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Instruction Sheet 559 56/54/52

Scattering Chamber after Rutherford
Gold Foil in Holder
Aluminium Foil in Holder

The scattering chamber after Rutherford is a vacuum chamber by which it is especially simple to demonstrate the scattering of α-particles caused by thin metal foils in a qualitative and quantitative manner ('Rutherford scattering'). The alpha particles are recorded via a semiconductor detector with counter.

Moreover, the chamber can be used for experiments on alpha spectroscopy, together with the film holder for alpha scattering (559 55).

Examples of Experiments

Qualitative

- Deflection of alpha particles when passing through a gold foil
- Backscattering of alpha particles
- Scattering of alpha particles in air

Quantitative

- Dependency of scattering rate N on scattering angle ϑ in the case of Rutherford scattering
- Dependency of scattering rate N on atomic number Z
- Alpha spectroscopy

Principle

A beam of monoenergetic alpha rays is directed onto a thin metal foil (gold or aluminium). Besides those α-particles which penetrate the foil virtually without changing their direction, there are such α-particles which are scattered by the also positively charged nuclei of the foil material. These are deflected by different angles ϑ. Measurement of the scattering rate N (ϑ) allows to draw conclusions with respect to nuclear diameter and atomic number of foil material.

Bibliography :
Physics Experiments, Volume 3 (Optics - Atomic and Nuclear Physics - Solid-state Physics) 599 942

1 Safety Notes

- Never touch the metal foil!
- Very carefully vent scattering chamber (see Section 3.4) as otherwise the delicate foils will be damaged!
- Project only for a short time (max. 5 mins.) by the overhead projector!
- Only slightly tighten the knurled screws on clamping fixture ⑪ or swivel holder ⑥ !

2 Standard Equipment, Description, Technical Data
(559 56)

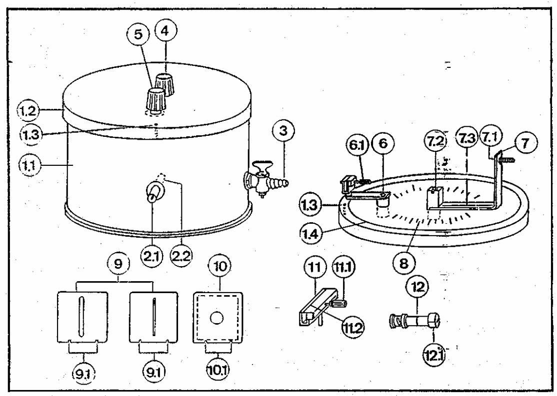


Fig. 1 Standard equipment

① Chamber, consisting of lower part (1.1) and lid (1.2), sealed by a rubber ring (1.4) (Spare Part No. 239 50 184), with positioning pin and borehole (1.3) for correct positioning of the lid

② BNC dual socket
  (2.1) for BNC cable (501 02) connected to discriminator preamplifier (559 93)
  (2.2) for alpha detector ⑫

③ Stop-cock with built-in air filter, for evacuating and venting, with hose nozzle for vacuum tubing of 8 to 10 mm I.D. (e. g. 307 68)

④ Rotary knob for swivel arm ⑦

⑤ Rotary knob for swivel holder ⑥

⑥ Swivel holder for foil (in qualitative experiments), with knurled-head screw (6.1) to fasten the foil

⑦ Swivel arm with 4-mm socket (7.1) for fitting the preparation, and with socket (7.2) for inserting the clamping fixture ⑪, with slit (7.3) for reading angles on scale ⑧

⑧ Angle scale, graduated in 5 degree steps, for adjustment of scattering angle

⑨ Collimator slit, 1 mm (5 mm) wide, in plastic plate (5 cm x 5 cm), with guide grooves (9.1) for correct positioning in clamping fixture ⑪

⑩ Gold foil on plastic plate (5 cm x 5 cm) with 12 mm opening,
foil thickness: 2 µm,
Spare Part No. 559 54

interchangeable with:
Aluminium foil (559 52)
foil thickness 7 µm, on plastic plate (5 cm x 5 cm), with 12 mm opening (not included in standard equipment)

⑪ Clamping fixture for fitting into (7.2), for collimator slit ⑨ and – for quantitative experiments – foil ⑩, with fastening screw (11.1) and guide edge (11.2) cutting the rotational axis

⑫ Alpha detector with BNC plug for plugging into socket (2.2), with slit diagram (12.1) 2 mm x 6 mm and marking on the circumference for perpendicular alignment of the slit

Dimensions of chamber: dia. 19 cm, height 11 cm
Weight: 1.8 kg

3 Use

> *Important:* When venting the chamber after the experiment, it is imperative to proceed according to Section 3.4.

3.1 Additionally required:

Americium-241 preparation	559 82
Vacuum pump, ultimate pressure < 100 Pa (≙ 1 mbar),	
e. g. Rotary vane vacuum pump S 1.5	101 01 S
Vacuum tubing	307 68
Discriminator preamplifier	559 93
Plug-in power supply unit	530 88
BNC cable, 1 m long (2x)	501 02
Counter, e.g.	
LH-digital counter	575 40
counter P	575 45
stopclock	313 05
screened cable BNC/4mm	575 24
Recommended: overhead projector, e.g.	
Overhead Projector NV-A4/315	452 11

3.2 Preparing the experimental set-up

Connect scattering chamber, discriminator preamplifier and counter as shown in Fig. 2. Set discriminator to zero (potentiometer fully anticlockwise). Connect detector ⑫ to socket (2.2) and fit vacuum tubing to hose nozzle ③.

3.3 Experiments

3.3.1 Deflection of alpha particles by a gold foil (qualitative)

Remove the lid. Push americium-241 preparation into socket (7.1) down to the stop. Bring swivel arm ⑦ to the +15° position by means of rotary knob ④ and insert clamping fixture ⑪ into (7.2). Insert 5-mm slit ⑨, grooves first (slit engages in mid position), and arrest it by **slightly** securing the knurled-head screw. Align clamping fixture so that the rays fall vertically on to the slit plane. Move swivel holder ⑥ toward the clamping fixture ⑪ as shown in Fig. 3. Insert gold foil ⑩ into the swivel holder ⑥ so that 5-mm slit and gold foil are positioned in parallel, close to each other.

Carry out vertical alignment of entrance slit (12.1) of the detector (marking on top). Place lid on to the chamber making sure of correct positioning (positioning pin in borehole (1.3)). Firmly press it on, if necessary. Then evacuate the chamber.

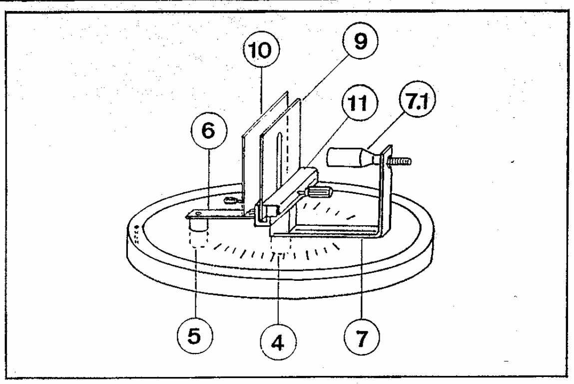


Fig. 3 Positioning of foil and collimator slit during sidescattering

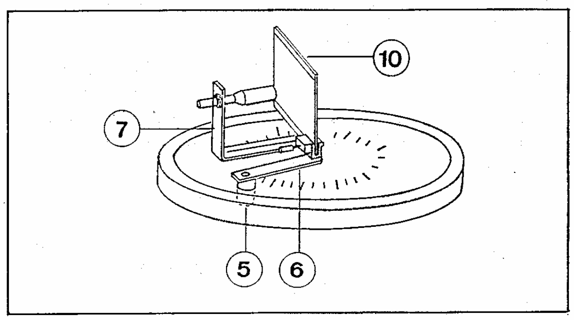


Fig. 4 Positioning of preparation and foil during backscattering

Carrying out the experiment:

Move the gold foil ⑩ to the side via rotary knob ⑤, and move swivel arm ⑦ to the 0° position. Observation: high counting rate.

Slowly bring swivel arm ⑦ to the +15° position. Observation: counting rate drops zo zero.

Again move the gold foil into the path of rays. Observation: counting rate is distinctly different from zero.

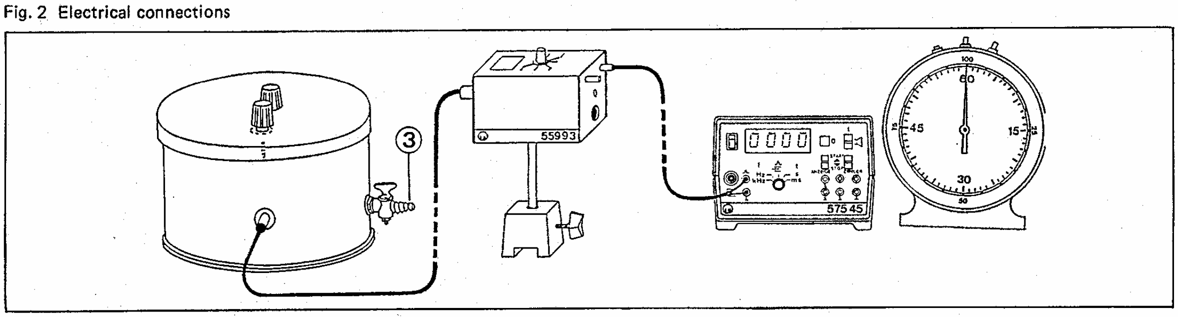
Result:

When passing through the gold foil, the alpha particles are deflected from their straight path and partly directed to the detector.

3.3.2 Backscattering of alpha particles (qualitative)

Insert Americium-241 preparation into socket (7.1) down to the stop. Bring swivel arm ⑦ to 150° position. Move swivel holder ⑥ to centre of chamber according to Fig. 4. Fasten gold foil ⑩ in the swivel holder so that the gold layer is at the outside and, after closing the chamber, in front of Americium-241 preparation and detector. Apply lid and evacuate the chamber.

Fig. 2 Electrical connections



Performing the experiment and result:

When the gold foil is positioned in front of detector and Americium-241 preparation, approx. 1 to 2 alpha particles per minute are scattered back from the foil into the detector (back-scattering). After moving the gold foil (knob ⑤) to the chamber's edge, the counting rate is zero.

3.3.3 Measuring the angle dependency N (ϑ) in the case of Rutherford scattering

Setting up and performing the experiment:

Insert americium-241 preparation into socket (7.2) of the swivel arm down to the stop.

Insert the gold foil ⑩ and the 1-mm slit ⑨ – grooves first – together into the clamping fixture ⑪ (allow it to engage in mid position), so that the gold foil is flush with the guide edge (11.2) and the rotational axis runs precisely through the foil (Fig. 5). Align the clamping fixture ⑪ so that the rays fall vertically on to the slit plane. Move swivel holder ⑥ to the chamber's edge so that the measurements are not disturbed. Align slit diaphragm ⑫ of the detector vertically (marking on diaphragm circumference on top). Close and evacuate the chamber.

> *Important:* During measurements avoid direct exposure of the delicate detector to rays, particularly from fluorescent lamps. If necessary, cover the chamber during measurement with a black cloth or similar.

Count at least ten particles (n (ϑ) > 10) each at $\vartheta = 0°$, $\pm 10°$, $\pm 20°$ and $\pm 30°$ and note down the required time Δt.

Calculate the counting rate $N = \frac{n(\vartheta)}{\Delta t}$ and plot a graph of log N = f (ϑ) (Fig. 6).

For plotting curves beyound $\pm 30°$ angles (long measuring times due to low counting rates; see Fig. 7), replace the 1-mm slit by the 5-mm slit; again determine the counting rate for 30° and calculate the conversion factor k:

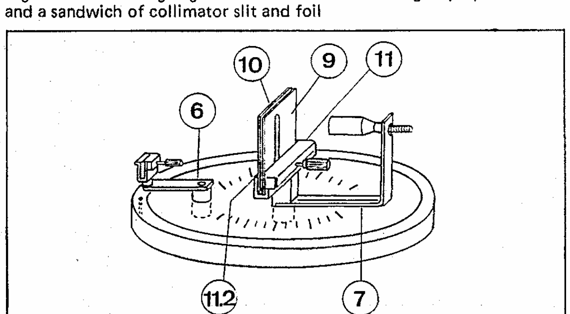
$$k = \frac{N(30°) \text{ with 5-mm slit}}{N(30°) \text{ with 1-mm slit}}$$

For adaptation to the measured values for $\vartheta \leqslant 30°$, divide the counting rates determined for $\vartheta = 40°, 50° \ldots$ by the conversion factor k.

Notes:

Inaccuracy of the collimator adjustment or non-centrical distribution of the radiation of the americium preparation in the holder may cause a shifting of the curve along the abscissa (angle shift < 3°; if necessary, displace the system of coordinates).

Fig. 5 For recording angular distribution: Positioning of preparation and a sandwich of collimator slit and foil



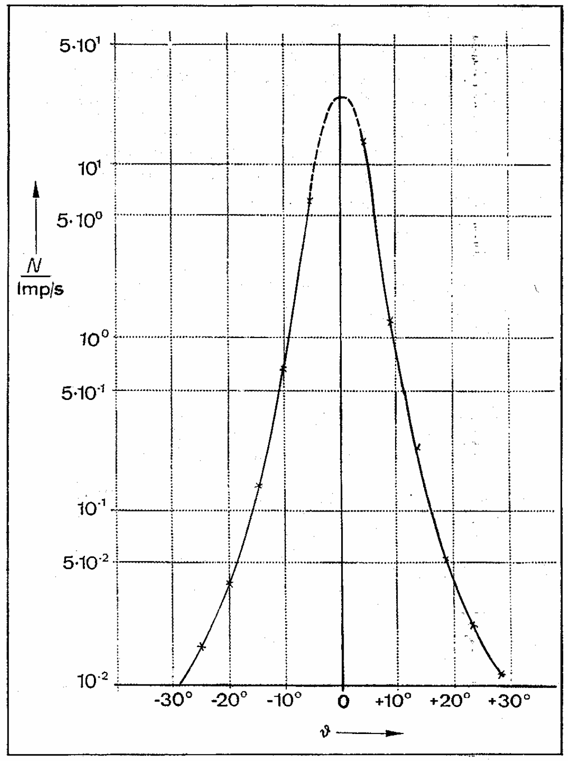
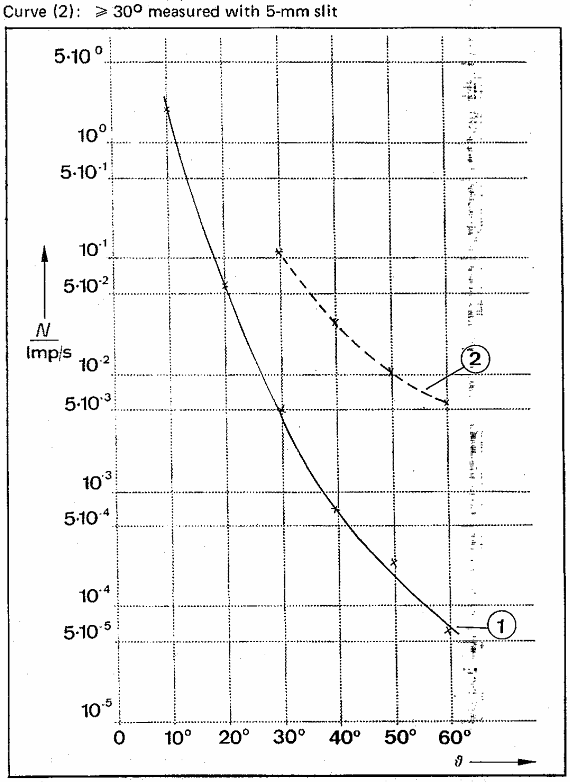


Fig. 6 log N = f (ϑ) in the ± 30° scattering range

Fig. 7
log N = f (ϑ) in the 0 . . . 60° scattering range
Curve (1): 0 . . . 30° measured with 1-mm slit > 30°: measured values of curve (2) converted to 1-mm slit
Curve (2): ⩾ 30° measured with 5-mm slit



Theoretically it applies:

$N(\vartheta) \sim 1/\sin^4(\vartheta/2)$.

It should be possible to bring to coincidence the measured-value diagram with the likewise semilogarithmically plotted function $f(\vartheta) = 1 \sin^4(\vartheta/2)$ by shifting along the ordinate.

Recommended alternatives for plotting the curve over large angle ranges: Recording the α-scattering on nuclear film (559 53) which is to be positioned in the film holder for α-scattering (559 55) as required for the experiment.

3.3.4 Determining the atomic number of aluminium

Compare scattering rates of gold foil and aluminium foil for a scattering angle of 10° (use 1 mm collimator slit).

It applies:

$$\frac{N_{Au}}{N_{Al}} = \frac{Z_{Au}^2 \, d_{Au}}{Z_{Al}^2 \, d_{Al}}$$

where N = counting rate
Z = atomic number
d = thickness of foil

Possible sources of error: faulty counts caused by disturbances from the mains.

Measurement Example:

$N_{Au} = 0.3\ s^{-1}$; $N_{Al} = 0.027\ s^{-1}$

With the values

$d_{Au} = 2\ \mu m$
$d_{Al} = 7\ \mu m$
$Z_{Au} = 79$

one obtains

$$Z_{Al} = \sqrt{\frac{79^2 \cdot 2 \cdot 0{,}027}{0.3 \cdot 7}} = 12{,}7 \qquad (Z_{Al} = 13)$$

3.4 Venting of the chamber

It is imperative for venting to proceed as follows:

Close venting cock ③.

Switch off the pump and vent the chamber.

Remove the gold foil (via rotary knob ⑥) from the danger zone of instreaming air, i. e. move it as close as possible to the chamber wall. If the foil is mounted in the clamping fixture ⑪, align the foil so that it is in parallel to the expected air flow.

Only then slowly and carefully open the venting cock ③ until a hissing sound is heard. Leave the cock in that position until the hissing stops and the chamber is completely vented.

3.5 Projection of chamber by the overhead projector

Place the chamber on the projector and focus the light beam so that a sharp image of the detector ⑫ appears. Measurements during projection are not possible due to the luminous sensitivity of the detector. Therefore, switch off the projector during measurements, which is also recommendable in order to avoid excessive heating of the inside of the chamber (there is no heat flow in vacuum!).

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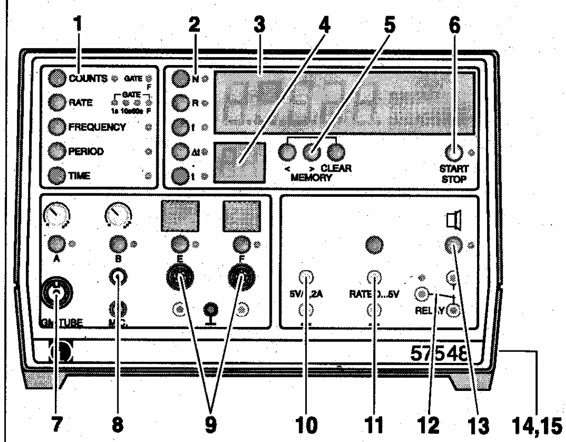


Instruction sheet 575 48

Digital Counter (575 48)

The digital counter is designed for use in lectures, in demonstration experiments and in practical exercises. All parameters are set via keys on the front panel; the corresponding LEDs indicate which settings are currently active. This means that you can use the instrument easily and intuitively, without having to look up each function every time before using.

The device can store up to 2000 measured values. After measuring, these can be accessed one by one or output to a computer via the serial interface (RS 232) on the rear of the device. The device is supplied with the necessary software.

Safety note

The function of the digital counter can be impaired by static electricity or voltage peaks in the mains supply.

If necessary, provide for electrostatic discharge in the vicinity of the device, or use a line filter.

1 Description, technical data

- Five-digit 25 mm high digital display (plus indicator field for units: Imp (pulse counts), 1/s, 1/min., Hz, kHz, rpm, s, ms)
- Two-digit 12 mm high storage counter
- 2 display fields for edge selection and mode
- Direct connection for counter tube with adjustable high voltage 0 - 640 V)
- BNC input (1 MΩ) for rate, frequency or period measurements (frequencies up to 2 MHz) with adjustable trigger threshold (0.1 - 5 V) and switchable coupling (DC or AC)
- Microphone input (3.5 mm jack)
- 2 light-barrier inputs (also via 4-mm sockets) fur simultaneous frequency, period or time measurements (time resolution 1 µs, edges selectable)
- Separate voltage output (5 V / 200 mA)
- Recorder output for rate measurements at input A
- Built-in loudspeaker (switchable)
- Relay switches synchronized with start of measurement
- Stores up to 2000 measured values
- Electrically isolated serial interface (RS 232) for computer connection
- Measuring and evaluation software for Windows 95 and Windows NT (updates available free of charge at our website http://www.leybold-didactic.de).

2 Operation

1 Selection of measurement quantity
2 Selection of quantity/unit to be displayed
3 Display of measured value
4 Storage counter
5 Storage replay keys
6 START/TOP key
7 Counter tube input with high voltage adjuster
8 Frequency input (BNC and microphone connection) with trigger threshold adjuster
9 2 light barrier inputs (also via 4 mm sockets)
10 Fixed-voltage output
11 Recorder output for rate measurement, with range adjuster
12 Changeover relay
13 Toggle key for built-in loudspeaker
14 Serial interface (RS 232)
15 Voltage supply for discriminator preamplifier (559 93)

2.1 Measurement quantity (control panel top left)

You can select the desired measurement quantity in field **(1)**. However, if a measurement is currently running, you must first stop this before you can change the measurement quantity. The previous displayed value is reset when a new measurement quantity is selected. The following measurement quantities are available:

Measurement quantity	Input	Display (with options)
Count (pulses)	A, B or E (F for ext. gate)	N in pulses
Rate	A, B or E (F for ext. gate)	R in /s (in /min., N/pulses, Δt/s)
Frequency	B or E and additionally F	f/Hz (f/kHz, f/rpm)
Period	B or E and additionally F	Δt/s (Δt/ms, f/Hz, f/kHz, f/rpm)
Time	E and additionally F	t/s (t/ms, Δt/s, Δt/ms)

In pulse counting an external gate can be simultaneously toggled on and off at input F. Similarly, the gate time can additionally be selected in rate measurements (1 s, 10 s, 60 s).

2.2 Inputs (control panel bottom left)

After selecting the desired quantity, inputs can be configured as required, as shown in the table above. Additionally, the counter tube voltage can be selected at input A **(7)** (displayed during change), the trigger threshold at input B **(8)** (displayed during change) and the coupling (DC or AC, after pressing key B), as well as the edges at inputs E and F **(9)** (displayed in real time in the corresponding display elements). Various options are provided for setting the edge (e.g. positive edge, negative edge, light pulse, dark pulse, high-level, low-level, stopclock, P=pendulum, i.e. only ever other edge is counted).

Simultaneous measurements cannot be conducted at inputs A, B and E. To simplify operation, the device automatically switches between inputs when it registers a pulse at a different input. You can deactivate this automatic switchover by selecting inputs manually.

2.3 Display (control panel, top right)

Once you select the measurement quantity, the display **(3)** is set to the measurement quantity shown in the table. In accordance with the table, the display can also be switched to a different quantity (e.g. from R to N).

All measurements are started and stopped using the START/STOP key **(6)**. If no measurement has been run yet, no measured values appear in the display (the numerical fields of the display are blank). During measurement only the display can be changed (e.g. to a different unit of measure or different active input). If you try to make a change which is prohibited during measuring, an arrow appears above the START/STOP key as a reminder that you have to stop the measurement first.

During the measurement the measured values are stored in the internal memory and the storage counter **(4)** is incremented accordingly. As the storage counter is only equipped with a two-digit display, a counter overflow is indicated by a decimal point which appears following the second digit.

When the memory is full, i.e. 2000 measured values have been stored, the measurement continues running but no new measured values are stored. The storage counter then displays two dashes. When the measurement is stopped the storage counter shows the last value stored. You can browse through all measured values backward with < and forward with >. The corresponding storage count **(4)** flashes during the readout. You can erase the memory by pressing CLEAR and < simultanously. Pressing CLEAR alone erases only the current value.

During the measurement and when reading out the memory, the LEDs of the inputs and the display elements for the edges no longer display the selected settings, but rather the inputs and edges which correspond to the currently displayed measured value. For example, when rising edges are to be measured at E and F, both inputs display these edges before the measurement. During the measurement and when reading out the memory, however, only the edge which corresponds to the currently displayed time is indicated.

As the LEDs of the inputs and the edge displays are also utilized in readout, it is not possible to change the settings of these inputs directly. Any attempt to change these settings (by pressing A,B,E or F) terminates the read-out, and the current values are displayed again. You can then change the settings as desired.

2.4 Outputs (lower right)

You can activate the built-in loudspeaker by pressing key **(13)**. Each registered pulse is then audible as a click. Also, a rate measured at input A is output at recorder output **(11)** in the form of a voltage from 0 to 5 V. The voltage at this output can be set using the corresponding key **(11)** in steps from 10 /s/V (1 V corresponds to 10 pulses/s) to 10,000 /s/V (1 V corresponds to 10,000 pulses/s). The current setting appears in the display when this key is pressed. Pressing this key repeatedly changes this setting in increments. The output voltage is averaged electronically. Thus, it changes continuously, and not in discrete steps like the displayed digital value of the rate measurement.

The changeover relay **(12)** de-energizes at each measurement start, and re-energizes again when the measurement is stopped. This makes it ideal for controlling a holding magnet for timing measurements.

Also, a fixed voltage output **(10)** (5 V / 200 mA) is available for any purpose, e.g. for supplying simple light barriers.

The rear panel contains the serial interface **(14)** for outputting data to a computer and an additional voltage output **(15)** suitable e.g. for the discriminator preamplifier (559 93).

3 Examples

3.1 Pulse counter (Counts)

You can choose between inputs A, B and E. Pulse counting begins when you press the START/STOP key. Each pulse increments the displayed counter stand by 1. When the measurement is stopped, the counter is halted and the count stored in memory. Restarting the measurement resets the count to zero and starts a new count.

Alternatively, the pulse count can be controlled after starting via an external signal at input F (GATE F) .

At the end of the measurement series you can read out the memory with < and > and erase it with < + CLEAR.

You can output the registered pulses via the built-in loudspeaker.

3.2 Rate

When you select the ratemeter function, you must also set the desired gate time (1 s, 10 s, 60 s or external gate via input F). You can choose between inputs A, B and E. When using input F for gate control, select the desired pulse shape for the open gate using this input.

The rate measurement is started and stopped by pressing START/STOP. The measured rate is displayed and stored at the end of each gate time.

You can choose between display of N, R and Δt. To change the displayed unit (e.g. 1/s to 1/min.), simply press the corresponding key again.

You can output the registered pulses via the built-in loudspeaker. The measured rate is present in the form of a voltage at the recorder output RATE.

3.3 Frequency

You can choose between inputs B, E and F. Inputs B/F or E/F additionally permit two-channel measurements. Inputs E and F also allow you to define whether only ever other edge is to be counted (display shows "P" for pendulum mode).

The frequency measurement is started and stopped by pressing START/STOP. The measured frequency is displayed and stored every second. When measuring at two inputs at once (e.g. B,E and F), both frequencies are stored. You can switch the display between the two frequencies using the E and F keys.

You can also select the unit of the displayed frequency by pressing the corresponding key. You can choose between the units Hz, kHz and rpm (revolutions per minute). When displaying rpm values, remember that the display has a resolution of only 100 rpm (due to the short measuring time of 1 s).

3.4 Period

You can choose between inputs B, E and F. Inputs B/F or E/F also permit two-channel measurements. Inputs E and F additionally allow you to define whether only ever other edge is to be counted (display shows "P" for pendulum mode).

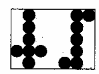
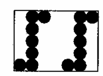
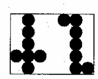
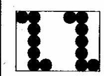
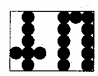
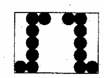
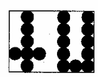
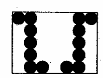
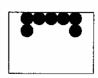
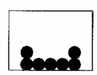
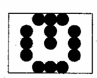
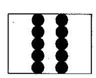
The period measurement is started and stopped by pressing START/STOP. The device displays and stores the measured period. When measuring at two inputs at once (e.g. B,E and F), both periods are stored. You can switch the display between the two periods using the E and F keys.

You can choose between display of Δt and f. For display of f, the measured period is automatically converted to a frequency. To change the displayed unit (e.g. Hz to kHz), simply press the corresponding key again. Note that period measurement is less accurate than frequency measurement for frequencies above 1 kHz. Period mode does not provide any measured values at frequencies above around 10 kHz.

3.5 Stopclock (Time)

You can choose between inputs E and F. The setting at input E allows you to choose between 7 possible edge parameters (positive edge, negative edge, light pulse, dark pulse, high-level, low-level, stopclock). Input F only passes edges which match input E.

The following table explains the symbols of the edge display for measuring times as a function of the selected display quantity:

Symbol for t	displayed time	Symbol for Δt	displayed time difference
	Start until rising edge		Between 2 edges (E/E or E/F)
	Start until falling edge		Between 2 edges (E/E or E/F)
	Start until high pulse		Long high
	Start until low pulse		Long low
	Time for all high levels (additive)		
	Time for all low levels (additive)		
	(intermediate time	clock running)	
	Pause		

The edge settings high level and low level enable connection of a bouncing switch for timing. The time is then always measured as long as the selected level is maintained (also additive timing). The stopclock setting provides a standard stopclock for measuring times independently of inputs E and F. You can also start a measurement and take intermediate times, pause or end the measurement. In additive measurements, the time resolution in manual stopclock mode is limited to 0.01 s instead of the 1 μs possible in other modes.

The stopclock is started and stopped by pressing START/STOP. The time display continues to run as long as no pulse is registered at inputs E and F. The time of each registered pulse is stored. You can select the times to be displayed after starting using the keys E and F.

You can choose between display of t and Δt. To change the displayed unit (e.g. s to ms), simply press the corresponding key again. When t is selected, the digital counter only displays measuring times from the start of the measurement until the current edge, while in the setting Δt the counter additionally calculates the time differences between individual consecutive edges.

Attention:

Timing is automatically halted when two consecutive edges arrive at the same interval separated by less than $\Delta t = 1$ ms. The measurement continues to run as long as this time difference is greater. Smaller intervals are only possible in elapsed-time measurements (measurements between the two inputs E and F), as only a single measurement, and thus the corresponding difference, is recorded for E and F (no continuous measurement).

4 Software

The enclosed software is not required in order to operate the digital counter. However, it greatly enhances the measuring and evaluation possibilities.

To install the software, you need a computer on which Windows 9x or Windows NT are properly installed. The program SETUP.EXE on the disk prompts you to specify the language and installation directory, and then installs the software automatically. You can subsequently change the language of the software at any time. After installation is complete, the software can be found in the "Start" menu under "Programs" —› "Digital Counter".

If the software cannot find the digital counter on starting, it outputs a corresponding error message (possible causes: voltage source or serial cable not properly connected, wrong serial interface). You can change the serial interface by pressing key F5 (dialog box "Settings" —› tab "General"); you can save this setting by clicking on "Save New Parameters".

You can uninstall the software at any time using the Software icon in the Control Panel.

The program contains detailed help on the use of all functions. We recommend that you take the time to become familiar with the program by reading these help texts, which are accessible with F1, after starting the program, and even printing them out.

All future software updates (enhancements, patches) will be made available as they appear free of charge on our website http://www.leybold-didactic.de.