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PHYSICS EXPERIMENTS

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Experiments
Lab manual sample

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Chaptor 1

Experi-
ments

Speed of sound in air (w/ student timer)

Objective

Measuring the speed of sound in atmospheric air.

Principle

An electronic timer is started and stopped by the signal from two microphones placed with a certain distance between them. The sound source is placed so the sound passes the start microphone first and later reaches the stop microphone.

Equipment list

The complete list below may coveniently be referred to as Item no. 131410.

Item no.	#	Text
200285	1	Student timer
248600	2	Microphone
248200	1	Clapper board
000420	2	Retort stand foot, square

Also required

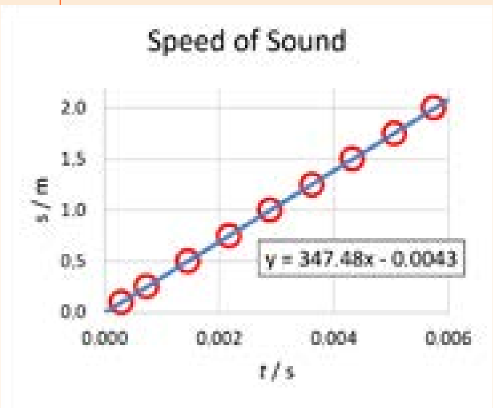
— Ruler or tape measure (like 140510 or 140010)

Sample results

These results were obtained with a room temperature of 25.3 °C and a relative humidity of 60 %. In the lab manual you will find a simplified formula for the expected speed of sound, resulting (for these conditions) in a value of 347.4 m/s.

s / m	t / ms
0.10	0.29
0.25	0.73
0.50	1.46
0.75	2.17
1.00	2.89
1.25	3.62
1.50	4.33
1.75	5.06
2.00	5.75

When plotted, the measurements very closely fall on a straight line through (0,0) with a slope that gives the experimental result 347.5 m/s.



Speed of sound in air (w/ speedgate)

Objective

Measuring the speed of sound in atmospheric air.

Principle

An electronic stopwatch is started and stopped by the signals from two microphones which are placed with some distance between them. The source of the sound is positioned so that the sound first passes the start microphone and after that the stop microphone.

This version of the experiment uses the versatile SpeedGate as an electronic stopwatch. Although primarily designed as a photogate, the built-in timer functions just as well with external signals.

This equipment option enables you to make more experiments within a limited budget.

Precision of results

You can expect exactly the same level of precision as when using for instance our 200285 Student Timer as the stopwatch – please refer to experiment 131410-EN for sample measurements.

Equipment list

The complete list below may conveniently be referred to as Item no. 131415.

Item no.	#	Text
197570	1	SpeedGate (includes one 197571)
248600	2	Microphone
197571	1	Cable modular plugs crossed 2m
248200	1	Clapper board
000420	2	Retort stand foot, square

Also required

— Ruler or tape measure (like 140510 or 140010)

Speed of sound in steel (w/ student timer)

Objective

To determine the speed of sound in steel. Two types of waves or pulses are investigated: Longitudinal and transverse.

Principle

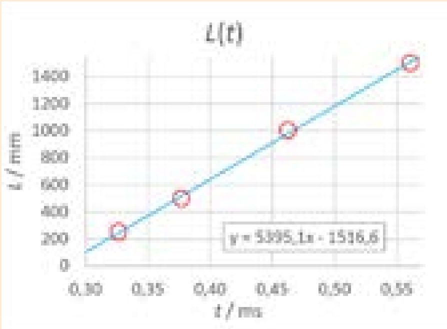
An electronic stopwatch is started and stopped by electric signals from the two ends of a steel rod carrying the waves.

The rod is connected to one of the black sockets on the stopwatch (0 V). The sound pulse is started by hitting the end of the rod with a smaller steel rod, connected to the red Start socket. This starts the timing. When the pulse reaches the opposite end of the rod, it will kick another short rod away. This breaks the connection to the red Stop socket and the timing stops.

Sample results

After averaging, the results can be plotted with rod length as a function of the time, and the speed of the sound pulses is found as the slope of the graph.
(Below: Result for transversal waves.)

The result demonstrates that the speed of sound is an order of magnitude larger in a solid than in air.



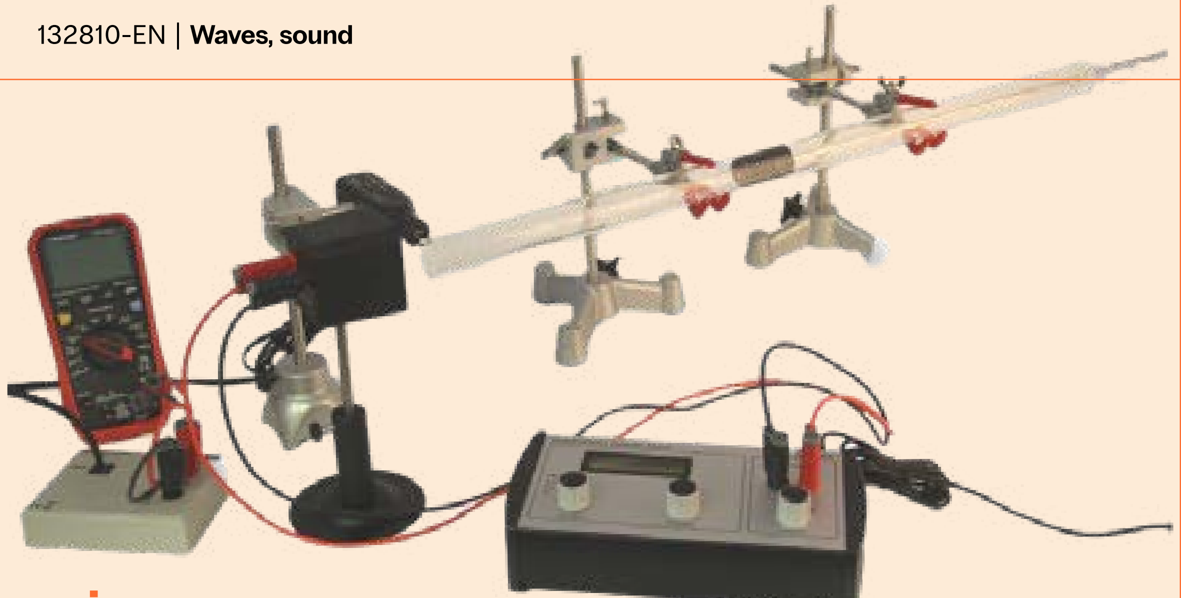
Equipment list

The complete list below may conveniently be referred to as Item no. 134520.

Item no.	#	Text
200285	1	Student Timer
000860	3	Retort stand rod 10 cm
000850	2	Retort stand rod 25 cm
000830	1	Retort stand rod 50 cm
000810	1	Retort stand rod 100 cm
000800	1	Retort stand rod 150 cm
002310	2	Bosshead, square
001800	2	Stand clamp
000600	2	Stand base, tripod, 1.0 kg
000420	1	Stand base, square 0.57 kg
105740	1	Safety cable 100 cm, black
105741	1	Safety cable 100 cm, red
105751	1	Safety cable 200 cm, red
109020	1	Insulated crocodile clip, Black
109021	2	Insulated crocodile clip, Red

Also required

— Tape measure 200 cm (like 140010)
— Rubber bands (like 591050)



Resonance in an air column

Objective

Investigating standing waves in the air column in a closed-end (i.e. half-open) pipe. Determining the speed of sound in air.

Principle

Resonance in the pipe happens at certain combinations of the frequency of the sound and the length of the air column. In this experiment we will vary one of these parameters at a time.

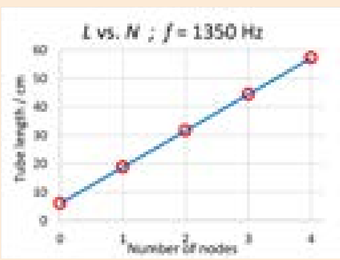
The results from the measurments will be matching pairs of frequencies and wavelengths – from these, the speed of sound can be found.

Sample results

In one of the measurement series the length of the tube is varied while the frequency is fixed at 1.35 kHz. The lengths where resonance occurs are plotted as a function of the number of resonance nodes.

The graph shows how the data points fall precisely on a straight line. The slope of the line equals half of the wavelength. Combining this with the known frequency, the speed of sound can be found to be 345.6 m/s.

(This is 0.3 % off at 24°C and 65 % rel.hum.)



Equipment list

The complete list below may conveniently be referred to as one of the following Item no.:
Choose between option A: Student function generator or option B: Function generator 250350.
(The photo shows option A)

Item no.	#	Note	Text
250310	(1)	a	Student Funct. Generator *Option A*
250350	(1)	a	Function Generator *Option B*
247500	1		Kundt's tube (Plexiglas)
250515	1		Loudspeaker on post
248600	1		Microphone
251565	1		Battery box
386231	1	b	Multimeter DMM-8062
000600	2		Stand base
000850	2		Steel rod, 25 cm
002310	2		Bosshead, square
001800	2		Stand clamp, overlapping jaws
000410	2		Stand base, square
105720	1		Safety cable, silicone 50 cm, black
105721	1		Safety cable, silicone 50 cm, red
105740	1		Safety cable, silicone 100 cm, black
105741	1		Safety cable, silicone 100 cm, red

Notes

a) Select one option
b) … or similar. Resolution: 0.1 mV AC

Also required

— 060010 Thermometer (or similar)
— 185000 Hygrometer (or similar) – or data from a nearby meteorological station

Resonance – standing waves on a string

Objective

A study of standing waves on a tight string, with a focus on the frequency of the harmonics.

The relationship between the frequency of the natural oscillations and the thickness and tension of the string is investigated.

The propagation velocity of the waves is determined.

Principle

A function generator connected to a vibrator emits a wave train along the string. The wave train is reflected at both ends of the string. At certain frequencies, strong standing waves are observed. The phenomenon is called resonance. At the resonance frequencies it is easy to determine the wavelength.

Progression of the lab manual

The first section calls for only elementary math and a modest abstraction level.

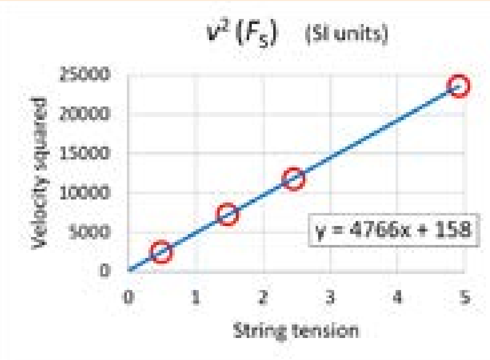
The following two sections are more demanding. The sample results below are from these.

Sample results

According to theory, the square of the propagation speed of waves on a string should be proportional to the string tension. The proportionality constant should be the reciprocal of the mass per unit length of the string.

The results shown in the graph was obtained with a line weighing 0.208 g/m.

The reciprocal of the slope 1/(4766 m/kg) gives 0.000210 kg/m or 0.210 g/m – a deviation of only 0.9 %.



Equipment list

The complete list below may conveniently be referred to as one of the following item numbers:
132860A (option A: Student function generator)
132860B (option B: Function generator 250350).
(The photo shows option A)

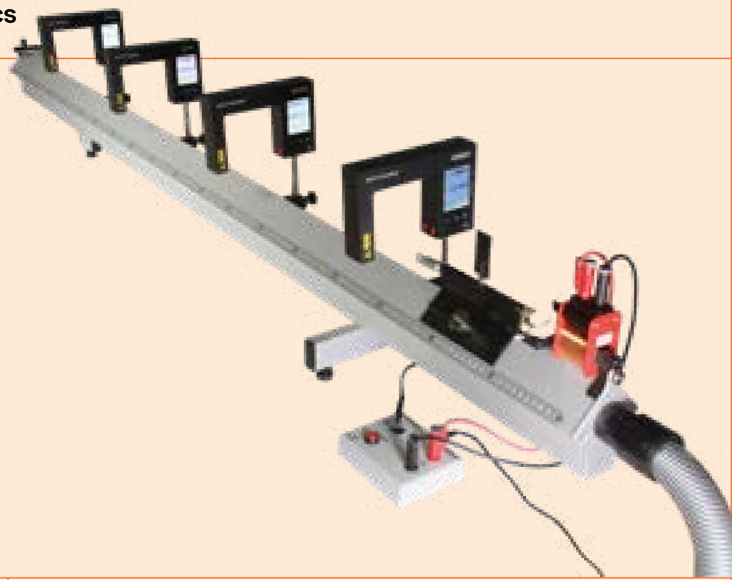
Item no.	#	Note	Text
250310	(1)	a	Student Funct. Generator *Option A*
250350	(1)	a	Function Generator *Option B*
218500	1		Electromagnetic vibrator
208500	1		Pulley on rod
103840	1		Dynamometer 5 N
116600	1		Line, braided, 50 m
799109	1		Mason cord, 120 m
767022	1		Line, braided, 20 m
000820	1		Retort stand rod, 75 cm
000850	2		Retort stand rod, 25 cm
001600	2		Table Clamp
002310	2		Square boss head
105720	1		Safety cable, silicone, 50 cm, black
105721	1		Safety cable, silicone, 50 cm, red

Notes

a) Select one option

Also required

— 102900 Digital scales 300 g / 0,01 g – or similar
— 140010 Tape measure 200 cm – or similar



Galileo's incline

Objective

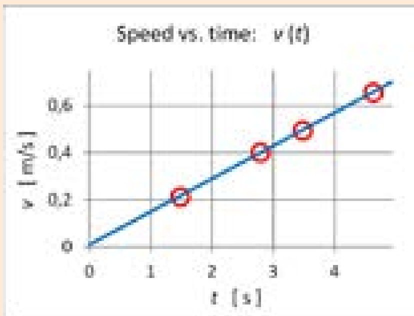
A demonstration of constant accelerated motion.

Principle

An air track with its virtually friction-less motion constitutes a modern alternative to Galileo's inclined wooden groove.

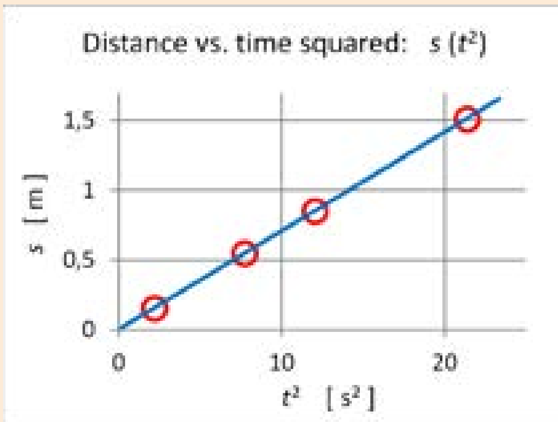
Along the air track, several SpeedGates measure the speed as well as the time from the start of the motion to the passage of the SpeedGate.

With the SpeedGates, we can also demonstrate that the speed increases linearly with time.



Sample results

With bronze balls rolling on his incline, Galileo demonstrated that the distance travelled is proportional with the square of the time – which is convincingly confirmed with our equipment, as seen below.



Equipment list

The complete list below may conveniently be referred to as Item no. 134640.

Item no.	#	Note	Text
195050	1		Air track
197080	1		Air blower
197570	4	a	SpeedGate
195055	4	a	Mounting bracket for 197570
195210	1		Electric launcher
198515	1		Switch Box
361600	1		Power supply (-or similar)
105720	2		Safety cable, silicone, 50 cm, black
105721	2		Safety cable, silicone, 50 cm, red
105740	1		Safety cable, silicone, 100 cm, black
105741	1		Safety cable, silicone, 100 cm, red

Notes

a) Any number of SpeedGates can be used (see lab manual)

Free fall – Measuring g

Objective

Examining the laws of free fall; determining the acceleration of gravity.

Principle

A metal ball is held by a magnet and creates electric contact between the two connectors in the release device at the top.
When the magnet is suddenly removed the ball drops which starts the timer.

The ball hits the plate at the bottom which sends a stop pulse to the timer.

The path length of the free fall is measured by a ruler or a tape measure.

Equipment list

The complete list below may conveniently be referred to as Item no. 134510.

Item no.	#	Text
200285	1	Student timer
198010	1	Free Fall apparatus
000800	1	Retort stand rod 150 cm
002310	1	Square bosshead
000100	1	Retort stand base 2.0 kg
105750	1	Safety cable, silicone, 200 cm, black
105751	1	Safety cable, silicone, 200 cm, red
105740	1	Safety cable, silicone, 100 cm, black
105741	1	Safety cable, silicone, 100 cm, red

Also required

— Tape measure 200 cm (like 140010)

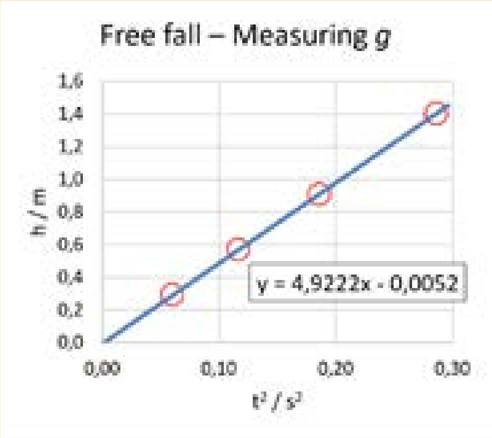
Sample results

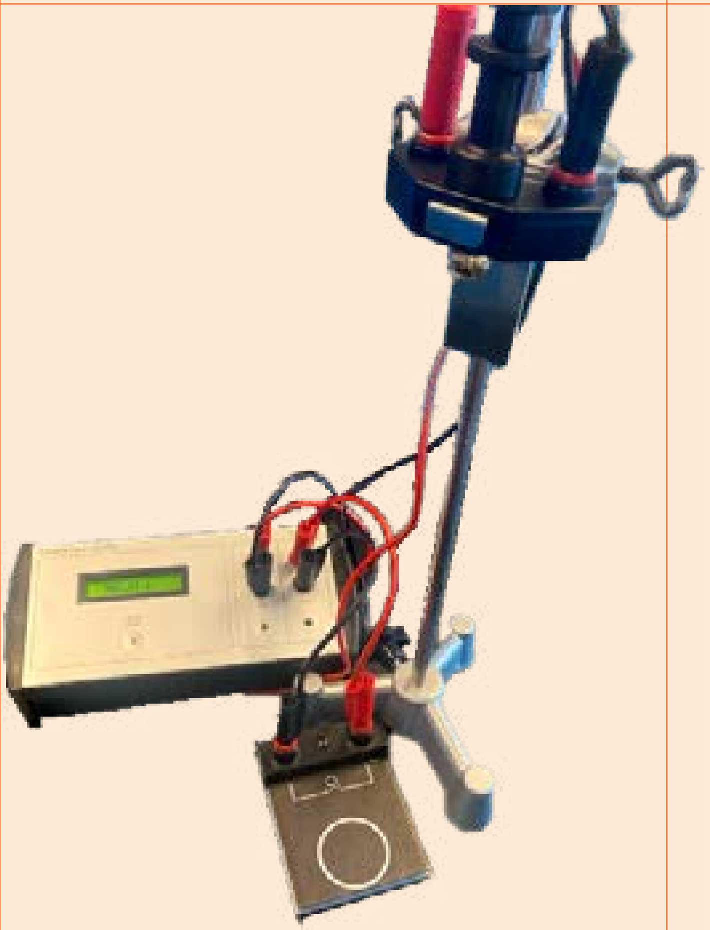
The following table shows typical results. The values in the time column were averaged over three measurements.

h / cm	t / ms
29.2	245.54
56.9	341.57
91.0	431.41
140.4	534.97

The results are plotted with h as a function of t^2 and the slope is found. From this, the acceleration due to gravity can be found:

$$g = 2 \cdot 4.92\ \frac{\text{m}}{\text{s}^2} = 9.84\ \frac{\text{m}}{\text{s}^2}$$





Conservation of energy in the gravitational field

Objective

To examine the conservation of mechanical energy.

Principle

A weight (pendulum bob) swings as a pendulum in a thread.

When in the extreme positions of the swing, we can determine the vertical position of the weight and hence its potential energy.

In the lowest (centre) position, the weight passes a photogate. We can thereby determine the speed of the weight and calculate its kinetic energy.

Equipment list

The complete list below may conveniently be referred to as Item no. 134570.

Item no.	#	Note	Text
200285	1		Student timer
197560	1		Photo Cell w. modular connector
272502	1		Aluminium weight 100 g
105711	1		Safety cable, silicone 25cm, red
000850	1		Retort stand rod 25 cm
000830	1		Retort stand rod 50 cm
000800	1		Retort stand rod 150 cm
002310	3		Square bosshead
000100	2	a	Retort stand base 2.0 kg
116500	1		Extra strong thread

Also required

— Ruler or tape measure (like 140500 or 140010)
— 102961 Digital scales (200 g/0.1 g) – or similar

Sample results

The diameter of the weight is measured to be 29.7 mm. This is the distance the weight must travel from breaking the light beam until letting it through again.

A few measurements:

h_0 / m	h / m	Δt / ms	Δh / m	v / m/s	E_{pot} / J	E_{kin} / J	ΔE
0.213	0.310	21.71	0.097	1.368	0.0952	0.0936	-1.7%
0.213	0.301	22.78	0.088	1.304	0.0864	0.0850	-1.6%
0.213	0.414	15.13	0.201	1.963	0.1973	0.1928	-2.3%

The calculated energy loss is of course very sensitive to the measured diameter as well as the table value used for g, the acceleration due to gravity.

Circular motion with conical pendulum

Objective

To investigate how the centripetal force depends on orbital radius and orbital period.

Principle

We use a conical pendulum in this experiment. The bob performs a circular motion under the under the influence of the tension of the string and the force of gravity. The angle between these two forces is read on the fly on the graduated scale on the conical pendulum.

The orbital period can be found with a stopwatch or with a photo-gate; the latter is to be preferred.

Sample results

One of the measurement series keeps the orbital radius fixed while varying the length of the pendulum and hence the orbital period.

In the first line below, the radius r is calculated. In the next three lines,a value for φ is calculated (based on the fixed r value). The motor speed is adjusted to obtain this angle.

Measured			Const.	Compared with theory		
L / cm	φ / °	T / s	r / cm	$F_{c,meas}$ / mN	$F_{c,theo}$ / mN	devi.
16.9	61	0.5704	14.78	107.7	109.0	-1.3%
19.0	51	0.7052	14.78	73.9	71.3	3.6%
21.4	44	0.7772	14.78	57.0	58.7	-2.9%
25.0	36	0.9005	14.78	43.8	43.8	0.0%

The measured centripetal force is found from the mass of the pendulum bob and the relation:

$$F_c = m \cdot g \cdot \tan(\varphi)$$

- In agreement with theoretical values given by:

$$F_c = \frac{4\pi^2 \cdot m \cdot r}{T^2}$$

Equipment list [a]

The complete list below may conveniently be referred to as one of the following item numbers:
135710 SpeedGate

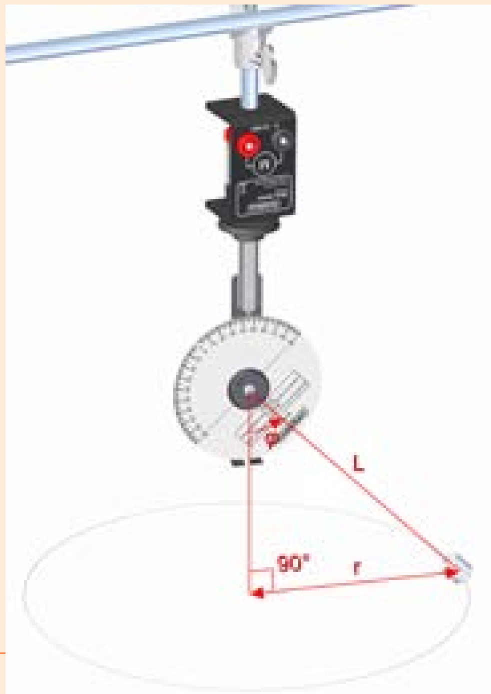
Item no.	#	Note	Text
207010	1		Conical pendulum
202555	1		Gear motor
361600	1	b	Power supply 0-12 V, 3 A
197570	(1)		SpeedGate *Option A*
000800	1		Retort stand rod 150 cm
000810	2		Retort stand rod 100 cm
002310	4		Square Bosshead
001600	2		Table clamp
105750	1		Safety cable, silicone, 200 cm, black
105751	1		Safety cable, silicone, 200 cm, red

Notes

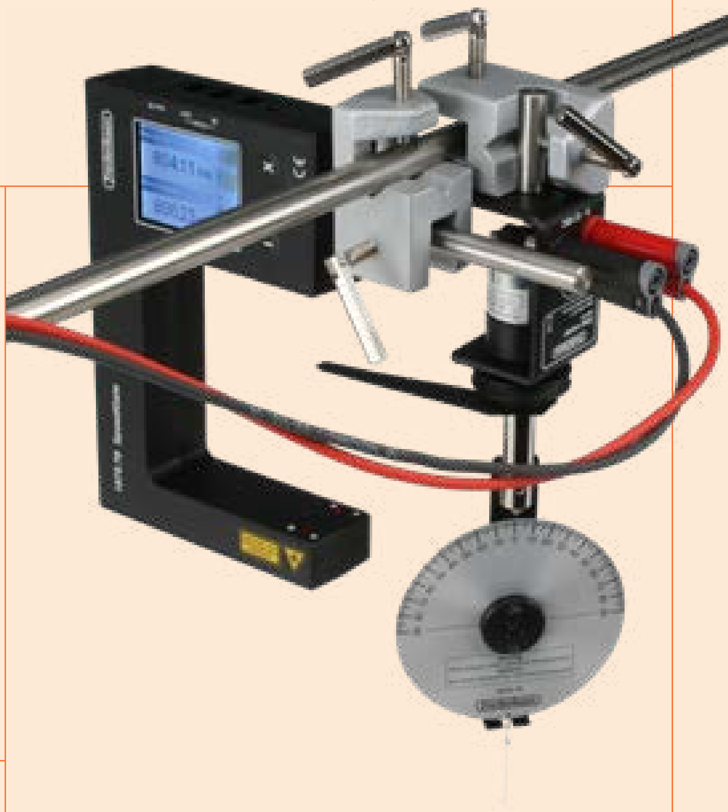
a) The same equipment is used in Exp. 135730
b) Alternative power supply: 364000

Also required

— Paperboard, scissors, ruler, digital scales



The Bessel pendulum



Objective

To determine the acceleration due to gravity by means of a conical pendulum.

Principle

We use a conical pendulum in this experiment. The bob performs a circular motion under the influence of the tension of the string and the force of gravity. The angle between these two forces is read on the fly on the graduated scale on the conical pendulum.

The orbital period can be found with a stopwatch or with a photogate.

From the measured quantities, g can be calculated.

Sample results

It is possible to calculate g for each complete measurement like this:

$$g = \frac{4 \cdot \pi^2 \cdot \cos(\varphi) \cdot L}{T^2} = \frac{4 \cdot \pi^2 \cdot \cos(61°) \cdot 0.231\ \mathrm{m}}{(0.66744\ \mathrm{s})^2} = 9.92\ \mathrm{m/s^2}$$

Pendulum length:	231 mm
Angle:	61°
Period:	667.44 ms

After a series of measurements, an average value can be found.

The students are encouraged to consider other means of analysing the experimental data – like plotting $4\pi^2 \cdot L \cdot \cos(\varphi)$ as a function of T^2 for a data series with fixed L.

Equipment list [a)]

The complete list below may conveniently be referred to as one of the following item numbers:
135710 SpeedGate

Item no.	#	Note	Text
207010	1		Conical pendulum
202555	1		Gear motor with winding shaft
361600	1	b	Power supply 0-12 V, 3 A
197570	(1)	c	SpeedGate *Option A*
000800	1		Retort stand rod 150 cm
000810	2		Retort stand rod 100 cm
002310	4		Square Bosshead
001600	2		Table clamp
105750	1		Safety cable, silicone, 200 cm, black
105751	1		Safety cable, silicone, 200 cm, red

Notes

a) The same equipment is used in Exp. 135710
b) Alternative power supply: 364000
c) Select one option

Also required

— Paperboard, scissors, ruler

Collisions on an air track

Objective

To investigate elastic and inelastic collisions between two carts on an air track. For both kinds of collisions, conservation of both momentum and energy are examined.

Principle

The air track enables virtually frictionless motion in one dimension. This ensures that the only forces acting parallel with the track are the mutual influence between the two carts. The carts can therefore be considered an isolated system.

The two carts are launched towards each other with different speeds. The masses of the carts are also varied.

The speeds of the carts are measured by two SpeedGates that can display the speed when passed. SpeedGate remembers the previous measurement and fits perfectly with collision experiments where the cart typically passes the photogate once on its way to the collision and once on its way back.

Sample results

Raw data from one collision:

Masses

m_1 = 310.8 g
m_2 = 312.1 g

Velocities before collision

u_1 = 0.333 m/s
u_2 = -0.418 m/s

Velocities after collision

v_1 = -0.425 m/s
v_2 = 0.316 m/s

From this we calculate total momenta and kinetic energies before and after the collision. For the sake of assessing the result we also find the numerically largest of the two momenta before the collision:

Momenta

$p_{\text{tot, before}}$ = -0.0270 kg·m/s
$p_{\text{tot, after}}$ = -0.0335 kg·m/s
$|p|_{\text{max, before}}$ = 0.1321 kg·m/s

Energies

$E_{\text{kin, before}}$ = 44.5 mJ
$E_{\text{kin, after}}$ = 43.7 mJ

In any collision, the total momentum is expected to be conserved. To compare the experimental results with theory, students are asked to find the deviation as a percentage of the largest incoming momentum.

In this example, we get less than 5 % difference.

The energy loss can also be found. In this example it amounts to about 2 %. This means that we have an (almost) elastic collision.

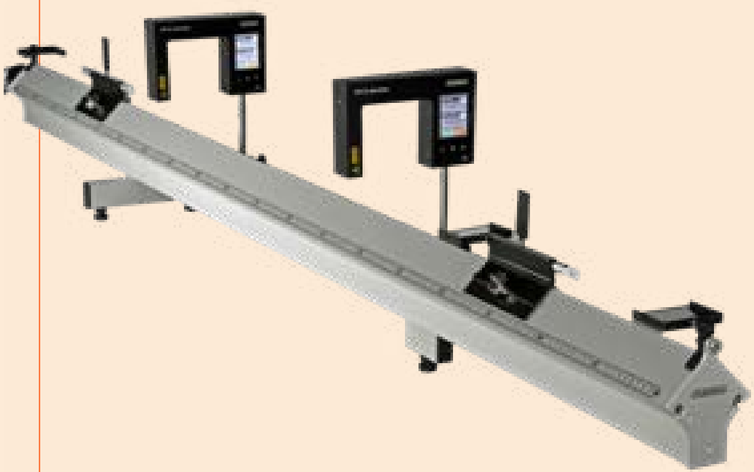
Equipment list

The complete list below may conveniently be referred to as Item no. 134720.

Item no.	#	Text
195050	1	Air track w/ accessories
197080	1	Air blower
197570	2	SpeedGate
195055	2	Mounting bracket for SpeedGate

Also required

— 102962 Digital scales (500 g/0.1 g) – or similar



Newton's second law

Objective

An experimental demonstration of Newton's second law.

Principle

A cart (glider) on a horizontal air track accelerates using a thread, a pulley, and a weight influenced by gravity. The mass of the weight and the cart are weighed.

At two different positions, photogates measure the speed of the cart as well as the time interval spent between the two photogates. The actual acceleration of the cart is calculated from these measurements.

Newton's second law leads to a theoretical value of the acceleration which is compared to the measured one.

Sample results

The table shows the results from one of a range of measurements. The cart weighs 205.89 g and is pulled by a 10.74 g weight.

Speeds measured by the SpeedGates are 0.362 m/s, resp. 0.903 m/s, and the time spent between the SpeedGates is 1.13383 s.

The latter is corrected for finite measurement intervals and from these figures, the experimentally determined acceleration a_{meas} can be found.

This actual acceleration is compared to the theoretical acceleration, predicted by Newton's second law:

The force of gravity on the pulling weight is calculated. This force acts on the combined mass of the cart, the weight itself and the equivalent mass of the pulley, leading to the theoretical value a_{theo}.

In this example, the measured and the theoretical accelerations are very close – actually more than twice this deviation is still acceptable, given the experimental uncertainties involved.

Equipment list

The complete list below may conveniently be referred to as Item no. 134710.

Item no.	#	Text
195050	1	Air track (incl. accessories)
197080	1	Air blower
197570	2	SpeedGate
195055	2	Mounting bracket for 197570
116500	1	Extra strong thread

Also required

— 102900 Digital scales (300 g/0.01 g) – or similar

m_c = 0.20589 kg							
m_w kg	V_A m/s	V_B m/s	t_{AB} s	t_{corr} s	a_{meas} m/s²	a_{theo} m/s²	dev. %
0.01074	0.362	0.903	1.13383	1.11728	0.4842	0.4813	0.6%

The speed of light

Objective

To measure the speed of light in atmospheric air.

Principle

We measure time of flight and distance travelled by the light – from which the speed can be calculated immediately

The equipment emits very short flashes of light. The light hits a reflector and returns to the apparatus where a sensor converts the flash into an electric pulse. Using an oscilloscope, we measure the delay of the light resulting from its trip back and forth.

Trivially easy alignment

The reflector board included with 201710 has a surface that shows retroflection – i.e. it sends incoming light back in the same direction it came from.

This makes it much easier to direct the light back into the apparatus than if e.g. a mirror was used.

The alignment is so non-critical that a demo version of the experiment can be made by walking back and forth with the reflector in your hand.

Sample results

The 'scope screens below corre-spond to a distance to the reflector of 0 m (fig. A) and almost 10 m (fig. B). The red trace is a synchronization signal, the yellow trace is the sensor output.

The bottom screen shows directly the time of flight of the light pulses (in this case 63.6 ns).

Precision turns out to be close to the pixel resolution of the oscilloscope screen.

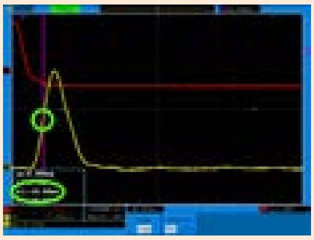


fig. A

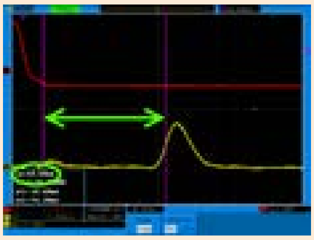


fig. B

Setting up the oscilloscope

It doesn't take an expert to complete this lab.

For each of the two recommended oscilloscopes, the lab manual includes an appendix with a detailed walk-through of the setup.

Equipment list

The complete list below may conveniently be referred to as one of the following item numbers:
133890A (option A: Bench oscilloscope 400150)
133890B (option B: PC oscilloscope 400100).
(Photo shows an older oscilloscope.)

Item no.	#	Note	Text
201710	1		The speed of light
400150	(1)	a	Digital oscilloscope, 60 MHz *Option A*
400110	(1)	a	PC oscilloscope, 100 MHz *Option B*

Notes-

a) Select one option

Also required

— Tape measure (140010 or similar) or long ruler


ERP

H.C. Oersted's experiment

Objective

We will examine the magnetic field around a current-carrying wire. The observations are compared to an easy to remember rule of thumb.

Principle

The direction of the magnetic field at a given position can be found by a small compass. The north pole of the compass needle points in the direction of the field.

In this experiment we examine the magnetic field below and above a horizontal wire (Oersted's classical experiment) as well as around a vertical wire.

Student challenge

This experiment is meant to form part of the introduction to electromagnetism. The fundamental rules are therefore yet to be established. The following challenge is part of the lab manual:

Grip rule
– which hand?

The current is called I. The direction of the current is shown with the white arrow. The magnetic field is called B, its direction is shown with red arrows.

Only one side of the figure can be correct!

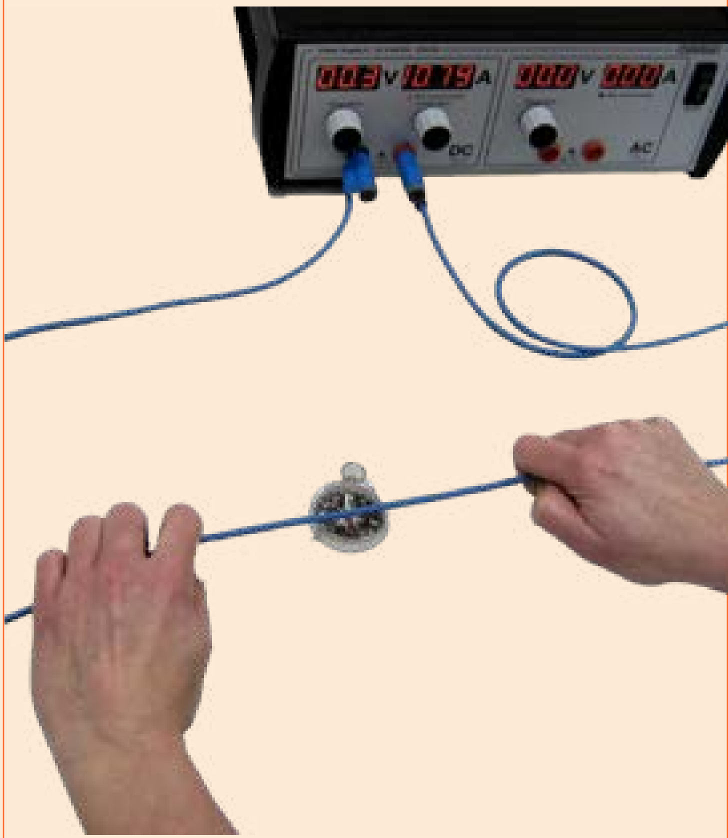
Equipment list

The complete list below may conveniently be referred to as Item no.: 137110

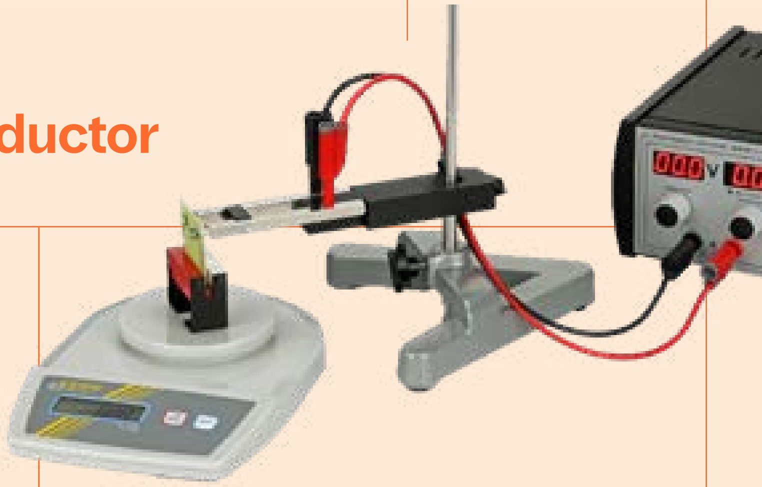
Item no.	#	Note	Text
340505	1		Pocket Compass with ring Ø40 mm
364000	1	a	Power supply
105753	1		Safety cables, silicone, 200 cm, blue

Notes

a) This power supply features a variable current limiter. (The wire in the experiment is actually a short circuit!)



Magnetic force on a conductor



Objective

To examine the force on a current carrying conductor in a magnetic field.

To confirm the theoretical expression for the force (Laplace's force, Lorentz force).

Principle

We use the magnetic field from a permanent magnet placed on digital scales.

The size of the force on the magnet is equal to the force on the conductor and has the opposite direction (action = reaction).

Reading of the scales can therefore be used to find the force on the conductor.

Equipment list

The complete list below may conveniently be referred to as Item no.: 137230

Item no.	#	Note	Text
456500	1		Current balance
364000	1	a	Power supply
105720	1		Safety cable 50 cm, sort
105721	1		Safety cable 50 cm, red
000100	1		Stand base
000850	1		Retort stand rods, 25 cm

Notes

a) This power supply features a variable current limiter. (The conductor in the current balance is actually a short circuit!)

Also required

— Ruler or calliper gauge
— 102964 Kern scales 200 g / 0,01 g – or similar

Sample results

Varying the current through one of the conductors shows a nice, linear relationship as seen below. (*fig. A*)

The conductors are on printed circuit boards that are easily swapped to vary the length.

The graph below (*fig. B*) shows the magnetic force as a function of the length of the conductor.

The number of magnets in the holder can be varied as well. The corresponding graph (not shown) displays a slight saturation effect when adding the last couple of magnets.

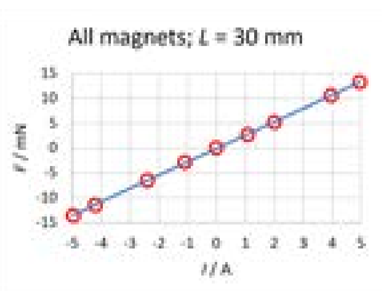


fig. A

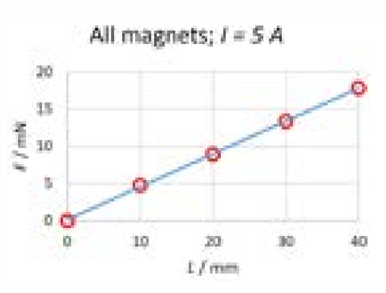


fig. B

Laplace's force law

Objective

To examine the force on a current carrying conductor in a magnetic field including the angle dependency.

To confirm the theoretical expression for the force (Laplace's force, Lorentz force).

Principle

We use the field from a permanent magnet placed on digital scales.

According to Newton's 3rd law, the force on the magnet and the force on the conductor are of equal size, but of opposite directions.

Reading the scales can therefore be used to find the force on the conductor.

Sample results

The raw results (*fig. A*) looks promisingly like a sine wave. In a more thorough analysis, a possible angle offset $\Delta\theta$ is introduced (turns out to be 1.7° in this sample result) – resulting in an excellent agreement with theory (*fig. B*).

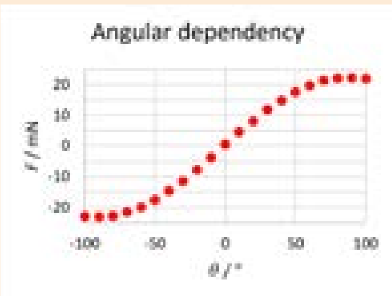


fig. A

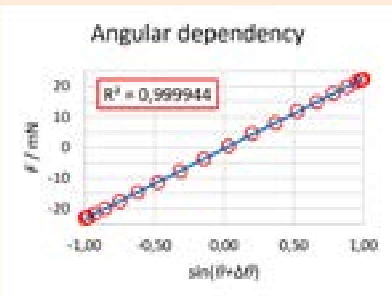


fig. B

Equipment list

The complete list below may conveniently be referred to as Item no.: 137240

Item no.	#	Note	Text
456500	1		Current balance
456510	1	a	Current balance, angle dependent
364000	1	b	Power supply
105720	1		Safety cable 50 cm, sort
105721	1		Safety cable 50 cm, red
000100	1		Stand base
000850	1		Retort stand rods, 25 cm

Notes

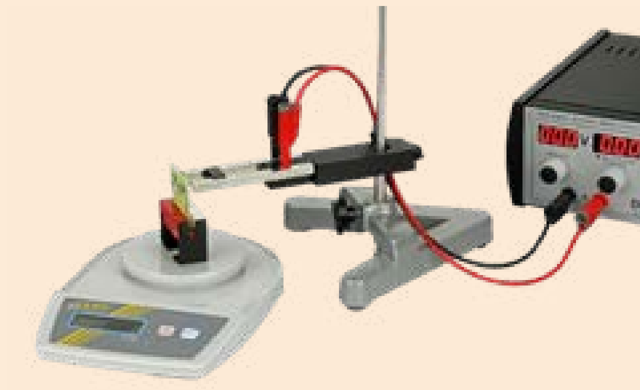
a) Accessory for 456500 – not a stand-alone unit.

b) This power supply features a variable current limiter. (The conductor in the current balance is actually a short circuit!)

Also required

— Ruler or calliper gauge

— 102964 Kern scales 200 g / 0,01 g – or similar



The transformer

Objective

We will examine a transformer built from individual coils and a UI core.

The results are compared to the theory for the ideal transformer.

Principle

With the interchangeable coils, the transformer is easy to build with many different winding combinations.

The primary voltage is measured on the built-in voltmeter in the power supply.*
The secondary voltage is measured by an external voltmeter.

*) A power supply without a voltmeter can also be used. Instructions are included in the manual.

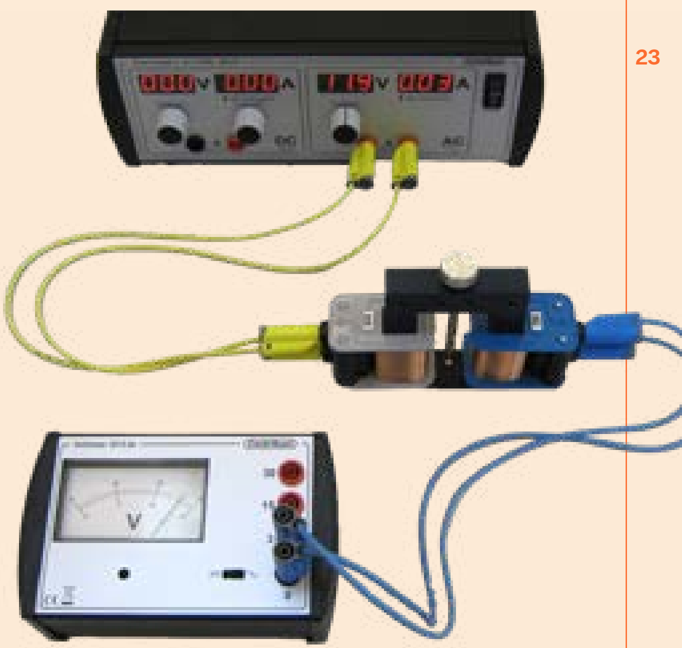
Equipment list

The complete list below may conveniently be referred to as Item no. 137710.

Item no.	#	Note	Text
463000	1		UI core
462510	1		Coil, 200 turns
462520	2		Coil, 400 turns
462525	1		Coil, 800 turns
381560	1		Voltmeter
364000	1	a	Power supply
105722	2		Safety cable, silicone, 50 cm yellow
105723	2		Safety cable, silicone, 50 cm blue

Notes

a) Others may be used (see details in lab manual).



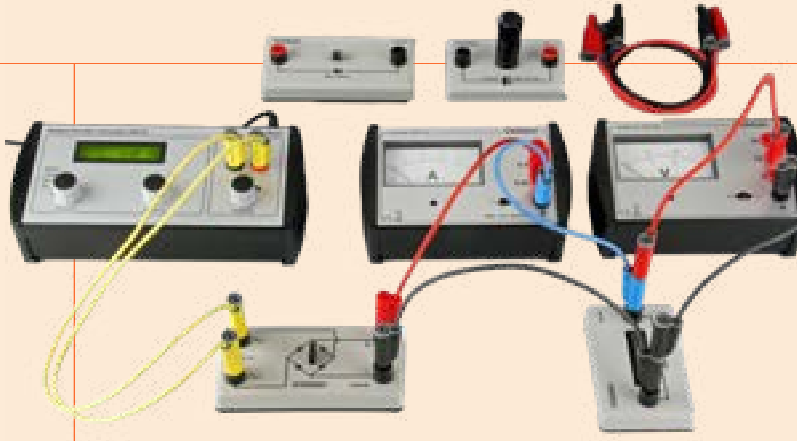
Sample results

Sample results showing a rather consistent deviation from the theoretical “ideal” transformer.

The deviation represents magnetic flux that escapes the secondary coil.

Given		Measured		Compared with theory		
N_p	N_s	U_p / V	U_s / V	N_s / N_p	U_s / V	devi.
200	400	5.9	10.57	2	11.8	-10.4%
200	800	6.0	21.30	4	24.0	-11.2%
800	400	12.5	5.52	0.5	6.25	-11.7%
800	200	12.7	2.82	0.25	3.175	-11.1%

Rectifier circuits



Objective

We investigate how a diode and a bridge rectifier converts the alternating voltage to a direct voltage.
We also see how a capacitor can be used to smoothen the pulsating direct current.

The rectifier circuit constitutes a very simple "power supply". In this lab exercise we will use a resistor as "a device to be powered".

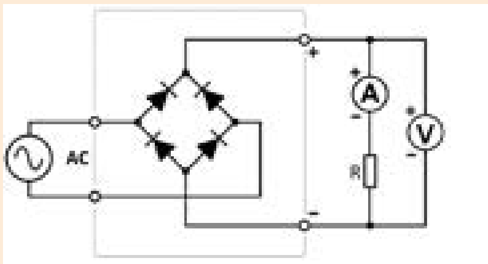
Principle

Normally, the rectifier circuit is placed after a transformer that converts the AC mains voltage from the wall socket to a lower voltage.
In order to be able to follow the variations in voltage and current, we don't use 50 Hz (or 60 Hz) AC voltage here but instead a function generator adjusted to e.g. 0.1 Hz

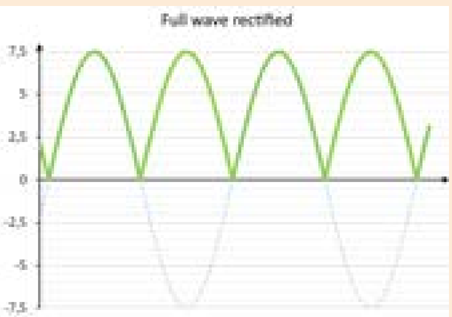
With such a "slow motion" AC voltage, the variations can be observed with analog (needle) meters.

Idea behind the lab manual

The students will build the circuits given in schematics form like the one below:



The "text book" graphs for the voltage versus time are given for each circuit and the students are challenged to draw the real behaviour as they experience it.



Behaviour of an "ideal rectifier bridge".

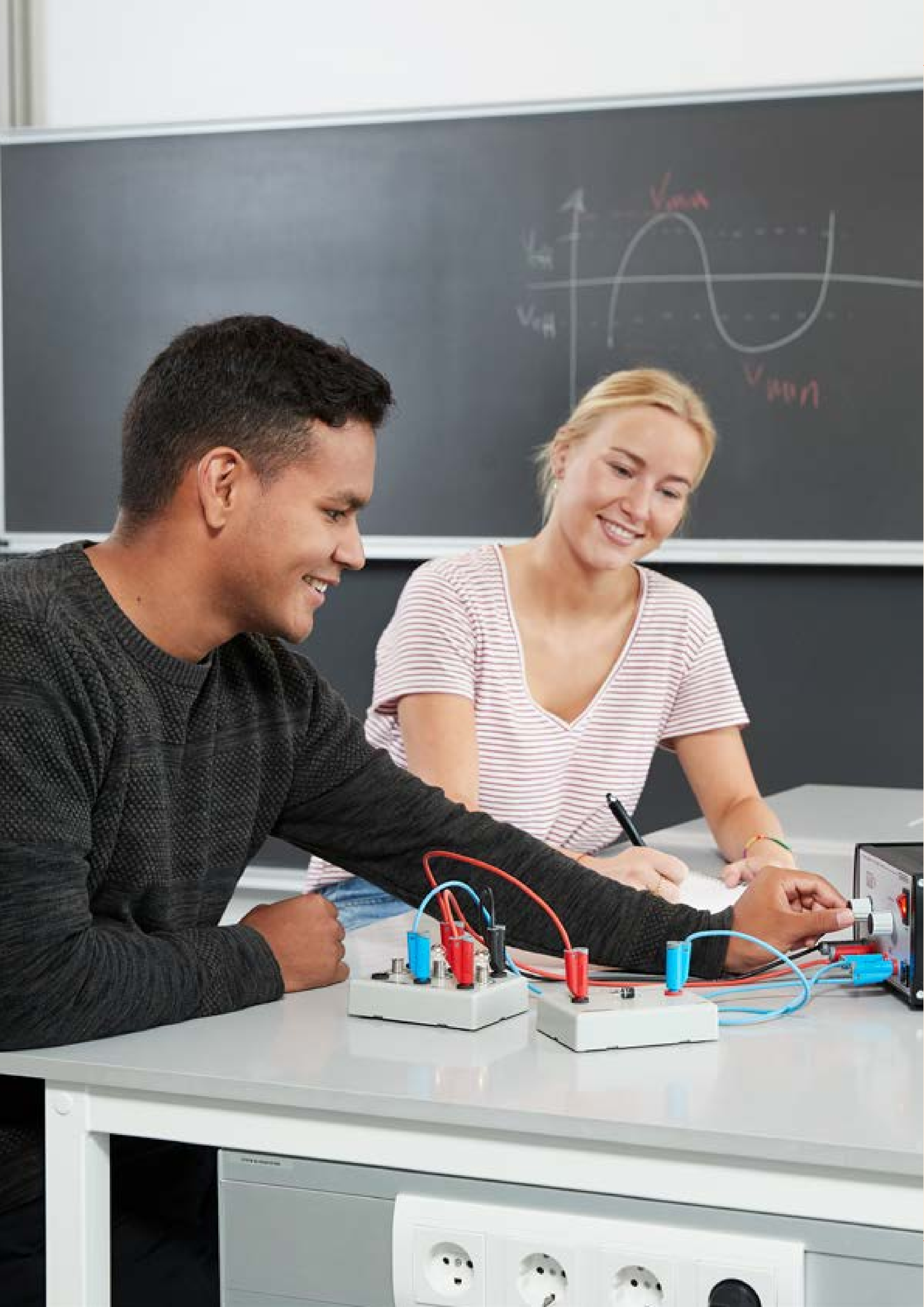
Equipment list

The complete list below may conveniently be referred to as one of the following item numbers:
136210A (option A: Student function generator)
136210B (option B: Function generator 250350).
The photo shows Option B.

Item no.	#	Note	Text
381560	1		Voltmeter
381570	1		Ammeter
429380	1		Rectifier on base
429390	1		Bridge rectifier on base
429200	1		Resistor, 470 Ω, 1%, 10 W
429310	1		Electrolytic capacitor 15000 µF 25 V
250310	(1)	a	Student func. generator *Option A*
250350	(1)	a	Function generator *Option B*
105720	3		Safety cable, silicone, 50 cm, black
105721	3		Safety cable, silicone, 50 cm, red
105722	2		Safety cable, silicone, 50 cm, yellow
105723	1		Safety cable, silicone, 50 cm, blue

Notes

a) Select one option


Vmax
Vmin

Effective voltage

Objective

Measuring the effective value (RMS value) of different voltages: AC voltage, half-wave rectified voltage as well as rectified and smoothed voltage.

Principle

The effective value of the different voltages are found by comparing the light yield from two bulbs, of which one is connected to a known DC voltage and the other is connected to the voltage to be investigated.

When the bulbs are equally bright, the effective value of the unknown voltage is just the same as the DC voltage.

Sample results

For a half-wave rectified sine wave, the effective voltage was measured as described:

U_{AC} input	U_{DC} meas.	U_{DC}/U_{AC}	Theory	Dev.
6.00 V	3.79 V	0.632	0.707	-10.7%

Students are asked to explain the deviation.
(The "theory" assumes an ideal diode. By subtracting the approx. 0.7 V voltage drop over a real diode, the input voltage is only about 5.3 V AC, making U_{DC}/U_{AC} = 0.715 – only a 1 % error.)

Equipment list

The complete list below may conveniently be referred to as Item no. 136220.

Item no.	#	Note	Text
361700	1	a	Power supply
429000	2		Lamp holder
429380	1		Rectifier diode
429310	1		Capacitor 15000 uF
105720	1		Safety cable, 50 cm, black
105721	1		Safety cable, 50 cm, red
105723	2		Safety cable, 50 cm, blue
105710	1		Safety cable, 25 cm, black
105711	2		Safety cable, 25 cm, red
425025	1	b	Pygmy bulbs 6 V 0,05 A

Notes

a) Power supply with a built-in voltmeter is strongly recommended

b) Two bulbs needed, package contents: 10 pcs.

Secret circuit boxes

Objective

The eight secret circuit boxes contain circuits with switches and incandescent lamps (bulbs).

One box is investigated at a time and the task of the students is to draw the schematics diagram for the circuit inside.

Principle

Each box is powered and examined in turn.

The students observe the lamps – both with the switch(es) closed and open.

They are allowed to unscrew one or more of the bulbs, testing every possible combination of switches and bulbs.

Based on a guess, a sketch of the circuit is drawn and predictions based on the sketch are compared with reality.

Equipment list

The complete list below may conveniently be referred to as Item no. 136040.

Item no.	#	Note	Text
429800	1		Secret circuit boxes
105723	2		Safety cables, 50 cm, blue
361600	1	a	Power supply 12 V AC/DC 3A

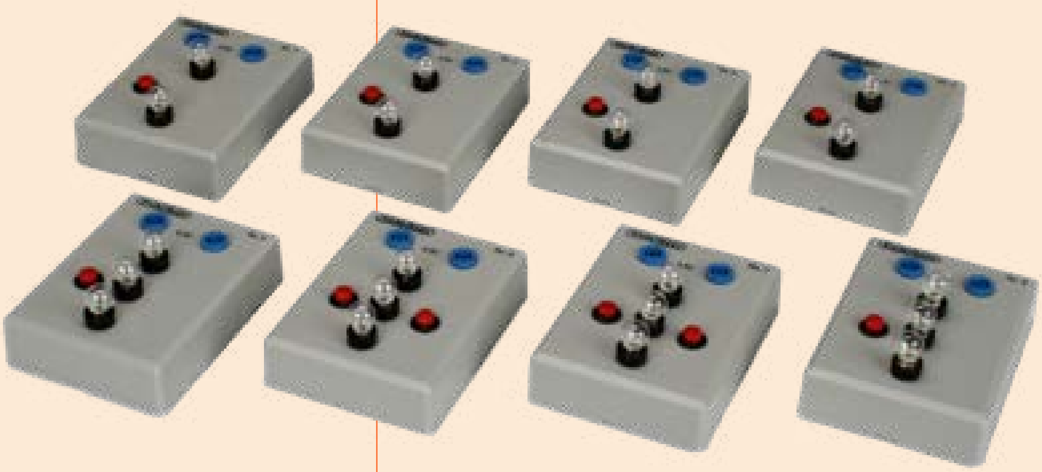
Notes

a) – or similar. Even a 4.5 V battery (350555) can be used with two crocodile clips

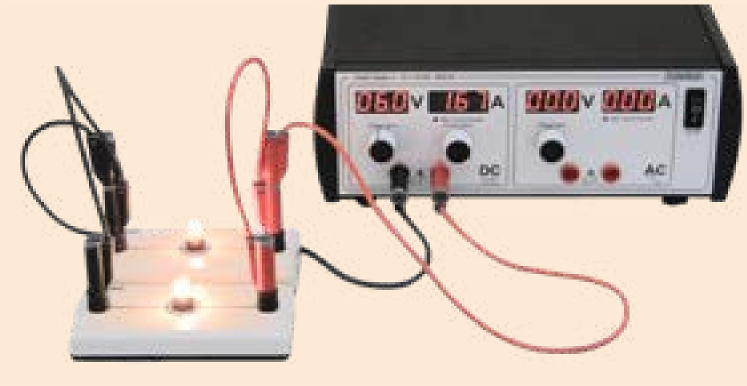
Evaluation

An answer sheet for the teacher follows each set of secret boxes. (This sheet cannot be downloaded.)

When comparing the students' drawings with the answer sheet, the teacher must be careful to consider the function and not the appearance (a few examples are mentioned of seemingly different schematics that are in fact equivalent).



Bulbs in series and parallel connection



Objective

To examine voltage and current in circuits with simple combinations of bulbs (incandescent lamps).

Principle

For one bulb alone – and for series and parallel connections of two bulbs – we find the voltage and current needed to make the bulbs light up normally.

The simplest setup uses a power supply with built-in voltmeter and ammeter.

(Other types of power supply may be used if two separate instruments are added as detailed in the lab manual – option B in the equipment list.)

Idea behind the lab manual

This is intended to be an introductory experiment. The students are lead step by step through the challenge.

During this lab, three circuits will be built. None of them are drawn as schematics – they are only presented as simple and clear photographs.

Afterwards, the students are asked to formulate rules for voltages and currents in parallel and series connections of identical bulbs – compared to one single bulb.

Equipment list

The complete list below may conveniently be referred to as one of the following item numbers:
136010A (opt. A: Power supply w/ built-in meters)
136010B (opt. B: Power supply + external meters)
The photo shows Option A.

Item no.	#	Note	Text
429000	2		Lamp holder E10, 2 connectors
425040	1	a	Light bulb 6 V, 1 A (pack of ten)
364000	(1)	b	Power supply 0-24 V Option A
361600	(1)	b	Power supply 0-12 V Option B
381560	(1)	b	Voltmeter Option B
381570	(1)	b	Ammeter Option B
105710	1		Safety cable 25cm, black
105711	1		Safety cable 25cm, red
105720	1		Safety cable 50 cm, black
105721	(1)	b	Safety cable 50 cm, red Option A
105721	(3)	b	Safety cable 50 cm, red Option B
105740	(1)	b	Safety cable 100 cm, black Option B

Notes

a) Two bulbs are used out of a pack of ten
b) Select one option

Also required

— "Post-It" (Small format) or similar for labelling

Resistors in series and parallel circuits

Objective

To investigate the behaviour of current, voltage and resistance in series and parallel circuits with two resistors.

The formulae for the total resistance in these two cases are validated.

Principle

Current and voltage are measured with two analog instruments. The resistance is found using Ohm's law – both for the two resistors individually and for the series and parallel circuits.

Sample results

Component values and measurement parameters has been tailored to make reading of analog meters as easy as possible.

The results cited in this paragraph were obtained by an experienced experimenter, hence the extra (interpolated) decimals in some of the numbers.

The individual resistors were spot on the nominal values according to these data:

	Mesured			Expected
	U / V	I / A	R / Ω	R / Ω
R_1	15.0	0.150	100	100
R_2	15.0	0.100	150	150

For the series connection, the measured resistance was off by 1.1 %:

	Mesured			Expected
	U / V	I / A	R / Ω	R / Ω
Series	12.0	0.0475	252.6	250

The parallel connection was off by only -0.4 %:

	Mesured			Expected
	U / V	I / A	R / Ω	R / Ω
Parallel	15.0	0.251	59.8	60

From this and previous data obtained at 15 V, the students can comment on the accordance with Kirchhoff's current law.

Likewise, the students are asked to reflect on the voltage drops over the individual resistors in the series circuit, compared to the voltage drop over both – this time without mentioning what to expect.

	Measured
	U / V
Series	12.0
R_1	4.9
R_2	7.3

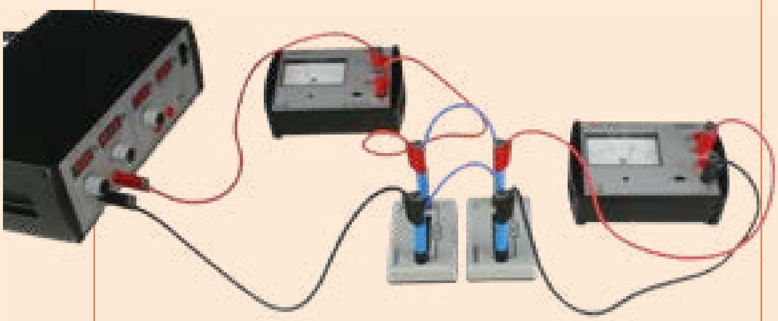
Equipment list

The complete list below may conveniently be referred to as one of the following item numbers: 136030A (opt. A: 24 V Power supply - recommended) 136030B (opt. B: 12 V Power supply)
The photo shows Option A.

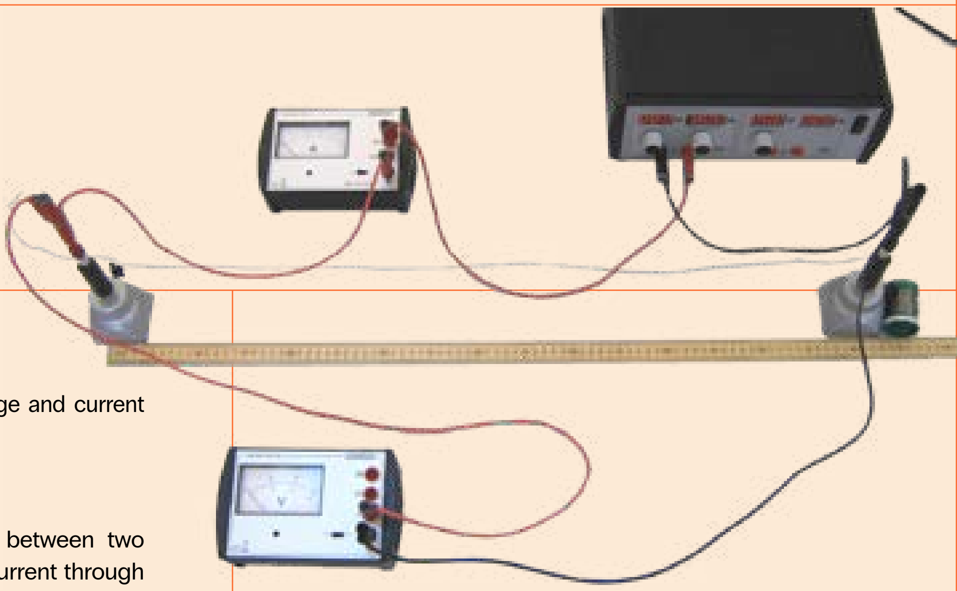
Item no.	#	Note	Text
381560	1		Voltmeter
381570	1		Ammeter
429180	1		Resistor 100 Ω, 1 %, 10 W
429190	1		Resistor 150 Ω, 1 %, 10 W
364000	(1)	a	Power supply 0-24 V *Option A*
361600	(1)	a	Power supply 0-12 V *Option B*
105720	2		Safety cable 50 cm, black
105721	3		Safety cable 50 cm, red
105713	2		Safety cable 25 cm, blue

Notes

a) Select one option



Ohm's law



Objective

Examining the relationship between voltage and current for a metal wire.

Principle

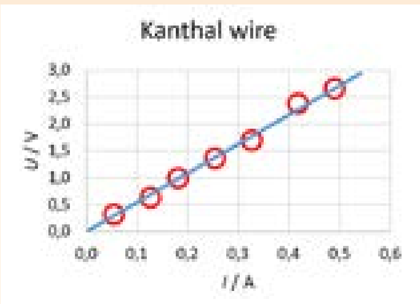
A length of Kanthal wire is extended between two terminal posts in order to measure the current through the wire and the voltage across it.
For comparison, the same measurements are carried out for a small light bulb.

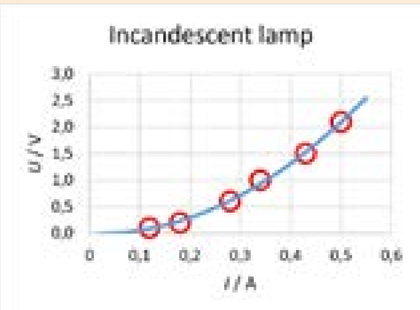
The results are analysed graphically and compared with Ohm's law.

Sample results

Sample graphs for U(I) for a metal wire and an incandescent light bulb are shown here.

The students are asked which of the two objects (if any) comply with Ohm's law.





Equipment list

The complete list below may conveniently be referred to as Item no. 136050.

Item no.	#	Note	Text
381570	1		Ammeter
381560	1		Voltmeter
115520	1		Kanthal wire 0.50 mm
425040	1	a	Bulb, 6 V, 1 A
429000	1		Lamp holder with 2 connectors, E10
361600	1	b	Power supply 0-12 V, 3 A
435010	1		Terminal posts, insulated (pair)
000420	2		Retort stand base, square
105720	1		Safety cable, silicone, black, 50 cm
105721	2		Safety cable, silicone, red, 50 cm
105740	1		Safety cable, silicone, black, 100 cm
105741	1		Safety cable, silicone, red, 100 cm

Notes

a) Box of ten (only one bulb is used)
b) Alternative power supply: 364000. The photo shows this model

Also required

— Ruler or tape measure (like 140510 or 140010)

Resistance in metal wires

Objective

To investigate how the resistance in a metal wire depends on the material, the length and diameter.

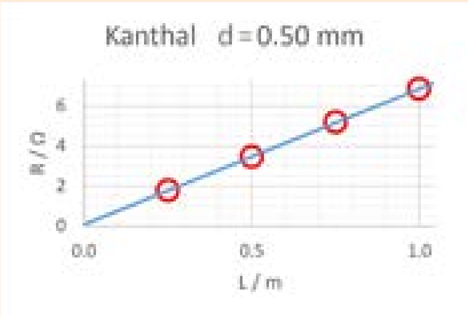
Principle

Different metal wires are stretched between two terminal posts. The current through the wire and the voltage across it are measured.

The resistance of the wire is found using Ohm's law.

Sample results

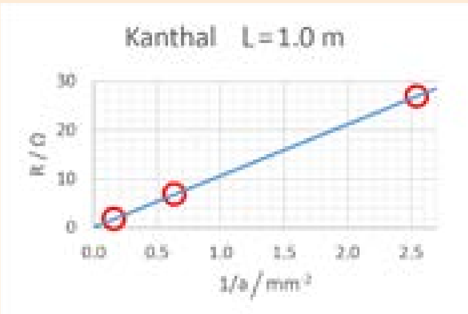
In one of the measurement series, resistance is measured as a function of the length of the wire. The following graph shows the results.



Students are expected to formulate this relationship in qualitative terms only. If the teacher deems it fitting for a particular class, the concepts of direct and inverse proportionality can be used.

The next graph shows inverse proportionality between resistance and the cross-section area of the wire.

– As can be seen, the rugged analog meters are excellent for this experiment.



Equipment list

The complete list below may conveniently be referred to as Item no. 136060.

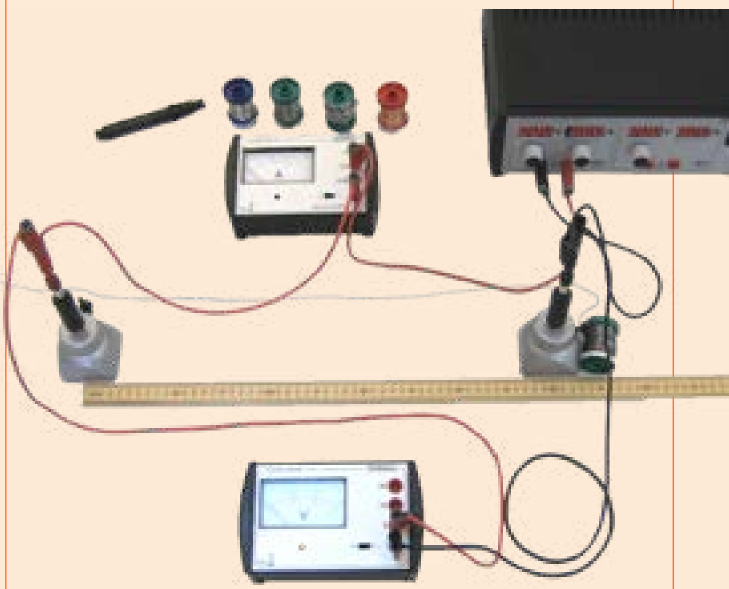
Item no.	#	Note	Text
381570	1		Ammeter
381560	1		Voltmeter
115510	1		Kanthal wire 0.25 mm
115520	1		Kanthal wire 0.50 mm
115530	1		Kanthal wire 1.00 mm
116000	1		Iron wire 0.5 mm
364000	1	a	Power supply
435010	1		Terminal posts, insulated (pair)
000420	2		Retort stand base, square
105720	1		Safety cable, silicone, black, 50 cm
105721	2		Safety cable, silicone, red 50 cm
105740	1		Safety cable, silicone, black 100 cm
105741	1		Safety cable, silicone, red 100 cm

Notes

a) Up to 5 A is needed in this experiment.

Also required

— Ruler or tape measure (like 140510 or 140010)



Capacitor – Charging and discharging

Objective

To investigate the discharging and charging curves for a capacitor and determine the capacitance.

Principle

With the components used, the voltage variations can be followed using a stopwatch and a voltmeter. Plotting the measurements in a spreadsheet enables us to find an exponential trend line and to find the capacitance from that.

Equipment list

The complete list below may conveniently be referred to as Item no. 136230.

Item no.	#	Note	Text
429310	1		Capacitor 15 000 μF
429230	1		Resistor 4,7 kΩ 10 W 1%
429080	1	a	Knife switch
364000	1	b	Power supply
105710	1		Safety cable, 25 cm, black
105711	2		Safety cable, 25 cm, red
105740	2		Safety cable, 100 cm, black
105741	2		Safety cable, 100 cm, red

Notes

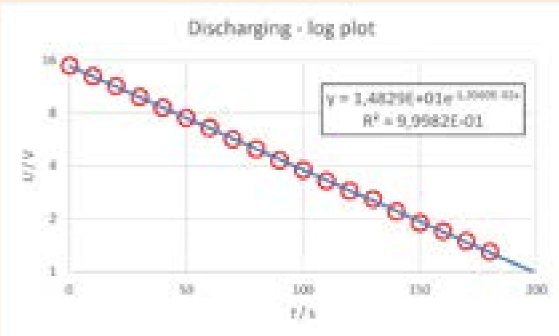
a) ... or similar: 429090, 429050 ...
b) 361600 or 361700 may also be used

Also required

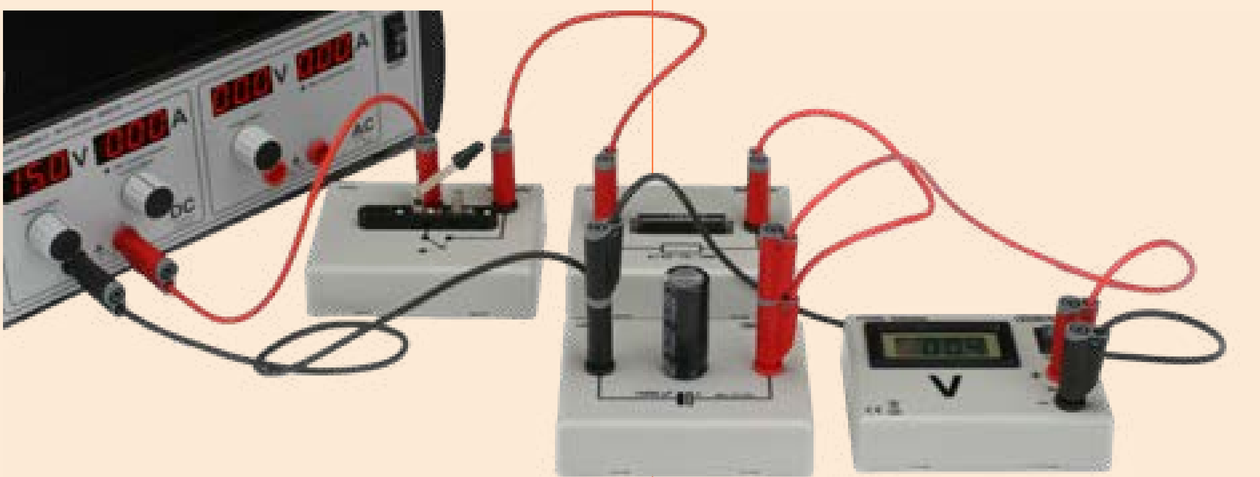
— Watch (e.g. 148550 Stopwatch, digital)

Sample results

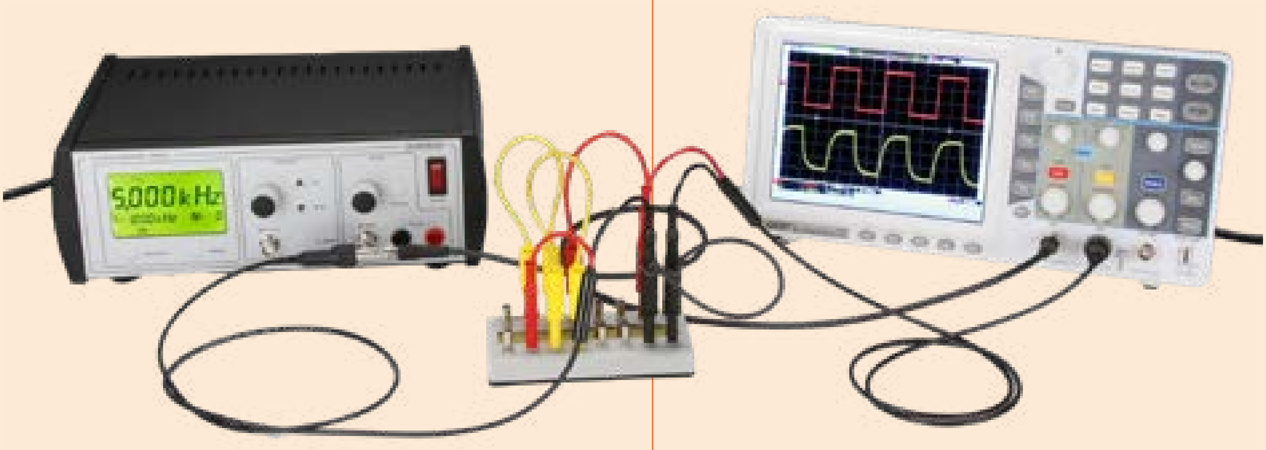
The exponential behaviour of the discharge process is nicely displayed with a logarithmic voltage axis.



From the function parameters and the known resistance, the size of the capacitor used can be calculated, here 15 780 μF (which is fine - the capacitor's specified tolerance is huge).



RC Low-pass filters



Objective

The behaviour of simple RC low-pass filters is investigated by measuring frequency response and step response.

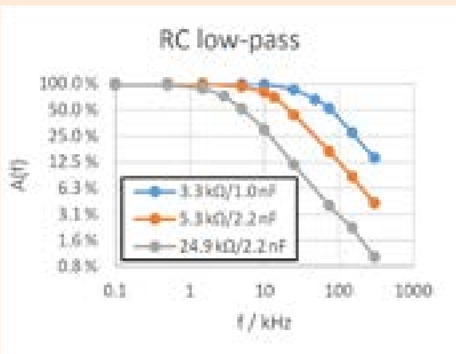
Principle

Frequency response: The amplitude of a sine wave signal is measured before and after passing the filter. The ratio between the two amplitudes is plotted with a logarithmic frequency axis.

Step response: A square wave signal is used as input and the output is studied on an oscilloscope.

Sample results (freq. response)

The graphs show the measured frequency responses for three different RC low-pass filters. Both axes are logarithmic. It is easy to see that the response curves run parallel for high frequencies.



Equipment list [a)]

The complete list below may conveniently be referred to as one of the following item numbers:
136310A (option A: Stand-alone oscilloscope)
136310B (option B: PC oscilloscope).
The photo shows Option A.

Item no.	#	Note	Text
429330	1		LCR-circuit
250350	1		Function generator
400150	(1)	b	Oscilloscope, digital 60 MHz *Option A*
400110	(1)	b	Oscilloscope 100 MHz PC-USB *Option B*
110002	2		Cable, BNC to two safety plugs
111100	1		BNC T adapter
110025	1		Coaxial cable, BNC, 50 Ohm
105710	1	c	Safety cable, silicone, 25 cm, black
105711	2	c	Safety cable, silicone, 25 cm, red
105712	2	c	Safety cable, silicone, 25 cm, yellow
105713	2	c	Safety cable, silicone, 25 cm, blue

Notes

a) Exp. 136310, -20, -30, -40 and -50 all use the same equipment.
b) Select one option.
c) Cables sufficient for all 5 experiments.

RC high-pass filters

Objective

The behaviour of simple RC high-pass filters is investigated by measuring frequency response and step response.

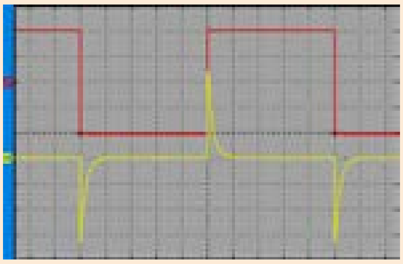
Principle

Frequency response: The amplitude of a sine wave signal is measured before and after passing the filter. The ratio between the two amplitudes is plotted with a logarithmic frequency axis.

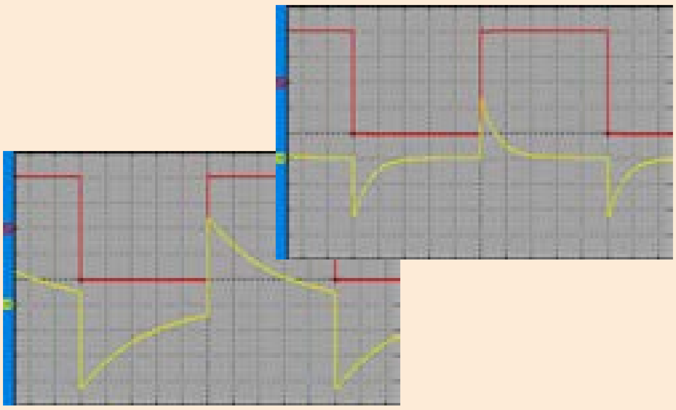
Step response: A square wave signal is used as input and the output is studied on an oscilloscope.

Sample results (step response)

The step response reveals a lot of information in a glance. The oscilloscope screen dump shows how a square wave (red) is shaped after passing the filter (yellow).



If all components and cables were ideal, the size of the jumps on the two curves should have the same height. In reality, the output (yellow) only jumps about 80% of the ideal value. This simply reflects the fact that no real filter has an infinite bandwidth.



Changing the cut-off frequency also changes the step response.

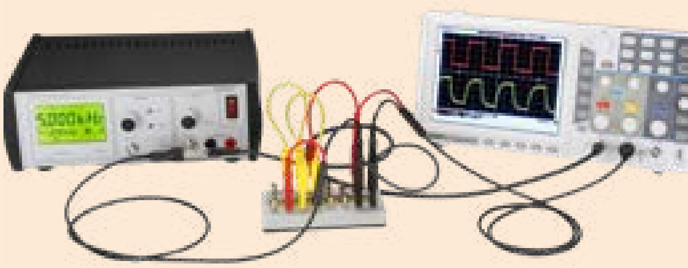
Equipment list [a]

The complete list below may conveniently be referred to as one of the following item numbers:
136310A (option A: Stand-alone oscilloscope)
136310B (option B: PC oscilloscope).
The photo shows Option A.

Item no.	#	Note	Text
429330	1		LCR-circuit
250350	1		Function generator
400150	(1)	b	Oscilloscope, digital 60 MHz *Opt. A*
400110	(1)	b	Oscilloscope 100 MHz PC-USB *Opt. B*
110002	2		Cable, BNC to two safety plugs
111100	1		BNC T adapter
110025	1		Coaxial cable, BNC, 50 Ohm
105710	1	c	Safety cable, silicone, 25 cm, black
105711	2	c	Safety cable, silicone, 25 cm, red
105712	2	c	Safety cable, silicone, 25 cm, yellow
105713	2	c	Safety cable, silicone, 25 cm, blue

Notes

a) Exp. 136310, -20, -30, -40 and -50 all use the same equipment.
b) Select one option.
c) Cables sufficient for all 5 experiments.



Resonant circuits – measuring inductance

Objective

By measuring resonance frequencies, coil inductance can be calculated. We work with two single coils, as well as series and parallel connections.

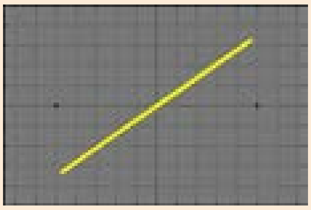
Principle

The (phase) resonance frequency is determined by using the oscilloscope in XY mode.

Sample results

Adjusting the frequency for 0° phase difference yields this oscilloscope image at 48.80 kHz:

(This means that the inductance of the coil used here can be found to be 4.8 mH ± 1 %)
The method is very sensitive – detuning the frequency to 50.00 kHz opens up the phase ellipsis as seen on the lower left image.

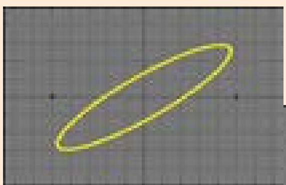


Sample results

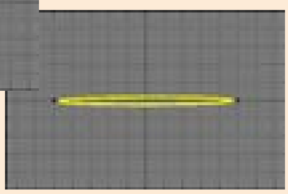
Adjusting the frequency for 0° phase difference yields this oscilloscope image at 48.80 kHz:

(This means that the inductance of the coil used here can be found to be 4.8 mH ± 1 %)
The method is very sensitive – detuning the frequency to 50.00 kHz opens up the phase ellipsis as seen on the lower left image.

Far away from the resonance frequency, the output signal is smaller (lower right image).



Not quite f_0



Far from f_0 (25 kHz)

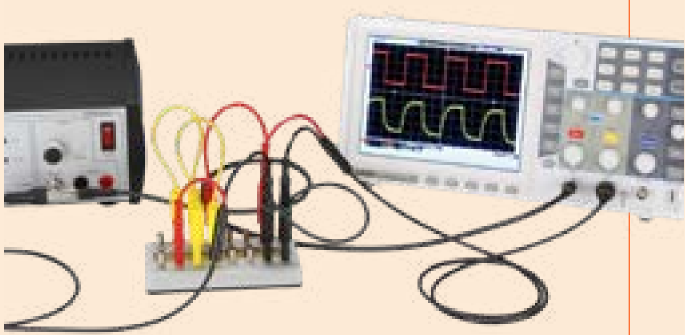
Equipment list [a]

The complete list below may conveniently be referred to as one of the following item numbers:
136310A (option A: Stand-alone oscilloscope)
136310B (option B: PC oscilloscope).
The photo shows Option A.

Item no.	#	Note	Text
429330	1		LCR-circuit
250350	1		Function generator
400150	(1)	b	Oscilloscope, digital 60 MHz *Option A*
400110	(1)	b	Oscilloscope 100 MHz PC-USB *Option B*
110002	2		Cable, BNC to two safety plugs
111100	1		BNC T adapter
110025	1		Coaxial cable, BNC, 50 Ohm
105710	1	c	Safety cable, silicone, 25 cm, black
105711	2	c	Safety cable, silicone, 25 cm, red
105712	2	c	Safety cable, silicone, 25 cm, yellow
105713	2	c	Safety cable, silicone, 25 cm, blue

Notes

a) Exp. 136310, -20, -30, -40 and -50 all use the same equipment.
b) Select one option.
c) Cables sufficient for all 5 experiments.



LCR band-pass and band-stop filters

Objective

The behaviour of LCR band-pass and band-stop filters are studied by measuring of frequency response.

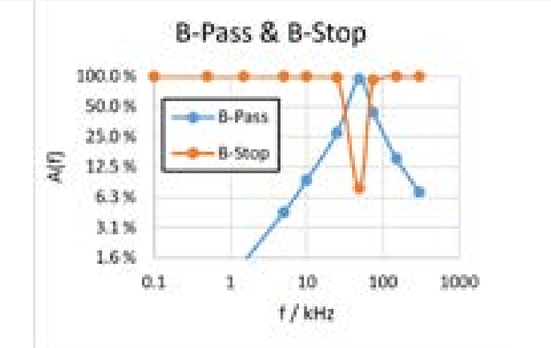
Principle

The centre frequency (or phase resonance frequency) is determined by using the oscilloscope in XY mode.

Frequency response: The amplitude of a sine wave signal is measured before and after passing the filter. The ratio of the signal amplitudes are plotted in a logarithmic coordinate system.

Sample results

Frequency response of two filters. Both axes are logarithmic.



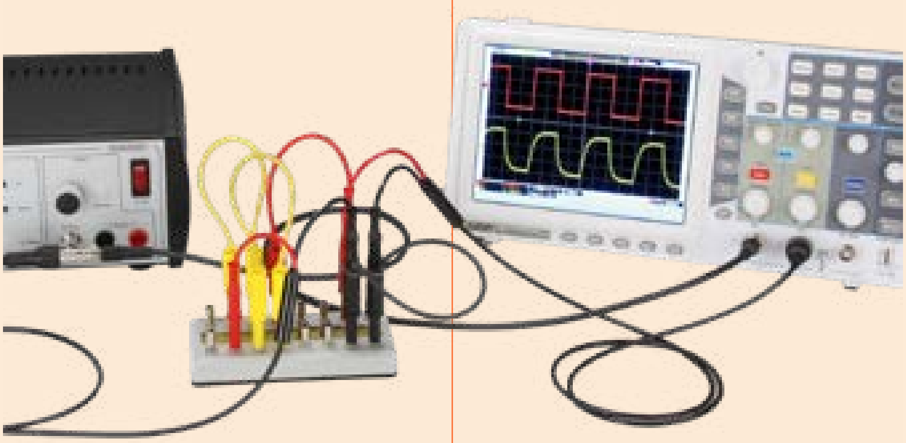
Equipment list [a]

The complete list below may conveniently be referred to as one of the following item numbers:
136310A (option A: Stand-alone oscilloscope)
136310B (option B: PC oscilloscope).
The photo shows Option A.

Item no.	#	Note	Text
429330	1		LCR-circuit
250350	1		Function generator
400150	(1)	b	Oscilloscope, digital 60 MHz *Opt. A*
400110	(1)	b	Oscilloscope 100 MHz PC-USB *Opt. B*
110002	2		Cable, BNC to two safety plugs
111100	1		BNC T adapter
110025	1		Coaxial cable, BNC, 50 Ohm
105710	1	c	Safety cable, silicone, 25 cm, black
105711	2	c	Safety cable, silicone, 25 cm, red
105712	2	c	Safety cable, silicone, 25 cm, yellow
105713	2	c	Safety cable, silicone, 25 cm, blue

Notes

a) Exp. 136310, -20, -30, -40 and -50 all use the same equipment.
b) Select one option.
c) Cables sufficient for all 5 experiments.



LCR Low-pass filters

Objective

The behaviour of LCR low-pass filters are studied by measuring the frequency response and step response.

Principle

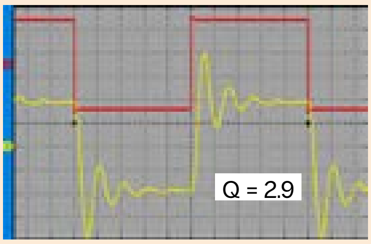
The cut-off frequency (or phase resonance frequency) is determined by using the oscilloscope in XY mode.

Frequency response: The amplitude of a sine wave signal is measured before and after passing the filter. The ratio of the signal amplitudes are plotted in a logarithmic coordinate system.

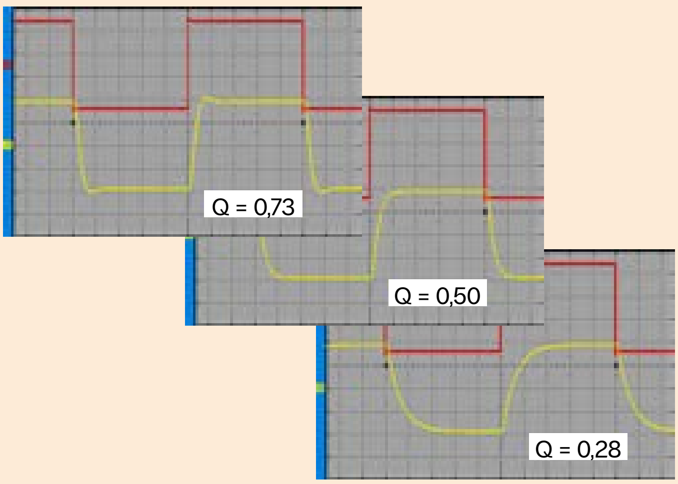
Step response: A square wave signal is used as input and the output is studied on an oscilloscope.

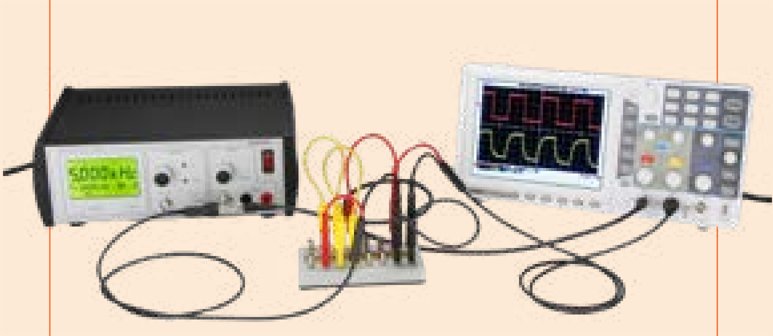
Sample results (step responses)

The oscilloscope images show how a square wave (red) is shaped after passing the filter (yellow).



The resistor (R) in the LCR filter determines the so-called Q factor which has a large impact on the step response. The four filters shown all have the same cut-off frequency but different Q factors.





Equipment list [a)]

The complete list below may conveniently be referred to as one of the following item numbers:
136310A (option A: Stand-alone oscilloscope)
136310B (option B: PC oscilloscope).
The photo shows Option A.

Item no.	#	Note	Text
429330	1		LCR-circuit
250350	1		Function generator
400150	(1)	b	Oscilloscope, digital 60 MHz *Option A*
400110	(1)	b	Oscilloscope 100 MHz PC-USB *Option B*
110002	2		Cable, BNC to two safety plugs
111100	1		BNC T adapter
110025	1		Coaxial cable, BNC, 50 Ohm
105710	1	c	Safety cable, silicone, 25 cm, black
105711	2	c	Safety cable, silicone, 25 cm, red
105712	2	c	Safety cable, silicone, 25 cm, yellow
105713	2	c	Safety cable, silicone, 25 cm, blue

Notes

a) Exp. 136310, -20, -30, -40 and -50 all use the same equipment.
b) Select one option.
c) Cables sufficient for all 5 experiments.

The solar panel – Characteristics and power

Objective

To investigate how a solar panel utilizes the solar energy best.

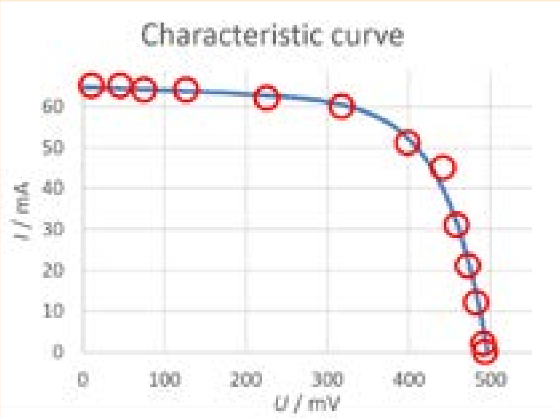
The characteristic curves for both a single cell and the whole panel are drawn and the maximum output power is found.

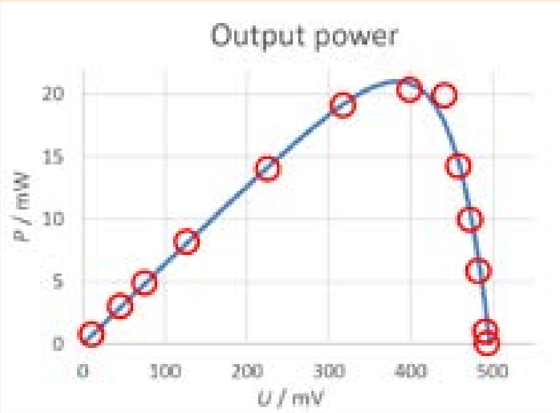
Principle

Voltage and current from the solar cell are measured with varying load. For each data point, the cell's output power is calculated. Current and power are plotted against voltage.

Sample results

Below, experimental results for a single solar cell are shown. (The students also draw similar curves for the series connected panel.)





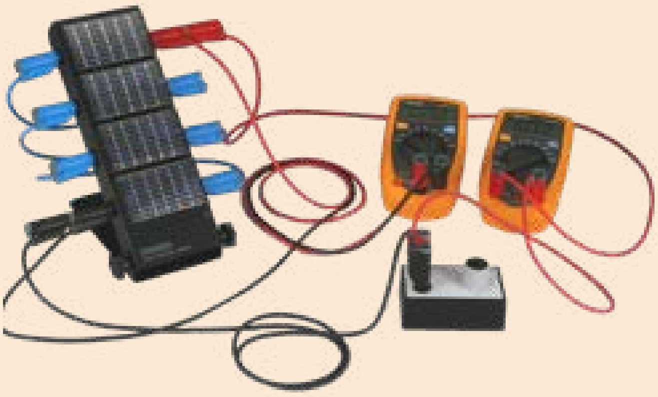
Equipment list

The complete list below may conveniently be referred to as Item no. 139230.

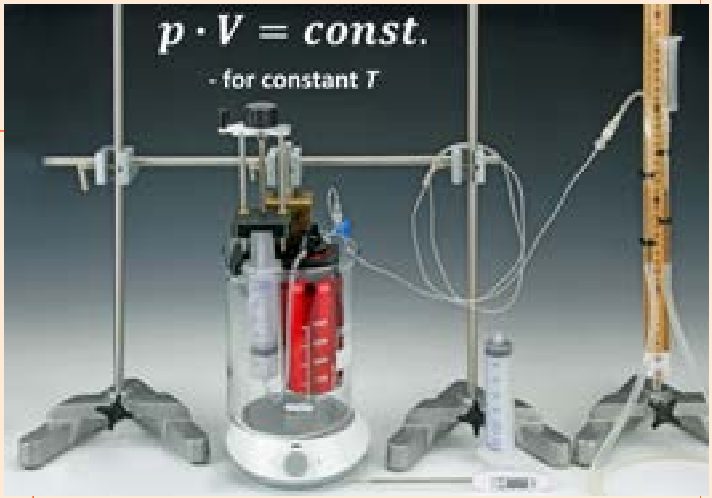
Item no.	#	Note	Text
488505	1		Solar panel
422320	1		Load box
280130	1	a	Halogen lamp, 120 W
386135	2		Multimeter DMM-135
105713	3		Safety cable, 25 cm, blue
105721	1		Safety cable, 50 cm, red
105740	2		Safety cable, 100 cm, black
105741	2		Safety cable, 100 cm, red

Notes

a) Not needed if the sun is shining from a cloudless sky.



Boyle's law



Objective

To demonstrate that in a gas with a fixed temperature, the volume is inversely proportional with the pressure.

Principle

We investigate a fixed amount of atmospheric air. Part of the air is in a plastic syringe that is controlled via a spindle with a crank.

The pressure is measured with a liquid manometer. To keep the volume constant for the gas that is not in the syringe, the manometer branches are adjusted manually to keep the liquid level of the inner branch at a fixed point in the tube.

Equipment list

The complete list below may conveniently be referred to as Item no. 132220.

Item no.	#	Note	Text
180700	1		Gas law apparatus
007560	1	a	Beaker, 2 L, Duran, Low form
062100	1	a	Digital thermometer
000100	3		Stand base
000840	3		Stand rod
002310	3		Bosshead

Notes

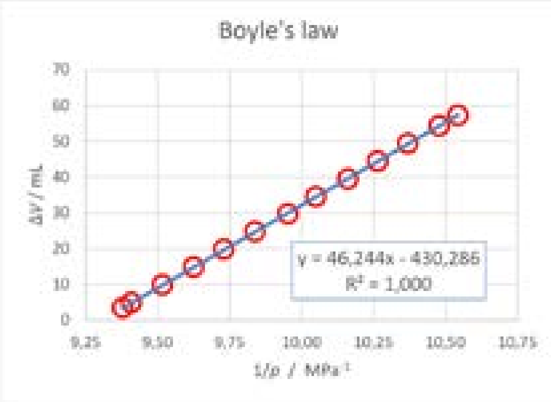
a) The experiment may be performed without these items – they are, however, needed for the other two gas law experiments: 132230-EN and 132240-EN

Also required

— Demineralised water
— Vacuum grease (042300)
— Magnetic stirrer (Note a) - e.g. 064045 (with Euro plug) or 064046 (with UK plug)

Sample results

The results below were obtained at room temperature and show excellent linearity.



From the equation for the straight line, we see that the fixed part of the gas volume is around 430 mL. This result is useful in Charles' law. (The manual also contains a procedure to check this number by independent measurements.)

Absolute zero (Gay-Lussac's law)

Objective

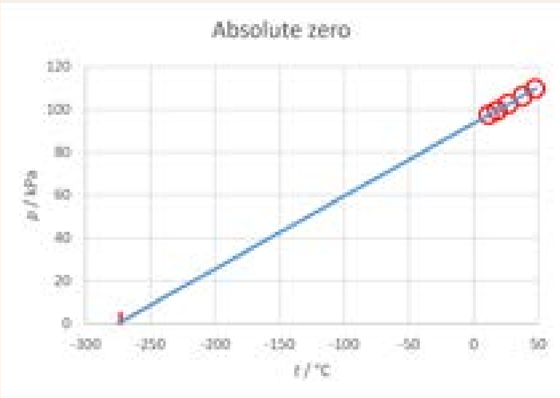
To demonstrate that the pressure in a gas with a constant volume increases linearly with temperature. By extrapolating to zero pressure, the absolute zero is found.

Principle

We investigate a fixed amount of atmospheric air with a temperature that is controlled by a water bath. The pressure is measured with a liquid manometer. To keep the volume constant, the manometer branches are moved manually to keep the liquid level in the inner branch at a fixed point in the tube.

Sample results

With the results plotted in a spreadsheet, the best straight line can be extrapolated to $p = 0$.



The intersection with the temperature axis is very close to the table value of the absolute zero, -273,15 °C.

Equipment list

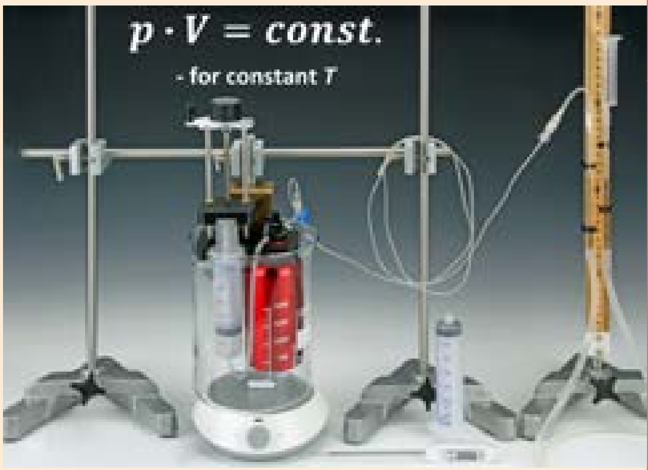
The complete list below may conveniently be referred to as Item no. 132230.

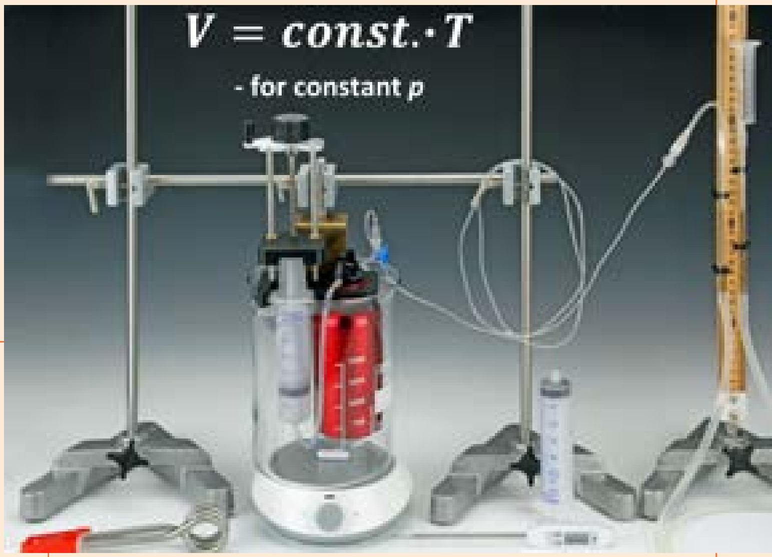
(Identical equipment used in exp. 132240-EN.)

Item no.	#	Text
180700	1	Gas law apparatus
007560	1	Beaker, 2 L, Duran, Low form
062100	1	Digital thermometer
000100	3	Stand base
000840	3	Stand rod
002310	3	Bosshead

Also required

— Demineralised water
— Vacuum grease (042300)
— Immersion heater, e.g. 275010 (with SCHUKO plug)
— Magnetic stirrer, e.g. 064045 (with Euro plug) or 064046 (with UK plug)





Charles' law

Objective

To demonstrate that the volume of a gas with a constant pressure increases linearly with temperature. By extrapolating to zero volume, the absolute zero is found.

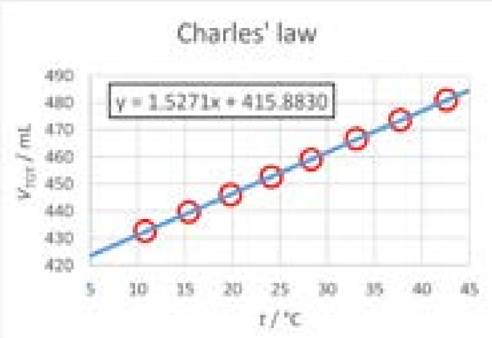
Principle

We investigate a fixed amount of atmospheric air with a temperature that is controlled by a water bath. Part of the air is contained in a plastic syringe, controlled with a spindle and a crank.

The pressure is measured with a liquid manometer. The liquid level in the manometer branches are kept at fixed positions.

Sample results

Impressive results can be obtained as shown below. To get the total gas volume, the nominal value for the fixed volume was added to the syringe volume.



The data points fit almost exactly a straight line. From the trend line equation, we get the temperature where the volume would be zero:

$$t = -\frac{415.8830\ \mathrm{mL}}{1.5271\ \frac{\mathrm{mL}}{^\circ\mathrm{C}}} = -272.3\ ^\circ\mathrm{C}$$

Equipment list

The complete list below may conveniently be referred to as Item no. 132230.

(Identical equipment used in exp. 132230-EN.)

Item no.	#	Text
180700	1	Gas law apparatus
007560	1	Beaker, 2 L, Duran, Low form
062100	1	Digital thermometer
000100	3	Stand base
000840	3	Stand rod
002310	3	Bosshead

Also required

— Demineralised water
— Vacuum grease (042300)
— Immersion heater, e.g. 275010 (with SCHUKO plug)
— Magnetic stirrer, e.g. 064045 (with Euro plug) or 064046 (with UK plug)

A note on radioactive sources and related equipment

In the following nuclear physics experiments, radioactive sources are used.

Regulations

As the sale and use of radioactive substances are regulated by national authorities, our customers are encouraged to familiarize themselves with the regulations that apply to the specific area and educational institution in question.

Frederiksen Scientific cannot provide radioactive sources unless we receive documentation that the customer and the end user are entitled to handling and using such sources.

Radioactive sources from Frederiksen Scientific

We provide the so-called “Risø” type of radio-active sources, recognizable by the M12 thread and the acrylic handles:

510010 Alpha (Am-241)
510020 Beta (Sr/Y-90)
510030 Gamma (Cs-137)

The first three of these are also available as a set (Item no. 510000) including a common container.

Please refer to our web site for details.

Other radioactive sources

Two other types of radioactive sources are widely used:

Disc-shaped (Ø 25 mm) sources

Cylindrical (Ø 12 mm) sources

Equipment related to radioactive sources

Some items in our program for nuclear physics are specifically designed to accommodate Risø sources – in the following designated “option A”.

In order to allow the use of our equipment with the two other source designs, special versions of the hardware have been designed. These will be marked “option B” (for disc sources), resp. “option C” (for cylindrical sources) in the following pages.

Shipment

Radioactive sources may need to be shipped separately from other ordered equipment.

Alpha, beta and gamma radioactivity

Objective

To investigate the radiation from the three sources concerning the ability to penetrate matter.

To observe the natural background radiation and that radiation arrives at irregular intervals.

Principle

For each source, counts are accumulated in 10-seconds intervals. (The distance to the sources is so small that absorption in the air is negligible.)

Sample results

The table below shows data from one of the measurements:
Beta particles are counted with a fixed distance between source and Geiger tube.

Different absorbers are inserted in front of the Geiger tube.

Source:	Beta, Risø 1979			
Period:	10 s			
Absorber:	(none)	paper	aluminium	lead
Counts:	4433	4117	1215	5
Corrected:	4431	4115	1213	3
% left:	**100%**	92.87%	27.37%	0.07%

With similar measurements on the other two types of sources, the students can formulate a qualitative description of their differences.

Equipment list [a)]

The complete list below may conveniently be referred to as one of the following item numbers:
138410A (option A: For Risø sources)
138410B (option B: For disc sources).
138410C (option C: For cylindrical sources).
Contact costumer service.

Item no.	#	Note	Text
514100	(1)	a	Experiment bench, f. Risø sources, including absorbers *Option A*
512515	1		GM tube with BNC plug
513620	1		GM counter

Notes

a) Please select one option. Regarding the three types of sources mentioned, please see p. 45.

Also required

— Set of sources: Alpha (Am-241), Beta (Sr/Y-90) and Gamma (Cs-137)
Please see p. 45 for details

— Paper (normal copier paper, 80 g/m2)

Alpha particles, the spark detector

Objective

In this experiment we study the alpha radiation from a radioactive source. We will investigate what it takes to stop the radiation and we will find the range of alpha particles in air.

Principle

The spark detector has two electrodes carrying a high voltage – just below the threshold for spontaneous sparking. When an alpha particle pass through the air between the electrodes, some of the air molecules are ionized. The ions and the free electrons will trigger a spark.

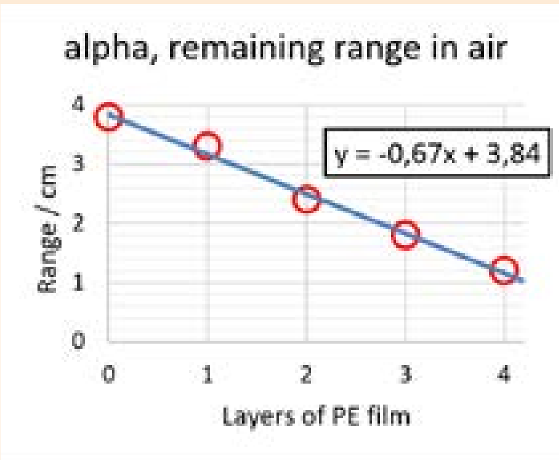
Different materials can be placed between the source and the detector and the distance can be varied.

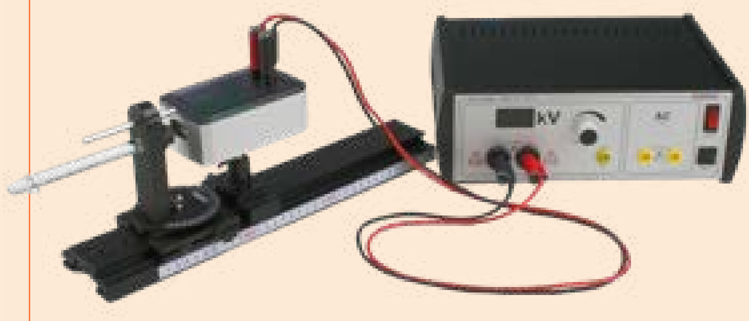
Sample results

The graph shows how the range in air is reduced when a number of cling film layers are inserted in front of the detector. One layer of this particular film reduces the range with 6.7 mm.

This can be compared with the thickness of the foil as declared on the package or even better with a measured thickness.

It turns out that the plastic foil in this case is equivalent to an air layer about 900 times thicker. (This ratio is not far from that between the density of the two materials.)





Equipment list

The complete list below may conveniently be referred to as one of the following item numbers:
138430A (option A: For Risø sources)
138430B (option B: For disc sources).
138430C (option C: For cylindrical sources).
The photo shows Option A.

Item no.	#	Note	Text
514100	(1)	a	Experiment bench, f. Risø sources, including absorbers *Option A*
514120	(1)	a	Experiment bench, f. disc sources, including absorbers *Option B*
514110	(1)	a	Exp. bench, f. cylindrical sources, including absorbers *Option C*
512110	1		Spark detector
367060	1		High voltage supply (0-6 kV)
105740	1		Safety cable 100 cm, black
105741	1		Safety cable 100 cm, red
118530	1		Aluminium foil, 20 m roll
118540	1		Cling film, 60 m roll

Notes

a) Please select one option. Regarding the three types of sources mentioned, please see p. 45

Also required

— Am-241 source. Please see p. 45 for details
— Paper (normal copier paper, 80 g/m²)

Deflection of beta particles – Demo

Objective

To demonstrate the deflection of beta particles in a magnetic field.

Determining the sign of the charge of beta particles.

Introducing the continuous energy distribution.

Principle

The radiation is collimated by a plastic aperture. It then passes an area where a strong magnetic field can be placed, using a pair of permanent magnets. The direction of the field can be reversed.

Sample results

This is a qualitative demonstration. The radiation intensity is monitored through the ticking from the loudspeaker in the Geiger counter. With the recommended beta source (37 kBq), it is easy to hear when the Geiger tube is moved to a position where it is hit by the beta particles.

(For larger audiences, data logging with results displayed on a large screen is an alternative to listening.)

Equipment list [a)]

The complete list below may conveniently be referred to as one of the following item numbers:
13840A (option A: For Risø sources)
138410B (option B: For disc sources).
138410C (option C: For cylindrical sources).
Contact costumer service.

Item no.	#	Note	Text
514105	(1)	b	Deflection of beta particles (for Risø source) *Option A*
514102	1	c	Rail for experiment bench, 40 cm
294610	1	c	Saddle with Ø10mm hole
330850	1		Bar magnets, pair
513620	1		Geiger counter
512515	1		Geiger-Müller tube with BNC-plug

Notes

a) Almost identical equipment list is used in Exp. 138530-EN and Exp. 138550-EN
b) Please select one option. Regarding the three source types mentioned, please see p. 45
c) Included with the Experiment Bench (514100, -10 or -20)

Also required

— Sr/Y-90 beta source. Please see p. 45 for details

The beta spectrum (simple version)

Objective

To investigate the energy distribution of beta radiation. An approximate value of the maximum energy of the beta radiation is to be found.

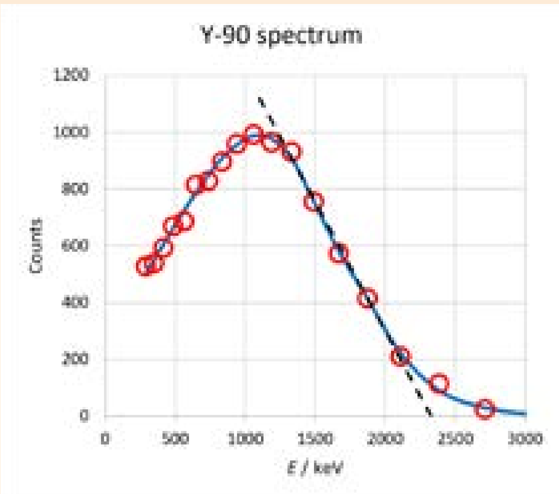
Principle

The radiation is collimated by a plastic aperture. After that, it passes an area with a strong magnetic field from a pair of permanent magnets. In the magnetic field the trajectory of the beta particles is circular with a radius that depends on the velocity of the particles.

The deflection angle is read on the apparatus and is converted into kinetic energy with the help of a graph.

Sample results

This (simple) version of the experiment requires only the most elementary math skills. As a result, the spectrum will be slightly distorted – but will nevertheless show the important features of a continuous spectrum. The maximum beta energy found is remarkably close to the table value.



More advanced students should go for the alternative version, 138550-EN.

Equipment list [a)]

The complete list below may conveniently be referred to as one of the following item numbers:
138430A (option A: For Risø sources)
138430B (option B: For disc sources).
138430C (option C: For cylindrical sources).
Contact costumer service.

Item no.	#	Note	Text
514105	(1)	b	Deflection of beta particles (for Risø source) *Option A*
513620	1		Geiger counter
512515	1		Geiger-Müller tube with BNC-plug
514102	1		Rail for experiment bench, 40 cm
294610	1		Saddle with Ø10mm hole
330850	1		Bar magnets, pair

Notes

a) Almost identical equipment list is used in Exp. 138550-EN

b) Please select one option. Regading the three source types mentioned, please see p. 45

Also required

— Sr/Y-90 beta source. Please see p. 45 for details

The beta spectrum (advanced version)

Objective

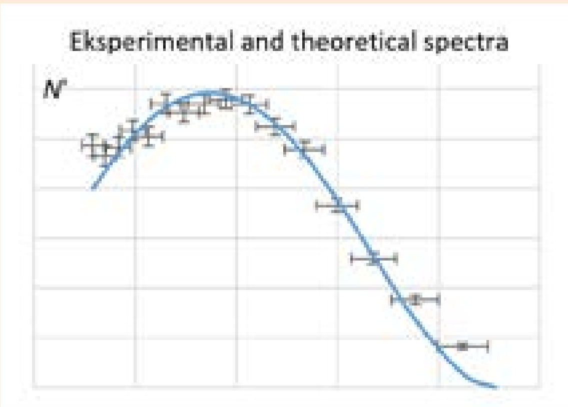
To investigate the energy distribution of beta radiation. The maximum energy of the radiation is found. The experimental and the theoretical spectrum are plotted and compared.

Principle

The radiation is collimated by a plastic aperture. After that, it passes an area with a strong magnetic field from a pair of permanent magnets. In the magnetic field the trajectory of the beta particles is circular with a radius that depends on the velocity of the particles.
The deflection angle is read on the apparatus and is converted into kinetic energy with the help of a graph.

Sample results

First, a Kurie plot is drawn to find the maximum beta energy. Next, this energy is used in Fermi's expression for the theoretical shape of the spectrum. The experimental and theoretical spectra are drawn.



Calculus and more advanced spreadsheet skills (for graph drawing) is used in this experiment.

Equipment list [a)]

The complete list below may conveniently be referred to as one of the following item numbers:
138410A (option A: For Risø sources)
138410B (option B: For disc sources).
138410C (option C: For cylindrical sources).
Contact costumer service.

Item no.	#	Note	Text
514105	(1)	b	Deflection of beta particles (for Risø source) *Option A*
513620	1		Geiger counter
512515	1		Geiger-Müller tube with BNC-plug
514102	1		Rail for experiment bench, 40 cm
294610	1		Saddle with Ø10mm hole
330850	1		Bar magnets, pair
406060	(1)	c	Teslameter

Notes

a) Identical equipment list is used in Exp. 138530-EN – except for 406050
b) Please select one option. Regarding the three source types mentioned, please see p. 45
c) May be omitted if optimum precision is not required – in this case: order 138530 instead.

Also required

— Sr/Y-90 beta source. Please see p. 45 for details

The interaction between cosmic rays and matter

Objective

Demonstrating the particle cascade from cosmic rays; demonstrating a penetrating component of the radiation.

Principle

Three Geiger tubes connect to a coincidence box. By successive addition of steel plates in front of the three Geiger tubes you first observe an increase in the coincidence counts, levelling off to a constant value.

The experiment repeats some of Bruno B. Rossi's historic discoveries of the behaviour of cosmic rays. Rossi invented in 1930 the first electronic coincidence circuit. Today, complicated coincidence measurements are indispensable in particle physics research.

Equipment list [a]

The complete list below may conveniently be referred to as Item no. 138970.

Item no.	#	Note	Text
514200	1		Myon observatory
513800	1		Coincidence box
512525	3		Geiger tube, large area
513620	1		Geiger counter
512565	1		USB communication adapter for 513610

Notes

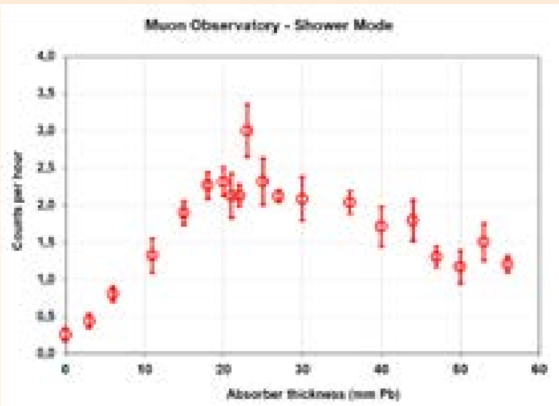
a) The same equipment is used in Exp. 138980

Also required

— PC with software (Freeware – see lab manual)

Sample results

The graph below shows the coincidence count rate as a function of the absorber thickness, revealing the surprising initial increase in count rate when absorbers are added. Likewise, the persisting high count rate for large absorber thickness indicates the existence of a penetrating component in the cosmic rays.



(These results were obtained with lead absorbers. The muon observatory is shipped with steel absorbers – the horizontal scale will be different.)

The angular distribution of secondary cosmic rays

Objective

Establishing a curve for the angular distribution of muons in the cosmic radiation.

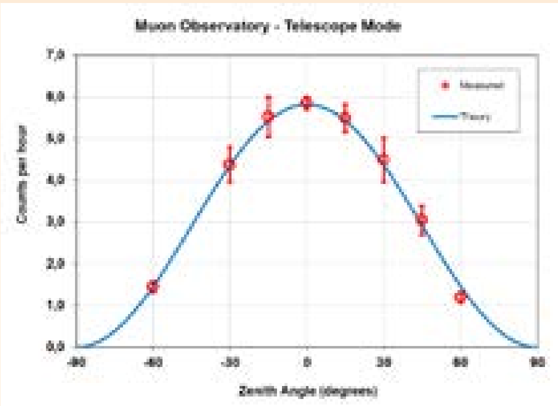
Principle

A line through two (or three) Geiger tubes defines the direction of the incoming particles. By placing a thick absorber between the tubes we ensure that only highly penetrating radiation is detected.

The first measurements of the angular distribution were done in the 1930'ies, shortly after the invention of the coincidence circuit.

Sample results

The muons registered are produced in the top of the atmosphere, it is therefore not surprising that the highest count rate is obtained for zero zenith angle.



When the angle is increased, the combined effect of absorption in the atmosphere and the decay of the muons on their way is observed.

Equipment list [a)]

The complete list below may conveniently be referred to as Item no. 138970.

Item no.	#	Note	Text
514200	1		Myon observatory
513800	1		Coincidence box
512525	3	b	Geiger tube, large area
513620	1		Geiger counter
512565	1		USB communication adapter for 513610

Notes

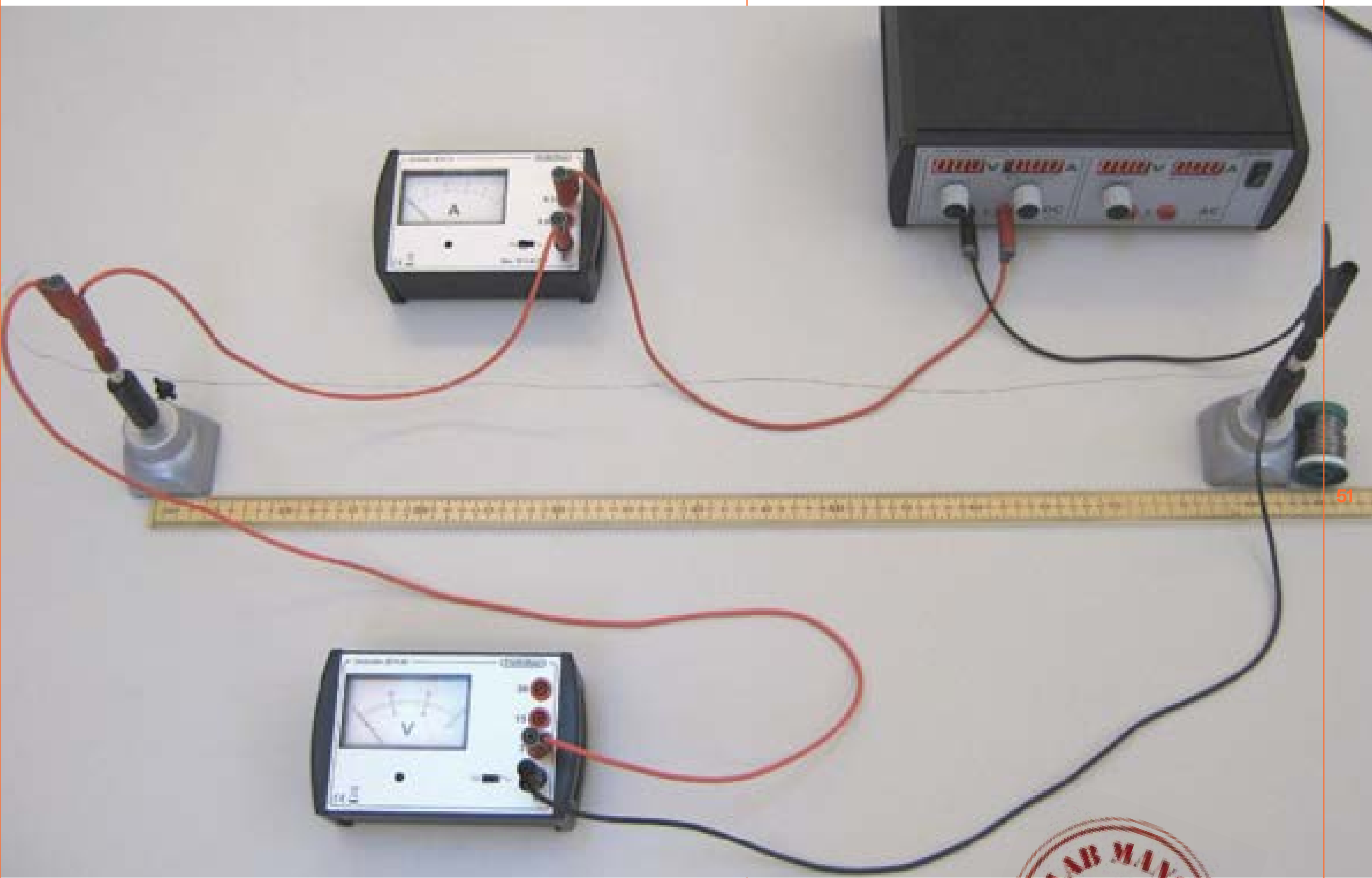
a) The same equipment is used in Exp. 138970
b) Minimum 2 Geiger tubes must be used

Chaptor 2

Lab manual sample

The following pages contain the manual for Ohm's law to illustrate a typical example.

Ohm's law



LAB MANUAL
SAMPLE

Ohm's law

Objective

Examining the relationship between voltage and current for a metal wire.

Principle

A length of Kanthal wire is extended between two terminal posts in order to measure the current through the wire and the voltage across it.
For comparison, the same measurements are carried out for a small incandescent lamp. The results are analysed graphically and compared with Ohm's law.

Equipment

(Detailed equipment list on last page)
— Power supply
— Volt- and ammeters
— Kanthal wire 0.50 mm
— Bulb, 6 V / 1 A
— Socket for light bulb
— Stand material
— Lab leads
— Ruler, 1 m

Using multimeters

Instead of Frederiksen's analog instruments, you can use digital multimeters. Hints for use:

As an ammeter

We will need a current of up to 0.5 A. The safest is to use the high current input of the meter. Look at the sockets: If there is a separate socket marked “10 A” – this is the one to use together with the “Com” socket.

As a voltmeter

If the multimeters hasn't auto ranging, pick a range that is capable of measuring 3 V.

If the meter has both a “mV” and a “V” socket, use “V” together with the “Com” socket.

Procedure

The wire can be reused many times. Don't cut it, unless explicitly instructed to do so. Instead, just let the coil stand next to the experiment and rewind the wire afterwards.

Fasten the wire thoroughly to the terminal posts with approximately 80 cm between the posts when the wire is tight.

Don't waste time on adjusting the length but measure the actual length accurately and write it down. If the power supply has a current limiter, the measurements can be carried out with this turned fully up, with only the voltage adjusted. Turn the voltage down to 0 V while setting up.

When you connect the volt- and ammeters, proceed systematically:

1. First, establish a circuit for the current to follow
2. Next, connect the voltmeter between the points where the voltage is to be measured.

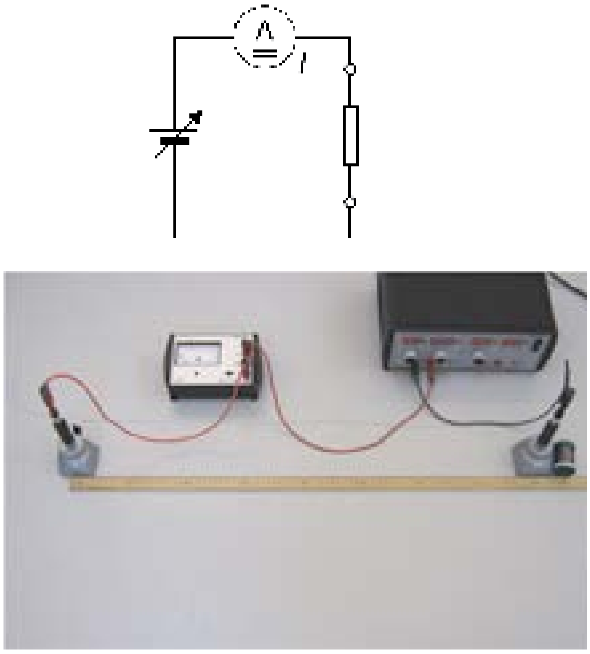
In this experiment, all measurements can be done with voltmeter range 3 V and ammeter range 0.5 A. Both voltage nor current must be kept below these limits.
The instruments are set to DC measurements.

Make a table for the result as shown below. When ready, turn up the voltage slightly. Both instruments should respond now. Continue carefully until you reach either 3 V or 0.5 A. Now you know the maximum values – write them down.

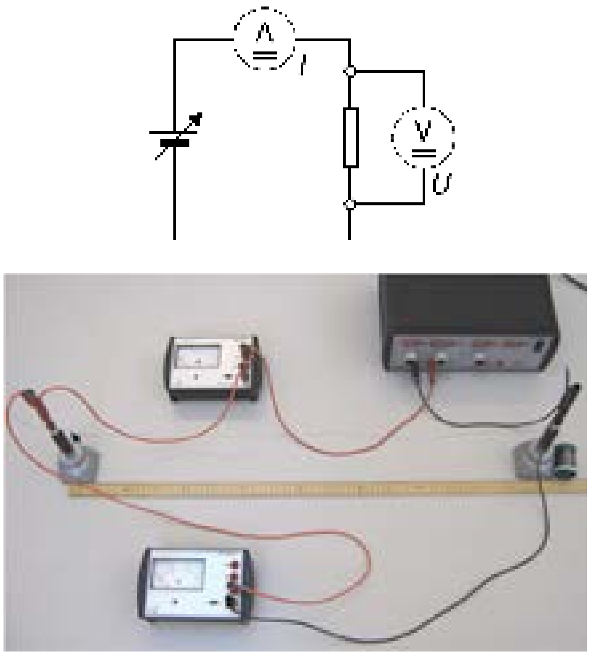
Now, you must plan and carry out a series of measurements – 7 to 10 all in all – with the voltage stepping up more or less evenly from 0 V to the maximum value.

For each measurement, write down both voltage and current in the table.

Now replace the wire and terminal posts with the 6 V / 1 A bulb in a socket. Repeat the entire measurement series. The lowest voltages are important here - try to hit about 0.1 V in one of the measurements.



1 First, establish a circuit for the current ...



2 ... then add the voltmeter.

Table for results

Make a table like the one below:

Measured		Calculated
U	*I*	*R*
V	*A*	*Ω*

Theory

The voltage U across an electric component often varies in step with the current I through it. U is said to be proportional to I , and the relationship is expressed mathematically as:

$$U = R \cdot I$$

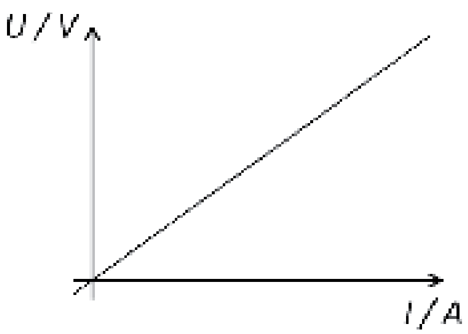
Here *R* is a constant, called the components resistance.

Thus, in this experiment we find the resistance of this length of wire. When you enter *U* in *V* and *I* in *A*, *R* will come out with the unit Ω (read: "ohm"). This formula is known as Ohm's law. A graph with I along the 1st axis and U along the 2nd axis results in a straight line through (0,0). Even if this relationship between current and voltage often is valid, it is absolutely not universally true.

If *U* and *I* are known, *R* can be found:

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

If Ohm's law holds true for a given component, the value of *R* is a constant – and vice versa. Even if Ohm's law does not apply, you can of course insert measured values of *U* and *I* to calculate *R* – but in that case it would not be correct to speak about a resistance.

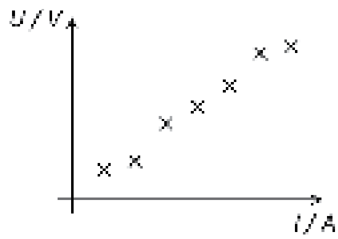


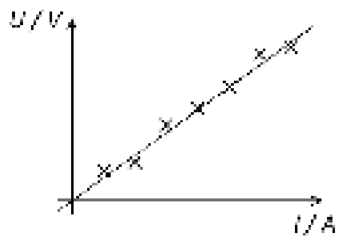
Calculations

Draw a graph of the results for the Kanthal wire. It can be done in a spreadsheet or on paper: The units on the axes should let 2 cm correspond to 0.1 A (1st axis) resp. 5 cm correspond to 1 V (2nd axis). Plot the measurement points – mark them with small crosses – the points must not be connected by lines.

When all result have been plotted, try to draw a straight line through (0,0), lying as close as possible to all the measured points. (A transparent ruler will be a great advantage.)

Calculate R for all measuring points in the table. Similarly, plot the points for the light bulb in a spreadsheet or on paper. – Is it possible again to fit the points with a straight line through (0,0) ?





Discussion and evaluation

We must always take into account that measured values have uncertainties, meaning that small deviations from theory are acceptable!
We are interested to know if the metal wire obeys Ohm's law. That can be decided in two ways:

— Do the points roughly lie on a straight line?
— Has R approximately a constant value?

Do the two methods give the same answer? Does the metal wire comply with Ohm's law? Does the light bulb? (Justify your answers.)

Teacher's notes

Concepts used
— Voltage
— Current
— Resistance

Mathematical skills
— Graph drawing
— Evaluation of a simple formula

About the equipment
The instruments 381560 and 381570 are overload protected. They will also tolerate wrong polarity although only positive values can be read.

It will eventually be possible to read the current on a built-in ammeter in the power supply – if you want to avoid an external meter.

On the other hand, from a pedagogical perspective, it will be undesirable to use a built-in voltmeter. It will not in this context cause real problems for the measurement, but the students should get used to connect the voltmeter directly across the component in question.

Detailed equipment list

Specifically for this experiment
381570 Ammeter
381560 Voltmeter
115520 Kanthal wire 0.50 mm
425040 Bulb 6 V / 1 A (box with 10)
412000 Lamp socket E10, 2 connectors

Standard lab equipment
361600 Power supply
(Alternative power supply: 364000. The photo on p. 1 shows this model)
435030 Terminal posts, insulated (pair)
000410 Retort stand base, square (2 pcs.)
105720 Safety cable, silicone, 50 cm, black
105721 Safety cable, silicone, 50 cm, red (2 pcs.)
105740 Safety cable, silicone, 100 cm, black
105741 Safety cable, silicone, 100 cm, red
140510 Ruler, 100 cm

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