display is integrated in the instrument assembly. It has a four-line display. Depending on the set operating mode, the above mentioned information is displayed. In this experiment, the communication between the radio and the display will be investigated. These two components communicate via the so-called " I²C" bus, whose bus signal will be recorded.

For further information on this subject see: <http://www.philipslogic.com/products/collateral/i2c/>.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Battery connection unit	738 03
1	Battery	738 04
	<i>or alternatively</i>	
	Power supply	738 026
1	Ignition switch	738 10
1	MID	739 705
1	Car radio	739 711
1	Short telescoping antenna	739 742
1	Broad band loudspeaker	739 731
1	PC with Windows 95/98/NT	
	or higher version	

Accessories required

1	Set of 51 safety connection leads	738 9821
5	Sets of 10 safety bridging plugs black	500 59
1	Set of 10 safety bridging plugs with tap	500 592

Experiment setup

Set up the experiment as shown in the drawing. Some devices are optional and are not required for carrying out the experiment! Connect the Sensor-CASSY to a serial RS232 port or a USB port of the computer. Connect the measurement inputs to the experiment setup as shown in the drawing.

Carrying out the experiment

- Load settings
- Switch the system on, first using the battery connection unit and then the ignition switch.
- Switch the radio on by pressing the volume key.
- Start the measurement by pressing **F9** or .
- Now switch over a station key of the radio to create a data flow.

Evaluation of the experiment

The following findings can be obtained from the diagrams:

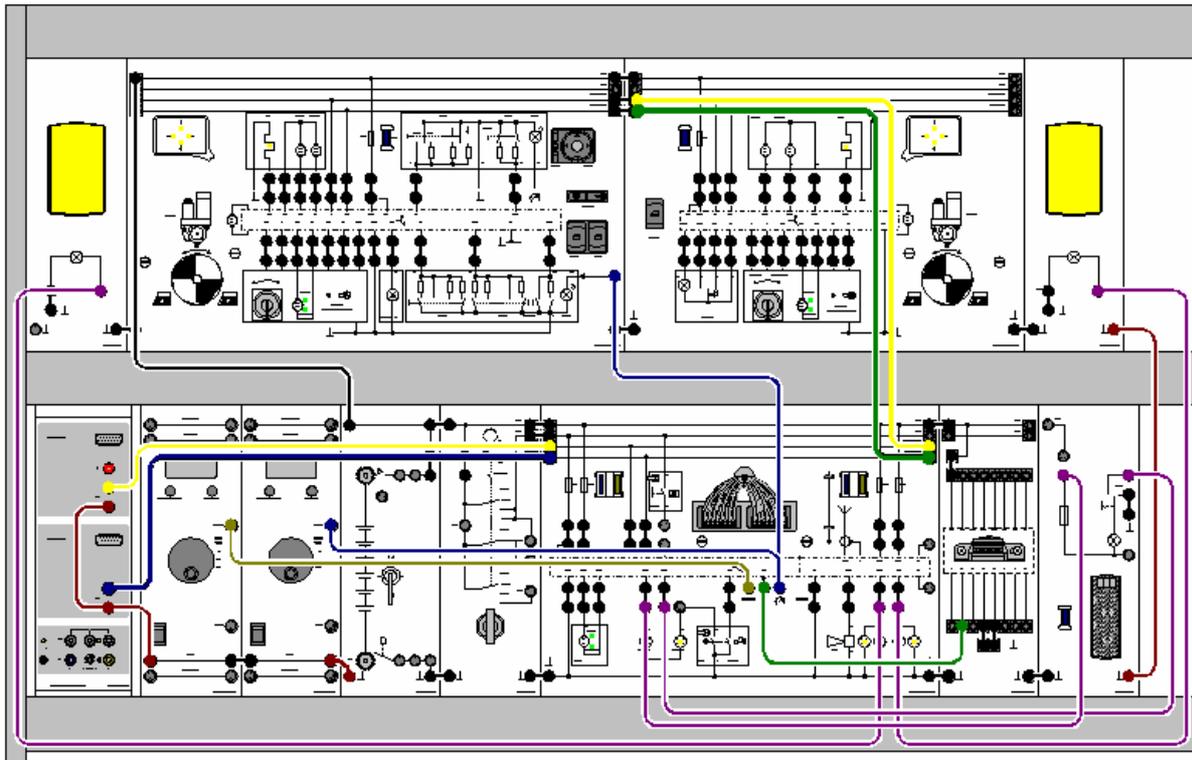
- The address of the display is: 1 0 0 1 0 1 0
- A write access from the display to the radio takes place (RW bit)

Further variations of the experiment and their evaluation are found in the associated experiment literature.

Further measurement examples

- Representation of the data frames for controlling the display
- Determining the bus levels

Motor vehicle – comfort system with CAN bus



■ Load example

Experiment description

The new comfort system was first used in the VW Passat in the model year 1997 and has been available in the VW Golf since the model year 1998. The individual functionalities that belong to the comfort system such as the central locking system, the mirror adjusting system and the theft-deterrent system have not changed essentially. What is new, however, is the structure and the organisation of the comfort system. In contrast to conventional systems, it has a decentralized structure. That means tasks are shared by several control units.

The control units of the comfort system are connected to one another via two lines, the CAN data bus. A permanent data exchange between the control units takes place via these lines.

For this a control unit has to:

- provide data of its own,
- send these data to other control units,
- receive data from other control units,
- check these data and, if required, accept them.

The system consists of a central control unit and two door control units. The central control unit has no higher-level function. There is no hierarchy among the control units. Apart from its functionalities within the comfort system, the central control unit establishes the connection between the remaining vehicle electrical system and the diagnosis cables.

Functionalities of the central control unit:

- Mirror adjustment,
- Interior light control,
- Remote release of the luggage compartment lid,
- Radio remote control,
- Theft-deterrent system.

The door control units monitor and control the functionalities of the comfort system carried out in the doors.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Battery connection unit	738 03
1	Battery	738 04
	<i>or alternatively</i>	
	Power supply	738 026
1	Ignition switch	738 10
1	Comfort system	739 58
1	PC with Windows 95/98/NT or higher version	

Accessories required

1	Set of 51 safety connection leads	738 9821
5	Sets of 10 safety bridging plugs black	500 59
1	Set of 10 safety bridging plugs with tap	500 592

Experiment setup (see drawing)

Set up the experiment as shown in the drawing. Connect the Sensor-CASSY to a serial RS232 port or a USB port of the computer. Connect the measurement inputs to the experiment setup as shown in the drawing.

Carrying out the experiment

■ Load settings

- First switch the system on using the battery connection unit.
- Now open one of the two doors by turning the corresponding key switch in the "OPEN" direction.
- Switch the ignition on using the ignition switch.
- Start the measurement by pressing **F9** or .

Evaluation of the experiment

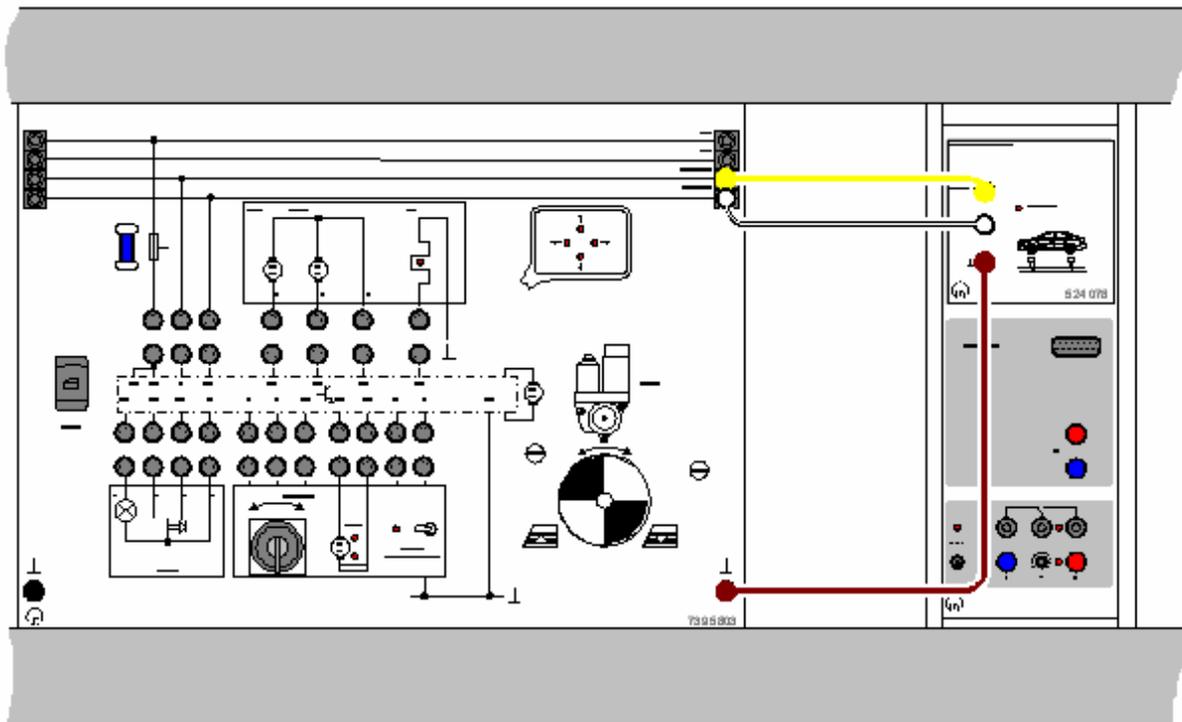
The following findings can be obtained from the diagrams:

- The signals on the lines CANH and CANL are mutually inverted.
- The messages are set in three frames with a repeat time of 20 ms.
- Two messages have equal lengths (approx. 1.34 ms) and one message is shorter (approx. 1 ms). The latter obviously concerns the door control unit of the co-driver side.

In addition to CANH and CANL, the **Difference** display also shows their difference $\Delta\text{CAN}=\text{CANH}-\text{CANL}$, which is defined as a formula.

Further variations of the experiment and their evaluation are found in the associated experiment literature 566 1481.

Motor vehicle – investigating CAN databus signals



■ Load example

Experiment description

In this example, a CAN message is recorded and evaluated graphically. This recording can be used to determine individual components of the protocol. These include:

- Start bit
- Identifier (incl. RTR)
- Length code (DLC)
- Data blocks
- Checksum (CRC)
- Acknowledgement field (ACK)
- End of file (EOF)

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	CAN bus box	524 078
1	PC with Windows 95/98/NT or higher version	

In addition, one of the following equipments is required:

- T 3.2.3.7: Automotive lighting with CAN bus
- T 3.2.7.5: Comfort system with CAN bus
- T 3.2.12.3: Networked vehicle systems 1 (lighting) and
- T 3.2.12.5: Networked vehicle systems 3 (infotainment)

Alternatively it is, of course, possible to use the CAN bus signals of a low-speed bus in an original vehicle.

Experiment setup (see drawing)

Connect the CAN bus box to a low-speed CAN bus in any position. Take care to establish a correct ground connection.

To gain workshop practice you may also connect the CAN bus of an available vehicle as long as it is a low-speed bus. Follow the manufacturer's circuit diagrams to get access to the two bus cables, and additionally connect the ground socket to the ground of the vehicle's body.

Hint: in modern vehicles, the CAN bus signals may be available at the 16-pole OBD socket!

Carrying out the experiment

- Load settings
- Start the measurement with **F9**
- The measurement is stopped automatically after the first received message has been recorded.
- The measurement can be repeated for other data to be transmitted. To do this, first select the corresponding identifier in the ID filter in the Settings CANA1 (right mouse button on CANA1) and restart with **F9**.

Evaluation

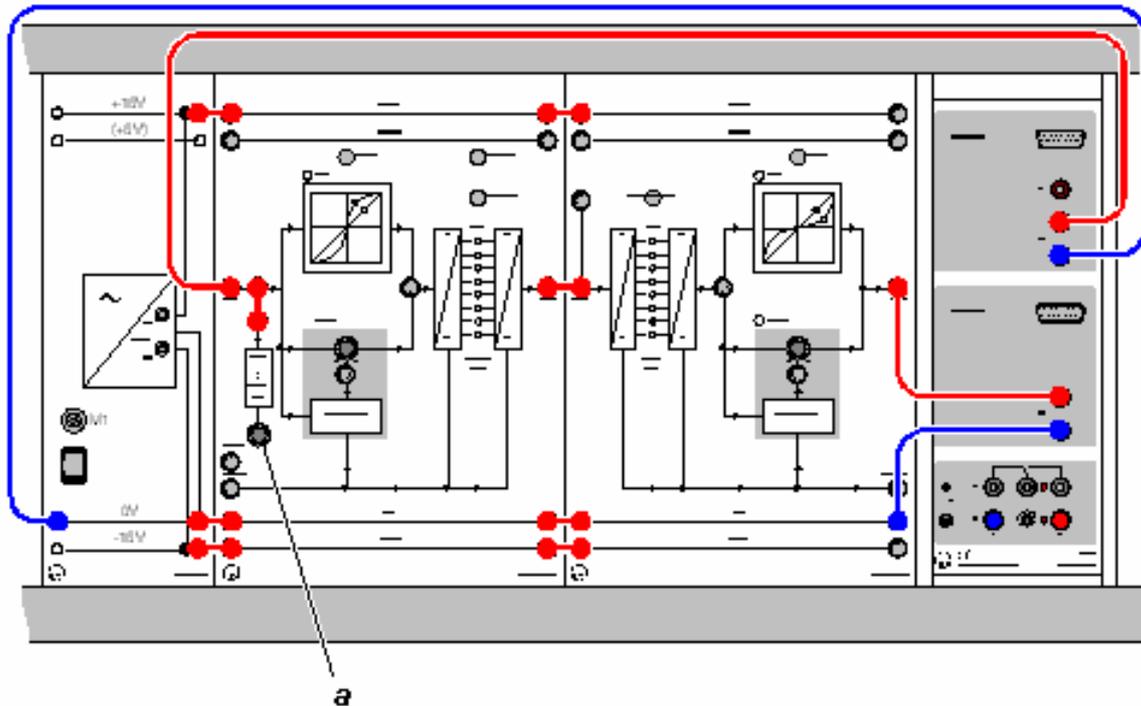
In the display all recorded messages are first shown as hexadecimal numbers. If there are more than two messages in the system which are repeated cyclically, the display shows these messages one after another. From the left to the right the following components are displayed:

- Identifier
- Data length code
- Data blocks
- Checksum
- Status of the acknowledgement

The displays are separated from one another by a blank character. In Settings CANA1 two different binary modes can also be selected:

- Raw data, i. e. all stuff bits are contained
- Binary data, i. e. all stuff bits are filtered out

Pulse code modulation (quantization)



- Load example (linear quantization characteristic, 5 Bit)
- Load example (linear quantization characteristic, 8 Bit)
- Load example (non-linear quantization characteristic, 5 Bit)
- Load example (compressor characteristic, 8 Bit)
- Load example (expander characteristic, 8 Bit)

Experiment description

The conversion of an analog signal into a digital signal requires 3 steps:

- Scanning
- Quantization
- Coding

Quantization will now be investigated experimentally. Switching on/off individual bits enables the resolution of the quantization to be reduced and the process to be represented graphically in an impressive manner. In addition, the expander and compressor characteristics are recorded during companding.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	PCM modulator	736 101
1	PCM demodulator	736 111
1	DC power supply ± 15 V, 3 A	726 86
1	Set of 10 bridging plugs	501 511
2	Pair of cables, red and blue, 100 cm	501 46
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Prepare the experiment setup and the cabling as indicated above and switch the power supply on. Please pay particular attention to the following points:

- Switch bits off coming from the LSB (key buttons SELECT and ON / OFF, see below).
- Turn the potentiometer *a* only slowly.
- In the range of small input voltages (< -10 V), overdriving the A/D converter can lead to a signal jump 0 V \rightarrow -9.5 V. That is not critical, you may start the measurement at approx. -9.5 V.
- Theoretical and experimental aspects relating to this subject are discussed comprehensively in the manual (see T7.2.2.1 Pulse code modulation 564 001, page 52).

Carrying out the experiment

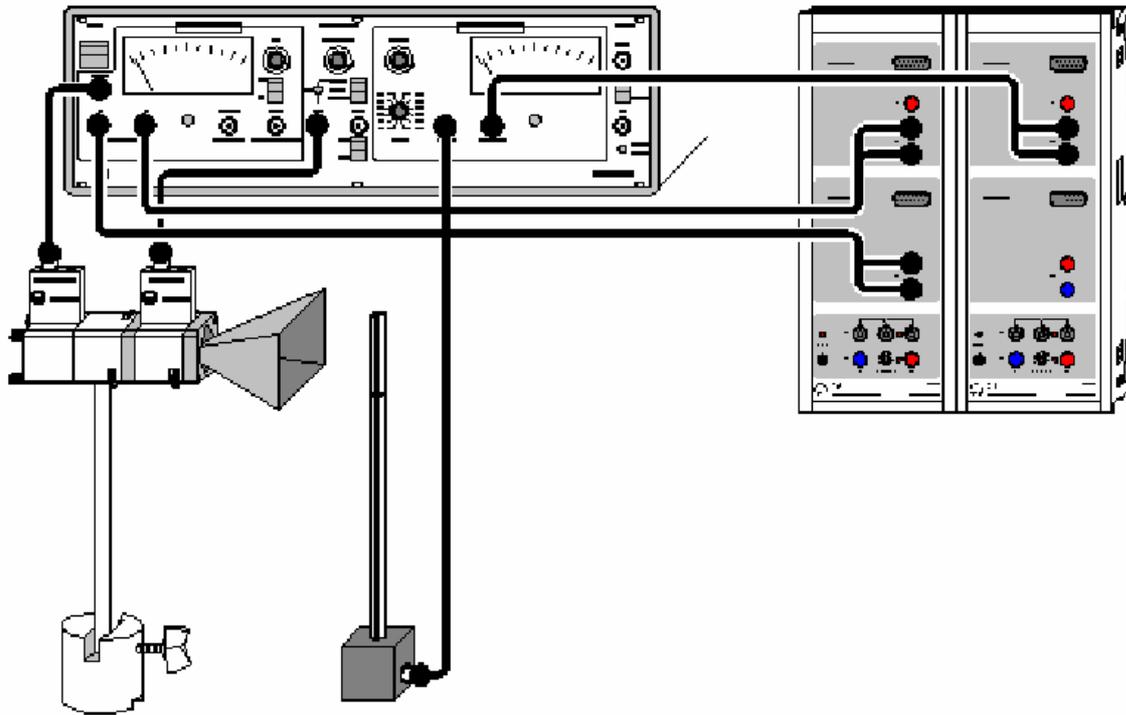
■ Load settings

- Turn the potentiometer all the way round to the left.
- Start the measurement with **F9** or .
- Turn the potentiometer *a* to the right. Now there is a voltage at the input of the PCM modulator (736 101), which increases slowly from -10 V up to $+10$ V. This input voltage is displayed as the voltage U_{A1} . The output voltage (after quantization) at the PCM demodulator (736 111) is displayed as the voltage U_{B1} .
- After recording the quantization characteristic, stop the measurement with **F9**.

Variations

- Reduction of the resolution from 8 to 5 bits.
Deactivate the 3 least significant bits (LSB) of the PCM modulator by pressing SELECT and ON/OFF. The position of the desired bit is reached by pressing SELECT repeatedly. ON/OFF changes between active/inactive. Turn the potentiometer *a* back to the left (minimum input voltage: approx. -10 V) and record the quantization characteristic again. The 32 steps of **equal height** resulting from the 5 bits are clearly seen.
- Non-linear quantization
Press the MODE key buttons of the PCM modulator and of the PCM demodulator **once** each. Now both devices work in the non-linear quantization mode (in each case each indicated by an LED in the 13 segment characteristics). Then record the characteristic again.
- Compressor/expander characteristic
For recording the compressor/expander characteristic, only one of the two devices is operated in the non-linear mode, whereas the other one works in the linear mode.

Physical principles of microwave technology (characteristics of the Gunn oscillator)



- Load example (characteristics with two Sensor-CASSYs)
- Load example (current-voltage)
- Load example (current-voltage-microwave power)

Experiment description

Gunn oscillators consist of a cavity resonator (= closed metallic cavity) and a Gunn element. The current-voltage characteristic $I_G=f(U_G)$ of the Gunn element exhibits a region with a negative slope. Only in this region of the characteristic does the Gunn element reduce damping and can balance the losses in the resonator so that a lasting oscillation and thus usable microwave power is generated. In this experiment, the Gunn current I_G and the microwave power P_M are displayed as functions of the DC voltage U_G of the Gunn element.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Gunn oscillator	737 01
1	Gunn power supply with SWR meter	737 021
1	PIN modulator	737 05
1	Isolator	737 06
1	Support for waveguide components	737 15
1	Large horn antenna	737 21
1	E-field probe	737 35
1	Saddle base	300 11
3	BNC cables, 1 m	501 02
3	Screened cables BNC/4 mm	575 24
1	Book: Physical Principles of Microwave Technology	568 722
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Prepare the experiment setup and the cabling as indicated above and switch the Gunn power supply on. Please pay particular attention to the following points:

- Connections between the power supply and the Gunn oscillator and between the PIN modulator and the E-field probe with BNC cables male/male.
- Connections between the power supply (AMP OUT and RECORDER X,Y, respectively) and the Sensor-CASSY with screened cables BNC/4 mm.
- Power supply, MODULATION: select PIN INT.
- Select a suitable gain at the SWR meter (v/dB and ZERO).
- Theoretical and experimental aspects relating to this subject are discussed comprehensively in the manual (see pages 11ff).

Remark

The illustration shows an experiment setup with a cascade arrangement of 2 Sensor-CASSYs. With this arrangement the characteristics $I_G=f(U_G)$ and $P_M=f(U_G)$ are recorded simultaneously. The second characteristic represents the microwave power of the Gunn oscillator as a function of the DC voltage U_G of the Gunn element.

If only one Sensor-CASSY is available, the experiment is carried out in two steps.

Carrying out the experiment with 2 Sensor-CASSYs

■ Load settings

- Turn the potentiometer U_G all the way round to the left ($U_G = 0$ V).
- Start the measurement with **F9**.
- Turn the potentiometer U_G to the right. The Gunn voltage, the Gunn current and the microwave power are displayed on dedicated display instruments.
- After recording the two characteristics $I_G=f(U_G)$ and $P_M=f(U_G)$, stop the measurement with **F9**.

Carrying out the experiment with 1 Sensor-CASSY

■ Load settings

- Turn the potentiometer U_G all the way round to the left ($U_G = 0$ V).
- Start the measurement with **F9**.
- Turn the potentiometer U_G to the right. The Gunn voltage and the Gunn current are displayed on dedicated display instruments.
- After recording the characteristic $I_G=f(U_G)$, stop the measurement with **F9**.

The second characteristic $P_M=f(U_G)$ is recorded subsequently with the same Sensor-CASSY and the same settings. Therefore the relative microwave power is displayed in the Gunn current display instrument. For this:

- Disconnect the Sensor-CASSY from the Gunn power supply (RECORDER Y) and change to AMP OUT.
- Select a suitable gain at the SWR meter (v/dB and ZERO).
- Record the characteristic again.

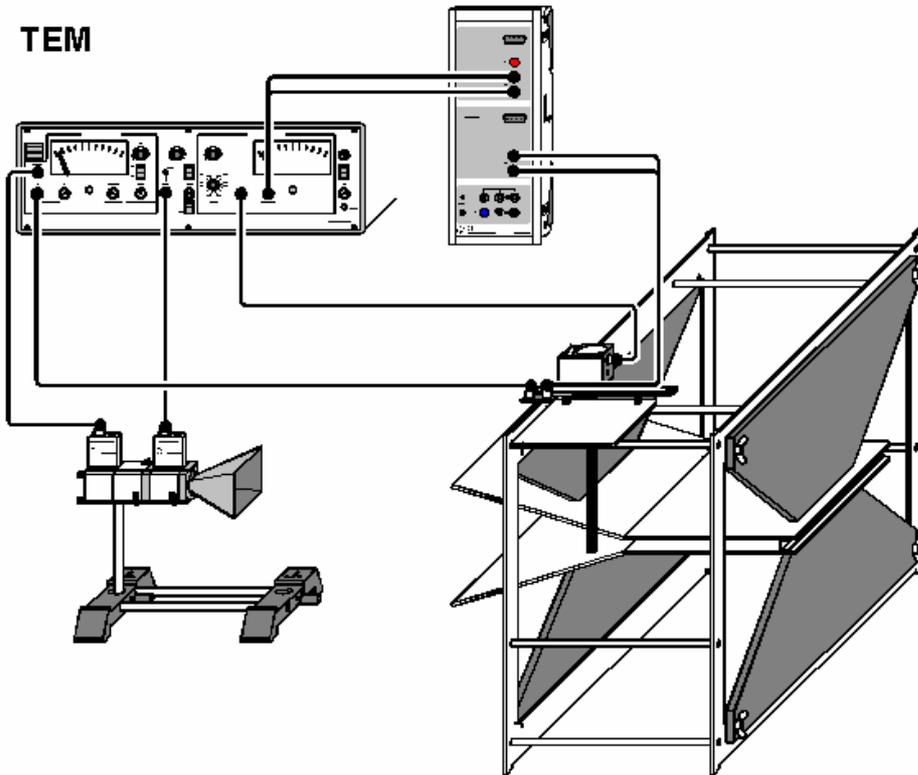
Remarks

Characteristics of active elements in microwave experiments exhibit wide scattering. Therefore the characteristics shown in the examples should only be considered as examples. The important thing is the connection between the falling region of the current-voltage characteristic and the generation of microwave power. The absolute values or the shape of the curves can vary considerably, depending on the Gunn element used.

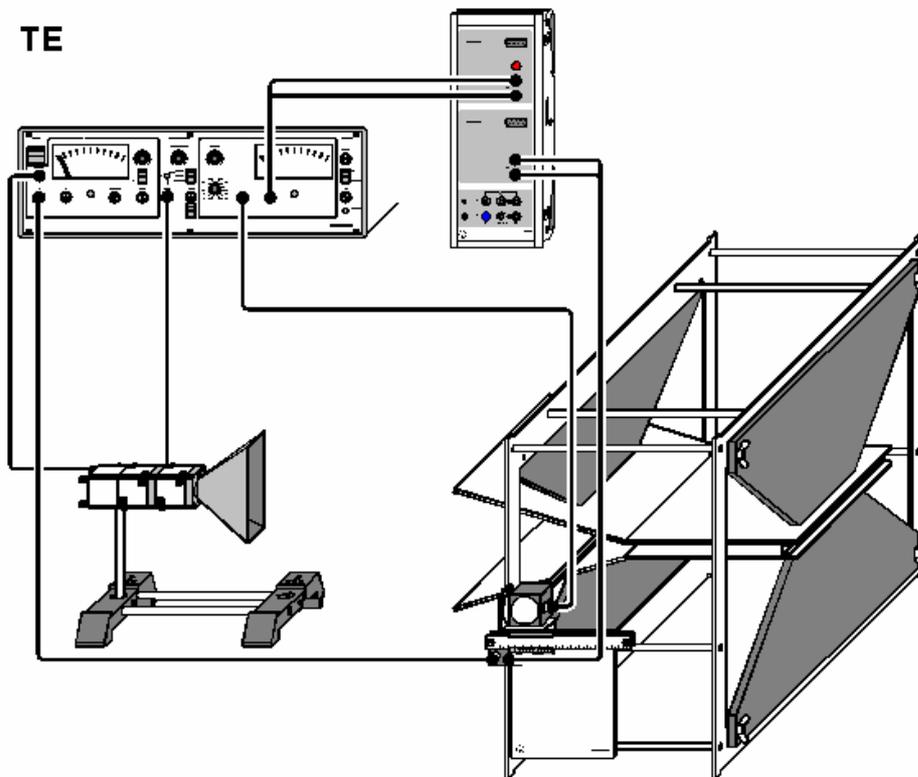
The measurement of the microwave power P_M is made with an uncalibrated detector. Therefore its numerical value is arbitrary.

Parallel plate line (TEM and TE modes)

TEM



TE



- Load example (TEM)
- Load example (TE 22 mm plate distance)
- Load example (TE 13 mm plate distance, cut-off)

Experiment description

TEM or TE waves can be excited on the parallel plate line by rotating the direction of polarization of the exciting microwave field (pay attention to this in the experiment!). TE waves exhibit a cut-off phenomenon, i. e. for a given frequency of the exciting field, TE waves can only propagate if the plate distance exceeds a certain minimum value. In the case of an excitation with a variable frequency and a fixed plate distance, TE waves cannot propagate if the frequency is below the so-called cut-off frequency. As microwave experiments in free space are only permitted at certain, fixed frequencies, this experiment is carried out with a variable plate distance.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Gunn oscillator	737 01
1	Gunn power supply with SWR meter	737 021
1	PIN modulator	737 05
1	Isolator	737 06
1	Two-plate waveguide	737 07
1	Measuring carriage for parallel plate line	737 071
1	Support for waveguide components	737 15
1	Large horn antenna	737 21
1	E-field probe	737 35
2	BNC cables, 1 m	501 02
2	BNC cables, 2 m	501 022
2	Screened cables BNC/4 mm	575 24
2	Stand bases MF	301 21
1	Book: Parallel Plate Line	568 661
1	PC with Windows 95/98/NT or higher version	

Experiment setup TEM or TE (see drawing TEM or TE)

Prepare the experiment setup and the cabling as indicated above and switch the Gunn power supply on. Please pay particular attention to the following points:

- Connections from the power supply to the Gunn oscillator, to the PIN modulator and to the measuring carriage for parallel plate line (input IN 8-24 V) with BNC cables male/male.
- Connections from the power supply (AMP OUT) and from the measuring carriage for parallel plate line (output X) to the Sensor-CASSY with screened cables BNC/4 mm.
- Set the Gunn voltage to $U_G = 10 \text{ V}$ at the power supply.
- Power supply, MODULATION: select PIN INT.
- Place the measuring carriage for parallel plate line on the props of the parallel plate line such that the E-field probe just reaches into the parallel part of the two-plate waveguide when it is at the left stop.
- The E-field probe should always be in mechanical contact with the edge of the plate when it is moved because this helps to avoid variations in position.
- One after another terminate the two-plate waveguides with the termination profiles 13 mm and 22 mm.
- For additional notes see the instruction sheets 737 07 and 737 071.
- Theoretical and experimental aspects relating to this subject are discussed comprehensively in the manual (see page 27).

Carrying out the experiment

■ Load settings

- Slide the calliper gauge of the measuring carriage (737 071) to the right ($x = 75 \text{ mm}$).
- Use the mouse to take the numerical value of the displayed voltage U_{B1} into the display instrument voltage U_{75} (drag & drop, right calibration point for position measurement).
- Slide the calliper gauge of the measuring carriage (737 071) to the left ($x = 25 \text{ mm}$).
- Use the mouse to take the numerical value of the displayed voltage U_{B1} into the display instrument voltage U_{25} (drag & drop, left calibration point for position measurement).
- Slide the calliper gauge to the left ($x = 0 \text{ mm}$).



- Start the measurement with **F9**.
- Slowly move the calliper gauge to the right.
- You may readjust the gain v/dB and / or ZERO until the desired measuring signal arises. Keep the settings for the subsequent experiments!
- After recording the field as a function of the displacement, stop the measurement with **F9**.

Evaluation wavelength

The wavelength $\lambda_g=B$ on the parallel plate line and the standing wave ratio $SWR=C$ can be calculated directly from the measuring results with a free fit and the formula describing the dependence of the electric field E on x ,

$$A \cdot \sqrt{\cos(360/B \cdot x + D)^2 + 1/C^2 \cdot \sin(360/B \cdot x + D)^2}$$

or, in technical notation,

$$A \cdot \sqrt{\left[\cos\left(\frac{2\pi}{\lambda_g} \cdot x + \varphi\right) \right]^2 + \frac{1}{SWR^2} \left[\sin\left(\frac{2\pi}{\lambda_g} \cdot x + \varphi\right) \right]^2}$$

with

A: amplitude of the electric field strength

λ_g : waveguide length

SWR: standing wave ratio

φ : phase shift

(see also experiment Measurement of the standing wave ratio).

The initial values, in particular for the wavelength $\lambda_g=B$ and the standing wave ratio $SWR=C$, have to be chosen sensibly because otherwise the free fit will not find any result or it will not find the best result. A fitted curve can be discarded by a double click on the curve. Then the fit can be repeated with other initial values.

The initial values entered should be $\lambda_g=B=32$ mm (free-space wavelength) for TEM modes, $\lambda_g=B=45$ mm (waveguide wavelength) for TE modes, and $SWR=C=10$ for the standing wave ratio.

Evaluation cut-off

If the plate distance is too small in the TE arrangement with 13 mm, TE modes can not be excited any more (cut-off). The exponential shape of the field can be approximated with a free fit and the formula

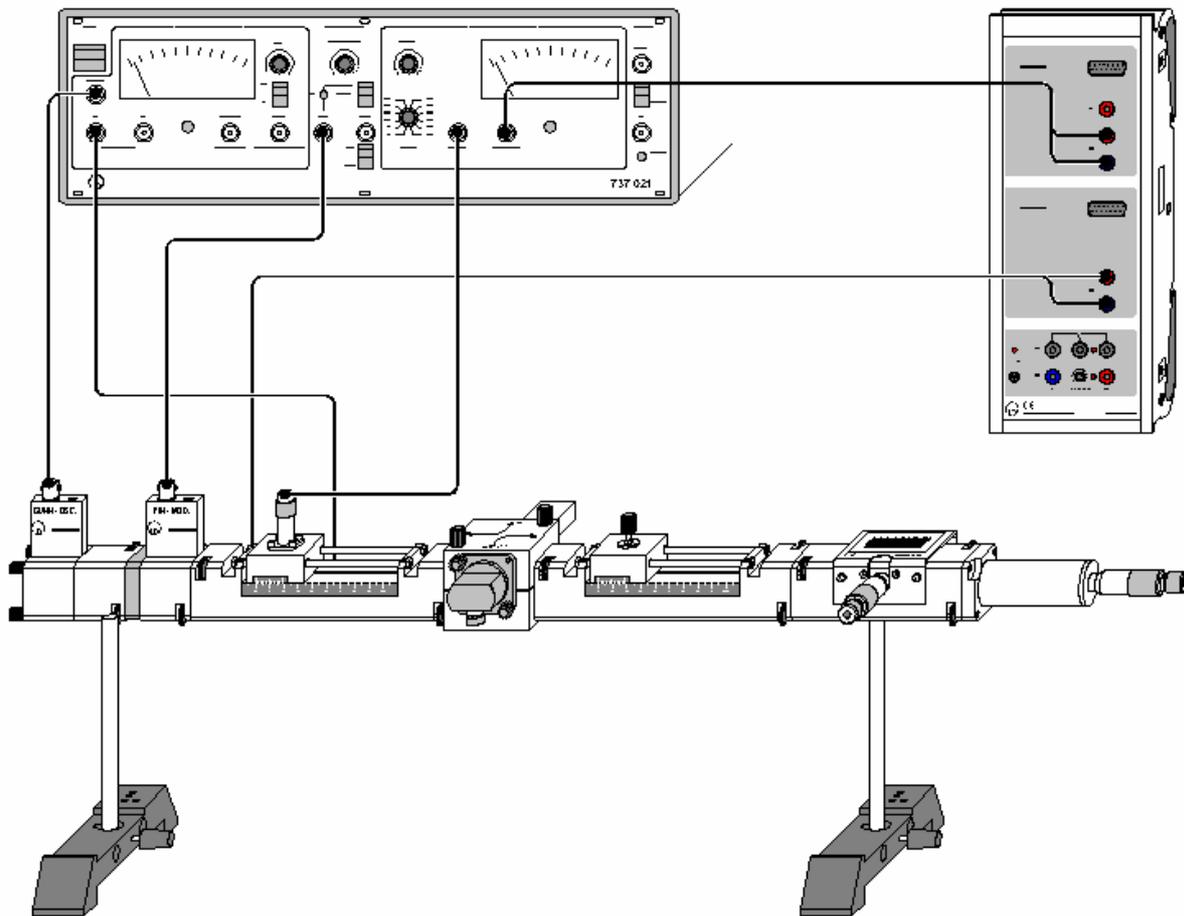
$$A \cdot \exp(-x/B) + C.$$

Enter approximately 10 mm as initial value for B.

Remark

The measured voltage U_{A1} is proportional to the microwave power. Under the assumption that the characteristic of the coax detector is quadratic, this voltage can be converted into the electric field strength $E \propto \sqrt{U_{A1}}$. As the detector characteristic is not calibrated, the numerical value of E is arbitrary.

Microwave propagation in waveguides (measurement of the standing wave ratio)



- Load example (SWR = 3)
- Load example (SWR = 1.1, matched)

Experiment description

The standing wave ratio (SWR) is a scalar measure of the match. In experiments with microwaves, it determines the power transfer from the source to the load and the magnitude of the field strength in the components of the circuit. Therefore an SWR of approximately 1 is desired in most cases. In this experiment, the standing wave ratios of various waveguide terminations are compared. A variable attenuator (alters the magnitude of reflections) and an adjustable movable short (alters the phase of reflections) in series connection are used as a complex microwave load. For the case of an average standing wave ratio (SWR approximately 3), the match is improved by means of a slide screw transformer.

Equipment list

1	Sensor-CASSY	524 010
1	CASSY Lab	524 200
1	Gunn oscillator	737 01
1	Coax detector	737 03
1	Transition waveguide / coax	737 035
1	Gunn power supply with SWR meter	737 021
1	PIN modulator	737 05
1	Isolator	737 06
1	Variable attenuator	737 09
1	Movable short	737 10
1	Slotted measuring line	737 111



1	Slide screw transformer	737 13
1	Waveguide terminator	737 14
1	Cross coupler	737 18
2	Supports for waveguide components	737 15
4	BNC cables, 1 m	501 02
2	Screened cables BNC/4 mm	575 24
2	Stand base MF	301 21
1	Book: Microwave Propagation in Waveguides	568 731
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Prepare the experiment setup and the cabling as indicated above and switch the Gunn power supply on. Please pay particular attention to the following points:

- Connections from the power supply to the Gunn oscillator, the PIN modulator and the slotted measuring line (INPUT) with BNC cables male/male.
- Connections from the power supply (AMP OUT) and the slotted measuring line (output X) to the Sensor-CASSY with screened cables BNC/4 mm.
- Set the Gunn voltage to $U_G = 10 \text{ V}$ at the power supply.
- Power supply, MODULATION: select PIN INT.
- Connect INPUT at the slotted measuring line to RECORDER X at the power supply.
- Mount the cross coupler with two cross-shaped holes. Port 1 to slotted measuring line. Port 2 to slide screw transformer. Port 3 to transition waveguide / coax. Port 4 to waveguide termination.
- Turn the screw of the slide screw transformer far out of the waveguide. Position of the movable short arbitrary.
- Theoretical and experimental aspects relating to this subject are discussed comprehensively in the manual (see page 27ff).

Carrying out the experiment

■ Load settings

- Slide the calliper gauge of the slotted measuring line (737 111) to the right ($x = 75 \text{ mm}$).
- Use the mouse to take the numerical value of the displayed voltage U_{B1} into the display instrument voltage U_{75} (drag & drop, right calibration point for position measurement).
- Slide the calliper gauge of the slotted measuring line (737 111) to the left ($x = 25 \text{ mm}$).
- Use the mouse to take the numerical value of the displayed voltage U_{B1} into the display instrument voltage U_{25} (drag & drop, left calibration point for position measurement).
- Slide the calliper gauge to the left ($x = 0 \text{ mm}$).
- Set the attenuator to 0 dB.
- Start the measurement with **F9**.
- Slowly move the calliper gauge to the right.
- You may readjust the gain v/dB and / or ZERO until the desired measuring signal arises. Keep the settings for the subsequent experiments!
- After recording the field as a function of the displacement, stop the measurement with **F9**.

Evaluation

The wavelength $\lambda_g = B$ in the waveguide and the standing wave ratio $SWR = C$ can be calculated directly from the measuring results with a free fit and the formula describing the dependence of the electric field E on x ,

$$A \cdot \sqrt{\cos^2\left(\frac{360}{B} \cdot x + D\right) + \frac{1}{C^2} \sin^2\left(\frac{360}{B} \cdot x + D\right)}$$

or, in technical notation,

$$A \cdot \sqrt{\left[\cos\left(\frac{2\pi}{\lambda_g} \cdot x + \varphi\right)\right]^2 + \frac{1}{SWR^2} \left[\sin\left(\frac{2\pi}{\lambda_g} \cdot x + \varphi\right)\right]^2}$$

with

A: amplitude of the electric field strength
 λ_g : waveguide wavelength
SWR: standing wave ratio
 φ : phase shift.

The initial values, in particular for the wavelength $\lambda_g=B$ and the standing wave ratio $SWR=C$, have to be chosen sensibly (in this case $B=45$ mm and $C=10$) because otherwise the free fit will not find any result or it will not find the best result. A fitted curve can be discarded by a double click on the curve. Then the fit can be repeated with other initial values.

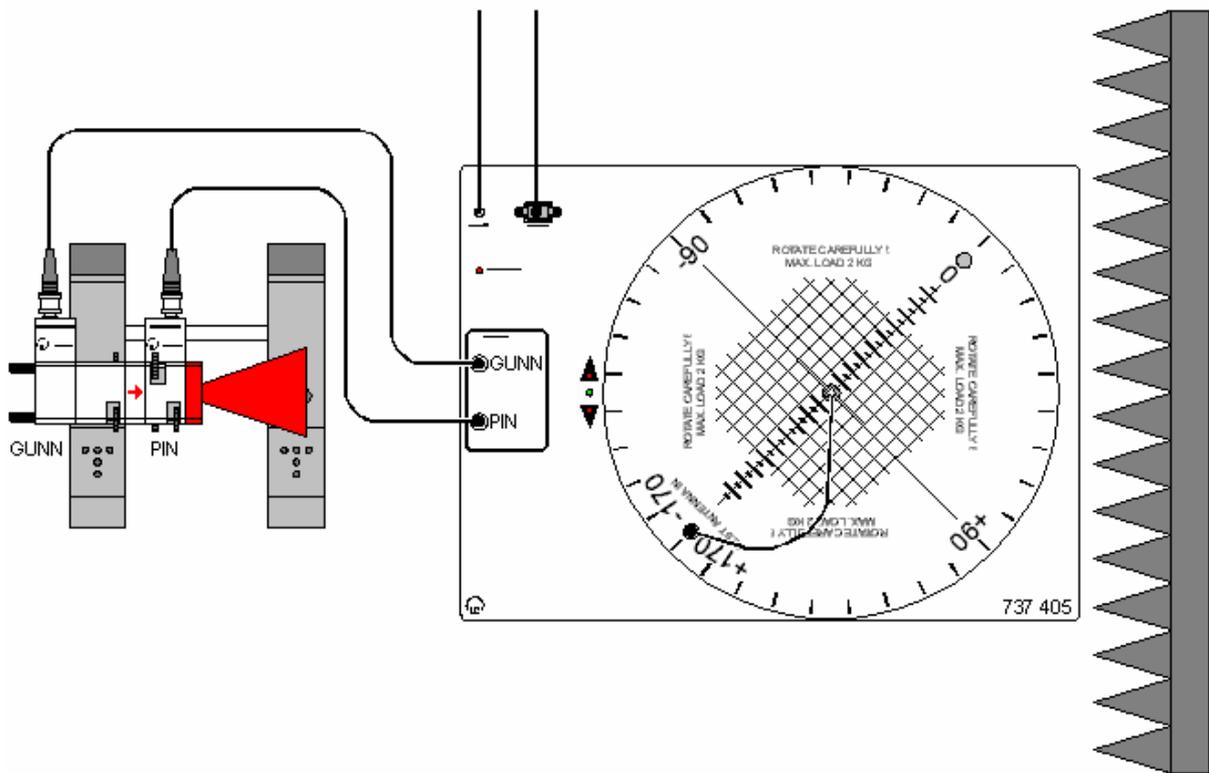
Variations

- Recording the standing wave ratio for reduced reflection. The SWR is decreased by adjusting the attenuator ($a > 0$ dB).
- Improving the match with the aid of the slide screw transformer.
- Set $a=3$ dB at the attenuator. Now only 25 % of the incoming microwave power is reflected. The reflection coefficient is $r=0.5$ and the SWR is 3.
- Make a new measurement to verify what has changed.
- Screw the coax detector on the transition waveguide / coax. Now only the reflected signal is measured.
- Change the penetration depth and the position of the adjusting screw of the slide screw transformer, and reduce the reflected signal to its minimum.
- Screw the coax detector on the slotted measuring line again, and measure the SWR curve anew.

Remark

The measured voltage U_{A1} is proportional to the microwave power. Under the assumption that the characteristic of the coax detector is quadratic, this voltage can be converted into the electric field strength $E \propto \text{sqr } U_{A1}$. As the detector characteristic is not calibrated, the numerical value of E is arbitrary.

Antenna technology



- Load example (horizontal directional diagram of a $\lambda/2$ dipole)

Safety notes

Due to the low power of the Gunn oscillator (approx. 10 mW), there can be no danger to experimenters during antenna measurements. However, if stronger HF sources are used, the following rules should be kept to:

- Under no circumstances "look" directly "into" the transmitting antenna while it is radiating. This also applies to free ends of hollow conductors and horn antennas.
- When components of waveguides are exchanged during changes to the experimental setup, the supply voltage of the Gunn oscillator has to be switched off.

Experiment description

Antennas serve to transmit or receive electromagnetic waves. For this they have to convert the conducted wave of the supply line into a free-space wave. Antennas therefore are transition structures, which connect the lines and free space to one another. The radiation characteristics of an antenna are of particular interest. They can vary considerably, depending on their use in broadcasting, microwave transmission or radar. A widespread type of antennas is given e. g. by antennas with a strong directivity.

Here the use of the antenna measuring station T 7.6.1 in conjunction with the rotating antenna platform (737 405) is explained. A $\lambda/2$ dipole antenna serves as an example of how to record a directional diagram. Readers who are interested in measurements with other test antennas (sets T 7.6.2 to T 7.6.5) are referred to the experiment manual T 7.6 Antenna Technology (568 701). Additional remarks are obtained from the instruction sheet 737 405.

Equipment list

1	Rotating antenna platform	737 405
1	Gunn oscillator	737 01
1	Isolator (recommendable)	737 06
1	PIN modulator (recommendable)	737 05
1	Large horn antenna	737 21

2	Stand bases MF	301 21
1	Set of absorbers	737 390
1	Dipole antenna kit	737411
1	PC with Windows 95/98/NT or higher version	

Experiment setup (see drawing)

Set up the experiment as shown in the drawing. Use the 345 mm stand rods supplied with the rotating antenna platform for setting up the transmitter (microwave components). For further remarks see instruction sheet 737 405. As a rule, the distance r_0 between the transmitting and the test antenna should fulfil the far-field condition. For dipole antennas this is fulfilled for $r_0 > 100$ cm in most cases. The Far-field computer to be found in the Settings A determines the minimum distance r_0 for the transition to the far field after DT has been entered.

Insert the test antenna ($\lambda/2$ dipole) in the central mounting for plug-in axles in the rotating antenna platform so that the axis is aligned with the reference lines on the rotary plate. Connect the BNC output socket of the test antenna to the BNC socket TEST ANTENNA IN in the rotary plate via a coaxial cable. Align the antenna so that its main-beam direction is in the 0° position. Switch the rotating antenna platform on by connecting the plug-in unit. The rotary plate moves to the starting position -180° .

Carrying out the experiment

■ Load settings

- If you have not yet selected the rotating antenna platform as the connected device, do it now. For this connect the rotating antenna platform to the desired serial interface in General settings. After this has been done, **Save New Defaults** saves this assignment.
- If necessary, change the settings of the rotating antenna platform in Settings A. If the dipole antenna is used, the bias current has to be switched on. If no PIN modulator is available, you have to switch over to Gunn modulation.
- Start the measurement with **F9** (stop clock). After a short break, the rotary plate starts to run in the forward direction, whereby the actual measurement of the directional diagram takes place. Immediately after reaching the set final angle, the rotary plate begins to return to its starting position.
- Normalize $A(\vartheta)$ with **Normalize Level** in Settings A so that it is 1 in the maximum.

Evaluation

The measurement example shows the horizontal directional diagram of a $\lambda/2$ dipole. In Settings A the maximum of the measured curve was rotated to 0° . The black curve represents the measured curve whereas the theoretical directional diagram is given by the red curve. The theoretical curve was obtained by means of a Free fit (see below).

Remarks

- The axis of symmetry of the test antenna and the centre of the rotary plate have to be in line. If the antenna has been inserted in the central mounting of the rotary plate, this is in general fulfilled. However, there are test antennas which are mounted by means of stand material. In this case, the antenna has to be aligned carefully over the centre of the rotary plate in order that during rotation no eccentric motion occurs (which would lead to asymmetries in the directional diagrams).
- If the main lobe of the test antenna is to be located at 0° in the directional diagram, the test antenna has to be aligned so that its main-beam direction points into the 0° direction. Furthermore it has to be aligned with the transmitting antenna. That means its "back" "looks over" to the exiting source antenna. The reason for this lies in the nature of the process: the main-beam direction is thus measured in one run instead of being divided into two halves. Environmental influences on the system thus have less effect on the important region of the main lobe.
- Depending on the test antenna, the measurement can be made at various degrees of angular resolution. In principle complicated antennas with many or narrow lobes have to be measured at high resolution.
- The measurement process can be observed simultaneously on the measuring instruments (e. g for the angle, voltage and level), which can be inserted/hidden, and in the graphical display. In the graphical display, the directional diagram is constructed step by step (Cartesian co-ordinates or polar diagram with freely selectable axes). Scaling can be shifted with the left mouse button and it can be changed with the right mouse button.



- The actual antenna signal A from the detector cannot be measured directly. Only the voltage drop U generated by detector current at the measuring amplifier is measurable. In general, U is not proportional to A but

$$U \propto A^m$$

The exponent m describes the detector characteristic. If the antenna signal $A(\vartheta)$ is normalized with **Normalize Level** in Settings A so that it is 1 in the maximum, we have:

$$A = \left(\frac{U}{U_{\max}} \right)^{\frac{1}{m}}$$

$$a = 20 \cdot \log(A)$$

where U_{\max} is the maximum voltage U measured.

the exponent m depends on the power of the incoming microwaves. In the low-power range it is $m=2$, i.e.

$$U \propto A^2$$

Experience has shown that the assumed quadratic behaviour only applies at very low microwave powers or received voltages $U < 5$ mV. However, the antenna measurement system makes it possible to enter other detector characteristics. Strictly speaking, the selected characteristic has to be checked. For this a variable attenuator (737 09) is required which enables the antenna signal in front of the detector to be attenuated in a well-defined way.

Further measurement examples

Measurements with PIN modulator and isolator

- $1\lambda/2$ dipole
- $1\lambda/2$ dipole (vertical)
- $2\lambda/2$ dipole
- $3\lambda/2$ dipole
- $4\lambda/2$ dipole
- $8\lambda/2$ dipole
- helical antenna, right-handed
- Yagi antenna with 4 directors and 1 reflector
- Yagi antenna with 4 directors and 1 reflector (vertical)
- Yagi antenna with 1 director and 1 reflector
- Yagi antenna with 1 director
- Yagi antenna with 1 reflector
- display of the electronic beam rotation (Phase Array) at the slot antenna (737 424)

Measurements without PIN modulator, with direct Gunn modulation

- $1\lambda/2$ dipole, the lower modulation depth in direct modulation leads to a considerably weaker received signal and a correspondingly reduced signal-to-noise ratio
- helical antenna, left-handed
- Yagi antenna with 4 directors and 1 reflector

Formulas in directional diagrams

Measuring results can be compared with theoretical directional diagrams if a suitable formula is available or can be derived. Formulas can be used in various ways:

- The formula can be defined as a new quantity. Then all parameters of the Formula have to be entered explicitly.
- The formula can be entered for carrying out a Free fit. In this case, up to 4 parameters of the formula are varied automatically so that the best agreement between the measuring results and the formula is obtained. The method is very elegant in the case of antenna measurements and shall be explained briefly in the following paragraphs.

Free fit for directional diagrams

After the measurement with the rotating antenna platform has been carried out, the following steps are required for performing a Free fit:

- Select the Cartesian representation (Change Axis Assignment in the diagram with the right mouse button and switch off the **Polar** button under the x-axis)
- Select Free fit (click Fit Function in the diagram with the right mouse button and select Free fit)
- Enter the formula in the input field, select it from the list, or copy it via the clipboard (via copy and paste, e.g. the examples below) having marked just the formula.
- Having estimated sensible starting values for A, B, C and D (see examples below), enter them.
- Mark the result as a new channel (parameter). This leads to a new column in the table when the evaluation takes place with the calculated values of the theoretical directional diagram.
- Select **Mark range**, and mark the entire measuring curve with the left mouse button. Then the fit is performed, and the best approximation of the formula found during the fitting procedure is displayed.
- Select the polar representation (Change Axis Assignment in the diagram with the right mouse button and switch the **Polar** button under the x-axis on again)

Examples

Remark: the formulas given in the following examples can simply be marked with the cursor and copied into the input field.

1 Technical dipoles

$$A * \left| \frac{\cos\left(\frac{\pi * l_{el}}{\lambda_0}\right) * \sin(\vartheta + \vartheta_0) - \cos\left(\frac{\pi * l_{el}}{\lambda_0}\right)}{\cos(\vartheta + \vartheta_0)} \right|$$

The formula describes the dependence of the directional diagram on the polar angle in the case of a dipole antenna for which a sinusoidal distribution of the currents on the antenna conductors has been assumed. Distortions due to current displacement, which is down to a low reduction factor (finite thickness of the antenna conductors), are not taken into account.

- ϑ polar angle
- ϑ_0 angular misalignment
- l_{el} electric length of the dipole (shortening not taken into account)
- λ_0 wavelength in free space

Formula to copy

A*abs((cos(180*B/32*sin(x+D))-cos(180*B/32))/cos(x+D))

- x polar angle ϑ
- 32 wavelength in free space in mm ($\lambda_0 = 32$ mm for 9.40 GHz).

From the measured values, the program obtains optimum values for:

- A amplitude fit
- B electric length l_{el}
- D angular misalignment ϑ_0 (deviation of the antenna from the direction of reference)

Starting values for the parameters A, B and D

Antenna	A	B/mm	D/deg
$\lambda/2$ dipole	1	16	0
λ dipole	1	32	0
$3\lambda/2$ dipole	1	48	0
2λ dipole	1	64	0
4λ dipole	1	128	0



2 Yagi antennas

2.1 Yagis with one parasitic element

- Yagi-R: dipole and 1 reflector
- Yagi-D: dipole and 1 director

Both cases are approximately described by the directional diagram of a conducting sheet (reflector):

$$A * |\cos(\vartheta + \vartheta_0)| * \left| \cos\left(\frac{\pi}{2} + \frac{\pi * a}{\lambda_0} * \cos(\vartheta + \vartheta_0)\right) \right|$$

- A amplitude fit
 a distance between the dipole and the reflector
 ϑ polar angle
 λ_0 wavelength in free space

Formula to copy

$$A * \text{abs}(\cos(x+B)) * \text{abs}(\cos(C+D * \cos(x+B)))$$

The factor $A * \cos(x+B)$ corresponds to the directional diagram of a Hertz dipole. This ideal transmitting antenna is so short as compared with the wavelength that the current distribution on it can be assumed to be constant. The factor $\text{abs}(\cos(C+D * \cos(x+B)))$ describes the effect of the parasitic element (reflector or director).

- x polar angle ϑ

Starting values

- A =1 amplitude fit
 B =0 angular misalignment ϑ_0 , deviation of the antenna from the direction of reference
 C =90 phase
 D =60 factor depending on the construction, takes into account the ratio a/λ_0

2.2 Yagis with several parasitic elements

These cases are approximately described by the directional diagram of a single dipole and so-called array factors (here: horizontal array factor):

$$A * |\cos(\vartheta)| * \left| \frac{\cos\left(n * \left(\frac{\beta_0}{2} + \frac{\pi * a}{\lambda_0} * \cos(\vartheta)\right)\right)}{\cos\left(\frac{\beta_0}{2} + \frac{\pi * a}{\lambda_0} * \cos(\vartheta)\right)} \right|$$

- A amplitude fit
 n number of Yagi elements, including the dipole
 a average distance between the parasitic elements (directors, reflector)
 β_0 phase angle
 ϑ polar angle
 λ_0 wavelength in free space

Formula to copy

$$A * \text{abs}(\cos(x)) * \text{abs}(\cos(B * (C+D * \cos(x)))) / \cos(C+D * \cos(x))$$

- x polar angle

Starting values

- A =0,4 amplitude fit
 B =3 (6) number n of transmitting elements, including dipole (select **constant**)
 C =-60 (-20) phase angle β_0
 D =50 (36) factor depending on the construction, takes into account the ratio a/λ_0

3 Slot antenna

The horizontal directional diagram of a slot antenna contains the factors D*H*R:

- D directional diagram of the individual transmitting element
- H horizontal array factor
- R reflector factor

$$A * |\sin(\vartheta + \vartheta_0)| * \left| \frac{\sin\left(\frac{n * \pi * b}{\lambda_0} * \cos(\vartheta + \vartheta_0)\right)}{\sin\left(\frac{\pi * b}{\lambda_0} * \cos(\vartheta + \vartheta_0)\right)} \right| * \left| 2 * \cos\left\{\frac{\pi}{4} * (-1 + \sin(\vartheta + \vartheta_0))\right\} \right|$$

- A amplitude fit
- n number of transmitting slots
- b distance between slots (half waveguide wavelength $\lambda_G/2$)
- ϑ polar angle
- ϑ_0 angular misalignment
- λ_0 wavelength in free space

Formula to copy

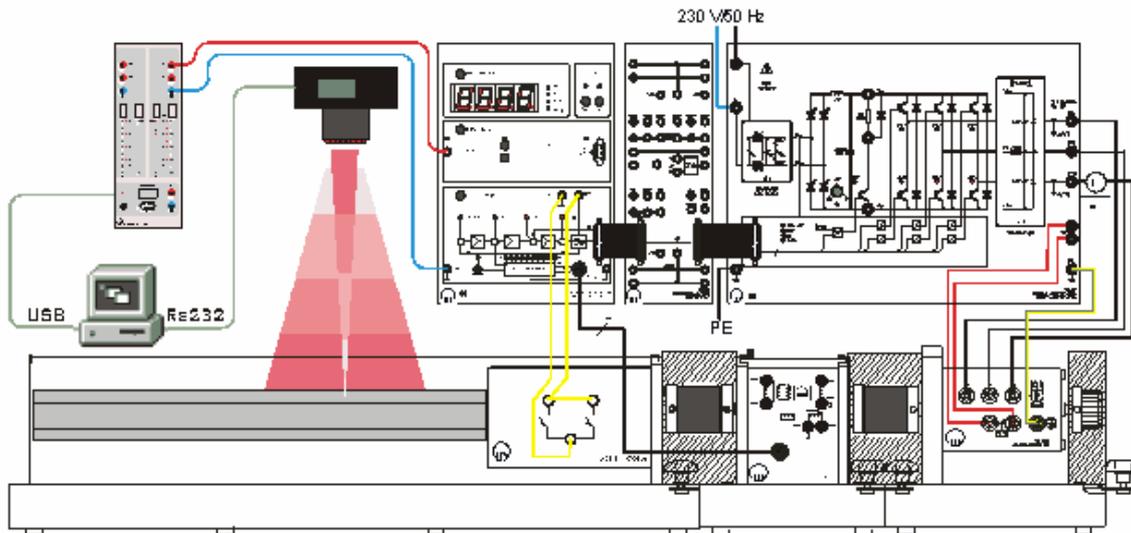
$$A * \text{abs}(\sin(x+B)) * \text{abs}\left(\frac{\sin(D * 180 * C / 32 * \cos(x+B))}{\sin(180 * C / 32 * \cos(x+B))}\right) * \cos(45 * (-1 + \sin(x+B)))$$

- x polar angle ϑ

Starting values

- A =1 amplitude fit
- B =0 angle fit ϑ_0
- C =23 distance b between slots
- D =7 number n of slots (select **constant**)

Drive engineering



■ Load example

Safety notes

Be sure to get familiar with the devices and the respective instruction sheets before putting the devices into operation!

Mind the connection between the position switches of the linear unit and the control unit sine commutation!

Experiment description

Servo drives are frequently used for positioning purposes. In this experiment a AC servo with sine commutation drives a linear unit which moves the workpiece to be positioned. In the process of position control with "direct positioning", the VideoCom camera, which uses a single-line CCD (Charge-Coupled Device), registers the controlled variable "position". The software logs the controlled variable and calculates the manipulated variable "voltage" for the AC servo based on the reference input variable specified in the PC.

For recording the movement, a strip of retroreflecting film is attached to the simulated workpiece. VideoCom detects the light pulses of the flash LEDs reflected by the film and pinpoints the actual positions of the body. By repeating this position detection in regular intervals, a high-resolution, contact-free record of the movement is obtained.

Equipment list

1	Profi-CASSY	524 016
1	CASSY Lab	524 200
1	VideoCom	337 47
1	Universal converter 3x230 V	735 297
1	Control unit sine commutation	735 293
1	AC servo 0.3	731 994
1	Resolver	731 094
1	Linear unit 0.1/0.3	731 085
2	Coupling guards	731 081
1	Shaft end guard	731 071
2	Couplings 0.1/0.3	731 06
1	Camera tripod, e. g.	300 59
	various safety connecting leads	
1	PC with Windows 98/2000 or higher version	

For connecting the universal converter to the mains, a single-phase supply unit (e. g. 726 71) is recommendable.

Experiment setup

Set up the experiment according to the drawing. Connect the Profi-CASSY to a USB port and the VideoCom to a serial RS232 port of the PC. Do **NOT** yet couple the linear unit to the drive line! Couple the AC servo and the resolver as described in the instruction sheet, and put the system into operation. Turn the slide of the linear unit approximately into the centre. Attach the camera to a stand at a height of approximately 1 m over the centre of the linear unit. Switch the control unit sine commutation into the mode "Closed-loop Speed Control".

Carrying out the experiment

■ Load settings

- If you have not yet selected VideoCom as the connected device, do it now. For this assign VideoCom to the desired port in the General Settings. Then save this assignment with **Save New Defaults**.
- If no value is displayed in the window for the controlled variable path s , adjust the camera so that the position is displayed.
- Set the reference input variable w to a value of 0.5 m.
- Start the measurement with **F9** (stop clock). The motor starts up. Turn the positioning unit manually until the motor stops.
- Now couple the positioning unit and the drive line together. By changing the reference input variable w you can specify positions, which then are approached.
- Now you can change the control parameters K_p and T_n and observe the effect of these changes on the control. In the same way you can set the limits for the speed and the current at the control unit sine commutation (see instruction sheet).



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