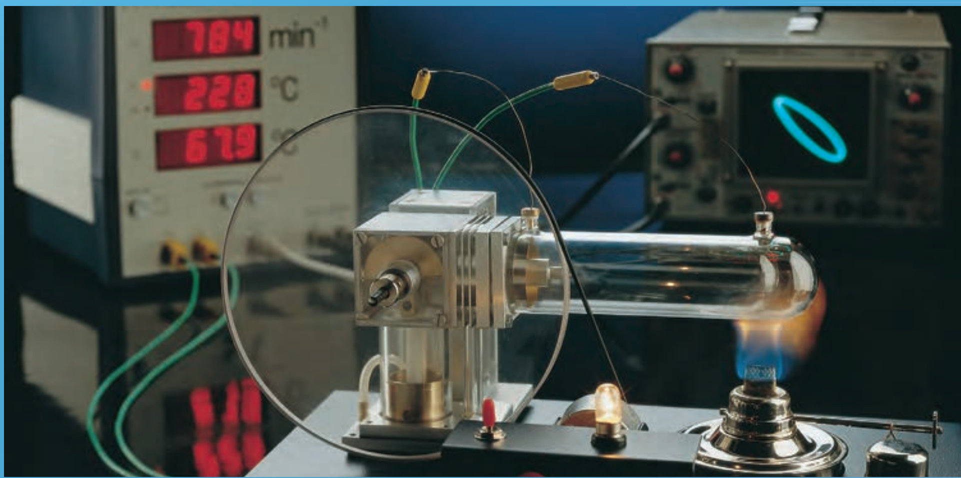
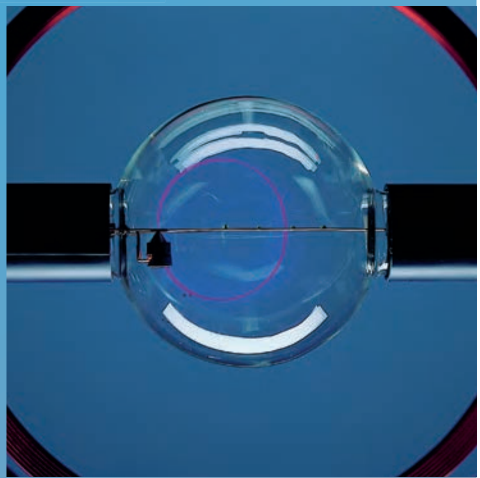
TESS expert PHYWE

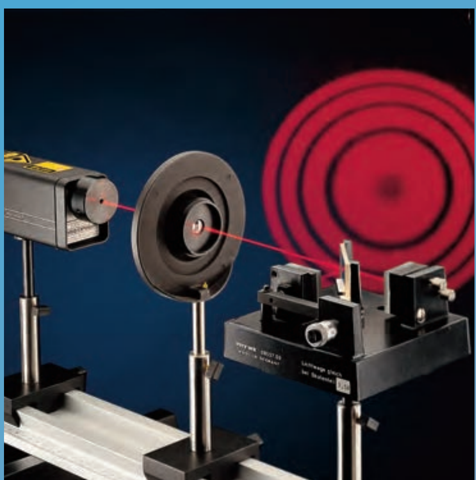
Demo expert PHYWE

PhySci

May 2017







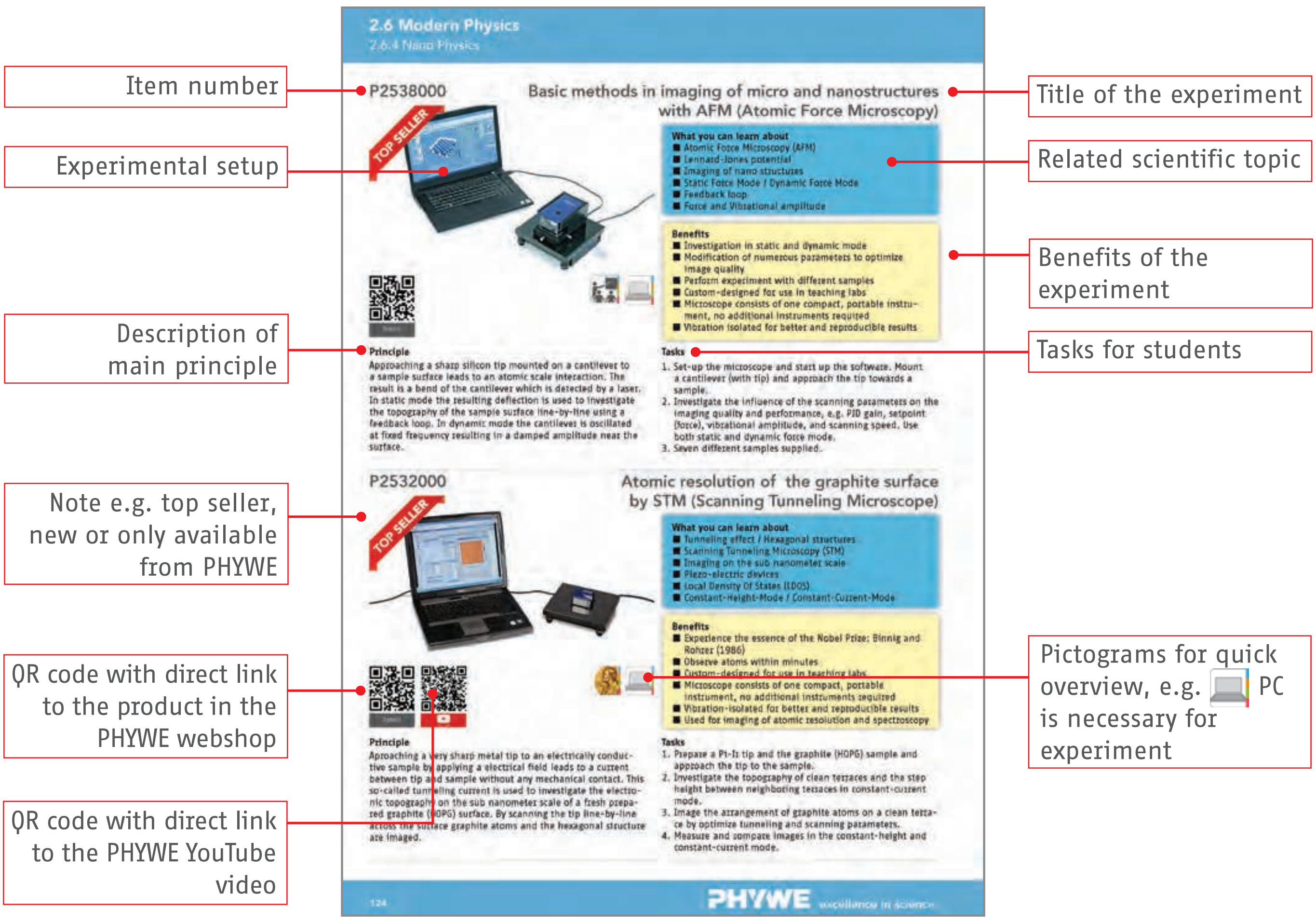
Physics & Applied Sciences

University Experiments

PHYWE excellence in science

How to use
the catalogue pages

The TESS and Demo expert catalogue is adapted to the PHYWE reference curriculum. PHYWE's experiments fit the content of experimental lectures and lab courses of schools, colleges and universities. The description of each experiment offers you a lot of information:



Pictograms for a quick overview of categories, related films or information:

Experiments with the computer-based measuring system Cobra4	Experiments for which a PC is required
Experiments are suitable for tablet teaching	Nobel Prize-awarded experiment
Basic set, suitable for included experiments and required for extension sets	Extension set requiring a basic set
Training recommended	Experiments with laser
Experiments with radioactivity	Product movie available. QR Code to the PHYWE channel on YouTube
Further information about the experiment. QR code to the PHYWE website.	

Physics: Curricula Compliant Experiments –

for your educational needs

PHYWE™ experiments are matched to the curricula of more than 30 selected universities worldwide. The interaction between PHYWE's experiments and the supporting content of experimental lectures and lab courses has led to the creation of a teaching package that is highly relevant to the taught curricula worldwide.

Physics

Bachelor of Science Courses - Reference Curriculum

Content	1. Sem.	2. Sem.	3. Sem.	4. Sem.	5. Sem.	6. Sem.
Laboratory Experiments	Mechanics, Acoustics (Chapters 2.1, 2.2) Measurement Techniques (Chapter 2.1)	Thermo-dynamics (Chapter 2.3)	Electricity, Magnetism (Chapter 2.4)	Optics, Laser Physics-Photonics (Chapter 2.5)	Quantum Physics, Solid State Physics (Chapter 2.6)	X-ray Physics, Nuclear Physics - Radioactivity, Particle Physics (Chapter 2.6)
Experimental Physics	Classical Experimental Physics Lecture + Tutorial (Chapters 2.1, 2.2, 2.3, 2.4)		Structure of Matter, Nano Physics Lecture + Tutorial (Chapter 2.6)		Atomic Physics, Molecule and Solid State Physics Lecture + Tutorial (Chapter 2.6)	
Interdisciplinary Subject	Mathematics		Computational Physics		Subsidiary and Elective Subjects	Subsidiary and Elective Subjects
Theoretical Courses	Classical Theoretical Physics Lecture + Tutorial			Modern Theoretical Physics Lecture + Tutorial		
Bachelor Thesis						Bachelor Thesis

100% of the lab courses are covered by PHYWE experiments!

PHYWE Experiments available in the Physics chapters of this catalogue

Download all catalogues at the PHYWE Website or watch them online in your browser

Lab course experiments for students of **medical sciences, biology, chemistry and engineering** with suggestions of popular experiments in mechanics, electricity, thermodynamics, optics, modern physics and specialised topics.
For further experiments please refer to the Applied Sciences chapters 3.1 to 3.4.

Physics as a minor subject

Reference Curriculum

Subject	Medical Sciences	Biology	Chemistry	Mechanical Engineering	Electrical Engineering	Biomedical Engineering	Pages in Physics	Pages in Applied Sciences
I. General physics lab								
Measurement of basic constants	X	X	X	X	X	X	14	-
Ohm's law	X	X	X	X	X	X	68	170
Wheatstone bridge	X	X	X	X	X	X	68	170
Kirchhoff's law	X	X	X	X	X	X	71	171
Law of lenses and optical instruments	X	X	X	X	X	X	92	-
Surface tension with the ring method (Du Nouy method)	X	X	X	X		X	30	-
Free fall	X	X	X	X			16, 17	-
Equation of state for ideal gases (gas laws: Gay-Lussac, Amontons, Boyle)	X	X	X			X	44	178
Mechanical equivalent of heat	X	X	X	X			48	179
Dispersion and resolving power of a prism and a grating spectroscope	X	X	X		X		93	-
Modulus of elasticity / Young's Modulus	X			X	X		25	154
Viscosity measurement with the falling ball viscometer	X	X	X				29	-
Heat capacity of metals	X	X	X				47, 48	156, 179
Transformer	X	X	X		X		77	173, 181
Polarisation through quarter-wave plates	X	X	X			X	99	-
II. Mechanics and thermodynamics lab								
Mechanical hysteresis				X	X		25	154
Moments				X			24	154
Forced oscillations - Pohl's pendulum				X			35	-
Velocity of sound using Kundt's tube and digital function generator				X			40	-
Mechanical conservation of energy/ Maxwell's wheel				X		X	21	-
Stefan-Boltzmann's law of radiation			X	X		X	50	185
Solar ray collector				X			57	185
Electric compression heat pump				X			53	183
III. Electricity lab								
RLC circuit				X	X		80	174
Franck-Hertz experiment with a Hg-tube			X		X	X	108	-
Hall effect in n- and p-germanium				X	X		117	157, 175f
Electric fields and potentials in the plate capacitor					X		62	171
Characteristic curves of semiconductors					X		69, 70	171, 179
Charging curve of a capacitor					X		64, 65	172, 180
Magnetic moment in the magnetic field					X		73	-
Ferromagnetic hysteresis					X		76	159
Resistance, phase shift and power in AC circuits					X		82	-
RC filters					X		81	174
Specific charge of the electron - e/m					X		107	-
IV. Specialty physics lab								
XR 4.0 X-ray system, complete set to perform more than 50 experiments	X	X	X	X		X	136ff	162f, 193f
Mechanics of flow	X	X		X		X	28	197
Ultrasonic echography (A-Scan)	X			X		X	-	167, 197
Detection of discontinuities				X		X	-	166
Compact MRT to perform 5 experiments from NMR to Spin Echo 3D	X		X			X	113	195
Basic methods in imaging of micro and nanostructures with AFM				X		X	124	160
Inverse-square law and absorption of gamma or beta rays	X	X	X			X	130	-

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- Up-to-date software downloads
- **Free-of-charge experiment guides**
- Operating manuals and instruction sheets to download
- Complete list of equipment

1. Language
2. Education level = School (age 11-16 and age 16-19), University
3. Media e. g. product videos
4. Downloads e. g. experimental literature, operating instruction or software
5. Free newsletter - stay informed

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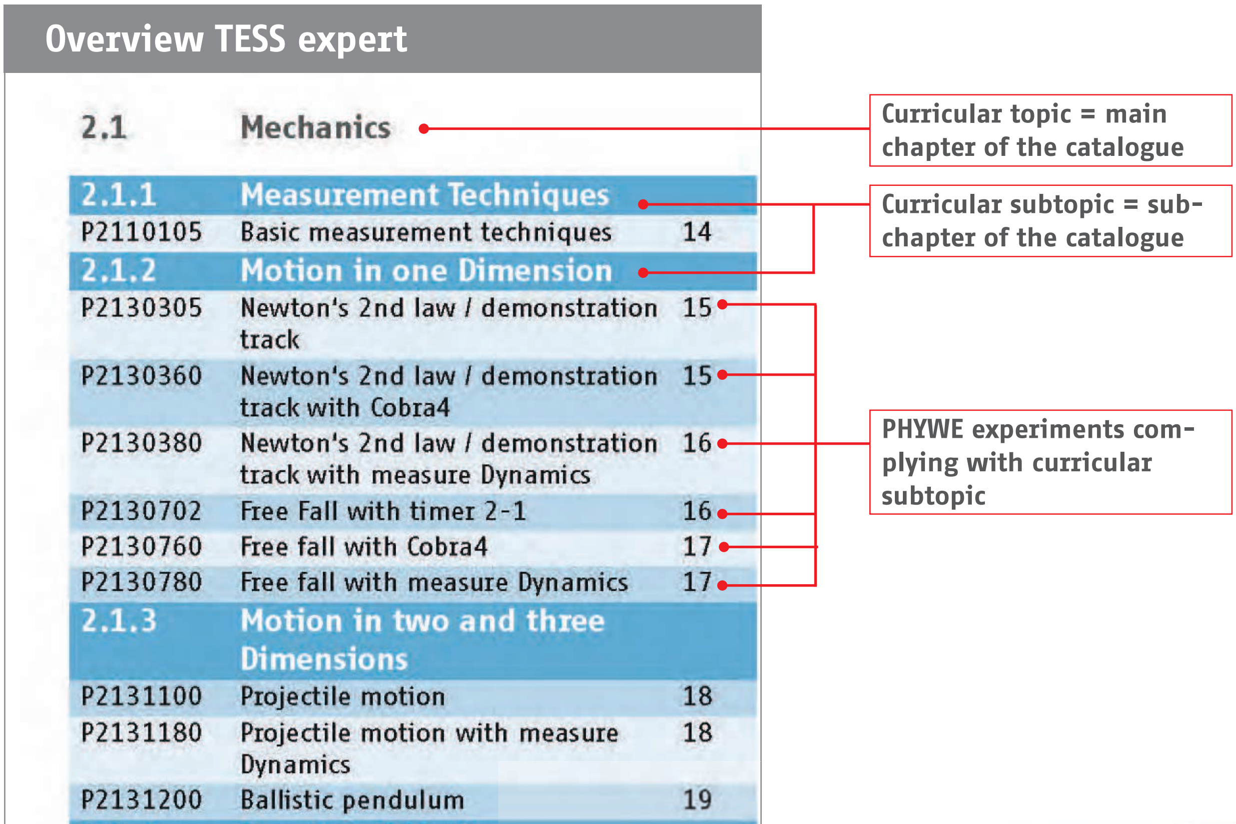
TESS & Demo expert Physics

How to use
the table of contents

Use the curricula-based content on the next pages to find your topics and our corresponding experiments. The TESS™ and Demo expert catalogue is adapted to international university curricula making it easy for you to find experiments corresponding to your desired topic. On each page you find the detailed description of one of our university-level experiments. More information including the complete experiment guides is available on our website **www.phywe.com.**



Find the overview of all experiments fitting to the international Reference Curriculum on our hompage!

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2 Physics

2.1 Mechanics

2.2 Oscillations and Mechanical Waves, Acoustics

2.5 Light and Optics


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3 Applied Sciences

3.1 Material Sciences

3.2 Electrical Engineering

3.3 Renewable Energy


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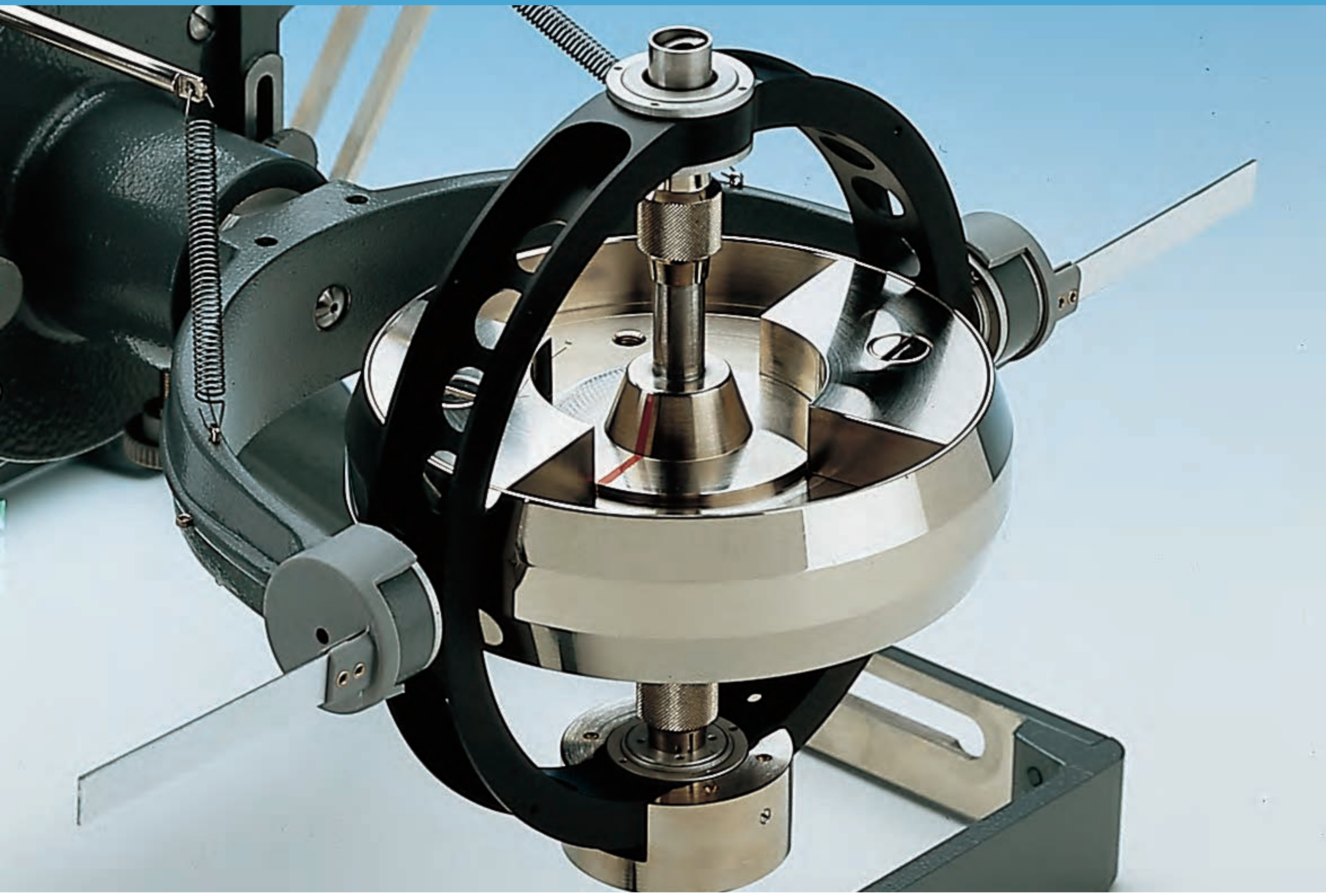


2.1 Mechanics

P2110105

Basic measurement techniques

Details

What you can learn about
- Length
- Diameter
- Inside diameter thickness
- Curvature
- Vernier

Benefits
- Foundation of every practical sciences lab course
- Aquire the skills to measure basic mechanical variables
- Realise the limits of measuring accuracy
- Combine different measurements to determine a quantity of interest
- Determine curvatures using the spherometer

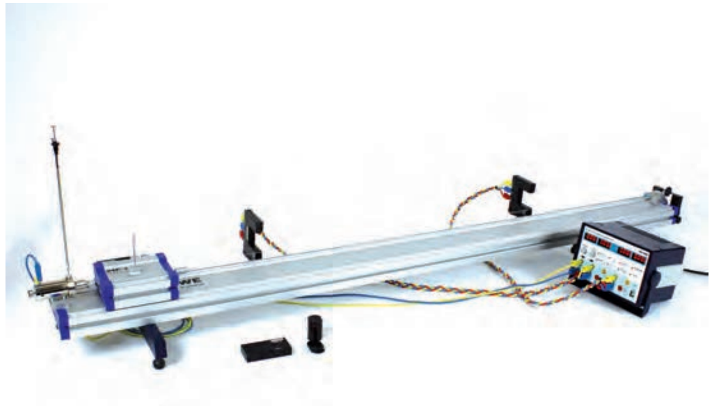
Principle
Caliper gauges, micrometers and spherometers are used for the accurate measurement of lengths, thicknesses, diameters and curvatures. Measuring procedures, accuracy of measurement and reading accuracy are demonstrated.

Tasks
1. Determination of the volume of tubes with the caliper gauge.
2. Determination of the thickness of wires, cubes and plates with the micrometer.
3. Determination of the thickness of plates and the radius of curvature of watch glasses with the spherometer.

Newton's 2nd law / demonstration track P2130305

What you can learn about
- Velocity
- Acceleration
- Force
- Acceleration of gravity

Benefits
- Accurate results due to measurements with low friction: cart with sapphire bearings
- Over the entire track length adjustable feet for a very simple alignment of the track even on small tables
- Extremely robust accessories, for example no overloading of carts due to elastic bearing of base plate, prevent unnecessary breakdowns
- Detailed, illustrated step-by-step manual



Details

Principle

The distance-time law, the velocity time law, and the relationship between mass, acceleration and force are determined with the aid of the demonstration track rail for uniformly accelerated motion in a straight line.

Tasks

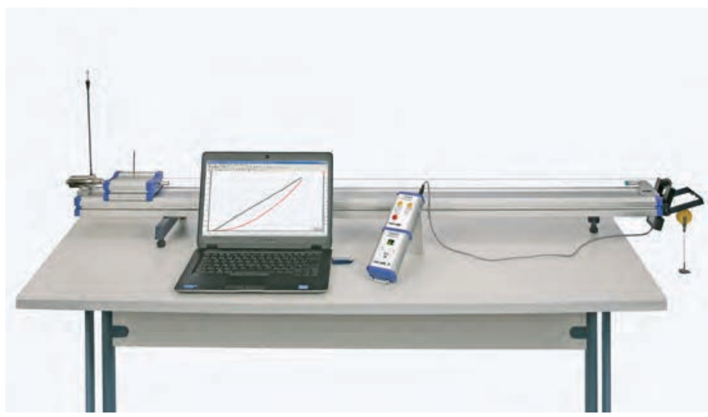
Determination of:

1. Distance travelled as a function of time
2. Velocity as a function of time
3. Acceleration as a function of the accelerated mass
4. Acceleration as a function of force.

Newton's 2nd law / demonstration track with Cobra4 P2130360

What you can learn about
- Linear motion
- Velocity
- Acceleration
- Conservation of energy

Benefits
- Accurate results due to measurements with low friction: cart with sapphire bearings
- Over the entire track length adjustable feet for a very simple alignment of the track even on small tables
- Extremely robust accessories, for example no overloading of carts due to elastic bearing of base plate, prevent unnecessary breakdowns
- Silent operation



Details

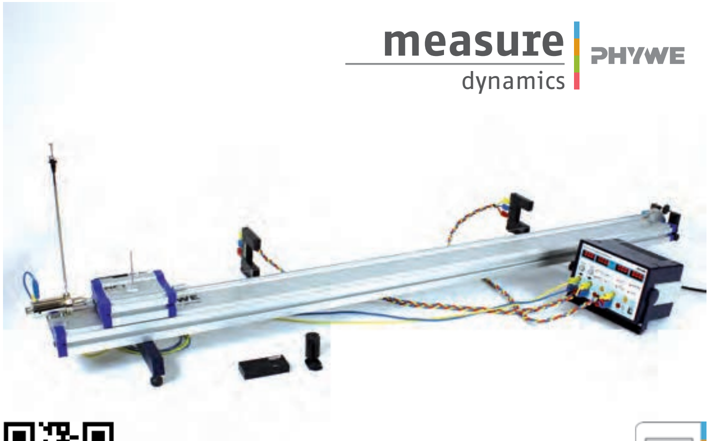
Principle

According to Newton's 2nd law of motion for a mass point, the relationship between mass, acceleration and force are investigated.

Tasks

1. The distance-time law, the velocity time law and the relationship between mass, acceleration and force are determined.
2. The conservation of energy can be investigated.

P2130380 Newton's 2nd law / demonstration track with measure Dynamics



Details

What you can learn about
- Linear motion
- Velocity
- Acceleration
- Conservation of energy
- Kinetic energy
- Potential energy

Benefits
- Accurate results due to measurements with low friction: cart with sapphire bearings
- Very demostrative and easy way to evaluate results by using measure Dynamics
- Extremely robust accessories, for example no overloading of carts due to elastic bearing of base plate, prevent unnecessary breakdowns

Principle
The motion an accelerated cart will be recorded by way of a video camera. The relationship between distance and time, velocity and time, and the relationship between mass, acceleration, and force will be determined. In addition, the conversion of potential energy into kinetic energy will be displayed graphically as well as by integrating the various forms of energy into the video in the form of bars.

Tasks
1. Determination of the distance covered as a function of time.
2. Determination of the velocity as a function of time.
3. Integration of the velocity into the video.
4. Graphical display of the conversion of potential energy into kinetic energy while demonstrating the law of conservation of energy.
5. Integration of the potential, kinetic, and total energy into the video.

P2130702 Free Fall with timer 2-1

Details

What you can learn about
- Linear motion due to constant acceleration
- Laws of falling bodies
- Gravitational acceleration

Benefits
- Gravitation scrutinized
- Find out how the velocity of a falling object increases
- Didactical demonstration of the falling distances
- Visualise the squared distance-time law
- Steady set-up
- All crucial parts directly engineered for this experiment

Principle
A sphere falls freely over certain distances. The falling time is measured and evaluated from diagrams. The acceleration due to gravity can be determined.

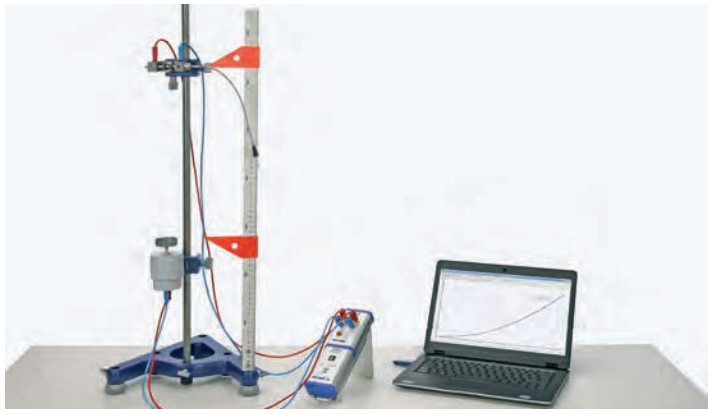
Tasks
1. To determine the functional relationship between height of fall and falling time.
2. To determine the acceleration due to gravity.

Free fall with Cobra4

P2130760

What you can learn about
- Linear motion due to constant acceleration
- Laws governing falling bodies
- Acceleration due to gravity

Benefits
- Gravitation scrutinized
- Find out how the velocity of a falling object increases
- Didactical demonstration of the falling distances
- Visualise the squared distance-time law
- Steady set-up
- All crucial parts directly engineered for this experiment



Details

Principle

The fall times t are measured for different heights of fall h. h is represented as the function of t or t^2, so the distance-time law of the free fall results as $h = 1/2 \cdot g \cdot t^2$. Then the measured values are taken to determine the acceleration due to gravity.

Tasks

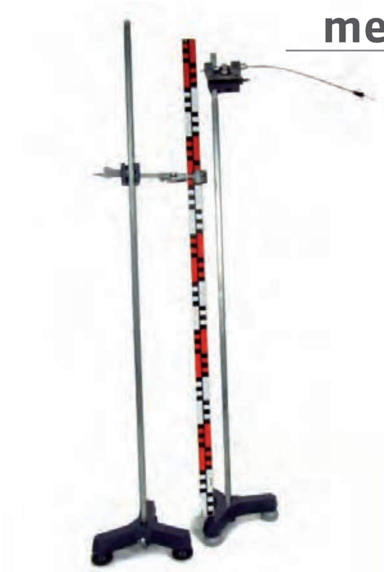
Determination of
1. Distance time law for the free fall,
2. Velocity-time law for the free fall,
3. Precise measurement of the acceleration due to gravity for the free fall.

Free fall with measure Dynamics

P2130780

What you can learn about
- Linear motion due to constant acceleration
- Laws governing falling bodies
- Acceleration due to gravity

Benefits
- Gravitation scrutinized
- Find out how the velocity of a falling object increases
- Didactical demonstration of the falling distances
- Visualise the squared distance-time law
- Steady set-up
- All crucial parts directly engineered for this experiment



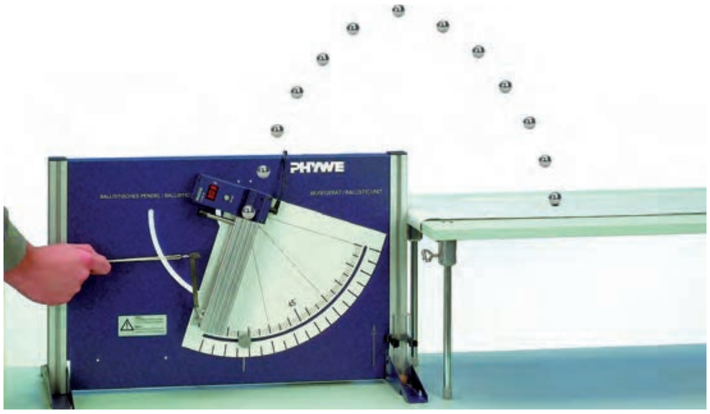
Details

Principle

The aim of this experiment is to film a high-speed video of a sphere falling from the height of fall h. The "measure Dynamics" software is used for the graphical representation of the distance as a function of time t and also as a function of the square of time t^2 as well as the graphical representation of the velocity v and acceleration a as a function of time t. Then, the measured values are used to determine the gravitational acceleration g. The velocity and acceleration are then integrated into the video, followed by a discussion of the results.

Tasks
1. Determination of the gravitational acceleration by way of the distance-time law for the free fall.
2. Determination of the gravitational acceleration by way of the velocity-time law for the free fall.
3. Determination of the gravitational acceleration.
4. Integration of the velocity and acceleration into the video.

P2131100 Projectile motion



Details

What you can learn about
- Trajectory parabola
- Motion involving uniform acceleration
- Ballistics

Benefits
- Learn a classic method to determine a projectile's velocity
- See how to utilize conservation laws for finding "hard to get" quantities
- Immediate evaluation with the integrated velocity measurement
- Magnetic mount of the different projectiles
- Quick and easy set-up for universal and modular use
- Equipment also suitable for demonstration experiments

Principle
A steel ball is fired by a spring at different velocities and at different angles to the horizontal. The relationships between the range, the height of projection, the angle of inclination and the firing velocity are determined.

Tasks
1. To determine the range as a function of the angle of inclination.
2. To determine the maximum height of projection as a function of the angle of inclination.
3. To determine the (maximum) range as a function of the initial velocity.

P2131180 Projectile motion with measure Dynamics

measure dynamics

Details

What you can learn about
- Trajectory parabola
- Motion involving uniform acceleration
- Ballistics

Benefits
- Learn a classic method to determine a projectile's velocity
- See how to utilize conservation laws for finding "hard to get" quantities
- Immediate evaluation with the included velocity measurement Magnetic mount of the different projectiles
- Quick and easy set-up for universal and modular use
- Equipment also suitable for demonstration experiments

Principle
A steel sphere is launched by a ballistic unit and the resulting trajectory is filmed with the aid of a video camera. The "measure Dynamics" software is used to demonstrate the dependence of the trajectory on the launching angle and on the initial velocity, and to determine the range and height of the trajectory. In addition, the resulting trajectory is integrated into the video, followed by a discussion of the course of the velocity.

Tasks
1. Determination of the trajectory.
2. Determination of the launching angle.
3. Determination of the initial velocity.
4. Determination of the range.
5. Determination of the maximum height.
6. Integration of the trajectory into the video.
7. Integration of the velocity vectors into the video.

Ballistic pendulum

P2131200

Details

Principle

A classic method of determining the velocity of a projectile is to shoot it into a resting mass hung as a pendulum. The projectile remains in the pendulum and swings with it. This is an inelastic collision in which the momentum remains unchanged. The velocity of the pendulum's mass (including the projectile's mass) at the lowest point of the pendulum can be derived from the amplitude of the pendulum's oscillation.

Additionally to the set-up, two light barriers and a time measuring device are available for an independent, direct measurement of the initial velocity of the ball.

Tasks

Measure the amplitude of the pendulum for three different initial velocities of the shot ball.

Benefits

- Use conservation laws to find hard-to-get quantities
- Direct velocity measurement for immediate evaluation
- Magnetic mount of the different projectiles
- Unique angle measurement with the trailing pointer
- Equipment also suitable for demonstration experiments

What you can learn about

- Rotational, potential and kinetic energy
- Moment of inertia
- Inelastic collision
- Principle of conservation of momentum
- Angular momentum

P2131305 Moment of inertia and angular acceleration with a precision pivot bearing

Details

What you can learn about
- Angular velocity
- Rotary motion
- Moment
- Moment of inertia of a disc
- Moment of inertia of a bar
- Moment of inertia of a mass point

Benefits
- Long runtime
- Nearly friction-less movement due to precision bearing and precision pulley
- Steady set-up prevents interferences

Principle
A moment acts on a body which can be rotated about a bearing without friction. The moment of inertia is determined from the angular acceleration.

Tasks
From the angular acceleration, the moment of inertia is determined as a function of the mass and the distance from the axis of rotation

1. of a disc
2. of a bar
3. of a mass point

P2131363 Moment of inertia and angular acceleration with Cobra4 and a precision pivot bearing

Details

What you can learn about
- Angular velocity
- Rotation
- Moment
- Torque
- Moment of inertia
- Rotational energy

Benefits
- Long runtime
- Nearly friction-less movement due to precision bearing
- Steady set-up prevents interferences
- Data logging reveals instantaneous results during measurement

Principle
If a constant torque is applied to a body that rotates without friction around a fixed axis, the changing angle of rotation increases proportionally to the square of the time and the angular velocity proportional to the time.

Tasks
1. Measurement of the laws of angle and angular velocity according to time for a uniform rotation movement.
2. Measurement of the laws of angle and angular velocity according to time for a uniformly accelerated rotational movement.
3. Rotation angle; is proportional to the time *t* required for the rotation.

Mechanical conservation of energy / Maxwell's wheel

P2131800

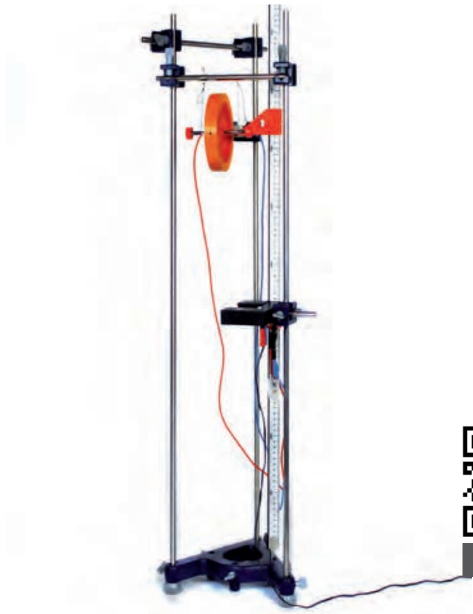
What you can learn about

- Maxwell disc
- Energy of translation and rotation
- Potential energy
- Moment of inertia
- Angular velocity and acceleration
- Instantaneous velocity

Gyroscope

Benefits

- High and sturdy set-up
- Expressive demonstration of energy conversion
- Convert potential energy in energy of rotation, energy of translation, and vice versa



Details

Principle

A wheel, which can unroll with its axis on two cords, moves in the gravitational field. Potential energy, energy of translatio-nand energy of rotation are converted into one another and aredetermined as a function of time.

Tasks

The moment of inertia of the Maxwell disc is determined. Using the Maxwell disc,

1. the potential energy,
2. the energy of translation,
3. the energy of rotation,

are determined as a function of time.

Mechanical conservation of energy / Maxwell's wheel with measure Dynamics

P2131880

What you can learn about

- Maxwell disc
- Energy of translation and rotation
- Potential energy
- Moment of inertia
- Angular velocity and acceleration
- Instantaneous velocity
- Gyroscope

Benefits

- High and sturdy set-up
- Expressive demonstration of energy conversion
- Convert potential energy in energy of rotation, energy of translation, and vice versa
- Easy measurement and evaluation via movement tracking software

measure dynamics PHYWE

Details

Principle

A wheel, which can unroll around its axis on two cords, moves a gravitational field. This process is filmed with a video camera. The potential energy, kinetic energy, and rotational energy are converted into one another and determined as a function of time with the aid of the "measure Dynamics" software.

Tasks

1. Determination of the moment of inertia of the Maxwell wheel by way of the distance-time relationship.
2. Determination of the moment of inertia of the Maxwell wheel by way of the velocity-time relationship.
3. Graphical representation of the potential energy, kinetic energy, and rotational energy as a function of time.

P2131900 Laws of gyroscopes / 3-axis gyroscope

Details

What you can learn about
- Momentum of inertia
- Torque
- Angular momentum
- Precession
- Nutation

Benefits
- Long-lasting motion due to low friction
- Slow rotation allows a comfortable measurement
- Quickly establish equilibrium with the easy to adjust counterweight
- Adjust the torque by adding additional weights

Principle
The momentum of inertia of the gyroscope is investigated by measuring the angular acceleration caused by torques of different known values. Two axes of the gyroscope are fixed. The relationship between precession frequency and gyro-frequency of the gyroscope with 3 free axes is examined for different torques applied to the axis of rotation. If the axis is slightly displaced, a nutation is induced. The nutation frequency will be investigated depending on the gyro-frequency.

Tasks
1. Determination of the momentum of inertia by measuring
   a) the angular acceleration, or
   b) the gyro-frequency and precession frequency.
2. Investigation of the relationship between precession and gyro-frequency and its dependence from torque.
3. Investigation of the relationship between nutation frequency and gyro-frequency.

P2132000 Laws of gyroscopes / cardanic gyroscope

Details

What you can learn about
- Moment of inertia
- Torque
- Angular momentum
- Nutation
- Precession

Benefits
- Unique set-up of the Magnus-type gyroscope
- Detailed manual with various further experiments, wide range of accessories, and sturdy storage box included
- Ideal for demonstration on university level
- Complies with the quality standards and requirements of the most demanding instructors in aeronautics education
- Large disc for demonstrative experiments

Principle
If the axis of rotation of the force-free gyroscope is displaced slightly, a nutation is produced. The relationship between precession frequency or nutation frequency and gyro-frequency is examined for different moments of inertia. Additional weights are applied to a gyroscope mounted on gimbals, so causing a precession.

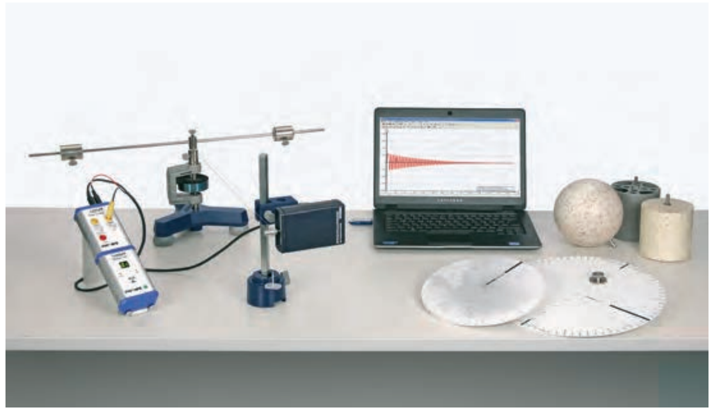
Tasks
1. To determine the precession frequency as a function of the torque and the angular velocity of the gyroscope.
2. To determine the nutational frequency as a function of the angular velocity and the moment of inertia.

Moments of inertia of different bodies / Steiner's theorem with Cobra4

P2132860

What you can learn about
- Rigid body
- Moment of inertia
- Centre of gravity
- Axis of rotation
- Torsional vibration
- Spring constant
- Angular restoring force

Benefits
- Angular oscillation apparaturs includes five different body shapes for in-depth experimenting
- High-precision movement sensor
- Very robust and durable setup



Details

Principle
The moment of inertia of a solid body depends on its mass distribution and the axis of rotation. Steiner's theorem elucidates this relationship.

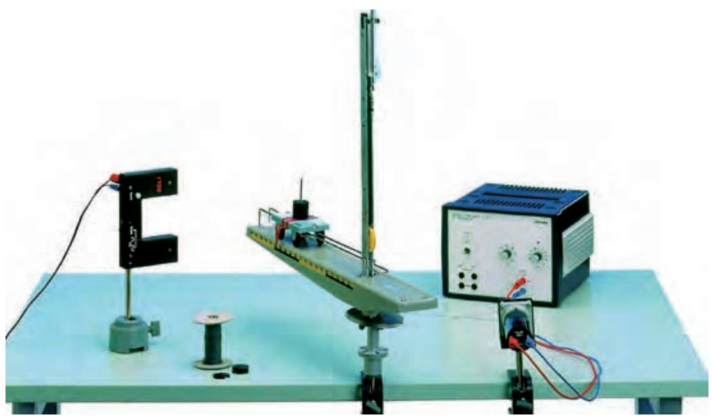
Tasks
1. The moments of inertia of different bodies are determined by oscillation measurements.
2. Steiner's theorem is verified.

Centrifugal force

P2131601

What you can learn about
- Centripetal force
- Rotary motion
- Angular velocity
- Apparent force

Benefits
- Easy to read measures
- Several loadable weights enable variable set-up
- Freely set various steady rotational velocities



Details

Principle
A body with variable mass moves on a circular path with adjustable radius and variable angular velocity. The centrifugal force of the body will be measured as a function of these parameters.

Tasks
Determination of the centrifugal force as a function
1. of the mass,
2. of the angular velocity,
3. of the distance from the axis of rotation to the centre of gravity of the car.

P2130101

Hooke's law

Details

What you can learn about
- Hooke's law
- Spring constant
- Limit of elasticity
- Elastic hysteresis
- Elastic after-effect

Benefits
- The law that governs the elongation of springs
- Determine the magnitude that describes the main characteristics of a spring
- Discover the main difference in the behaviour of springs and rubber bands

Principle
The validity of Hooke's law is determined for two helical springs with different spring constants. The elongation of the helical spring, which depends on the deforming force, is studied by means of the weights of masses. For comparison, a rubber band, for which no proportionality exists between the exerted force and the resulting elongation, is submitted to the same forces.

Tasks
1. Determining the spring constants of helical springs.
2. Study of the elongation of a rubberband.

P2120100

Moments

Details

What you can learn about
- Moments
- Coupling
- Equilibrium
- Statics
- Lever
- Coplanar forces

Benefits
- Understand the relation and the difference between moments and force.
- Smart designed equipment that makes measurements clear and easy.
- The famous quote of Archimedes in its quantitative formulation of todays physics: "Give me the place to stand, and I shall move the earth."

Principle
Coplanar forces (weight, spring balance) act on the moments disc on either side of the pivot. In equilibrium, the moments are determined as a function of the magnitude and direction of the forces and of the reference point.

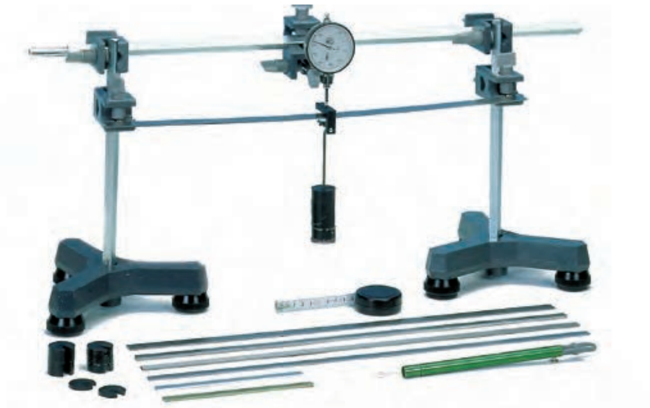
Tasks
1. Determination of the moment as a function of the distance between the origin of the coordinates and the point of action of the force.
2. Determination of the moment as a function of the angle between the force and the position vector to the point of action of the force.
3. Determination of the moment as a function of the force.

Modulus of elasticity / Youngs Modulus

P2120200

What you can learn about
- Young's modulus
- Modulus of elasticity
- Stress
- Deformation
- Poisson's ratio
- Hooke's law

Benefits
- Find out the parameters that give a bar stability
- Measure the difference of elasticity in various metals with different lengths
- Learn how to determine forces with a dial gauge



Details

Principle
A flat bar is supported at two points. It is bent by the action of a force acting at its centre. The modulus of elasticity is determined from the bending and the geometric data of the bar.

Tasks
1. Determination of the characteristic curve of the dial gauge.
2. Determination of the bending of flatbars as a function of the force; at constant force: of the thickness, of the width and of the distance between the support points.
3. Determination of the modulus of elasticity of steel, aluminium and brass.

Mechanical hysteresis

P2120300

What you can learn about
- Mechanical hysteresis
- Elasticity
- Plasticity
- Relaxation
- Torsion modulus
- Plastic flow
- Torque
- Hooke's law

Benefits
- Beyond Hooke's law
- Hysteresis mostly known from the field of magnetism can be experienced in mechanics
- Learn the meaning of the words stress, relaxation and equilibrium in a physics context
- Various torsion rods out of different material and with several diameters included

Details

Principle
The relationship between torque and angle of rotation is determined when metal bars are twisted. The hysteresis curve is recorded.

Tasks
1. Record the hysteresis curve of steel and copper rods.
2. Record the stress-relaxation curve with various relaxation times of different materials.

P2133100

Moments of inertia and torsional vibrations

Details

Principle
Various bodies perform torsional vibrations about axes through their centres of gravity. The vibration period is measured and the moment of inertia determined from this.

Tasks
The following will be determined:

1. The angular restoring moment of the spiral spring.
2. The moment of inertia
   a) of a disc, two cylinder, a sphere and a bar,
   b) of two point masses, as a function of the perpendicular distance to the axis of rotation.
   The centre of gravity lies in the axis of rotation.

What you can learn about
- Angular restoring moment
- Moment of inertia of various rigid bodies
- Moment of inertia of 2 point masses

Benefits
- Selection of materials allows demonstrating all aspects of moments of inertia in one experiment
- Clear and easy set-up

Determination of the gravitational constant / computerised Cavendish balance

P2130901

Details

Principle

Two small lead spheres are positioned on a freely suspended beam, while two large lead spheres are positioned symmetrically opposite to the small ones to eliminate the attractive forces. After repositioning the large spheres, the beam with the small spheres moves in a new equilibrium position where the attractive forces are equivalent to the force of the suspension's torsion. Hence, the gravitational constant can be determined.

Tasks

1. Calibration of an angular detector.
2. Determination of the oscillation time of a free and damped oscillating torsion pendulum.
3. Determination of the gravitational constant.

Benefits

- Compact system
- Simple and quick set-up
- Basic constant in physics easily determined
- Data logging via USB

What you can learn about

- Law of gravitation
- Free, damped, forced and torsional oscillations
- Moment of inertia of spheres and rods
- Steiner's theorem
- Shear modulus

P5140100 Mechanics of flow

Details

What you can learn about
- Ultrasonic Doppler effect
- Steady, laminar and turbulent flow
- Continuity equation
- Bernoulli's equation
- Hagen-Poiseuille law
- Flow velocity and flow resistance(static and dynamic)
- Pressure, pressure scales
- Viscosity and fluidity
- Ultrasonic flow measurements

Benefits
- Excellent introductory experiment for medical students to teach principles of flow
- Experiment setup can be varied and be used for other experiments
- Compact experiment setup
- Results can be read off easily from a scale

Principle

The ultrasonic Doppler effect is used for studying the laws of steadily and laminarly flowing liquids in a tube circuit. The experiment focuses on the relationship between the flow velocity and the cross-sectional tube area (continuity condition) as well as on the relationship between the flow resistance and the tube diameter (Hagen-Poiseuille law).

Tasks

1. Determine the mean and maximum Doppler frequency shift for different speeds and diameters.
2. Calculate the mean flow velocity in accordance with the Doppler law as well as the flow rates.
3. Measure the pressure drop for the various different flow velocities and tube diameters with the aid of the vertical tubes.
4. Calculate the flow resistance in accordance with Ohm's law. Examine the dependence of the flow resistance on the tube diameter (Hagen-Poiseuille law).
5. Calculate the Reynolds number for the different tube diameters.

P2140100 Density of liquids

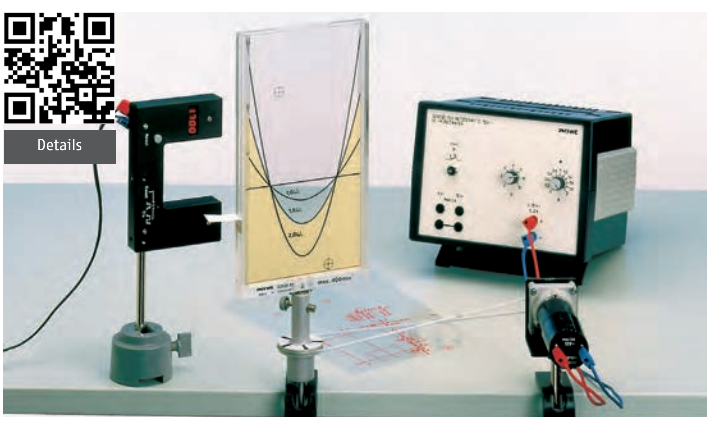
Details

What you can learn about
- Hydrogen bond
- Water anomaly
- Volume expansion
- Melting
- Evaporation
- Mohr balance

Benefits
- Mohr density balance enables high-precision measurements
- Interdisciplinary use also in applied sciences or physical chemistry

P2140200 Surface of rotating liquids

Details



What you can learn about
- Angular velocity
- Centrifugal force
- Rotary motion
- Paraboloid of rotation
- Equilibrium

Benefits
- Didactical unique
- Interdisciplinary use also in applied sciences or physical chemistry

Viscosity of Newtonian and non-Newtonian liquids (rotary viscometer) — P2140300

What you can learn about
- Shear stress
- Velocity gradient
- Internal friction
- Viscosity
- Plasticity

Benefits
- Classic experiment to determine the viscosity of various fluids
- Results directly shown on the built-in display
- Use several spindles that come with a storage rack
- Wearless torque measuring system with high accuracy
- Digital speed control
- Interdisciplinary use

Details

Principle

The viscosity of liquids can be determined with a rotation viscometer, in which a motor with variable rotation speed drives a cylinder immersed in the liquid to be investigated with a spiral spring. The viscosity of the liquid generates a moment of rotation at the cylinder which can be measured with the aid of the torsion of the spiral spring and read on a scale.

Tasks
1. Determine the gradient of the rotational velocity as a function of the torsional shearing stress for two Newtonian liquids (glycerine, liquid paraffin).
2. Investigate the temperature dependence of the viscosity of Castor oil and glycerine.
3. Determine the flow curve for a non Newtonian liquid (chocolate).

Viscosity measurement with the falling ball viscometer — P2140400

What you can learn about
- Liquid
- Newtonian liquid
- Stokes law
- Fluidity
- Dynamic and kinematic viscosity
- Viscosity measurements

Benefits
- Viscosity measurement for two fluids and any mix ratio
- Viscosity measurement for different temperatures possible
- Angle of falling ball viscometer can be changed
- Interdisciplinary use also in applied sciences or physical chemistry

Details

Principle

Due to internal friction among their particles, liquids and gases have different viscosities. The viscosity, a function of the substance's structure and its temperature, can be experimentally determined, for example, by measuring the rate of fall of a ball in a tube filled with the liquid to be investigated.

Tasks

Measure the viscosity
1. of methanol-water mixtures of various composition at a constant temperature,
2. of water as a function of temperature and
3. of methanol as a function of temperature.

From the temperature dependence of the viscosity, calculate the energy barriers for the displace ability of water and methanol.

P2140500 Surface tension with the ring method (Du Nouy method)

Details

What you can learn about
- Surface energy
- Interface
- Surface tension
- Adhesion
- Critical point
- Eötvös equation

Benefits
- High sensitivity measurement possible thanks to ring method
- Analogue set-up that can also be used as a demo experiment in the lecture hall
- Torsion dynamometer used can measure very small forces and is therefore suitable to measure other electrostatic and magnetic interactions between bodies
- Interdisciplinary use also in applied sciences or physical chemistry

Principle
The force is measured on a ring shortly before a liquid film tears using a torsion meter. The surface tension is calculated from the diameter of the ring and the tear-off force.

Tasks
1. Determine the surface tension of olive oil as a function of temperature.
2. Determine the surface tension of water/methanol mixtures as functions of the mixture ratio.

P2140501 Surface tension of liquids

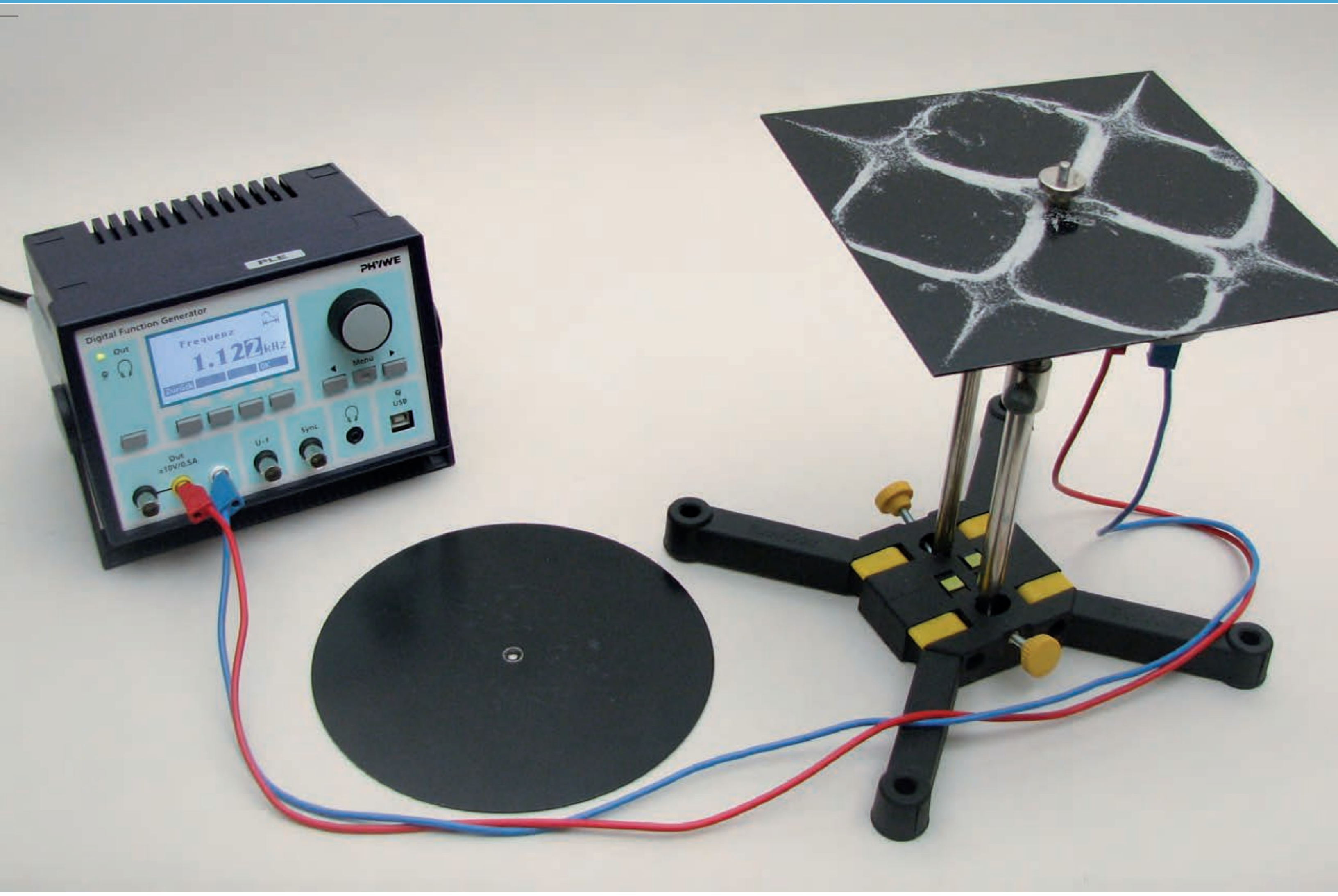
Details

What you can learn about
- Wetting and non-wetting liquids
- Capillarity

Benefits
- High sensitivity measurement possible thanks to ring method
- Analogue set-up that can also be used as a demo experiment in the lecture hall
- Interdisciplinary use also in applied sciences or physical chemistry

Principle
The cohesive forces in a liquid generate tension on its surface, the so-called surface tension. A metal ring that is plunged into a liquid is withdrawn from the liquid. At a certain tensile force, the liquid film will be disrupted from the ring. Based on the tensile force and ring diameter, the surface tension of a liquid can be calculated.

Tasks
Examine the surface tension of a liquid.



2.2 Oscillations and Mechanical Waves, Acoustics

P2132100

Mathematical pendulum

Details

What you can learn about
- Duration of oscillation
- Period
- Amplitude
- Harmonic oscillation

Benefits
- Quick and easy set-up
- Automatically measure the oscillation period using the light barrier

Principle

A mass, considered as of point form, suspended on a thread and subjected to the force of gravity, is deflected from its position of rest. The period of the oscillation thus produced is measured as a function of the thread length and the angle of deflection.

Tasks
1. For small deflections, the oscillation period is determined as a function of the cord length.
2. The acceleration due to gravity is determined.
3. The oscillation period is determined as a function of the deflection.

P2132200

Reversible pendulum

Details

What you can learn about
- Physical pendulum
- Moment of inertia
- Steiner's law
- Reduced length of pendulum
- Reversible pendulum
- Terrestrial gravitational acceleration

Benefits
- Determine the gravitational constant g immediately without knowledge of mass or moment of inertia
- Automatically measure the oscillation period using the light barrier

Principle

By means of a reversible pendulum, terrestrial gravitational acceleration g may be determined from the period of oscillation of a physical pendulum, knowing neither the mass nor the moment of inertia of the latter.

Tasks
1. Measurement of the period for different axes of rotation.
2. Determination of terrestrial gravitational acceleration *g*.

Variable g pendulum

P2132301

What you can learn about
- Oscillation period
- Harmonic oscillation
- Mathematical pendulum
- Physical pendulum
- Decomposition of force
- Moment of inertia

Benefits
- Immediately determine the gravitational constant g
- Automatically measure the oscillation period
- Simulate the pendulum oscillation as it would behave on the moon
- Investigate the pendulum oscillation for any arbitrary angle

Details

Principle
Investigate the oscillation behaviour of a rod pendulum by varying the components of the gravitational acceleration which enforce the oscillation period. The pendulum is constructed in such a manner that its oscillation plane can be progressively rotated from a vertical orientation to a horizontal one. The angle of this tilt can be directly read from the scale.

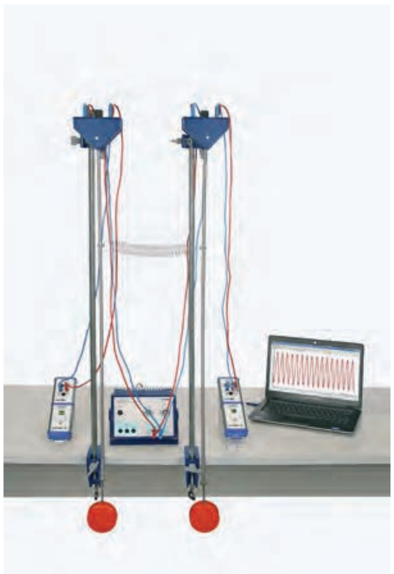
Tasks
1. Measure the oscillation period depending on the inclination angle for different pendulum lengths.
2. Analyse the measured correlations graphically and compare with the theoretical curves.
3. Incline the plane to obtain an oscillation that matches that of a freely swinging pendulum on Luna's surface, where the acceleration of gravity is lower than on Earth.

Coupled pendula with Cobra4 (advanced version)

P2132560

What you can learn about
- Torsional vibration
- Torque
- Beat
- Angular velocity and acceleration
- Characteristic frequency

Benefits
- Large and sturdy set-up suitable for demonstration and lab courses as well
- Live data-logging system to measure the oscillations of both pendula at once



Details

Principle
Two equal gravity pendula with a particular characteristic frequency are coupled by a "soft" spiral spring. The amplitudes of both pendula are recorded as a function of time for various vibrational modes and different coupling factors. The coupling factors are determined by different methods.

Tasks
1. Determine the spring constant of the coupling spring.
2. Determine and adjust the characteristic frequencies of the uncoupled pendula.
3. Determine the coupling factors for various coupling lengths.
4. Check the relation between the coupling lengths and a) the frequencies of the beat mode, and b) the frequency for "in opposite phase" vibration.
5. Determine the pendulum's characteristic frequency from the vibrational modes with coupling and compare it with that of the uncoupled pendula.

P2132580 Coupled pendula with measure Dynamics

What you can learn about
- Torsional vibration
- Torque
- Beat
- Angular velocity and acceleration
- Characteristic frequency

Benefits
- Large and sturdy set-up suitable for demonstration and lab courses as well
- Live data-logging system to measure the oscillations of both pendula at once
- Easy measurement and evaluation via movement tracking software

Principle
Two identical gravity pendula with a particular characteristic frequency are coupled via a “soft“ spiral spring. The amplitudes of both pendula are recorded as a function of time. The coupling factors are determined by way of different methods. Then, the local points of the oscillation are integrated into the video.

Tasks
1. Determine the spring constant of the coupling spring.
2. Determine and adjust the characteristic frequency as well as the moment of inertia of the uncoupled pendula.
3. Compare the determined oscillation frequency to the theoretical oscillation frequency for
   a) the “in phase“ oscillation,
   b) the “antiphase“ oscillation, and
   c) the beat case.

P2132660 Harmonic oscillations of spiral springs – linked in parallel and in series with Cobra4

What you can learn about
- Spring constant
- Hooke‘s law oscillations
- Limit of elasticity
- Parallel springs
- Serial springs
- Use of an interface

Benefits
- Large and sturdy set-up suitable for demonstration and lab courses as well
- Data logging reveals instantaneous results during measurement

Principle
The spring constant *D* is determined for different experimental set-ups from the oscillation period and the suspended mass.

Tasks
Determination of the spring constant *D* for different springs.

Determination of the spring constant for springs linked inparallel.

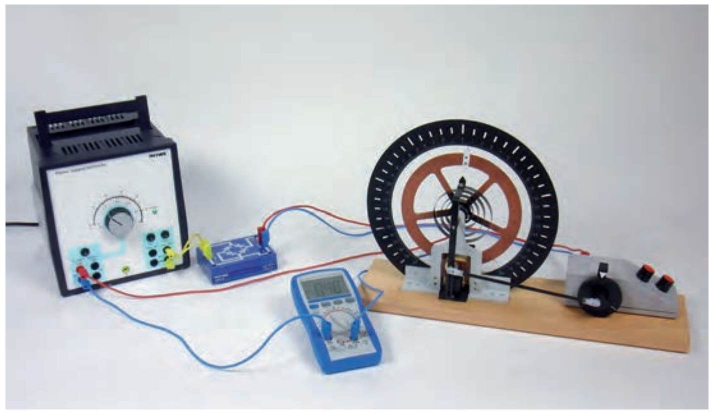
Determination of the spring constant for springs linked inseries.

Forced oscillations – Pohl's pendulum

P2132701

What you can learn about
- Angular, characteristic, and resonance frequency
- Torsion pendulum and torsional vibration
- Torque and restoring torque
  Damped / undamped free oscillation
- Aperiodic case

Benefits
- Long-lasting oscillation due to ball bearings
- Damping via abrasion-resistant eddy current brake
- Suitable for demonstration and student experiments as well
- Designed for large and clear shadow projection while experimenting



Details

Principle

If an oscillating system is allowed to oscillate freely, we can observe that the decrement of successive maximum amplitudes strongly depends on the damping value. If the oscillating system is caused to oscillate by an external torsional oscillation, one can observe that the amplitude in a stationary state is a function of the frequency and amplitude of the external periodic torsional oscillation and of the damping value.

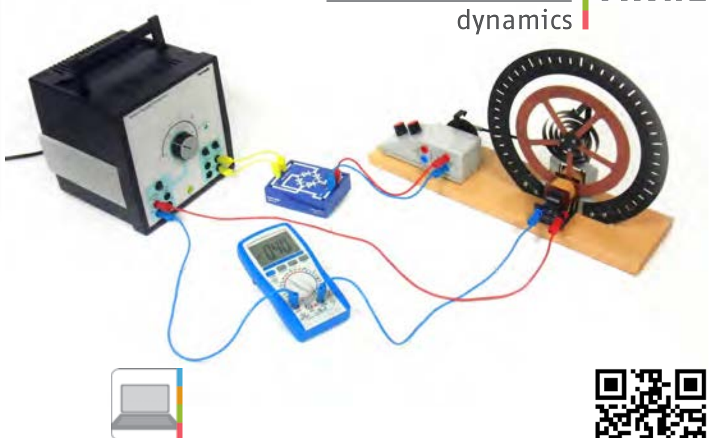
Tasks

Determine the characteristic frequency of the free oscillation as well as the resonance curve of a forced oscillation for different damping values.

P2132780 Forced oscillations - Pohl's pendulum with measure Dynamics

What you can learn about
- Angular, characteristic, and resonance frequency
- Torsion pendulum and torsional vibration
- Torque and restoring torque
- Damped / undamped free oscillation
- Aperiodic case

Benefits
- Long-lasting oscillation due to ball bearings
- Damping via abrasion-resistant eddy current brake
- Suitable for demonstration and student experiments as well
- Easy measurement and evaluation via movement tracking software



Details

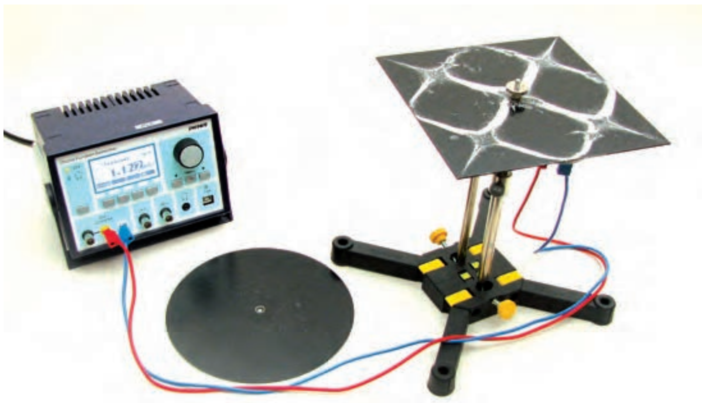
Principle

If an oscillating system is allowed to oscillate freely, we can observe that the decrement of successive maximum amplitudes strongly depends on the damping value. If the oscillating system is caused to oscillate by an external torsional oscillation, one can observe that the amplitude in a stationary state is a function of the frequency and amplitude of the external periodic torsional oscillation and of the damping value.

Tasks

Determine the characteristic frequency of the free oscillation as well as the resonance curve of a forced oscillation for different damping values.ll damping value with different excitation frequencies.

P2150501 Chladni figures



Details

What you can learn about
- Wave length
- Stationary waves
- Acoustic vibrations
- Two-dimensional standing waves
- Eigen-modes

Benefits
- Experiment set-up particularly suitable to visualize resonance
- Many experiment variations possible within a short time
- Digital function generator for quick frequency-tuning and multi-purpose use beyond the experiment

Principle

Square and round metal plates are brought to vibrate through acoustic stimulations by a loudspeaker. When the driving frequency corresponds to a given Eigen-frequency (natural vibration mode) of the plate, the nodal lines are made visible with sand. The sand is expelled from the vibrating regions of the plate and gathers in the lines because these are the only places where the amplitude of vibrations is close to zero.

Tasks

Determine the frequencies at which resonance occurs and drive the plate specifically at these frequencies.

P2133000 Torsional vibrations and torsion modulus

Details

What you can learn about
- Shear modulus
- Angular velocity
- Torque
- Moment of inertia
- Angular restoring torque
- G-modulus
- Modulus of elasticity

Benefits
- The use of eight different rods out of different material and with several diameters increase the understanding of all correlations
- Simple experimental set-up with immediate and clear results
- Extremely solid construction

Principle

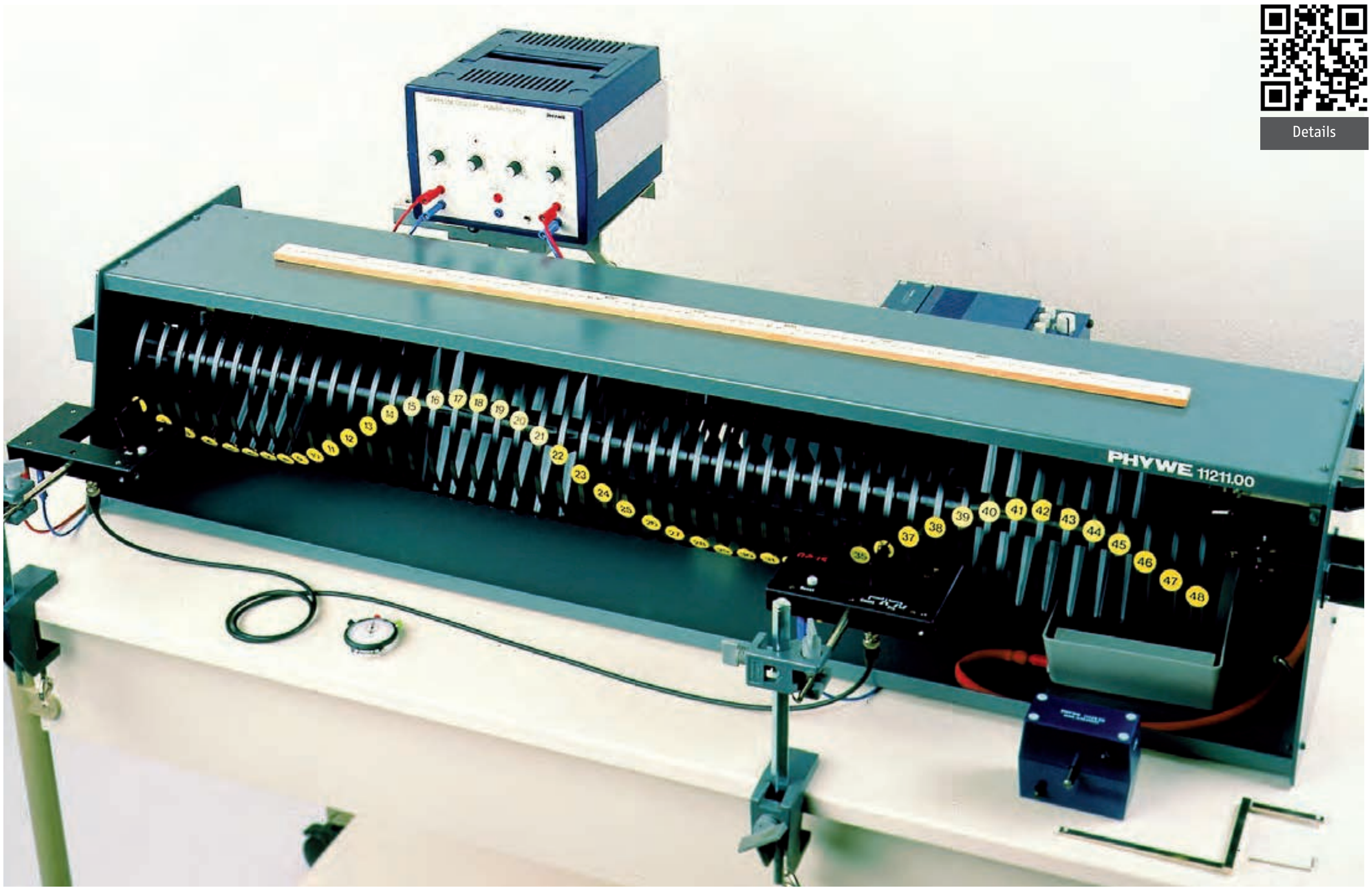
Bars of various materials will be exciting into torsional vibration. The relationship between the vibration period and the geometrical dimensions of the bars will be derived and the specific shear modulus for the material determined.

Tasks

1. Static determination of the torsion modulus of a bar.
2. Determination of the moment of inertia of the rod and weights fixed to the bar, from the vibration period.
3. Determination of the dependence of the vibration period on the length and thickness of the bars.
4. Determination of the shear modulus of steel, copper, aluminium and brass.

Propagation of a periodically excited continuous transverse wave P2133200

Details



Principle

The periodicity of connected stationary oscillators is demonstrated for a continuous, harmonic transverse wave generated by a wave machine. The number of oscillations carried out by different oscillators within a certain time is determined and the velocity of propagation is measured. A relation between frequency, wavelength and phase velocity is established. The formation of standing waves is demonstrated and studied.

Tasks

1. Determine the frequency of different oscillators for a particular frequency of excitation.
2. Determine the phase velocity of a transverse wave.
3. Measure the corresponding wavelengths for three different frequencies and shown that the product of frequency and wavelength is a constant.
4. Detect the lowest natural frequencies a) with two ends of the oscillator system fixed, and b) with one end of the oscillator system fixed and the other one free.

Benefits

- Large and very illustrative way to watch the propagation of waves including damping, coupling, standing waves and many more
- Slow propagation speed allows an excellent observation
- Easy fixation of wave images at any time

What you can learn about

- Periodic motion
- Frequency and wavelength
- Phase velocity
- Standing waves
- Damping of waves

P2133500 Interference and diffraction of water waves with the ripple tank

Details

What you can learn about
- Diffraction of water waves
- Interference of waves
- Huygens' principle
- Principle of "phased arrays antennas"
- Doppler-effect

Benefits
- See and understand the laws that govern wave phenomena
- Just add water – compact device offers fast and easy setup
- Bright green LED offers qualities even for a demonstration experiment

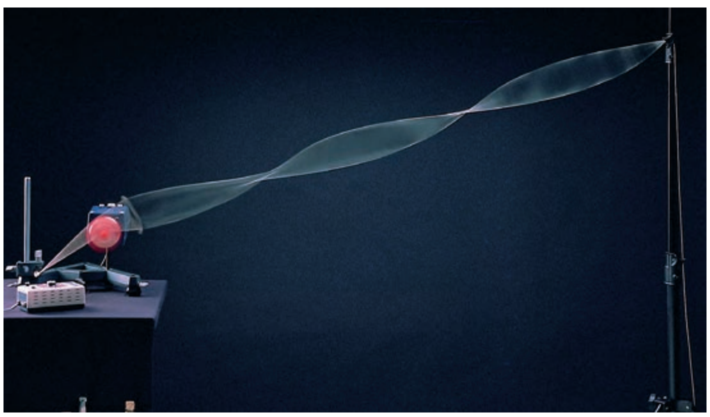
Principle

A set of circular water waves is simultaneously generated and the resulting interference is observed. By increasing the number of interfering circular waves, Huygens' Principle can be verified. Plane water waves are used to investigate diffraction phenomena at different obstacles (slit, edge, double-slit, etc.). Further, the principle of "phased array antennas" can be demonstrated: two circular waves are generated to interfere and the resulting interference pattern on varying the phase of one of the circular waves is observed.

Tasks

1. Use the comb to generate various numbers of circular waves and observe the resulting interference.
2. Generate plane water waves and use different barriers to demonstrate diffraction at an edge, behind a slit or a double-slit.
3. Use two wave generators, vary the phase of one of them and observe the resulting interference pattern.

P2133300 Phase velocity of rope waves



Details

What you can learn about
- Wavelength
- Phase velocity
- Group velocity
- Wave equation
- Harmonic wave

Benefits
- Difficult physics of phase velocity presented in a simple way
- High-precision results thanks to use of special rope and stroboscope
- Large and easy to see wave crests and troughs

Principle

A quadrangular rubber rope is inserted through the demonstration motor and a linear polarised fixed wave is generated. With the help of a stroboscope, the frequency and the wave length are determined. Then the phase velocity of ropewaves with a fixed tensile stress is ascertained. Subsequently, the mathematical relationship between the phase velocity of the rope and the tensile on the rope is examined.

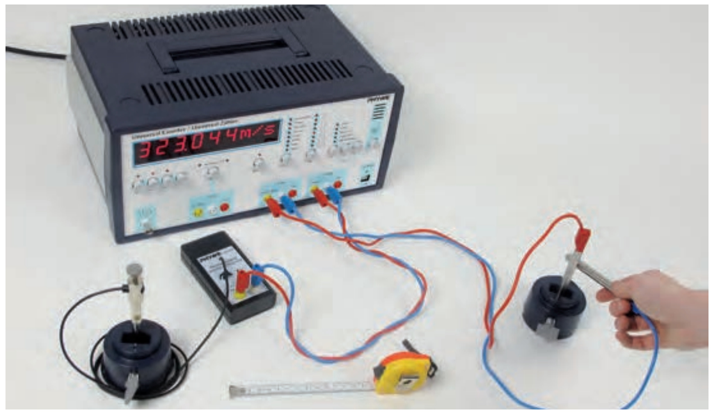
Tasks

1. Measure the frequency of the propagating wave along the rope at constant tensile stress. Determine the phase velocity by plotting the frequency against the inverse wavelength.
2. Measure the phase velocity of the rope waves depending on the tensile stress of the rope. Plot the quadrant of the phase velocity against the tensile stress.

Velocity of sound in air with universal counter P2150305

What you can learn about
- Wave propagation
- Longitudinal wave
- Air pressure variation
- Sound wave
- Impulse of sound

Benefits
- Perfect as demonstration and student experiment
- Easy setup and fast procedure
- Easy entry into the topic of error calculation possible



Details

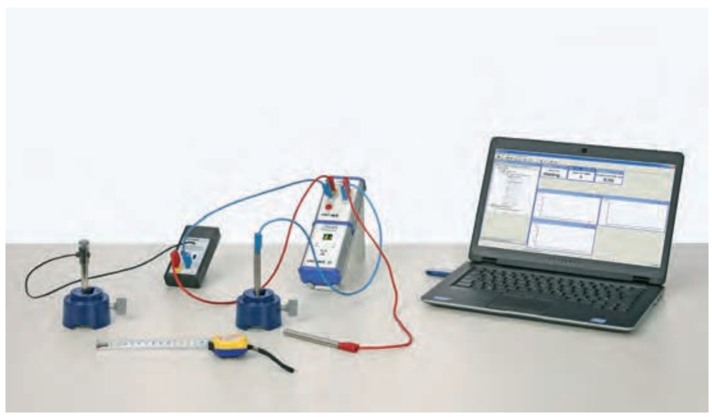
Principle
The velocity of sound in air is determined by measurements of sound travel times.

Tasks
Determine the sound velocity in air for different distances between sound source and microphone.

Measurement of the speed of sound in air with Cobra4 P2153060

What you can learn about
- Propagation of sound waves
- Velocity of sound
- Sound waves
- Sonic boom

Benefits
- Simple set-up and procedure
- Easy entry into the topic of error calculation possible
- Simplified implementation: all pre-settings already prepared



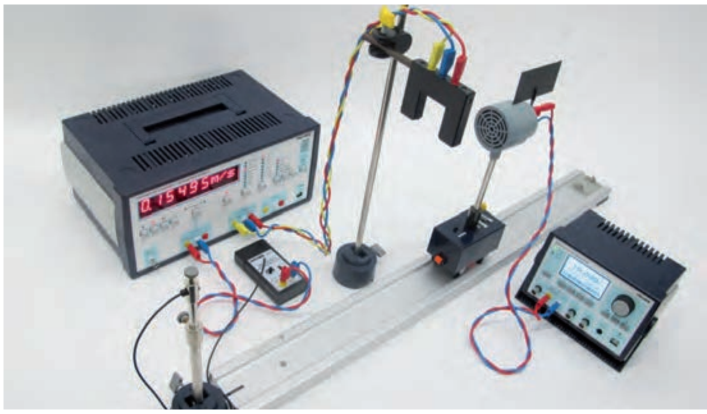
Cobra 4

Details

Principle
The velocity of sound in air is determined by measurements of sound travel times.

Tasks
Determine the sound velocity in air for different distances between sound source and microphone.

P2150405 Acoustic Doppler effect with universal counter



Details

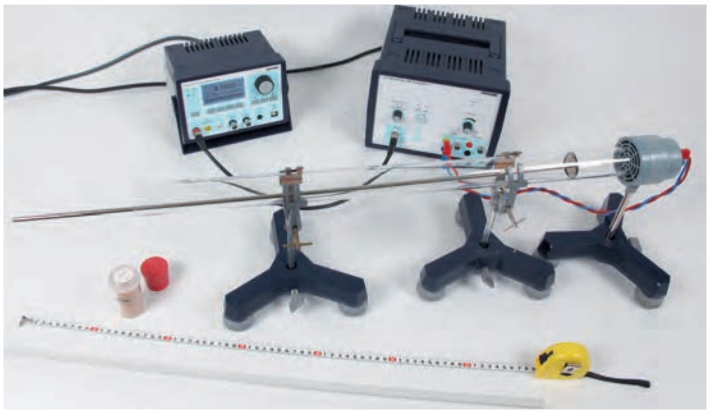
What you can learn about
- Wave propagation
- Doppler shift of frequency

Benefits
- Easy frequency setting thanks to digital function generator
- Intuitive measuring instrument
- Results well reproducible because of the motor-driven car

Principle
If an emitter of sound or a detector is set into motion relative to the medium of propagation, the frequency of the waves that are emitted or detected is shifted due to the Doppler effect.

Tasks
1. Measure the Doppler shift for varying frequencies and velocities for a moving sound emitter. Compare the measurements with the values predicted by theory and validate equation.
2. Measure the Doppler shift for varying frequencies and velocities for a moving detector. Compare the measurements with the values predicted by theory and validate equation.

P2150605 Velocity of sound using Kundt's tube and digital function generator



Details

What you can learn about
- Longitudinal waves
- Sound velocity in gases
- Frequency
- Wavelength
- Stationary waves
- Natural frequency

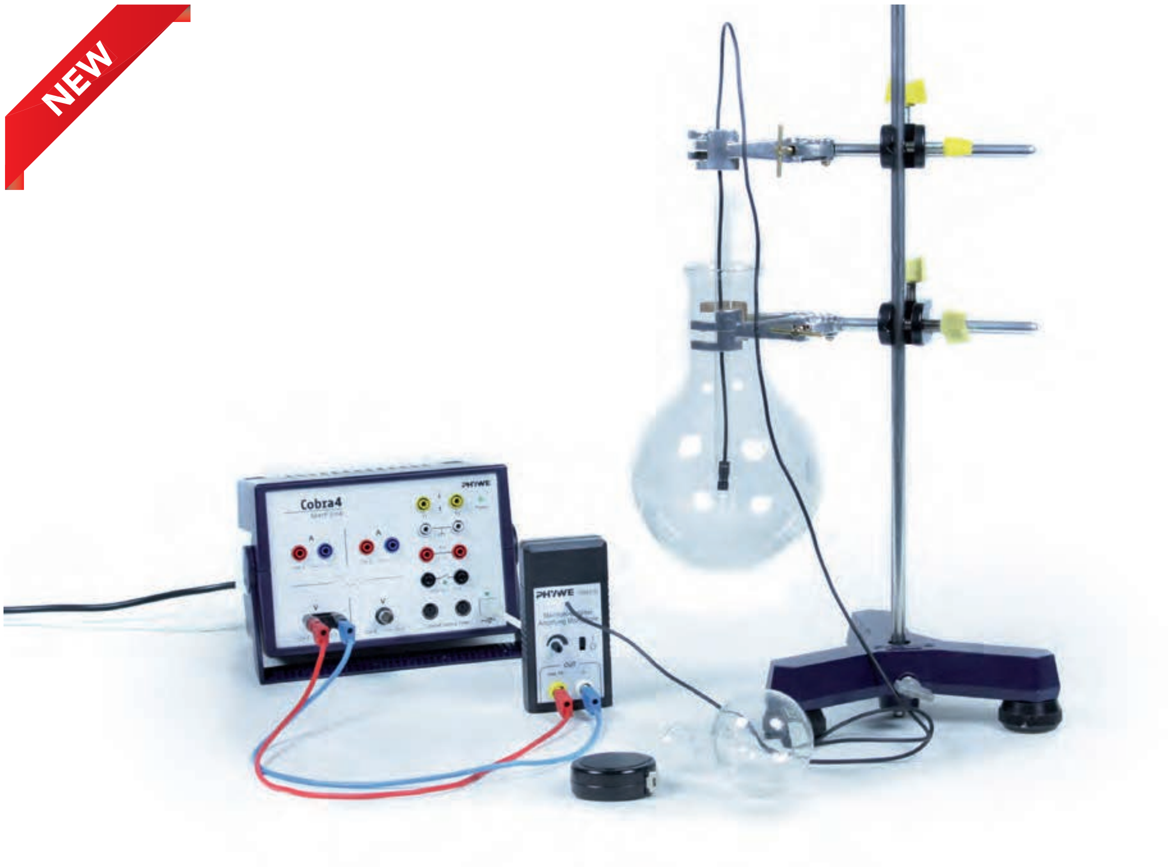
Benefits
- Two experiments in one: determination of the sound velocity and determination of the wavelength of standing waves
- Easy frequency setting thanks to digital function generator

Principle
Cork dust in a glass tube is set into tiniest motion by a soundwave. If the frequency of the sound wave matches the natural frequency of the volume in the glass tube, a standing wave will form. The cork dust then assembles in visible patterns that show the nodes of pressure and motion of the standing wave. From the length of the volume and the number of the nodes the velocity of sound in the tube can be calculated for each natural frequency.

Tasks
Determine the velocity of sound in air using Kundt's tube at different lengths of volume.

Resonance frequencies of Helmholtz resonators with Cobra4 Xpert-Link

P2150864



Details

Principle

Acoustic cavity resonators possess a characteristic frequency which is determined by their geometrical form. In this case the resonator is excited to vibrations in its resonance frequency by background noise.

Operating system-independent software included.

Tasks

Determine the different resonance frequencies of a resonator depending on the volume.

Benefits

- Measure without additional excitation by using only the ambient noise
- Observe immediately the sound wave signal and the resonance frequencies using FFT
- Measure live while changing the body volume and thus the resonance frequency
- Quick start with all pre-settings already prepared

What you can learn about

- Cavity resonator
- Resonance frequency
- Acoustic resonant circuit

YouTube

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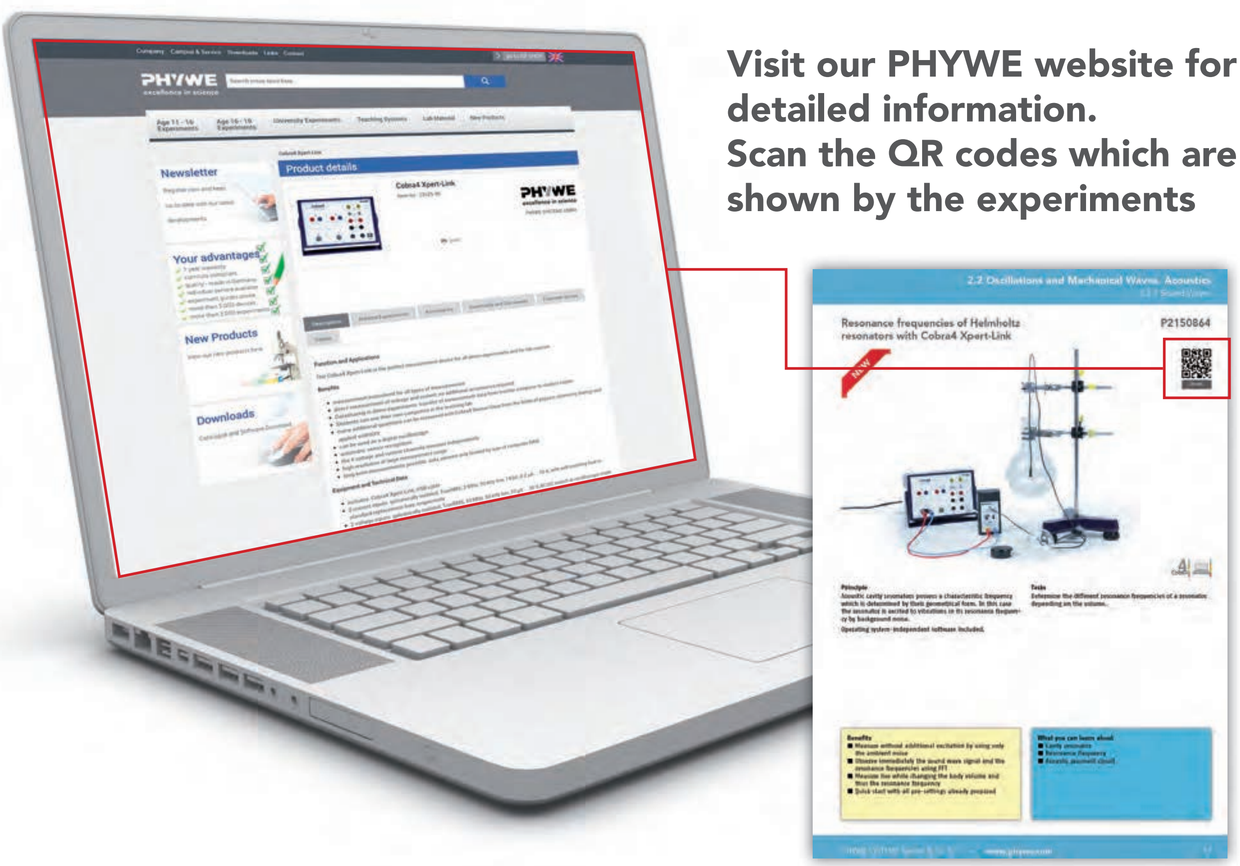
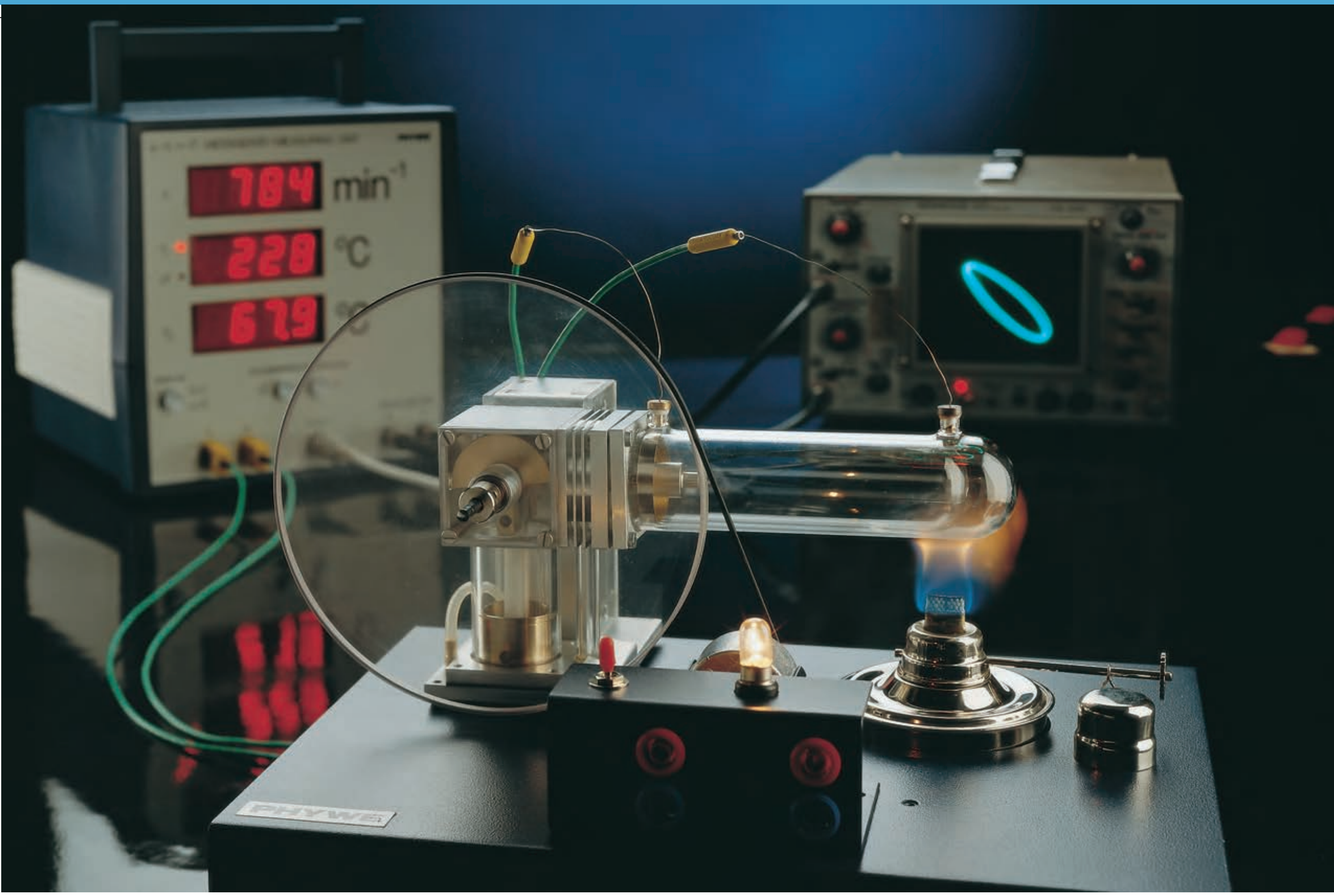


Visit our PHYWE website for all detailed information. Scan the QR codes which are shown by the experiments

PHYWE excellence in science



2.3 Thermodynamics

P2320162

Equation of state for ideal gases with Cobra4 (gas laws: Gay-Lussac, Amontons, Boyle)

Details

What you can learn about
- Thermal tension coefficient
- General equation of state for ideal gases
- Universal gas constant
- Amontons' law

Benefits
- All gas laws can be measured with the same setup
- Very compact setup, can be stored in the shelf and is always ready to use
- Very demonstrative: Volume is read directly at the gas syringe, temperature and pressure are measured with sensors in real-time

Principle

The state of a gas is determined by temperature, pressure and amount of substance. For the limiting case of ideal gases, these state variables are linked via the general equation of state.

Tasks

For a constant amount of gas (air) investigate the correlation of

1. Volume and pressure at constant temperature (Boyle and Mariotte's law)
2. Volume and temperature at constant pressure (Gay-Lussac's law)
3. Pressue and temperature at constant volume (Charles' (Amontons law)

From the relationships obtained calculate the universal gas constant as well as the coefficient of thermal expansion, the coefficient of thermal tension, and the coefficient of cubic compressibility.

P2320300

Maxwellian velocity distribution

Details

What you can learn about
- Kinetic theory of gases
- Temperature
- Gas molecules
- Model kinetic energy
- Average velocity
- Velocity distribution

Benefits
- For both demonstration and student experiments
- Unique experiment to quantitatively study kinetic gas theory
- With detailed experiment guide
- Visualization of the Maxwell Boltzmann distribution

Principle

By means of the model apparatus for kinetic theory of gases the motion of gas molecules is simulated and the velocities determined by registration of the throw distance of the glass balls. This velocity distribution is compared to the theoretical Maxwell-Boltzmann equation.

Tasks

1. Measure the velocity distribution of the "model gas".
2. Compare the result to theoretical behaviour as described by the Maxwell-Boltzmann distribution.
3. Discuss the results.

Heat capacity of gases with Cobra4

P2320261

What you can learn about
- Equation of state for ideal gases
- First law of thermodynamics
- Universal gas constant
- Degree of freedom
- Mole volumes
- Isobars and Isotherms
- Isochors and adiabatic changes of state

Benefits
- Determination of C_p and C_v
- For both demonstration and student experiments
- Suitable for many different gases
- Simplified implementation: all pre-settings already prepared

Details

Principle

Heat is added to a gas in a glass vessel by an electric heater which is switched on briefly. The temperature increase results in a pressure increase, which is measured with a manometer. Under isobaric conditions a temperature increase results in a volume dilatation, which can be read from a gas syringe. The molar heat capacities are calculated from the pressure or volume change.

Tasks

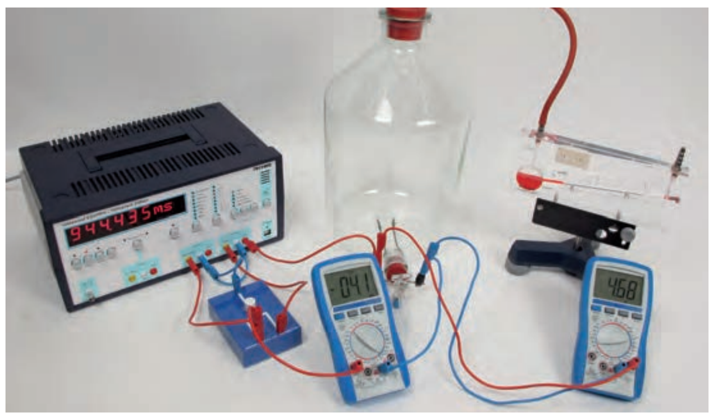
Determine the molar heat capacities of air at constant volume and at constant pressure.

Heat capacity of gases

P2320201

What you can learn about
- Equation of state for ideal gases
- First law of thermodynamics
- Universal gas constant
- Degree of freedom
- Mole volumes
- Isobars and Isotherms
- Isochors and adiabatic changes of state

Benefits
- Determination of C_p and C_v
- For both demonstration and student experiments
- Suitable for many different gases



Details

Principle

Heat is added to a gas in a glass vessel by an electric heater which is switched on briefly. The temperature increase results in a pressure increase, which is measured with a manometer. Under isobaric conditions a temperature increase results in a volume dilatation, which can be read from a gas syringe. The molar heat capacities of C_p and C_v are calculated from the pressure or volume change.

Tasks

Determine the molar heat capacities of air at constant volume C_v and at constant pressure C_p.

P2320400 Thermal equation of state and critical point

Details

What you can learn about
- Ideal gases and real gases
- Equations of state
- Van der Waals equation
- Boyle temperature
- Critical point
- Interaction potential
- Molecule radius

Benefits
- Experience the essence of the Nobel Prize: van der Waals (1910)
- Visualization of the critical point

Principle

A substance which is gaseous under normal conditions is enclosed in a variable volume and the variation of pressure with the volume is recorded at different temperatures. The critical point is determined graphically from a plot of the isotherms.

Tasks

1. Measure a number of p-V isotherms of ethane.
2. Determine the critical point and the critical quantities of ethane.
3. Calculate the constants of the Van der Waals equation, the Boyle temperature, the radius of the molecules and the parameters of the interaction potential.

P2320500 Adiabatic coefficient of gases – Flammersfeld oscillator

Details

What you can learn about
- Equation of adiabatic change of slate
- Polytropic equation
- Rüchardt's experiment
- Thermal capacity of gases

Benefits
- Suitable for many different gases
- Compact, easily transportable setup

Principle

A mass oscillates on a volume of gas in a precision glass tube. The oscillation is maintained by leading escaping gas back into the system. The adiabatic coefficient of various gases is determined from the periodic time of the oscillation.

Tasks

Determine the adiabatic coefficient of air nitrogen and carbondioxide (and also of argon, if available) from the periodic time of the oscillation T of the mass m on the volume V of gas.

Joule-Thomson effect

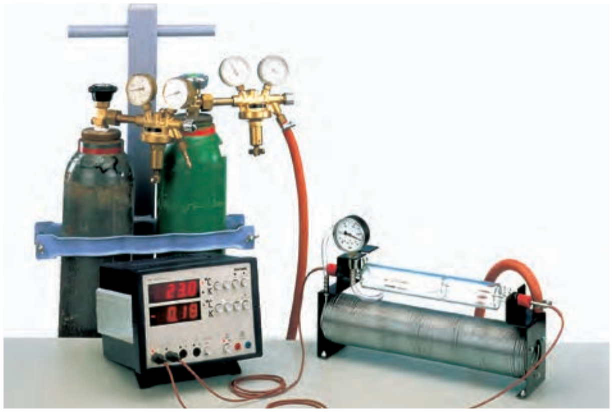
P2320600

What you can learn about

- Real gas
- Intrinsic energy
- Gay-Lussac theory
- Throttling
- Van der Waals equation
- Van der Waals force
- Inverse Joule-Thomson effect
- Inversion temperature

Benefits

- For both demonstration and student experiments
- With detailed experiment guide
- Affordable set-up



Details

Principle

A stream of gas is fed to a throttling point, where the gas (CO_2 or N_2) undergoes adiabatic expansion. The differences in temperature established between the two sides of the throttle point are measured at various pressures and the Joule-Thomson coefficients of the gases in question arecalculated.

Tasks

1. Determination of the Joule-Thomson coefficient of CO_2.
2. Determination of the Joule-Thomson coefficient of N_2.

Heat capacity of metals with Cobra4

P2330160

What you can learn about

- Mixture temperature
- Boiling point
- Dulong Petit's law
- Lattice vibration
- Internal energy
- Debye temperature

Benefits

- Flexible experimenting thanks to wireless data transmission
- Data acquisition with tablets possible
- Simplified implementation: all pre-settings already prepared

Details

Principle

Heated specimens are placed in a calorimeter filled with water at low temperature. The heat capacity of the specimen is determined from the rise in the temperature of the water.

Tasks

1. To determine the specific heat capacity of aluminium, iron and brass.
2. To verify Dulong Petit's law with the results of these experiments.

P2330101

Heat capacity of metals

Details

What you can learn about
- Mixture temperature
- Boiling point
- Dulong Petit's law
- Lattice vibration
- Internal energy
- Debye temperature

Benefits
- Compact, easily transportable setup
- For both demonstration and student experiments

Principle
Heated specimens are placed in a calorimeter filled with water at low temperature. The heat capacity of the specimen is determined from the rise in the temperature of the water.

Tasks
1. To determine the heat capacity of the calorimeter by filling it with hot water and determining the rise in temperature.
2. To determine the specific heat capacity of aluminium, iron and brass.
3. To verify Dulong Petit's law with the results of these experiments.

P2330200

Mechanical equivalent of heat

Details

What you can learn about
- Mechanical equivalent of heat
- Mechanical work
- Thermal energy
- Thermal capacity
- First law of thermodynamics
- Specific thermal capacity

Benefits
- Affordable set-up
- Perfect as demonstration and student experiment

Principle
In this experiment, a metal test body is rotated and heated by the friction due to a tensed band of synthetic material. The mechanical equivalent of heat for problem 1 is determined from the defined mechanical work and from the thermal energy increase deduced from the increase of temperature. Assuming the equivalence of mechanical work and heat, the specific thermal capacity of aluminium and brass is determined.

Tasks
1. Determination of the mechanical equivalent of heat.
2. Determination of the specific thermal capacity of aluminum and brass.

Boiling point elevation – Raoult's law

P3021001

What you can learn about

- Raoult's law
- Henry's law
- Ebullioscopic constants
- Chemical potential
- Gibbs-Helmholtz equation
- Concentration ratio
- Degree of dissociation

Benefits

- Simple presentation and execution
- Simultaneous display of current temperature and temperature difference
- Compact, easily transportable setup

Details

Principle

The boiling point of a solution is always higher than that of the pure solvent. The dependence of the temperature difference (elevated boiling point) on the concentration of the solute can be determined using a suitable apparatus.

Tasks

1. Measure the increase in the boiling point of water as a function of the concentration of table salt, urea and hydroquinone.
2. Investigate the relationship between the increase in boiling point and the number of pellets.
3. Determine the molar mass of the solute from the relationship between the increase in boiling point and the concentration.

Freezing point depression

P3021101

What you can learn about

- Raoult's law
- Cryoscopic constant
- Chemical potential
- Gibbs-Helmholtz equation
- Concentration ratio
- Degree of dissociation
- Van't Hoff factor

Benefits

- All relevant measured variables at a glance
- Experimentation made easy by intuitive operation
- With detailed experiment guide

Details

Principle

The freezing point of a solution is lower than that of the pure solvent. The depression of the freezing point can be determined experimentally using a suitable apparatus (cryoscopy). If the cryoscopy constants of the solvent are known, the molecular mass of the substance dissolved can be determined.

Tasks

1. Determine the size of freezing point depression after dissolving a strong electrolyte (NaCl) in water. By comparing the experimental value with the theoretical one predicted for this concentration, determine the number of ions into which the electrolyte dissociates.
2. Determine the molar mass of a non-electrolyte (hydroquinone) from the value of freezing point depression.

P2350164 Stefan-Boltzmann's law of radiation with Cobra4 Xpert-Link

Details

What you can learn about
- Black body radiation
- Thermoelectric e. m. f.
- Temperature dependence of resistances

Benefits
- Simplified implementation: all pre-settings already prepared
- Intuitive, touch-optimized software
- Recording of all required measured values via one device
- Cost savings: No need for an additional measuring amplifier

Principle
According to Stefan-Boltzmann's law, the energy emitted by a black body per unit area and unit time is proportional to the power "four" of the absolute temperature of the body. Stefan-Boltzmann's law is also valid for a so-called "grey" body whose surface shows a wavelength independent absorption-coefficient of less than one.

Tasks
1. To measure the resistance of the filament of the incandescent lamp at room temperature and to ascertain the filament's resistance R_0 at zero degrees centrigrade.
2. To measure the energy flux density of the lamp at different heating voltages.

P2350101 Stefan-Boltzmann's law of radiation with an amplifier

Details

What you can learn about
- Black body radiation
- Thermoelectric e. m. f.
- Temperature dependence of resistances

Benefits
- Simple, stable set-up
- With detailed experiment guide

Principle
According of Stefan-Boltzmann's law, the energy emitted by a black body per unit area and unit time is proportional to the power "four" of the absolute temperature of the body. Stefan-Boltzmann's law is also valid for a so-called „grey" body whose surface shows a wavelength independent absorption-coefficient of less than one.

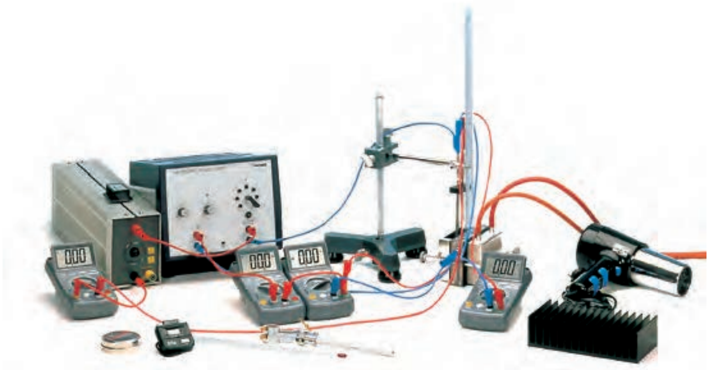
Tasks
1. To measure the resistance of the filament of the incandescent lamp at room temperature and to ascertain the filament's resistance R_0 at zero degrees centrigrade.
2. To measure the energy flux density of the lamp at different heating voltages.

Peltier heat pump

P2410800

What you can learn about
- Peltier effect
- Heat pipe
- Thermoelectric e. m. f.
- Peltier coefficient and Seebeck coefficient
- Cooling capacity and heating capacity
- Efficiency rating
- Thomson coefficient and equations
- Heat conduction
- Convection
- Forced cooling
- Joule effect

Benefits
- Open design allows to fully understand function and applications
- Individual instruments for distinct functions (no "black box")
- Key products of the experiment setup can also be used for investigating the Seebeck effect



Details

Principle

The (cooling capacity) heating capacity and efficiency rating of a Peltier heat pump are determined under different operating conditions.

Tasks

1. To determine the cooling capacity P_c of the pump as a function of the current and to calculate the efficiency rating hc at maximum output.
2. To determine the heating capacity P_w of the pump and its efficiency rating hw at constant current and constant temperature on the cold side.
3. To determine P_w, η_w and P_c , η_c from the relationship between temperature and time on the hot and cold sides.
4. To investigate the temperature behaviour when the pump is used for cooling, with the hot side air-cooled.

Boiling point elevation – Raoult's law with Cobra4

P3021060

What you can learn about
- Raoult's law
- Henry's law
- Ebullioscopic constants
- Chemical potential
- Gibbs-Helmholtz equation
- Concentration ratio
- Degree of dissociation

Benefits
- Perfect as demonstration and student experiment
- Simplified implementation: all pre-settings already prepared
- Data logging via tablet possible
- Flexible experimenting thanks to wireless data transmission

Details

Principle

Raoult's law states: The vapour pressure of an ideal solution is directly dependent on the vapour pressure of each chemical component and the mole fraction of the component present in the solution.
That's why the boiling point of a solution is always higher than that of the pure solvent. The dependence of the temperature difference (elevated boiling point) on the concentration of the solute can be determined using a suitabel apparatus.

Tasks

1. Measure the increase in the boiling point of water as a function of the concentration of table salt, urea and hydroquinone.
2. Investigate the relationship between the increase in boiling point and the number of pellets.
3. Determine the molar mass of the solute from the relationship between the increase in boiling point and the concentration.

P3030401 Boiling point diagram of a binary mixture

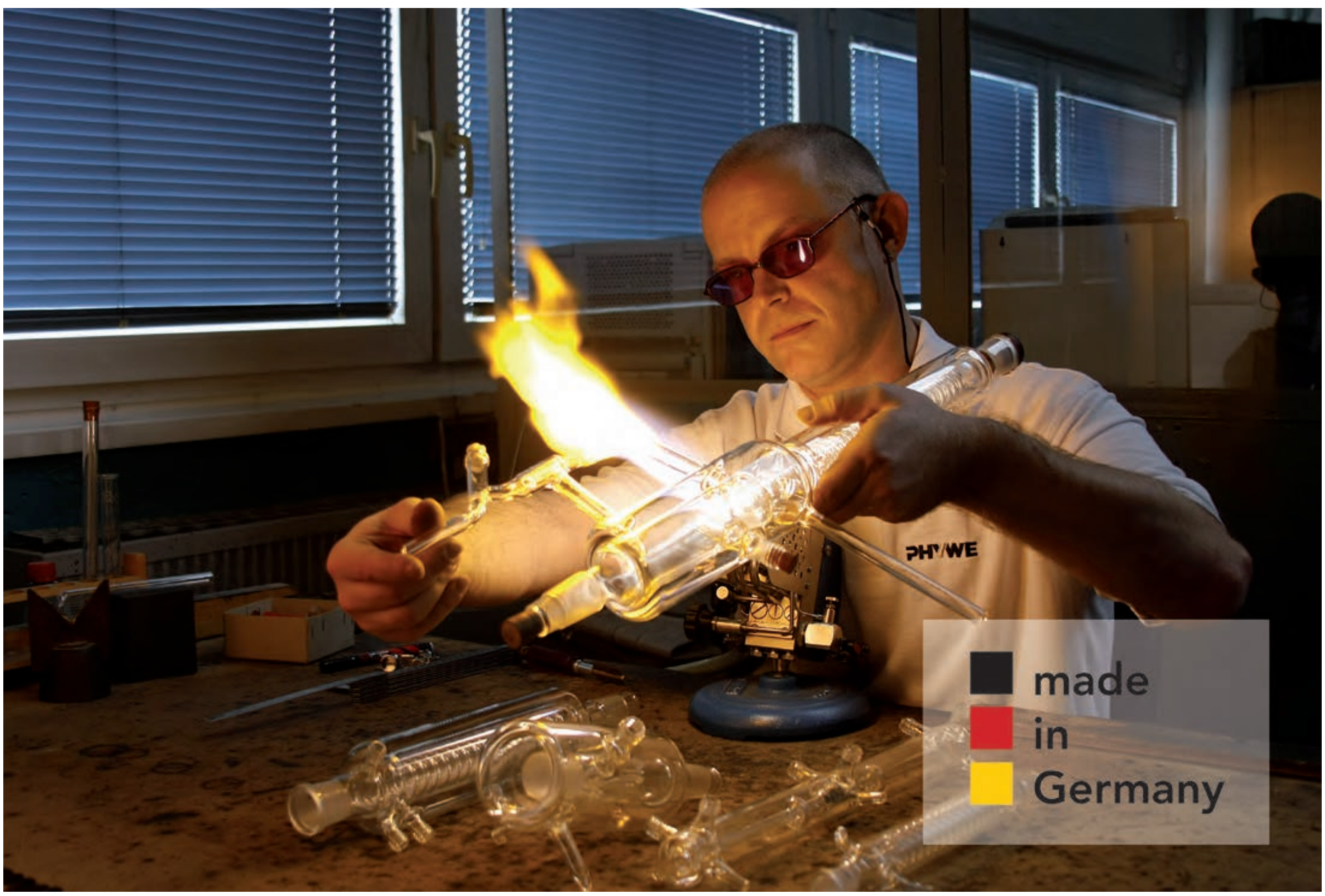
Details

What you can learn about
- Fundamentals of distillation
- Equilibrium diagram
- Chemical potential
- Activity coefficient
- Raoult's law

Benefits
- Important basic experiment for distillation
- Excellent for the introduction of refractometry

Principle
A boiling point diagram shows the boiling points of a binary mixture as a function of the vapour / liquid equilibrium of the mixture at constant pressure. The boiling points of various mixtures of methanol and chloroform are measured and the composition of the liquid phases are determined using refractometry and a calibration curve.

Tasks
1. Determine the refractive indices of the pure components and about 10 different mixtures of known composition.
2. Plot the boiling point diagram of the binary mixtures of methanol and chloroform.



Electric compression heat pump

P2360200

What you can learn about
- Refrigerator
- Compressor
- Restrictor valve
- Cycle
- Vaporization and Vaporization enthalpy
- Condensation
- Vapour pressure

Benefits
- Different operating modes possible
- For both demonstration and student experiments
- Simple set-up

Details

Principle

Pressures and temperatures in the circulation of the heat electrical compression heat pump are measured as a function of time when it is operated as a water-water heat pump. The energy taken up and released is calculated from the heating and cooling of the two water baths.

Tasks

Water heat pump: To measure pressure and temperature in the circuit and in the water reservoirs on the condenser side and the vaporiser side alternately. To calculate energy taken up and released, also the volume concentration in the circuit and the volumetric efficiency of the compressor.

Air-water heat pump: To measure vaporiser temperature and water bath temperature on the condenser side under different operating conditions on the vaporiser side
- with stream of cold air,
- with stream of hot air,
- without blower.

Stirling engine with an oscilloscope

P2360401

What you can learn about
- First and second law of thermodynamics
- Reversible cycles
- Isochoric and isothermal changes
- Gas laws
- Efficiency
- Stirling engine
- Conversion of heat
- Thermal pump

Benefits
- Didactically intuitive experiment
- For both demonstration and student experiments
- With detailed experiment guide

Details

Principle

The Stirling engine is submitted to a load by means of an adjustable torque meter, or by a coupled generator. Rotation frequency and temperature changes of the Stirling engine are observed.

Tasks

Determination of the burner's thermal efficiency.

1. Calibration of the sensor unit.
2. Calculation of the total energy produced by the engine through determination of the cycle area on the oscilloscope screen.
3. Assessment of the mechanical work per revolution, and calculation of the mechanical power output as a function of the rotation frequency.
4. Assessment of the electric power output.
5. Efficiency assessment.

P2360464 Stirling engine with Cobra4 Xpert-Link

NEW

Principle

The Stirling engine is submitted to a load by means of an adjustable torque meter, or by a coupled generator. Rotation frequency and temperature changes of the Stirling engine are observed.

Tasks

Determination of the burner's thermal efficiency

1. Calibration of the sensor unit.
2. Calculation of the total energy produced by the engine through determination of the cycle area.
3. Assessment of the mechanical work per revolution, and calculation of the mechanical power output as a function of the rotation frequency.
4. Assessment of the electric power output as a function of the rotation frequency.
5. Efficiency assessment.

What you can learn about

- First and second law of thermodynamics
- Reversible cycles
- Isochoric and isothermal changes
- Gas jaws
- Efficiency
- Stirling engine
- Conversion of heat
- Thermal pump

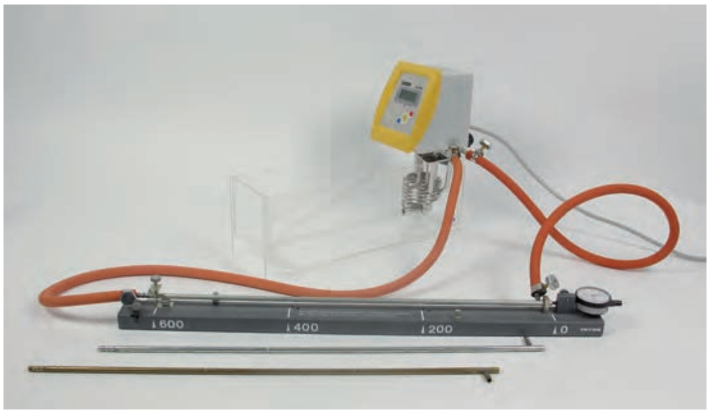
Benefits

- Simplified implementation: all pre-settings already prepared
- Intuitive, touch-optimized software

Thermal expansion in solids and liquids P2310100

What you can learn about
- Linear expansion
- Volume expansion of liquids
- Thermal capacity
- Lattice potential
- Equilibrium spacing
- Grüneisen equation

Benefits
- With detailed experiment guide
- Two experiments in one



Details

Principle
The volume expansion of liquids and the linear expansion of various materials is determined as a function of temperature.

Tasks
1. To determine the volume expansion of ethyl acetate ($C_4H_8O_2$), methylated spirit, olive oil, glycerol and water as a function of temperature, using the pycnometer.
2. To determine the linear expansion of brass, iron, copper, aluminium, duran glass and quartz glass as a function of temperature using a dilatometer.
3. To investigate the relationship between change in length and overall length in the case of aluminium.

Vapour pressure of water at high temperature P2340100

What you can learn about
- Boiling point
- Heat of vaporisation
- Clausius-Clapeyron equation
- Van't Hoff law
- Carnot cycle

Benefits
- No open flame in the setup - Reduction of thermal hazard
- No gas burner required - Easy to operate and no consumption of consumables
- Compact, easily transportable setup

Details

Principle
The high-pressure steam apparatus makes it possible to measure steam pressure in a temperature range of 100-250 °C. This allows for investigations to be performed on real gases and vapours. Typical equilibrium states between gas and liquid phases can be setup. For this purpose, water is heated in a closed pressure chamber at constant volume. The heat of vaporisation is determined at various temperatures from the measurement of vapour pressure as a function of temperature.

Tasks
1. Measure the vapour pressure of water as a function of temperature.
2. Calculate the heat of vaporisation at various temperatures from the values measured.
3. Determine boiling point at normal pressure by extrapolation.

P2340200 Vapour pressure of water below 100°C – molar heat of vaporisation

Details

What you can learn about
- Pressure
- Temperature
- Volume
- Vaporization
- Vapour pressure
- Clausius-Clapeyron equation

Benefits
- Compact, easily transportable setup
- For both demonstration and student experiments
- No gas burner required - Easy to operate and no consumption of consumables
- No open flame in the setup - Reduction of thermal hazard

Principle

The vapour pressure of water in the range of 40 °C to 85 °C is investigated. It is shown that the Clausius-Clapeyron equation describes the relation between temperature and pressure in an adequate manner. An average value for the heat of vaporisation of water is determined.

Tasks

1. About 250 ml of demineralised water are allowed to boil for about 10 minutes to eliminate all traces of dissolved gas. The water is then cooled down to room temperature.
2. The 3-neck round flask is filled about three-quarters full with gas-free water and heated. At 35 °C the space above the water within the round flask is evacuated. p and T are read in steps of 5 °C up to a maximum of T = 85 °C.

P2350200 Thermal and electrical conductivity of metals

Details

What you can learn about
- Electrical conductivity
- Wiedmann-Franz law
- Lorenz number
- Diffusion
- Temperature gradient
- Heat transport
- Specific heat
- Four-point measurement

Benefits
- Measurement of electrical and thermal conductivity in one set-up
- Compact, easily transportable setup

Principle

The thermal conductivity of copper and aluminium is determined in a constant temperature gradient from the calorimetrically measured heat flow. The electrical conductivity of copper and aluminium is determined and the Wiedmann-Franz law is tested.

Tasks

1. Determine the heat capacity of the calorimeter in a mixture experiment as a preliminary test. Measure the calefaction of water at a temperature of 0 °C in a calorimeter due to the action of the ambient temperature as a function of time.
2. To begin with, establish a constant temperature gradient in a metal rod with the use of two heat reservoirs (boiling water andice water).
3. Determine the electrical conductivity of copper and aluminium by recording a current-voltage characteristic line.
4. Test of the Wiedmann-Franz law.

Solar ray collector

P2360100

What you can learn about
- Absorption
- Heat radiation
- Greenhouse effect
- Convection
- Conduction of heat
- Collector equations
- Efficiency
- Energy ceiling

Benefits
- With detailed experiment guide
- Renewable energies at your fingertips

Details

Principle
The solar ray collector is illuminated with a halogen lamp of known light intensity. The heat energy absorbed by the collector can be calculated from the volume flow and the difference in the water temperatures at the inlet and outlet of the absorber, if the inlet temperature stays almost constant by releasing energy to a reservoir.

Tasks
To determine the efficiency of the solar ray collector under various experimental conditions.
- Absorption of energy from the environment (20 °C) without illumination by sun or halogen lamp, water temperature at the absorber inlet T_e = 5°C.
- Illumination with halogen lamp. Water temperature T_e = 20°C.
- Illumination with halogen lamp. Water temperature T_e = 50°C.

Cooling by evacuation

P2340660

What you can learn about
- Air pressure
- Kinetic gas theory
- Supercooling

Benefits
- Data logging via tablet possible
- For both demonstration and student experiments

Details

Principle
When the air pressure above a watersurface is reduced, the water begins to boil at a certain temperature. The temperature of the water is hereby reduced and further evacuation can finally bring it to 0 °C and even lower.

Tasks
Determine the temperature curve of water during pumping.

P2350400 Emittance of hot bodies (Leslie cube)

Details

What you can learn about
- Thermal radiation and emittance
- Kirchhoff's law of thermal radiation
- Leslie's cube
- Black and grey body

Benefits
- Simple set-up
- Affordable experiment
- For both demonstration and student experiments

Principle
Thermal radiation can be measured at all surfaces as long as their temperature differs from that of the surrounding. Therefore it applies that the hotter an object is, the more radiation it emits. Also the surface colour influences the behaviour: dark surfaces emit more thermal radiation than light ones. An example for application of this effect is a heat sink which is often coated with a black layer to emit more thermal radiation.

Tasks
1. Measurement of the room temperature T_0 (in Kelvin) before starting the experiment.
2. Determination and comparison of the emittance for all four sides of the Leslie cube at a constant high temperature. Determination and comparison of the emittance for all four sides of the Leslie cube depending on the temperature.
3. Plotting the thermoelectric voltage V_{th} as a function of the absolute temperature T or rather $T^4 - T_0^4$ for each side of the cube.

P3011400 Condensation of gases through an increase of pressure and through cooling

Details

What you can learn about
- Condensation
- Gas laws

Benefits
- Compact setup
- Perfect as demonstration and student experiment
- Beautiful illustration of the phase transition from gaseous to liquid

Principle
Gases are condensing when they are cooled and at high pressure. In this experiment butane is condensed by cooling it to ca. -15 °C. In the second part of the experiment butane is condensed by compressing it.

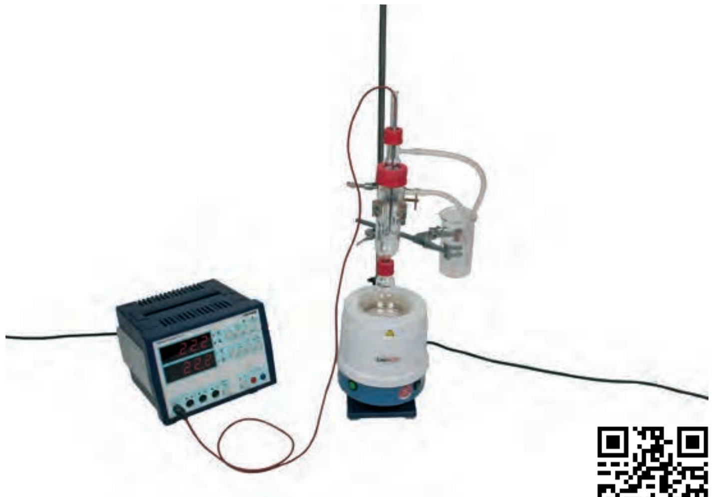
Tasks
1. Condense butane by cooling it under its boiling point of -0.4 °C.
2. Condense butane at high pressure.

Determination of molar masses via a measurement of the boiling point elevation (ebullioscopy)

P3021900

What you can learn about
- Molar mass
- Boiling point elevation
- Ebullioscopy
- Ebullioscopic constant

Benefits
- Compact, easily transportable setup
- Experimentation made easy by intuitive operation
- For both demonstration and student experiments



Details

Principle
Didactic setup to train and demonstrate the determination of molar masses by way of a measurement of the boiling point elevation. The boiling point elevation of aqueous solutions of different substances is determined using. The ebullioscopic constant of water is calculated from the experimental results.

Tasks
1. Determine the boiling point elevation of aqueous solutions of different substances.
2. Calculate the ebullioscopic constant of water from the experimental results.

Determination of molar masses via a measurement of the freezing point depression (cryoscopy)

P3022000

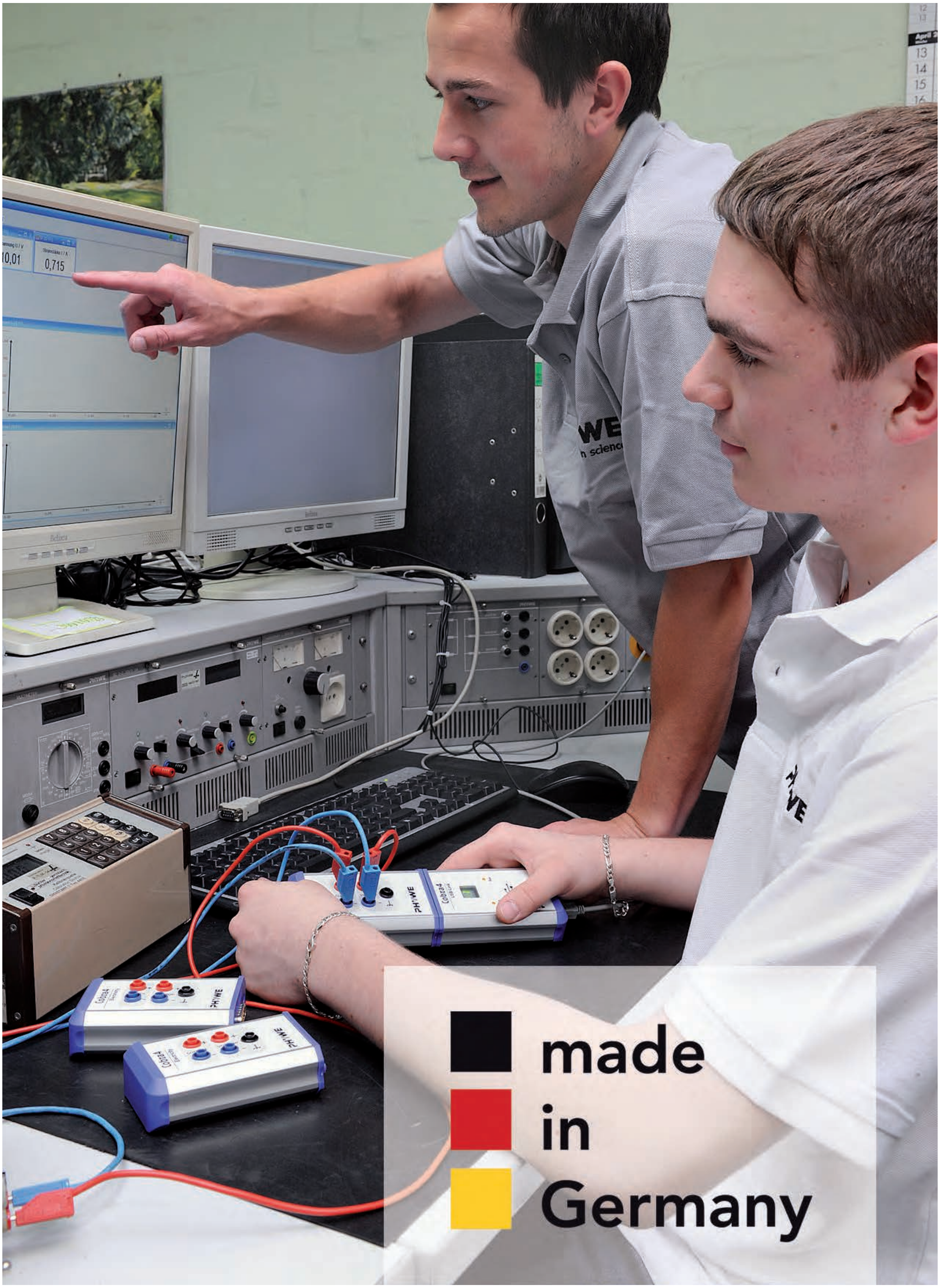
What you can learn about
- Cryoscopic constant
- Freezing point depression
- Molar mass

Benefits
- With detailed experiment guide
- Compact, easily transportable setup
- Simultaneous display of current temperature and temperature difference

Details

Principle
In order to train and demonstrate the determination of molar masses by way of a measurement of the freezing-point depression, urea or hydroquinone are used as test substances. The cryoscopic constant of water is determined from the freezing point depression.

Tasks
1. Determine the freezing point depression of water dissolving different amounts of hydroquinone and urea.
2. Calculate the cryoscopic constant from the experimental results.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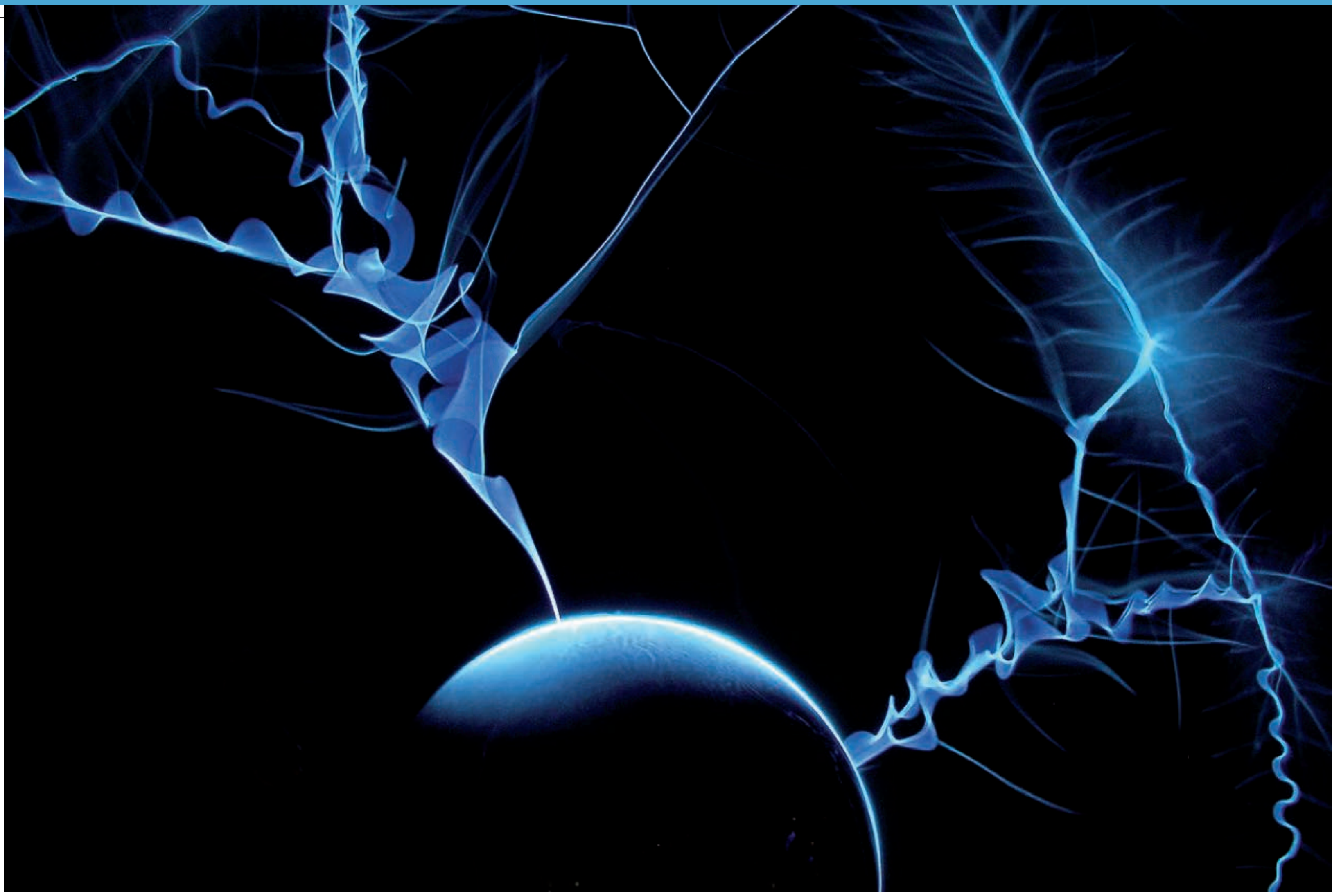


2.4 Electricity and Magnetism

P2420100 Electric fields and potentials in the plate capacitor

Details

What you can learn about
- Electric field strength and electric flux
- Electrostatic induction
- Surface charge density
- Dielectric displacement

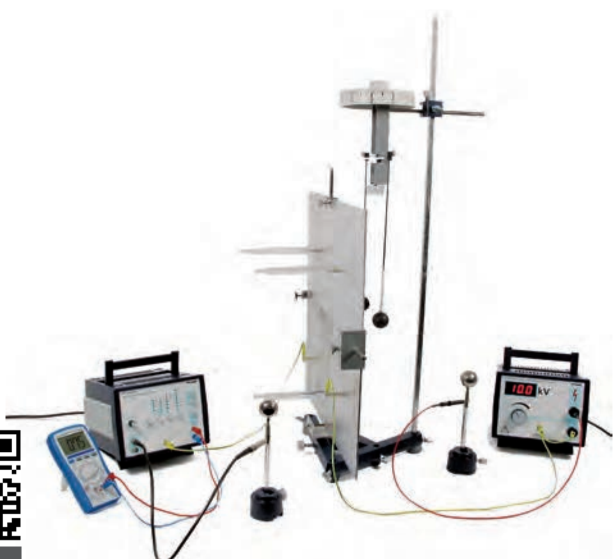
Benefits
- Loss-less measurement of electric field strength
- High-sensitive electric field meter also suitable for electrostatic measurement of voltages

Principle

A uniform electric field E is produced between the charged plates of a plate capacitor. The strength of the field is determined with the electric field strength meter, as a function of the plate spacing and the voltage. The potential, within the field is measured with a potential measuring probe.

Tasks
1. The relationship between voltage and electric field strength is investigated, with constant plate spacing.
2. The relationship between electric field strength and plate spacing is investigated, with constant voltage.
3. In the plate capacitor, the potential is measured with a probe, as a function of position.

P2420401 Coulomb's law / image charge



Details

What you can learn about
- Electric field
- Electric field strength
- Electric flux
- Electrostatic induction
- Electric constant
- Surface charge density
- Dielectric displacement
- Electrostatic potential

Benefits
- Experimental visualisation of a fundamental principle of electrodynamics
- Supplies non-hazardous high voltage
- Very sensitive measurement of the acting force

Principle

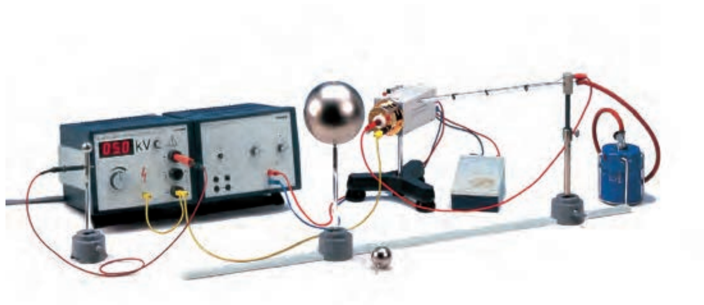
A small electrically charged ball is positioned at a certain distance in front of a metal plate lying at earth potential. The surface charge on the plate due to electrostatic induction together with the charged ball forms an electric field analogous to that which exists between two oppositely charged point charges. The electrostatic force acting on the ball can be measured with a sensitive torsion dynamometer.

Tasks
1. Establishment of the relation between the active force and the charge on the ball.
2. Establishment of the relation between force and distance, ball to metal plate.
3. Determination of the electric constant.

Coulomb potential and Coulomb field of metal spheres — P2420500

What you can learn about
- Gaussian rule
- Image charge and surface charge density
- Induction and capacitance
- Gradient
- Electrostatic potential

Benefits
- Supplies non-hazardous high voltage
- Loss-less measurement of electric field strength
- High-sensitive electric field meter also suitable for electrostatic measurement of voltages

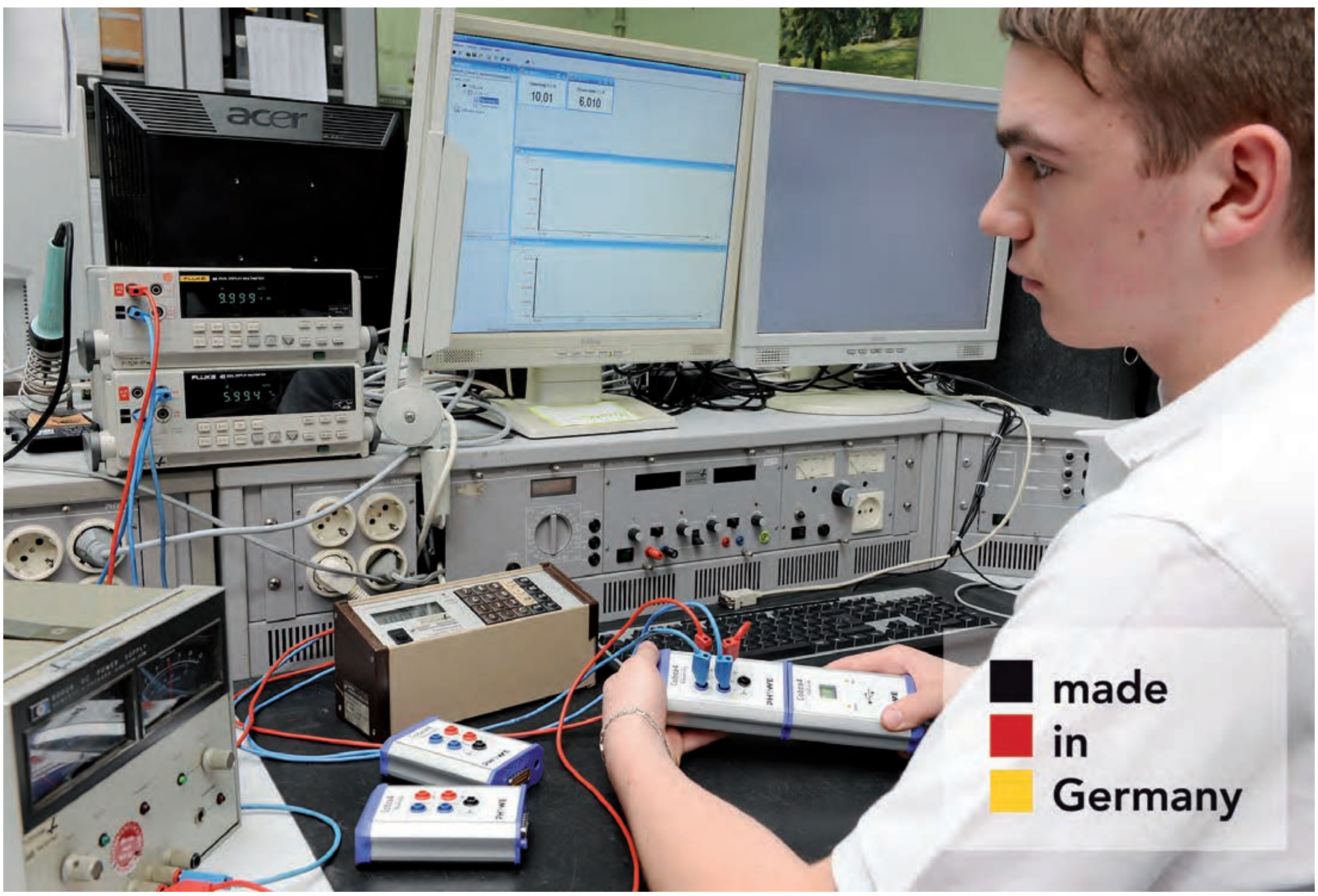


Details

Principle
Conducting spheres with different diameters are charged electrically. The static potentials and the accompanying electric field intensities are determined by means of an electric field meter with a potential measuring probe, as a function of position and voltage.

Tasks
Determine

a) the electrostatic potential and
b) the electric field strength of different conducting spheres depending either on the voltage or the distance.



P2411100 Characteristic curve and efficiency of a PEM fuel cell and a PEM electrolyser

Details

What you can learn about
- Electrolysis
- Electrode polarisation
- Decomposition voltage
- Galvanic elements
- Faraday's law

Benefits
- Quantitive determination of all relevant parameters
- Production of hydrogen and oxygen which can then be quantified
- Storage of the produced gases in a „gas bar" for reuse

Principle
In a PEM electrolyser, the electrolyte consists of a proton-conducting membrane and water (PEM = Proton-Exchange-Membrane). When an electric voltage is applied, hydrogen and oxygen are formed. The PEM fuel cell generates electrical energy from hydrogen and oxygen. To determine the efficiency, the gases are stored in small gasometers in order to be able to measure the quantities of the gases generated or consumed.

Tasks
1. Record the characteristic lines of the PEM electrolyser and of the PEM fuel cell. Then, determine the efficiencies of both, the PEM electrolysis unit and the PEM fuel cell.

P2420201 Charging curve of a capacitor / charging and discharging of a capacitor

Details

What you can learn about
- Charging
- Discharging
- Time constant
- Exponential function
- Half life

Benefits
- Simple and very clear set-up: only few components required
- Further experiments in electricity and electronics can be performed with the equipment

Principle
A capacitor is charged by way of a resistor. The current is measured as a function of time and the effects of capacitance, resistance and the voltage applied are determined.

Tasks
To measure the charging current over time:
1. using different capacitance values C, with constant voltage U and constant resistance R
2. using different resistance values (C and U constant)
3. using different voltages (R and C constant).

To determine the equation representing the current when a capacitor is being charged, from the values measured.

Charging curve of a capacitor and switch-on behaviour of an inductance with Cobra4 Xpert-Link P2420264

What you can learn about
- Charging and discharging
- Inductance
- Half-life

Benefits
- Simple and clear set-up: only few components required
- One device for everything: Xpert-Link serves as power supply, switch, and trigger as well
- Quick start with all pre-settings already prepared
- Further experiments in electricity and electronics can be performed with the equipment

Details

Principle

The behaviour of a capacitor while charging and discharging depends on the other components included in the circuit. The effects of capacitance, resistance and applied voltage on the current over time are to be investigated.

The equipment can be used for the additional experiment “Switch-on behaviour of a coil“.

Tasks
1. Measure the charging current over time using different capacities for constant voltage and constant resistance.
2. Measure the charging current over time for different resistance values.
3. Measure the charging curve over time for different voltages.
4. Derive the equation for current over time from the measured values.

Capacitance of metal spheres and of a spherical capacitor P2420300

What you can learn about
- Electric field and electrostatic induction
- Potential
- Capacitance
- Dielectrics

Benefits
- Supplies non-hazardous high voltage
- Several conductive spheres included
- Clever investment: The included universal measuring amplifier can also be used for other applications

Details

Principle

Metal spheres with different radii and a spherical capacitor are charged by means of a variable voltage. The induced charges are determined with a measuring amplifier. The corresponding capacitances are deduced from voltage and charge values.

Tasks
1. Determination of the capacitance of three metal spheres with different diameters.
2. Determination of the capacitance of a spherical capacitor.
3. Determination of the diameters of each test body and calculation of their capacitance values.

P2420600 Dielectric constant of different materials

Details

What you can learn about
- Maxwell's equations
- Real and free charges
- Dielectric displacement and polarisation

Benefits
- Supplies non-hazardous high voltage
- Easy experimental set-up due to clear and compact design
- Clever investment: The included universal measuring amplifier can also be used for other applications

Principle

The electric constant is determined by measuring the charge of a plate capacitor to which a voltage is applied. The dielectric constant is determined in the same way, with plastic or glass filling the space between the plates.

Tasks

The relation between charge Q and voltage U is to be measured.
1. Determine the electric constant from the relation between charge and voltage for a plate capacitor.
2. Measure the charge of a plate capacitor as a function of the inverse distance between the plates for a constant voltage.
3. Place different dielectric media between the plates and determine the corresponding dielectric constants.

P3060962 Nernst equation with Cobra4

Details

What you can learn about
- Electrode potentials and their concentration dependence
- Redox electrodes
- Electrochemical cells

Benefits
- Interesting and important for chemists and physicists
- By supplementing the large scale display can be used optimally as a demonstration experiment
- Data logging via tablet possible

Principle

The Nernst equation expresses how the electrical potential of an electrode in contact with a solution of ions depends upon the concentrations (more accurately, activities) of those ions. The equation may be experimentally verified using an electrochemical cell formed from an inert indicator electrode coupled with a convenient reference electrode. The potential of the indicator electrode, and hence the e.m.f. of the cell, is monitored as the ionic composition of the electrolyte solution is changed.

Tasks

Using a reference electrode, measure the potential of a platinum electrode in contact with solutions containing known concentrations of the iron(II) and iron(III) complex ions.

Determination of Faraday's constant

P3062101

What you can learn about
- Electrolysis coulometry
- Charge
- Faraday's laws
- Avogadro's number
- General equation of state for ideal gases

Benefits
- Standard experiment in introductory physics and chemistry
- Failsafe and elegant determination of an important natural constant
- Excellent for the introduction of refractometry

Details

Principle

Faraday's laws of electrolysis describe the correlation between the amounts of substances transformed in the reactions at the electrodes and the charge applied (amount of electricity). Faraday's constant, which appears as a proportionality factor, can be determined experimentally from the dependence.

Tasks

Determine Faraday's constant from the dependence of the volumes of hydrogen and oxygen envolved on the charge applied in the hydrolysis of dilute sulphuric acid.

Conductivity of strong and weak electrolytes with Cobra4

P3060660

What you can learn about
- Kohlrausch's law
- Equivalent conductivity
- Temperature-dependence of conductivity
- Ostwald's dilution law

Benefits
- With detailed experiment guide
- Simplified implementation: all pre-settings already prepared
- Easy evaluation via software

Details

Principle

It is possible to differentiate between strong and weak electrolytes by measuring their electrical conductance. Strong electrolytes follow Kohlrausch's law, whereas weak electrolytes are described by Ostwald's dilution law. The examination of the concentration dependence of the conductivity allows the molar conductivities of infinitely diluted electrolytes to be determined, and facilitates the calculation of degree of dissociation and the dissociation constants of weak electrolytes.

Tasks

1. Determine the concentration dependence of the electrical conductivity of potassium chloride and acetic acid solutions.
2. Calculate the molar conductivity using data from the measurements taken and determine the molar conductivity at infinite dilution by extrapolation.
3. Determine the dissociation constant of acetic acid.

P2410101 4 Point Method / Measurement of low resistances / Ohm's Law

Details

What you can learn about
- Ohm's law
- Resistivity
- Contact resistance
- Conductivity
- Four-wire method of measurement

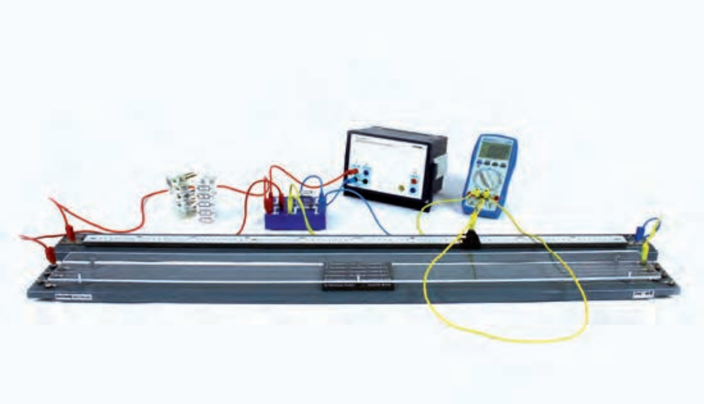
Benefits
- Measurement at two different metals possible
- Conductivity rods can be used both for electrical and thermal conductivity experiments
- Measurement amplifier can be used for both AC and DC measurements and amplifies up to 10,000 times

Principle

The resistances of various conductors are determined by recording the current / voltage characteristic. The resistivity of metal rods and the contact resistance of connecting cords are calculated.

Tasks
1. To plot the current / voltage characteristics of metal rods (copper and aluminium) and to calculate their resistivity.
2. To determine the resistance of various connecting cords by plotting their current / voltage characteristics and calculating the contact resistances.

P2410200 Wheatstone bridge



Details

What you can learn about
- Kirchhoff's laws
- Conductor
- Circuit
- Voltage
- Resistance
- Parallel connection
- Series connection

Benefits
- Highly precise and reproducible measurements possible
- Many different measurement variations possible
- Also suitable for measurement of low resistances

Principle

The Wheatstone bridge circuit is used to determine unknown resistances. The total resistance of resistors connected in parallel and in series is measured.

Tasks
1. Determination of unknown resistances.
2. Determination of the total resistance of resistors in series and of resistors in parallel.
3. Determination of the resistance of a wire as a function of its cross-section.

Characteristic curves of a solar cell

P2410901

What you can learn about
- p-n junction
- Acceptors and donors
- Valence and conduction band
- Fermi level and energy-band diagram
- Diffusion potential
- Photo-conductive effect

Benefits
- Quantitative measurement regarding light intensity
- Determine relationship between short-circuit and light intensity
- Either neglect or measure the temperature effect

Details

Principle
The current-voltage characteristics of a solar cell are measured at different light intensities, the distance between the light source and the solar cell being varied. The dependence of no-load voltage and short-circuit current on temperature is determined.

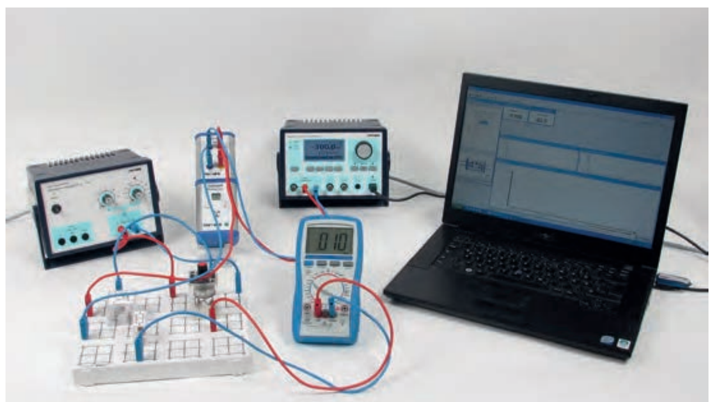
Tasks
1. Determine the light intensity with the thermopile.
2. Measure the short-circuit current and no-load.
3. Estimate the dependence of no-load voltage, and short-circuit current on temperature.
4. Determine the influence of different operating conditions: Cooling of the equipment, no cooling, and irradiation with sunlight.

Characteristic curves of semiconductors with Cobra4

P2410960

What you can learn about
- p-n junction
- Acceptors and donors
- Valence and conduction band
- Energy-band diagram
- Operating point of a transistor

Benefits
- Fast and easy experimenting
- Several types of semiconductors
- Quick start with all pre-settings already prepared
- Data logging for instant results during measurement

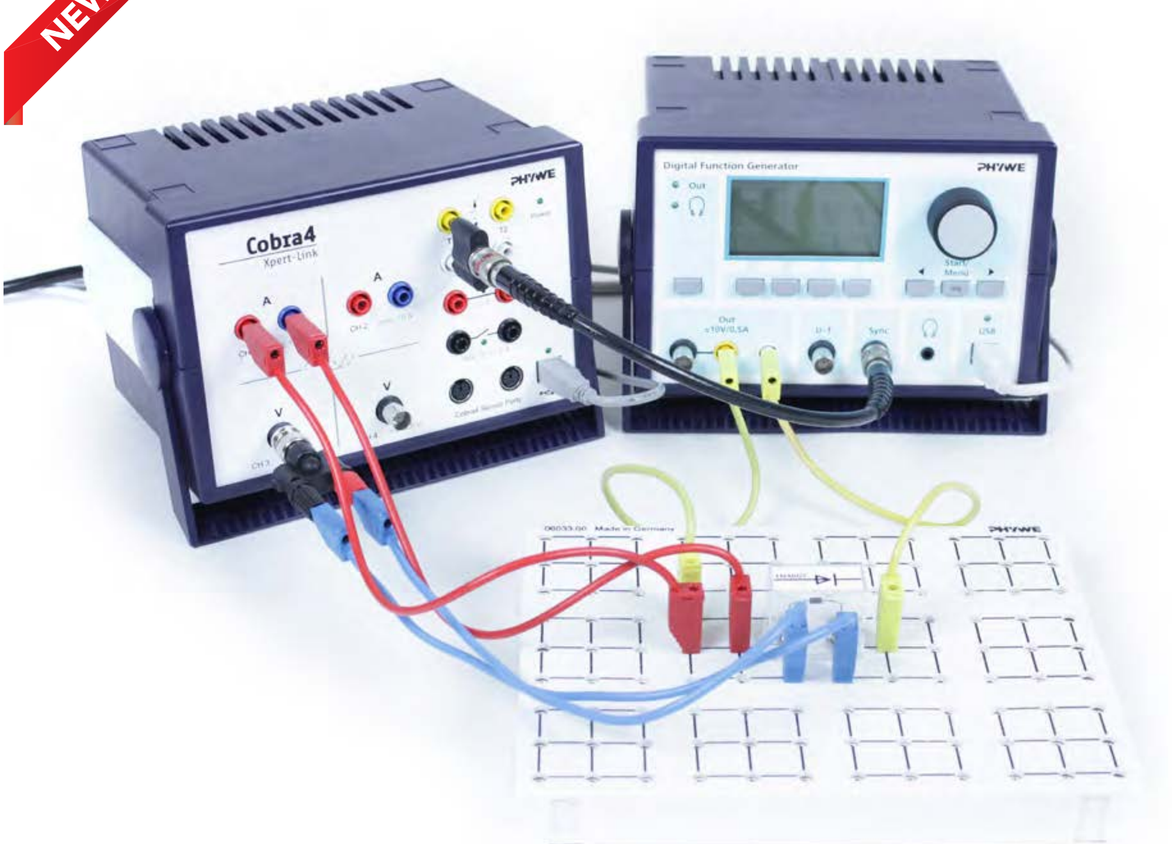


Details

Principle
The current-voltage characteristic of a semiconducting diode is measured. The collector current depending on the emitter-collector voltage is measured for different values of base current strength through an NPN transistor.

Tasks
1. Investigate the dependence of the current strength flowing through a semiconducting diode.
2. Determine the variations of the collector current with the collector voltage for various values of the base current intensity.

P2410964 Characteristic curves of semiconductors with Cobra4 Xpert-Link



Principle
The current-voltage characteristic of a semiconducting diode is measured. The collector current depending on the emitter-collector voltage is measured for different values of base current strength through an NPN transistor.

Tasks
Determine the current strength flowing through a semiconducting diode. Determine the collector current with the collector voltage for various values of the base current intensity.

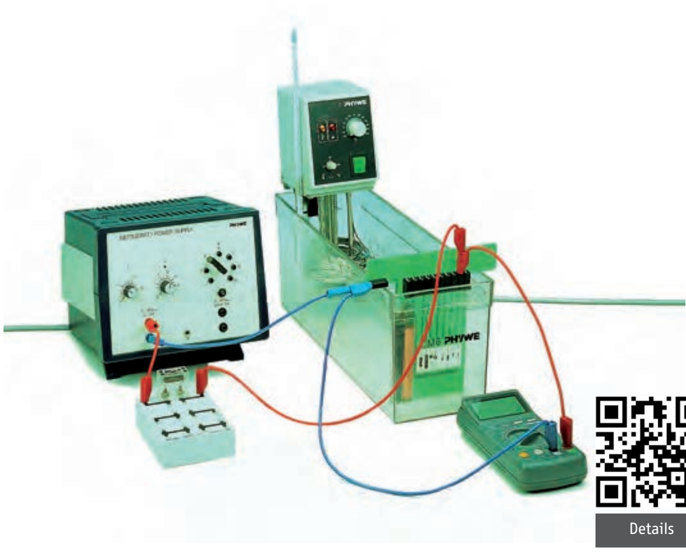
What you can learn about
- p-n junction
- Acceptors and donors
- Valence and conduction band
- Fermi level and energy-band diagram
- Diffusion potential
- Photo-conductive effect

Benefits
- Several types of semiconductors
- Extensive explanations and step-by-step instructions
- Measure simultaneously on four channels
- Quick start with all pre-settings already prepared
- Further experiments can be performed with the equipment

Temperature dependence of different resistors and diodes with a multimeter — P2410401

What you can learn about
- Carbon and metallic film resistor
- PTC and NTC
- Avalanche and Zener effect
- Charge carrier generation
- Mathie's rule

Benefits
- One setup to measure the electrical components, semiconducting diodes, and the blocking voltage
- All immersion probes are mounted on one convenient heat-resistant circuit board for easy handling



Details

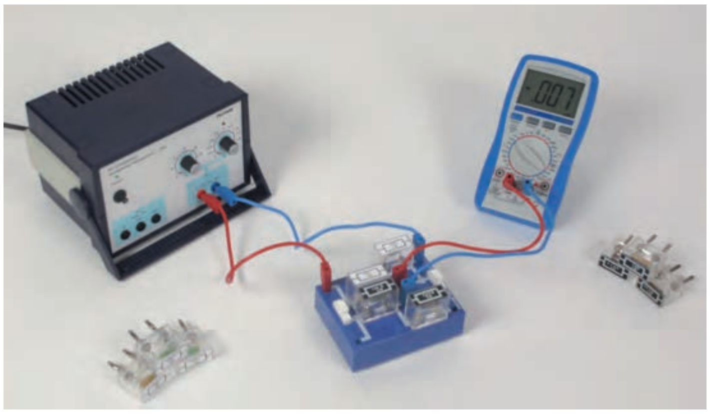
Principle
The temperature dependence of an electrical parameter (e.g. resistance, conducting-state voltage, and blocking voltage) of different components is determined. To do this, the immersion probe set is immersed in a water bath and the resistance is measured at regular temperature intervals.

Tasks
Measure the temperature dependence of a) the resistance of different electrical components, b) the conducting state voltage of semiconducting diodes, and c) the voltage in the Zener and the avalanche effects.

Kirchhoff's laws — P2410500

What you can learn about
- Kirchhoff's laws
- Induction law
- Maxwell's equations

Benefits
- Setup to measure both Kirchhoff's laws and to determine unknown resistances
- Components can also be used for other basic and advanced electricity experiments



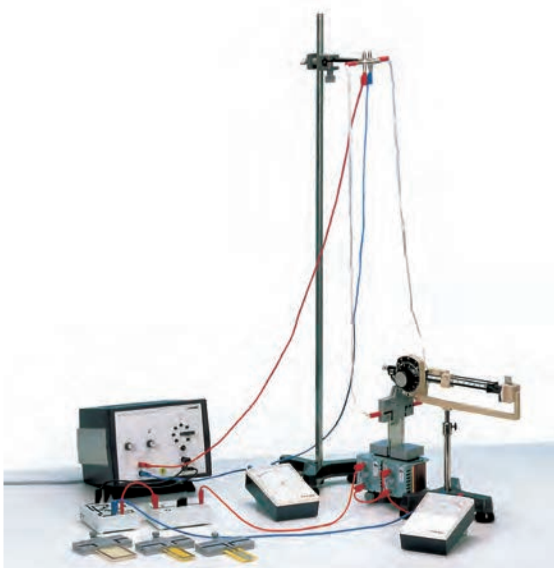
Details

Principle
Kirchhoff's laws are verified by measuring current, voltage and resistance in series and parallel circuits. In addition, the Wheatstone bridge circuit is used to determine unknown resistances more precisely.

Tasks
1. Verify Kirchhoff's laws by measuring current and voltage for series and parallel connected resistors for each resistor as well as the total values. From these measurements calculate the partial and total resistances.
2. Determine unknown resistances by the use of the Wheatstone bridge circuit.

P2410601

Current balance / force acting on a current-carrying conductor with an amperemeter



Details

What you can learn about
- Uniform magnetic field
- Magnetic induction (formerly magnetic-flux density)
- Lorentz force
- Moving charges

Benefits
- The use of a mechanic balance is especially suitable for a vivid demonstration of the Lorentz force
- Four different wire loops included: Clearer and deeper understanding of all correlations leads to an enhanced learning success

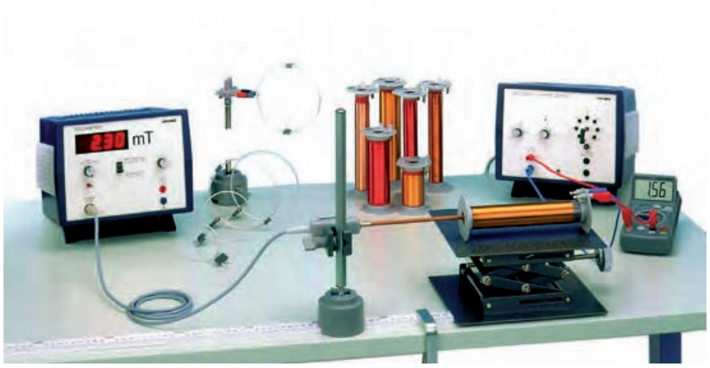
Principle

The force acting on a current-carrying conductor loop in a uniform magnetic field (Lorentz force) is measured with a balance. Conductor loops of various sizes are suspended in turn from the balance, and the Lorentz force is determined as a function of the current and magnetic induction. The uniform magnetic field is generated by an electromagnet. The magnetic induction can be varied with the coil current.

Tasks
1. Determine the direction of the force as a function of current and the direction of the magnetic field.
2. Measure the force as a function of current in the conductor loop, with a constant magnetic induction and for conductor loops of various sizes. Calculate the magnetic induction.
3. Measure the force on a conductor loop as a function of the coil current. In the range being considered, the magnetic induction is proportional to the coil current.

P2430201

Magnetic field of single coils / Biot-Savart's law with a teslameter



Details

What you can learn about
- Wire loop
- Biot-Savart's law
- Hall effect
- Magnetic field
- Magnetic flux density

Benefits
- Simple setup which allows an easy measurement of the magnetic flux density depending on different parameters
- No calibration needed, Teslameter is calibrated up to 1 T

Principle

The magnetic field along the axis of wire loops and coils of different dimensions is measured with a teslameter (Hall probe). The relationship between the maximum field strength and the dimensions is investigated and a comparison is made between the measured and the theoretical effects of position.

Tasks
1. To measure the magnetic flux density in the middle of various wire loops with the Hall probe and to investigate its dependence on the radius and number of turns.
2. To determine the magnetic field constant.
3. To measure the magnetic flux density along the axis of long coils and compare it with theoretical values.

Magnetic field of paired coils in a Helmholtz arrangement with a teslameter

P2430301

What you can learn about

- Maxwell's equations
- Wire loop
- Flat coils
- Biot-Savart's law
- Hall effect

Benefits

- Particularly homogeneous magnetic field and high flux density due to large Helmholtz coil diameter
- Helmholtz coils suitable for multiple other elementary experiments

Details

Principle

The spatial distribution of the field strength between a pair of coils in the Helmholtz arrangement is measured. The spacing at which a uniform magnetic field is produced is investigated and the superposition of the two individual fields to form the combined field of the pair of coils is demonstrated.

Tasks

1. Measure the magnetic flux density along the z-axis of the flat coils when the distance between them equals their radius, and when it is larger and smaller than this.
2. Measure the spatial distribution of the magnetic flux density when the distance between the coils is equal to their radius using the rotational symmetry of the set-up: a) measurement of the axial component, b) measurement of radial component.
3. Measure the radial components of the two individual coils in the plane midway between them and demonstrate the overlapping of the two fields.

Magnetic moment in the magnetic field

P2430400

What you can learn about

- Torque
- Magnetic flux
- Uniform magnetic field
- Helmholtz coils

Benefits

- Particularly homogeneous magnetic field and high flux density due to large Helmholtz coil diameter
- Torsion dynamometer offers highly precise measurements

Details

Principle

A conductor loop carrying a current in an uniform magnetic field experiences a torque. This is determined as a function of the radius, of the number of turns and the current in the conductorloop and of the strength of the external field.

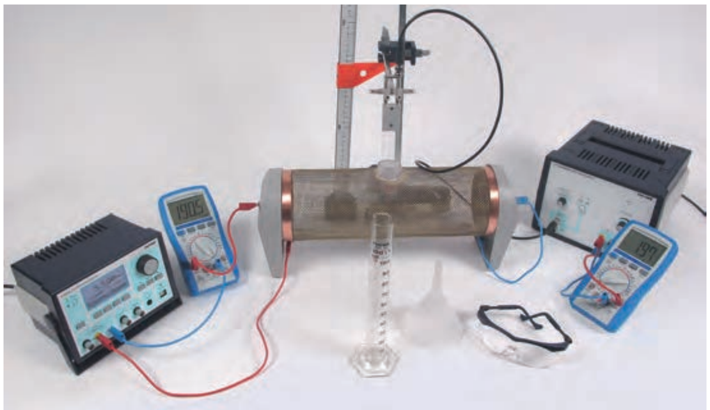
Tasks

Determination of the torque due to a magnetic moment in an uniform magnetic field, as a function

1. of the strength of the magnetic field,
2. of the angle between the magnetic field in the magnetic moment
3. of the strength of the magnetic moment.

P2430605

Magnetic field inside a conductor with digital function generator



Details

What you can learn about
- Maxwell's equations
- Magnetic flux
- Current density
- Field strength
- Electrolyte

Benefits
- Measure the magnetic field inside of liquid electrolytes
- Large unique hollow cylinder with conductive wire mesh prevents the influence of disturbing fields
- Easy frequency setting thanks to digital function generator

Principle
A current is passed through an electrolyte producing a magnetic field. This magnetic field inside the conductor is measured as function of position and current by determining the induction voltage.

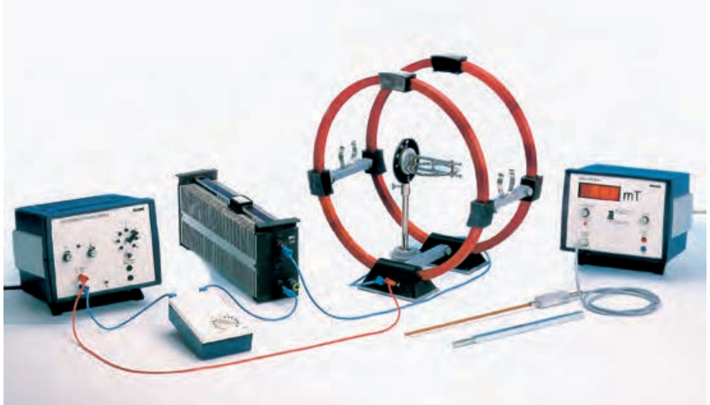
Tasks
Determine the magnetic field inside the conductor as a function of

1. the current in the conductor and verify the linear relationship.
2. the distance from the middle axis of the conductor and determine the position where the field inside the conductor vanishes.

Determination of the earth's magnetic field P2430100

What you can learn about
- Magnetic inclination and declination
- Isoclinic and isogenic lines
- Inclinometer
- Magnetic flow density
- Helmholtz coils

Benefits
- Particularly homogeneous magnetic field and high flux density due to large Helmholtz coil diameter
- Setup with precalibrated teslameter does not require additional magnets and coils for calibration



Details

Principle

A constant magnetic field, its magnitude and direction known, is superimposed on the unknown earth magnetic field. The earth-magnetic field can then be calculated from the magnitude and direction of the resulting flux density.

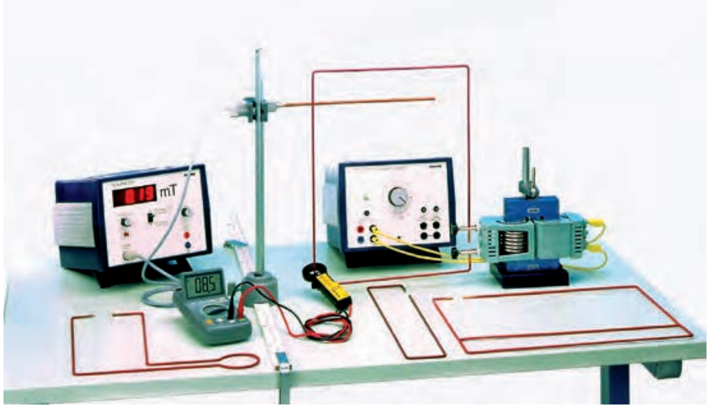
Tasks

1. Determine the magnetic flux of a pair of Helmholtz coils and plot it as a function of the coil current. Calculate the Helmholtz system calibration factor from the slope.
2. Determine the horizontal component of the earth-magnetic field through superimposition of the Helmholtz field.
3. Determine the angle of inclination in order to calculate the vertical component of the earth-magnetic field.

Magnetic field outside a straight conductor P2430500

What you can learn about
- Maxwell's equations
- Magnetic flux
- Induction
- Superimposition of magnetic fields
- Alternating current

Benefits
- Four different current conductors allow the observation of the magnetic field in different configurations
- Experimental setup allows the visualization of the Maxwell Equations
- No extra calibration needed, Teslameter is calibrated up to 1 T



Details

Principle

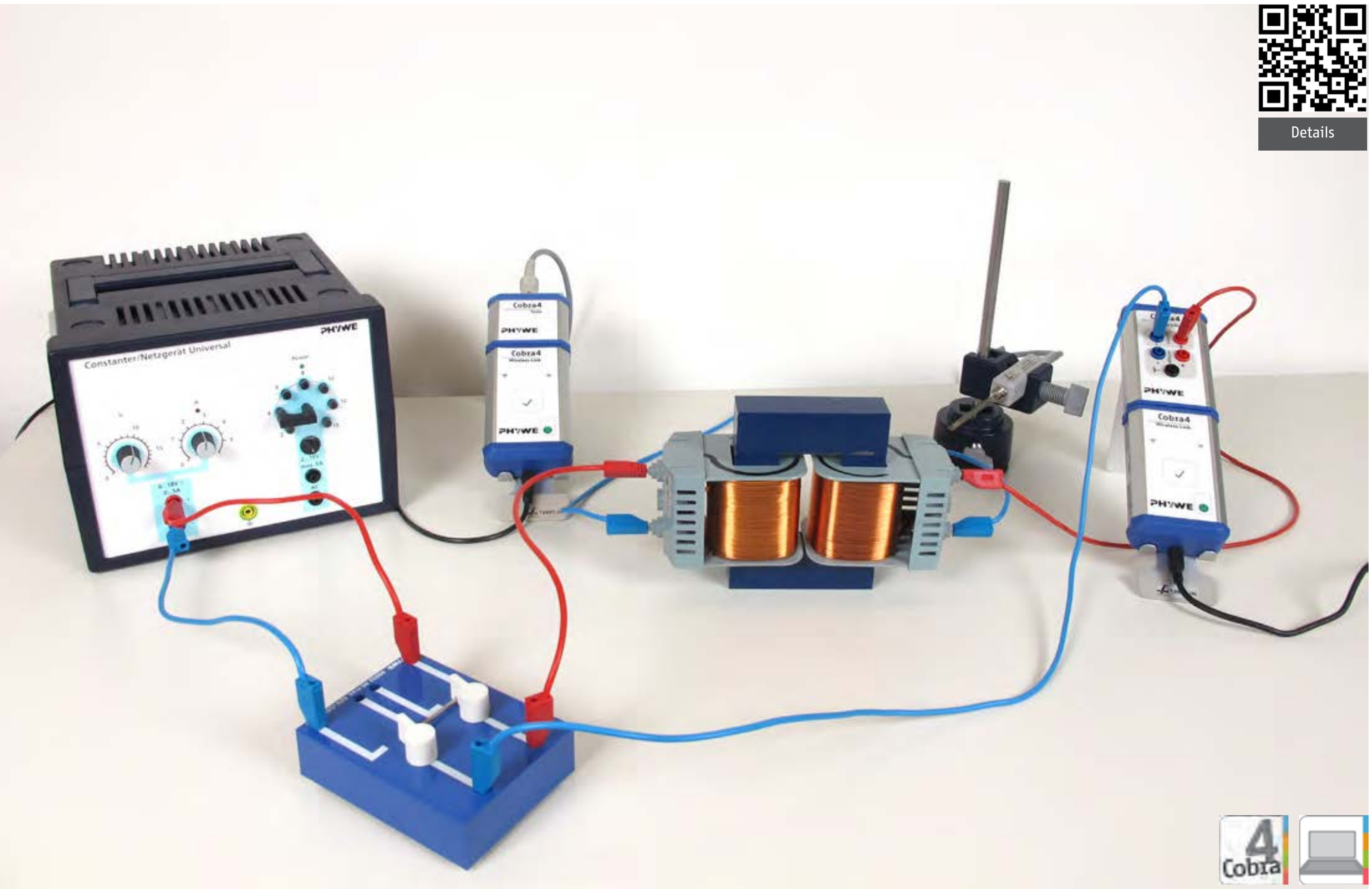
A current which flows through one or two neighbouring straight conductors produces a magnetic field around them. The dependences of these magnetic fields on the distance from the conductor and on the current are determined.

Tasks

Determination of the magnetic field

1. of a straight conductor as a function of the current,
2. of a straight conductor as a function of the distance from the conductor,
3. of two parallel conductors, in which the current is flowing in the same direction, as a function of the distance from one conductor on the line joining the two conductors,
4. of two parallel conductors, in which the current is flowing in opposite directions, as a function of the distance from one conductor on the line joining the two conductors.

P2430760 Ferromagnetic hysteresis with Cobra4



Principle

A magnetic field is generated in a ring-shaped iron core by a continuous adjustable direct current applied to two coils. The field strength $\hat{I}-$ and the flux density B are measured and the hysteresis recorded. The remanence and thecoercive field strength of two different iron cores can be compared.

Tasks

Record the hysteresis curve for a massive iron core and for a laminated one.

What you can learn about

- Induction
- Magnetic flux
- Magnetic field of coils
- Magnetic and coercive field strength
- Remanence

Benefits

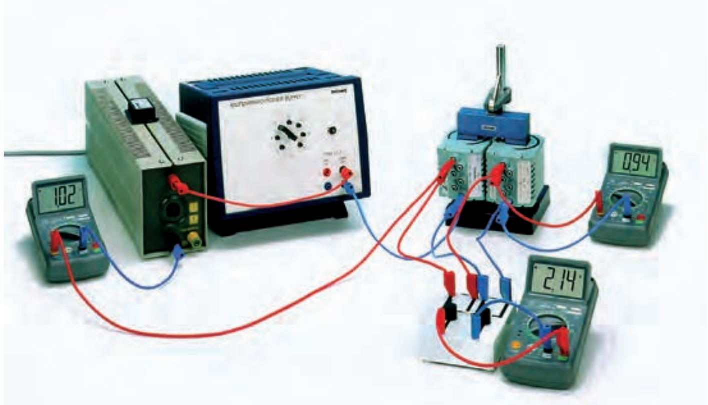
- Simple experimental setup and intuitive handling of the software: Better results in less time
- Added value due to the use of datalogging: Direct visualisation of the learning objective

Transformer

P2440100

What you can learn about
- Induction
- Magnetic flux
- Loaded transformer
- Unloaded transformer
- Coil

Benefits
- Coils with several tappings for various combinations of winding numbers between primary and secondary coil
- Quick, easy, and neat set-up



Details

Principle

An alternating voltage is applied to one of two coils (primary coil) which are located on a common iron core. The voltage induced in the second coil (secondary coil) and the current flowing in it are investigated as functions of the number of turns in the coilsand of the current flowing in the primary coil.

Tasks

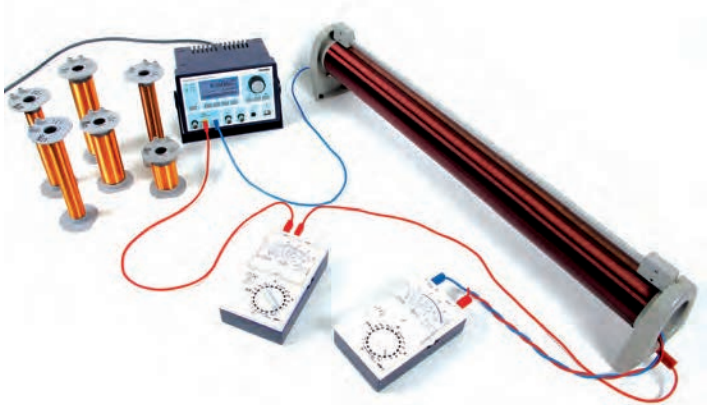
1. Determine the secondary voltage on the open circuited transformer as a function of number of coil turns and as a function of primary voltage.
2. Determine the short-circuit current on the secondary side as a function of the number of coil turns and as a function of primary current.
3. Determine the primary current for a loaded transformer as a function of number of coil turns and as a function of secondary current.

Magnetic induction

P2440201

What you can learn about
- Maxwell's equations
- Electrical eddy field
- Magnetic field of coils
- Magnetic flux

Benefits
- Huge field coil for homogenous magnetic field
- On-the-fly switching of the numerous induction coils
- Easy frequency setting thanks to digital function generator



Details

Principle

A magnetic field of variable frequency and varying strength is produced in a long coil. The voltages induced across thin coils which are pushed into the long coil are determined as a function of frequency, number of turns, diameter and field strength.

Tasks

Determination of the induction voltage as a function

1. of the strength of the magnetic field,
2. of the frequency of the magnetic field,
3. of the number of turns of the induction coil,
4. of the cross-section of the induction coil.

P2440301 Inductance of solenoids

Details

What you can learn about
- Lenz's law
- Self-inductance
- Oscillatory circuits and damped oscillation
- Resonance
- Q factor

Benefits
- Quick, easy, and neat set-up
- On-the-fly switching of the numerous induction coils for quick and easy experimenting
- Easy frequency setting thanks to digital function generator

Principle

A square wave voltage of low frequency is applied to oscillatory circuits comprising coils and capacitors to produce free, damped oscillations. The values of inductance are calculated from the natural frequencies measured, the capacitance being known.

Tasks

To connect coils of different dimensions (length, radius, number of turns) with a known capacitance C to form an oscillatory circuit. From the measurements of the natural frequencies, to calculate the inductances of the coils and determine the relationships between:

1. inductance and number of turns
2. inductance and length
3. inductance and radius.

P2440364 Inductance of solenoids with Cobra4 Xpert-Link

Details

What you can learn about
- Lenz's law
- Self-inductance
- Oscillatory circuits and damped oscillation
- Resonance
- Q factor

Benefits
- On-the-fly switching of coils for quick experimenting
- Intuitive, touch-optimized software that controls all devices simultaneously
- Quick start with all pre-settings already prepared
- Further experiments can be performed with the equipment

Principle

A square wave voltage of low frequency is applied to oscillatory circuits comprising coils and capacitors to produce free, damped oscillations. The values of inductance are calculated from the natural frequencies measured, the capacitance being known.

Tasks

1. Form an oscillatory circuit by connecting coils of different dimensions with a known capacitance.
2. Measure the natural frequencies to calculate the inductances of the coils and determine the relationships between a) inductance and number of turns, b) inductance and length, and c) inductance and radius.

Coil in the AC circuit with Cobra4 Xpert-Link

P2440464

What you can learn about
- Inductance
- Kirchhoff's laws
- Maxwell's equations
- AC impedance
- phase displacement

Benefits
- Intuitive, touch-optimized software that controls all devices simultaneously
- Quick start with all pre-settings already prepared
- Fast experimenting by simply switching components
- Compute impedance in real-time
- Further experiments can be performed with the equipment

Details

Principle
The coil is connected in a circuit with a voltage source of variable frequency. The impedance and phase displacements are determined as functions of frequency. Parallel and series impedances are measured.

Tasks
1. Determine the impedance of a coil as a function of frequency.
2. Determine the inductance of the coil.
3. Determine the phase displacement between the terminal voltage and total current as a function of the frequency in the circuit.
4. Determine the total impedance of coils connected in parallel and in series.

Capacitor in the AC circuit with Cobra4 Xpert-Link

P2440564

What you can learn about
- Capacitance
- Kirchhoff's laws
- Maxwell's equations
- AC impedance
- Phase displacement

Benefits
- Intuitive, touch-optimized software that controls all devices simultaneously
- Quick start with all pre-settings already prepared
- Fast experimenting by simply switching components
- Compute impedance in real-time
- Further experiments can be performed with the equipment

Details

Principle
A capacitor is connected in a circuit with a variable-frequency voltage source. The impedance and phase displacement are determined as a function of frequency and of capacitance. Parallel and series impedances are measured.

Tasks
1. Determine the impedance of a capacitor as a function of frequency.
2. Determine the phase displacement between the terminal voltage and total current as a function of the frequency in the circuit.
3. Determine the total impedance of capacitors connected in parallel and in series.

P2440664 — RLC circuit with Cobra4 Xpert-Link

Details

What you can learn about
- Periodic, damped, and forced oscillations
- Kirchhoff's laws
- Series- and parallel-tuned circuits
- Reactance and impedance
- Phase shift
- Q factor and bandwidth

Benefits
- Voltage and current measured directly and simultaneously
- Root mean square value and impedance in real-time
- Fast and easy experimenting simply by switching components
- Cost savings: integrated oscilloscope functions

Principle

In an RLC circuit, energy is exchanged periodically between a capacitor and a coil. When the electric field of the capacitor decreases by discharge over the coil, a magnetic field is established in the coil. As soon as the capacitor is completely depleted, the current flow through the coil vanishes. The magnetic field decreases again and the capacitor is charged, again. If this process could run loss-free, the energy would oscillate continuously between capacitor and coil with the resonance frequency, that is depending on the used components.

Tasks
1. Measure the voltage drop over the LC component and the current through the circuit of a series-tuned and a parallel-tuned RLC circuit and determine the resonance frequencies.
2. Determine the impedance of the various RLC circuits.
3. Determine the bandwidth and the Q-factor from the resonance curves of the respective RLC circuit.

P2440700 — Rectifier circuits

Details

What you can learn about
- Half-wave, full-wave, and Graetz rectifier
- Diode and Zener diode
- Avalanche effect
- Internal resistance
- Smoothing factor
- Voltage stabilisation and doubling

Benefits
- Get to know several types of rectifier circuits
- Suitable for vocational classes

Principle

The ripple of the output voltage of various rectifier circuits is measured as a function of the load current strength and the charging capacitance. The characteristics of a voltage stabilizer and of a multiplier are investigated.

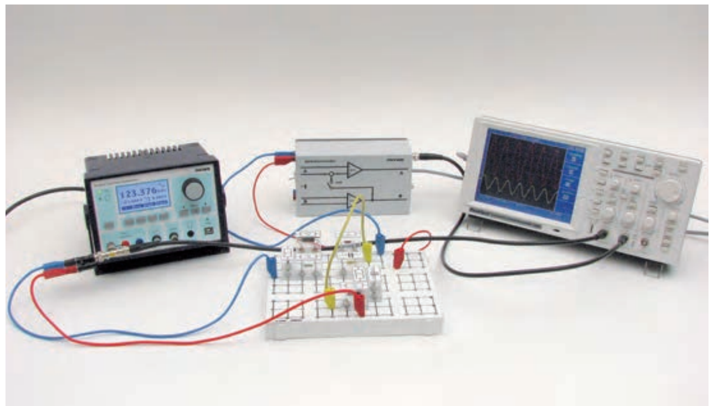
Tasks
1. Set-up a) the half-wave rectifier and b) the bridge rectifier to investigate the influence and effect of current, voltage, capacitance, and ripple.
2. Measure the voltage at the charging capacitor, and the output voltage of a stabilised voltage source as a function of the input voltage.
3. Compare the voltages of a voltage multiplier circuit.

RC filters

P2440801

What you can learn about
- High- and low-pass filter, parallel-T filters
- Wien-Robinson bridge
- Differentiating and integrating network
- Step response
- Transfer function

Benefits
- Investigate several types of frequency filters
- High-resistance inputs of the difference amplifier allow measurements without influencing the electrical behaviour of the circuit
- Easy frequency setting with the function generator



Details

Principle
Resistor-Capacitor (RC) circuits serve as filters for frequencies. The frequency response of the most commonly used RC filters is recorded by point-by-point measurements as well as the frequency sweep method, and displayed on the oscilloscope. The results are plotted and verified using the measure analysis software.

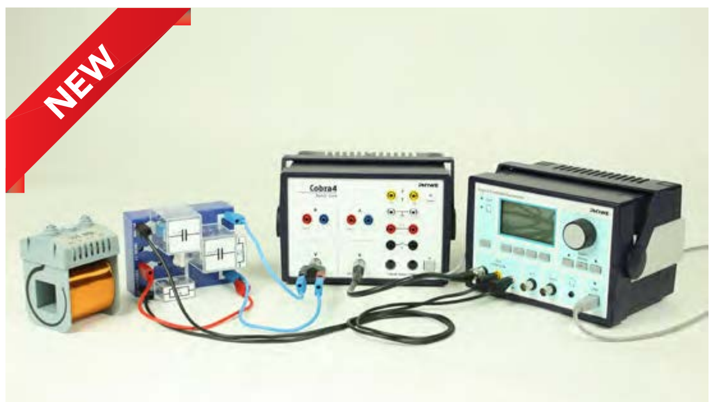
Tasks
1. Record the frequency response of the output voltage of a) a high-pass filter, b) a low-pass filter, c) a band-pass filter, d) a Wien-Robinson bridge, and e) a parallel-T filter.
2. Investigate the step response of a) a differentiating network, and b) an integrating network.

High-pass and low-pass filters with Cobra4 Xpert-Link

P2440964

What you can learn about
- Resistance, capacitance, inductance
- Phase displacement
- Filter
- Kirchhoff's laws
- Bode diagram

Benefits
- Simple and very clear set-up: only few components required
- Cost savings: No need for an additional power supply
- Quick start with all pre-settings already prepared. The software controls all devices simultaneously
- Further experiments can be performed with the equipment



Details

Principle
A coil, a capacitor, an ohmic resistance and combinations of these components are investigated for their filter characteristics as a function of frequency. The phase displacement of the filters is determined also as a function of frequency.

Tasks
1. Determine the ratio of output voltage to input voltage with a) the RC/CR network, b) the RL/LR network, c) the CL/LC network, and d) two CR networks connected in series.
2. Determine the phase displacement with a) the RC/CR network, and b) two CR networks connected in series.

P2441005 RLC measuring bridge

Details

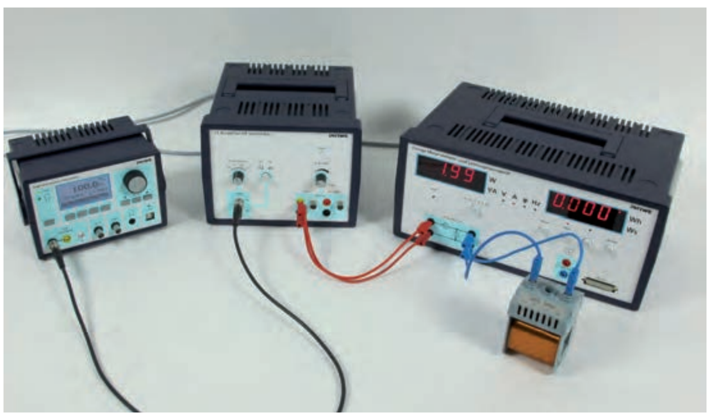
What you can learn about
- Wheatstone bridge
- Inductive and capacitive reactance
- Ohmic resistance
- Impedance
- Kirchhoff's laws

Benefits
- Quickly obtain experiment results using the Wheatstone bridge
- Easy to tune by aural measurement relying on the sensitivity of the human ear
- Save time while switching the numerous coils, resistance and capacities on-the-fly

Principle
Ohmic resistances, inductances and capacitances are determined in a Wheatstone bridge circuit operated on AC. Balancing is done aurally through headphones, using the high sensitivity of the human ear.

Tasks
Determine a) ohmic resistances, b) inductances, and c) capacitances with the Wheatstone bridge, using bridge balancing.

P2441101 Resistance, phase shift and power in AC circuits with digital function generator



Details

What you can learn about
- Impedance
- Phase shift
- Phasor diagram
- Capacitance
- Self-inductance

Benefits
- Quick set-up
- Investigate the influence of electrical components in an AC circuit.
- Directly measure the real or apparent power

Principle
Series circuits containing self-inductances or capacitances and ohmic resistances are investigated as a function of frequency. Measuring the electrical magnitudes with a work or power measurement instrument, real power or apparent power can be displayed directly.

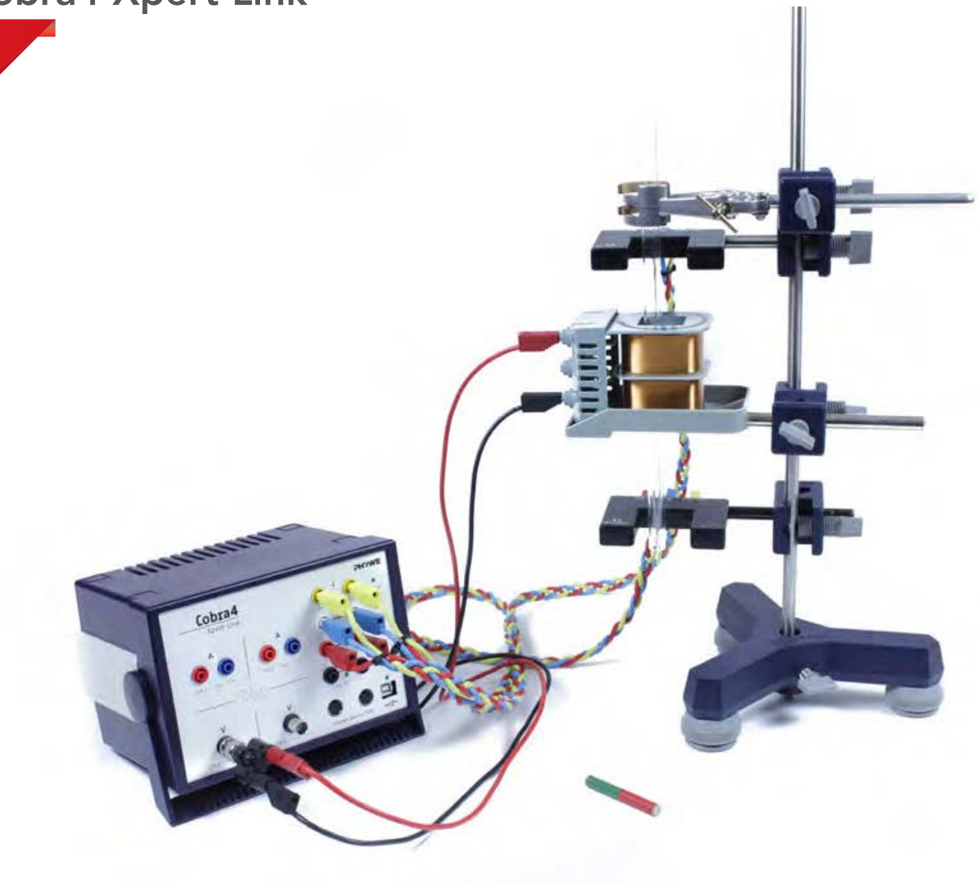
Tasks
1. Set-up a series circuit a) of self-inductance and resistor and b) of capacitor and resistor and perform the following tasks.
2. Investigate the impedance and phase shift as a function of frequency. Investigate the relation between real power and current intensity.
3. Determine either self-inductance or capacitance, and ohmic resistance.

Induced voltage pulse and Faraday's law of induction with Cobra4 Xpert-Link

P2441264

NEW

Details



Principle

A permanent magnet drops through a coil with different velocities. The change in the magnetic flux generates an induced voltage pulse. It is shown that the total induced voltage during the entire fall is constant and therefore independent of the velocity. In respect to the magnet polarity, the induced voltage changes from plus to minus or vice versa.

Tasks

1. Observe the induced voltage during the fall of the magnet through the coil for both magnet polarisations.
2. Evaluate the influence of the number of windings and of the falling height on the induced voltage.

Benefits

- Intuitive, touch-optimized software that controls all devices simultaneously
- Quick start with all pre-settings already prepared
- Investigate the influence of different falling velocities with high frequency/resolution measurements

What you can learn about

- Faraday's law of induction
- Maxwell's equations
- Magnetic flux
- Magnetic flux density
- Magnetic field lines

P2430900 Ferromagnetism, paramagnetism and diamagnetism

Details

What you can learn about
- Ferromagnetism
- Paramagnetism
- Diagmagnetism
- Magnetic field intensity

Benefits
- Compact system to study the types of magnetism
- Robust setup

Principle

The aim of this experiment is to study the behaviour of nickel, tungsten, and bismuth rods in a strong, inhomogeneous magnetic field. This field is formed, for example, between cone-shaped pole pieces that sit on a permanent magnet. The rods are suspended horizontally on a long and very thin silk thread so that they can move freely.

Tasks

1. Study the behaviour of nickel, tungsten, and bismuth rods in a strong, inhomogeneous magnetic field.

P2460201 Polarization of microwaves

Details

What you can learn about
- Microwaves
- Electromagnetic waves
- Transverse waves
- Polarization
- Malus law

Benefits
- Convenient all-in-one set
- With the same set, all aspects of microwave physics can be studied quantitatively
- Very detailed experiment guides for all experiments

Principle

Electromagnetic waves impact on a grating whose permeability depends on the rotation plane of the wave.

Tasks

The intensity of microwave radiation behind the grating is measured as a function of the angle.

Reflection, transmission and refraction of microwaves P2460301

What you can learn about
- Microwaves
- Electromagnetic waves
- Reflection
- Transmission
- Refraction
- Absorption

Benefits
- Convenient all-in-one set
- With the same set, all aspects of microwave physics can be studied quantitatively
- Very detailed experiment guides for all experiments

Details

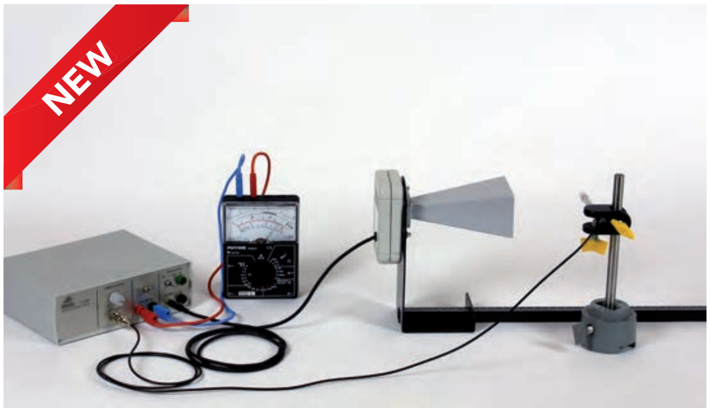
Principle
When electromagnetic waves encounter an obstacle, phenomena like reflection, transmission and refraction occur. In the present experiment these phenomena are verified and described by means of microwaves.

Tasks
Reflection, absorption and refraction are illustrated using various materials and the law of reflection is verified (angle of incidence = angle of reflection).

Propagation of microwaves (inverse square law) P2460401

What you can learn about
- Microwaves
- Electromagnetic waves
- Spherical waves
- Virtual source
- Reflection

Benefits
- Convenient all-in-one set
- With the same set, all aspects of microwave physics can be studied quantitatively
- Very detailed experiment guides for all experiments



Details

Principle
The intensity of a source of radiation, e.g. a microwave transmitter, at any given location depends on the distance of this location from the (approximately punctiform) source. Actually, due to its antenna geometry, a microwave transmitter can only be regarded as a punctiform source of radiation at long distances, which is why it is described as a virtual source for shorter distances.

Tasks
The radiation intensity of the microwave transmitter is measured for various distances and the position of the virtual source is determined.

P2460501 Standing waves in the range of microwaves

Details

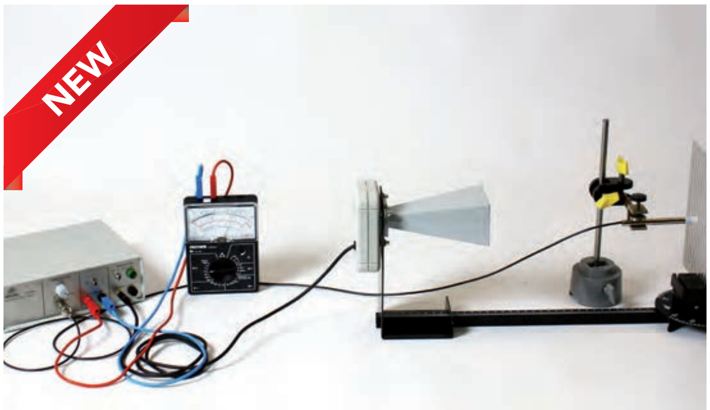
What you can learn about
- Microwaves
- Electromagnetic waves
- Reflection
- standing waves
- Distance law

Benefits
- Convenient all-in-one set
- With the same set, all aspects of microwave physics can be studied quantitatively
- Very detailed experiment guides for all experiments

Principle
When electromagnetic waves are bounced back and forth between two reflectors, a standing wave is formed. From the wavelength of the standing wave, the frequency of the waves can be determined.

Tasks
The wavelength of a standing wave is measured and the frequency determined. By extrapolation of the oscillating state on the reflector is determined.

P2460601 Conservation of energy in reflection and transmission of microwaves



Details

What you can learn about
- Microwaves
- Electromagnetic waves
- Reflection
- Transmission
- Polarization
- Conservation of energy

Benefits
- Convenient all-in-one set
- With the same set, all aspects of microwave physics can be studied quantitatively
- Very detailed experiment guides for all experiments

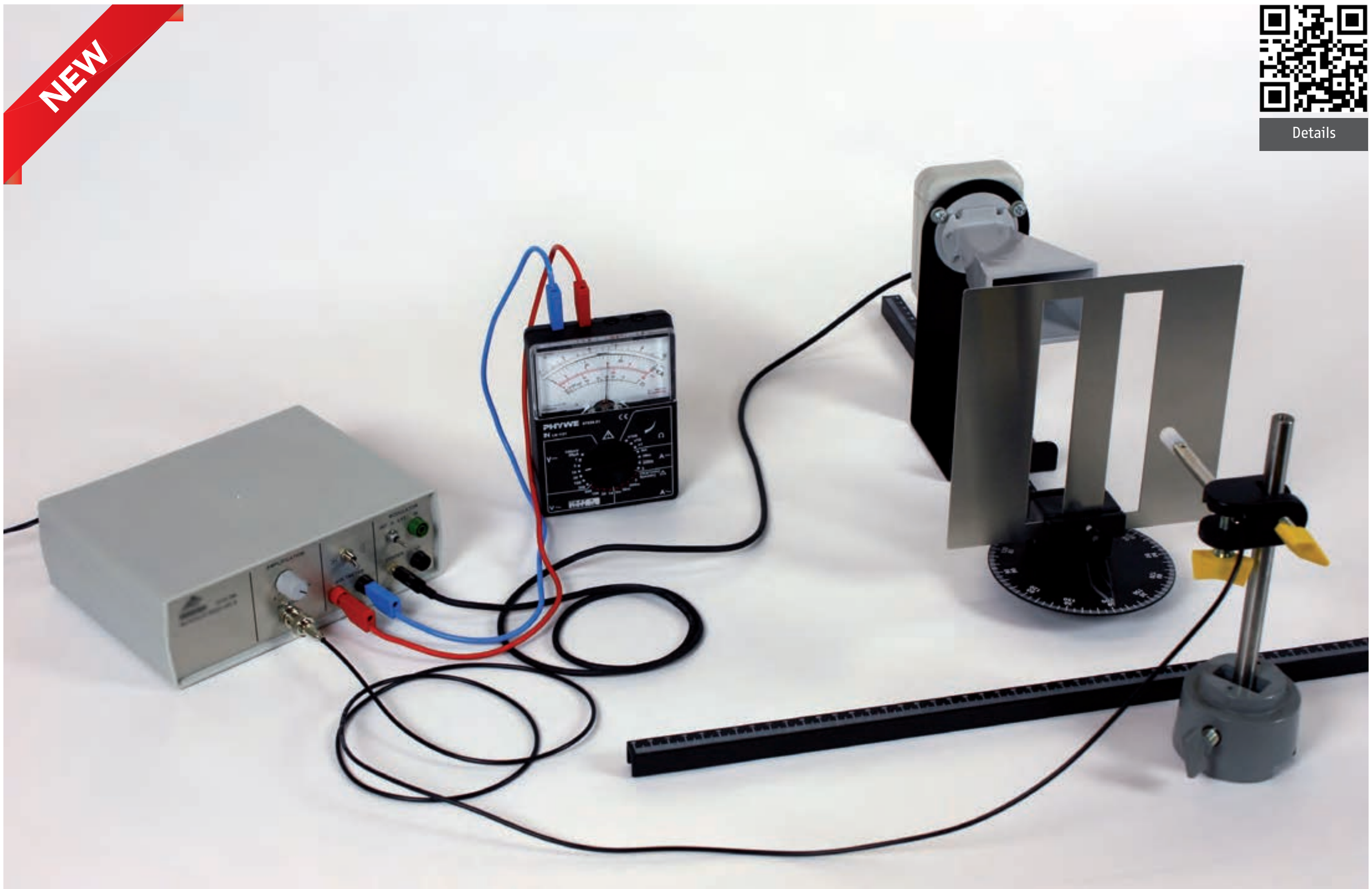
Principle
When electromagnetic waves encounter an obstacle, they are proportionately reflected, transmitted and absorbed. In this experiment, it is proved that the sum of the proportions is conserved.

Tasks
The relationship between reflection and transmission is determined by means of a polarization grating.

Diffraction and interference of microwaves

P2460901

Details



Principle

If a double-slit is positioned in the divergent microwave beam, a characteristic intensity profile results behind this double-slit. The periodicity of the intensity profile can be used to determine the wavelength of the microwaves that are used.

Tasks

First the phenomenon of diffraction through a single-slit and on a small obstacle is investigated. Then the intensity profile that results from a diffraction through a double-slit is measured and the wavelength of the electromagnetic wave that is used, based on this intensity profile, is determined.

Benefits

- Convenient all-in-one set
- With the same set, all aspects of microwave physics can be studied quantitatively
- Very detailed experiment guides for all experiments

What you can learn about

- Microwaves
- Electromagnetic waves
- Huygens principle
- Double-slit
- Interference

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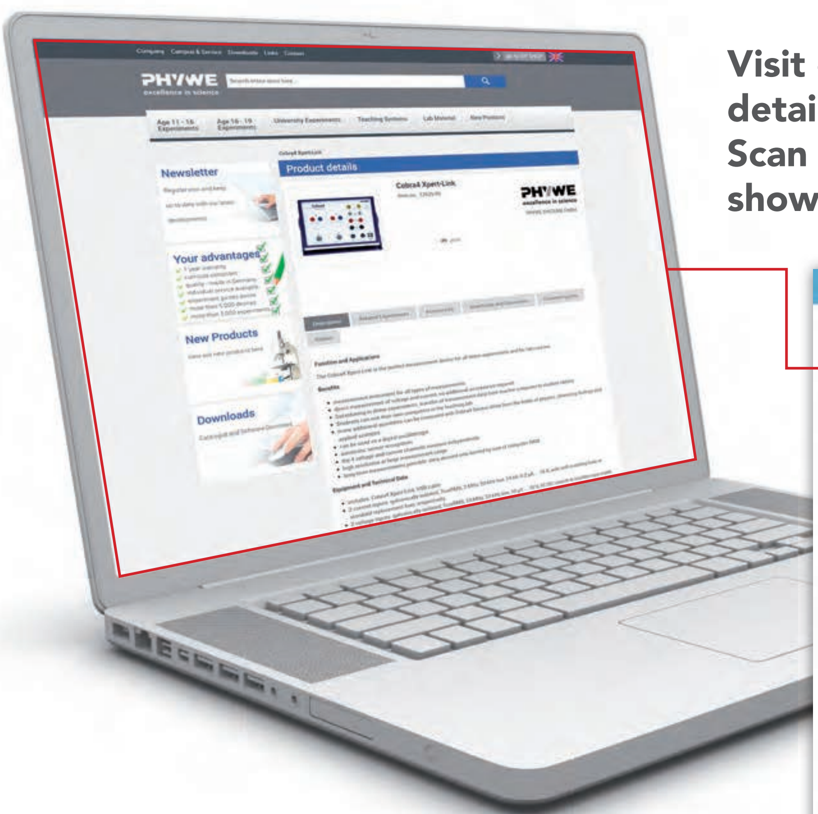


Visit our PHYWE website for all detailed information.
Scan the QR codes which are shown by the experiments

2.5 Light and Optics

P2210101 Measuring the velocity of light

Details

What you can learn about
- Refractive index
- Wavelength
- Frequency
- Phase
- Modulation
- Electric field constant
- Magnetic field constant

Benefits
- Determine yourself what the “speed of light“ actually is
- Find out how the velocity of light differs in material
- The size of a table top suffice

Principle
The intensity of the light is modulated and the phase relationship of the transmitter and receiver signal compared. The velocity of light is calculated from the relationship between the changes in the phase and the light path.

Tasks
1. To determine the velocity of light in air.
2. To determine the velocity of light in water and synthetic resin and to calculate the refractive indices.

P2240260 Photometric law of distance with Cobra4 – inverse square law

Details

What you can learn about
- Luminous flux
- Quantity of light
- Luminous intensity
- Illuminance
- Luminance

Benefits
- Find out how exactly it becomes darker with increasing distance from a lightsource
- Get results fast and reproducible with a data-logging system
- Analize results easily and compare them to theory using a computer

Principle
The luminous intensity emitted by a punctual source is determined as a function of distance.

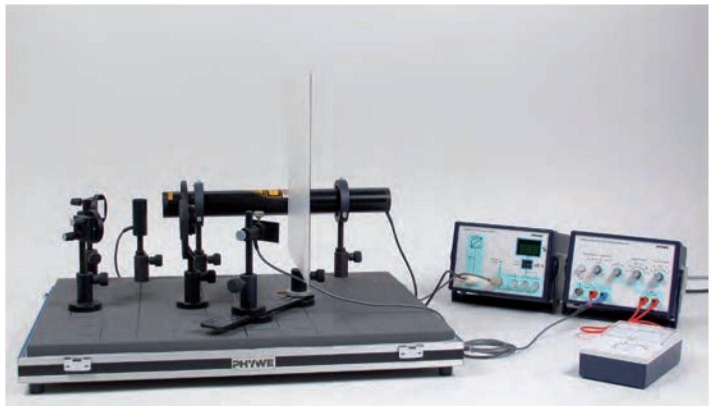
Tasks
1. The luminous intensity emitted by a punctual source is determined as a function of distance from the source.
2. The photometric law of distance is verified by plotting illuminance as a function of the reciprocal value of the square of the distance.

Lambert's law of radiation on optical base plate

P2240405

What you can learn about
- Luminous flux
- Light quantity
- Light intensity
- Illuminance
- Luminance

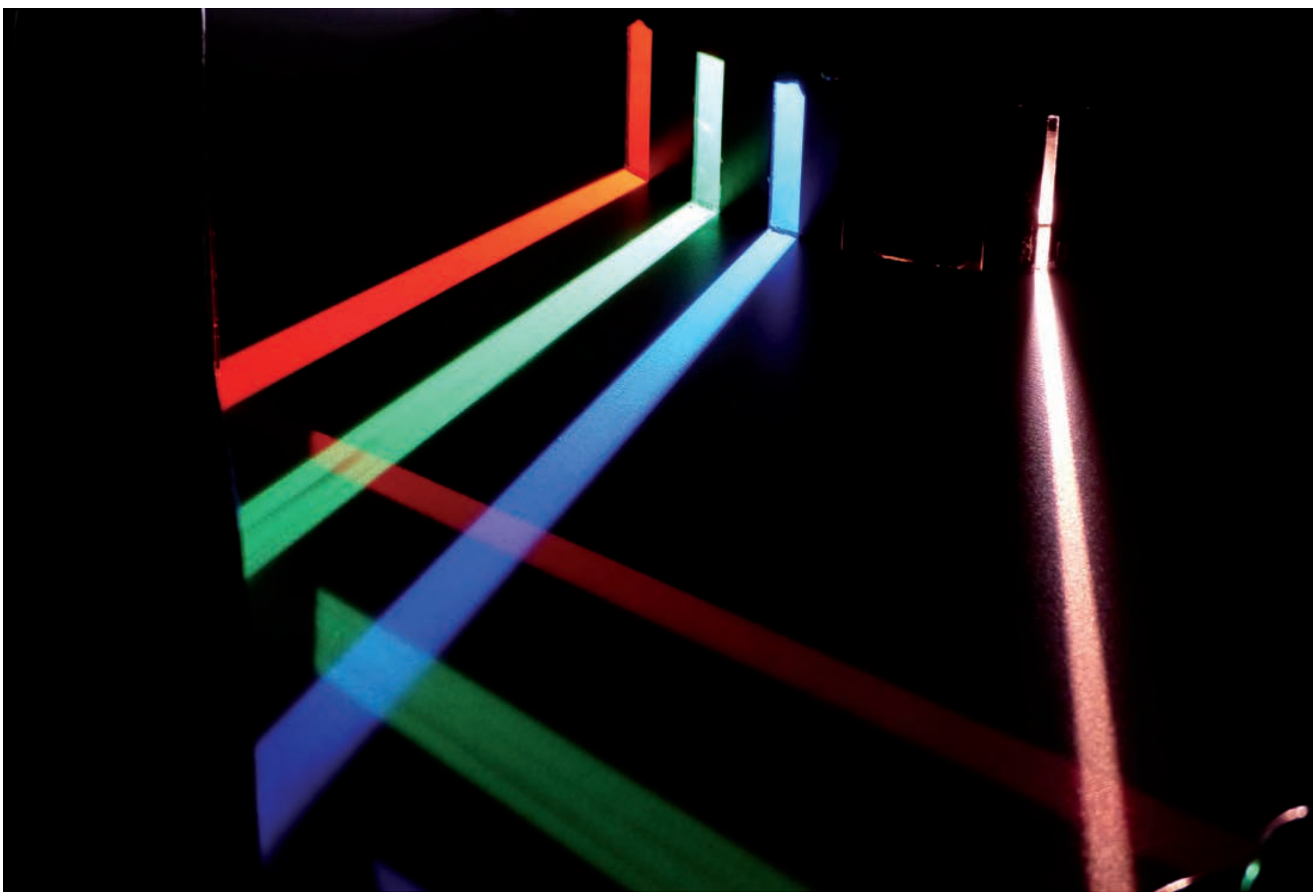
Benefits
- Study the light intensity that a sheet of paper is diffusely reflecting
- Learn about the different physical units associated with light
- Very versatile optical base plate



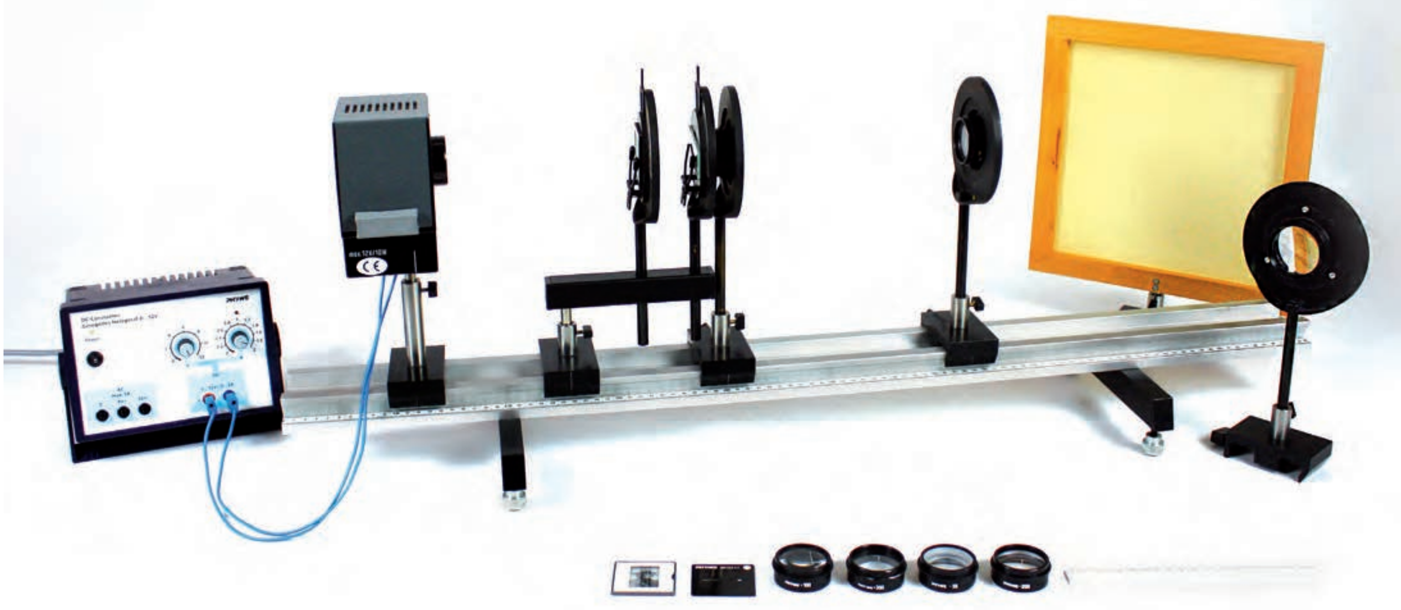
Details

Principle
Visible light impinges on a diffusely reflecting surface. The luminance of this surface is determined as a function of the angle of observation.

Tasks
1. The luminous flux emitted reflected by a diffusely reflecting surface is to be determined as a function of the angle of observation.
2. Lambert's law (cos-law) is to be verified using the graph of the measurement values.



P2210200 Laws of lenses and optical instruments



Details

Principle
The focal lengths of unknown lenses are determined by measuring the distances of image and object and by Bessel's method. Simple optical instruments are then constructed with these lenses.

Tasks
1. To determine the focal length of two unknown convex lenses by measuring the distances of image and object.
2. To determine the focal length of a convex lens and of acombination of a convex and a concave lens using Bessel's method.
3. To construct the following optical instruments:
   a) Slide projector; image scale to be determined
   b) Microscope; magnification to be determined
   c) Kepler-type telescope
   d) Galileo's telescope (opera glasses).

What you can learn about
- Law of lenses
- Magnification
- Focal length
- Object distance
- Telescope
- Microscope
- Path of a ray
- Convex lens
- Concave lens
- Real image
- Virtual image

Benefits
- Understand a basic optical component: the lens
- Learn how common optical instruments work
- Geometric optics in a nutshell

Dispersion and resolving power of a grating spectroscope — P2210300

What you can learn about
- Maxwell relationship
- Dispersion
- Polarisability
- Refractive index
- Prism
- Rowland grating
- Spectrometer
- Goniometer

Benefits
- Understand fundamentals of spectroscopy
- Compact setup
- Precise and reproducible results

Details

Principle
The refractive indices of liquids, crown glass and flint glass are determined as a function of the wave length by refraction of light through the prism at minimum deviation. The resolving power of the glass prisms is determined from the dispersion curves.

Tasks
1. To adjust the spectrometer-goniometer.
2. To determine the refractive index of various liquids in a hollow prisms.
3. To determine the refractive index of various glass prism.
4. To determine the wavelengths of the mercury spectral lines.
5. To demonstrate the relationship between refractive index and wavelength (dispersion curve).
6. To calculate the resolving power of the glass prisms from the slope of the dispersion curves.
7. Determination of the grating constant of a Rowland grating based on the diffraction angle (up to the third order) of the high intensity spectral lines of mercury.
8. Determination of the angular dispersion of a grating.
9. Determination of the resolving power required to separate the different Hg-lines. Comparison with theory.

Interference of light — P2220100

What you can learn about
- Wavelength
- Phase
- Fresnel biprism
- Fresnel mirror
- Virtual light source

Benefits
- Observe that light plus light can result in darkness
- Understand how to make use of the interference effect
- A laser as lightsource allows clear observation

Details

Principle
By dividing up the wave-front of a beam of light at the Fresnel mirror and the Fresnel biprism, interference is produced. The wavelength is determined from the interference patterns.

Tasks
Determination of the wavelength of light by interference
1. with Fresnel mirror,
2. with Fresnel biprism.

P2220200

Newton's rings with interference filters

What you can learn about
- Coherent light
- Phase relationship
- Path difference
- Interference in thin films
- Newton's ring apparatus

Benefits
- The color of soap bubbles is based on it: interference in thin films
- Use interference optics to determine most subtle differences
- Elaborate filters make quantitative measurements possible

Details

Principle

In a Newton's rings apparatus, monochromatic light interferes in the thin film of air between the slightly convex lens and a plane glass plate. The wavelengths are determined from the radii of the interference rings.

Tasks

Using the Newton's rings apparatus, to measure the diameter of the rings at different wavelengths and:

1. to determine the wavelengths for a given radius of curvature of the lens
2. to determine the radius of curvature at given wavelengths.

P2220400

Structure of a Fresnel zone plate

What you can learn about
- Huygens Fresnel principle
- Fresnel and Fraunhofer diffraction
- Interference
- Coherence
- Fresnel's zone construction
- Zone plates

Benefits
- Find out that optical lenses can be completely different from what you are used to
- Interference is used to produce effects commonly achieved with diffraction
- The use of a laser lightsource provides clear results

Details

Principle

A zone plate is illuminated with parallel laser light. The focal points of several orders of the zone plate are projected on a ground glass screen.

Tasks

1. The laser beam must be widened so that the zone plate is well illuminated. It must be assured that the laser lightbeam runs parallel over several meters.
2. The focal points of several orders of the zone plate are projected on a ground glass screen. The focal lengths to be determined are plotted against the reciprocal value of their order.
3. The radii of the zone plate are calculated.

Michelson interferometer

P2220500

What you can learn about
- Interference
- Wavelength
- Refractive index
- Velocity of light
- Phase
- Virtual light source

Benefits
- Experience the essence of the Nobel Prize: Michelson (1907)
- Lead to experimental findings that only special relativity theory could explain
- Pre setup of the critical components makes for short preparation time

Principle

In the Michelson arrangement interference will occur by the use of 2 mirrors. The wavelength is determined by displacing one mirror using the micrometer screw.

Tasks

Determination of the wavelength of the light of the used laser.

Coherence and width of spectral lines with the Michelson interferometer

P2220600

What you can learn about
- Fraunhofer and Fresnel diffraction
- Interference
- Spatial and time coherence
- Coherence conditions
- Coherence length for non punctual light sources
- Coherence time
- Spectral lines (shape and half width value)
- Broadening of lines due to Doppler effect and pressure broadening
- Michelson interferometer
- Magnification

Benefits
- Experience the essence of the Nobel Prize: Michelson (1907)
- Study the quantity that allows light to be used in interference experiments
- Analyze different spectral lines of a mercury lamp
- Make practical use of a Michelson interferometer to characterize light

Principle

The wavelengths and the corresponding lengths of coherence of the green spectral lines of an extreme high pressure Hg vapour lamp are determined by means of a Michelson interferometer. Different double slit combinations are illuminated to verify the coherence conditions of non punctual light sources. An illuminated auxiliary adjustable slit acts as a non punctual light source.

Tasks
1. Determination of the wavelength of the green Hg spectral line as well as of its coherence length.
2. The values determined in 1. are used to calculate the coherence time and the half width value of the spectral line.
3. Verification of the coherence condition for non punctual light sources.

P2220700

Refraction index of air and CO_2 with the Michelson interferometer

Details

What you can learn about
- Interference
- Wavelength
- Phase
- Refraction index
- Light velocity
- Virtual light source

Benefits
- Experience the essence of the Nobel Prize: Michelson (1907)
- See that even two transparent gases can have different optical properties
- A Michelson interferometer is used to measure subtle-differences in the refractive indices
- Thoughtful engineered components allow effective experimenting

Principle

A measurement cuvette set in the beam path of a Michelson interferometer can be evacuated or filled with CO_2. The refraction indexes of air or CO_2 are determined through the assessed modification of the interference pattern.

The illustration doesn't show all included objects.

Tasks
1. Determine the refraction index of air
2. Determine the refraction index of CO_2

P2220900

Michelson interferometer – High resolution

Details

What you can learn about
- Interference
- Wavelength
- Diffraction index
- Speed of light
- Phase
- Virtual light source

Benefits
- The principle that made it possible to observe gravitational waves
- Construct the instrument yourself from separate components
- Find out that even lasers have limited coherence length

Principle

With the aid of two mirrors in a Michelson arrangement, light is brought to interference. While moving one of the mirrors, the alteration in the interference pattern is observed and the wave length of the laser light determined.

Tasks
1. Construction of a Michelson interferometer using separate components.
2. The interferometer is used to determine the wavelength of the laser light.
3. The contrast function K is qualitatively recorded in order to determine the coherence length with it.

Fabry-Perot interferometer – optical resonator modes P2221206

What you can learn about
- Interference
- Wavelength
- Diffraction index
- Speed of light
- Phase
- Virtual light source
- Two-beam interferometer

Benefits
- Study a fundamental component of lasers
- Fascinating patterns emerge in a surprisingly symmetric setup
- Learn about a widely used type of interferometer

Details

Principle

Two mirrors are assembled to form a Fabry-Perot interferometer. Using them, the multi beam interference of a laser's light beam is investigated. On moving one of the mirrors, the change in the intensity distribution of the interference pattern is studied. This is a qualitative experiment, to study the shape of different laser modes and compare it with some photos given in this description.

Tasks
1. Construction of a Fabry-Perot interferometer using separate optical components.
2. The interferometer is used to observe different resonator modes within the interferometer.

Diffraction of light at a slit and an edge P2230200

What you can learn about
- Intensity
- Fresnel integrals
- Fraunhofer diffraction

Benefits
- Learn that the transition region from light to shadow is not a sharp line, but a diffraction pattern
- You can make use of diffraction patterns to determine properties of the objects causing them
- Simple setup with very few components

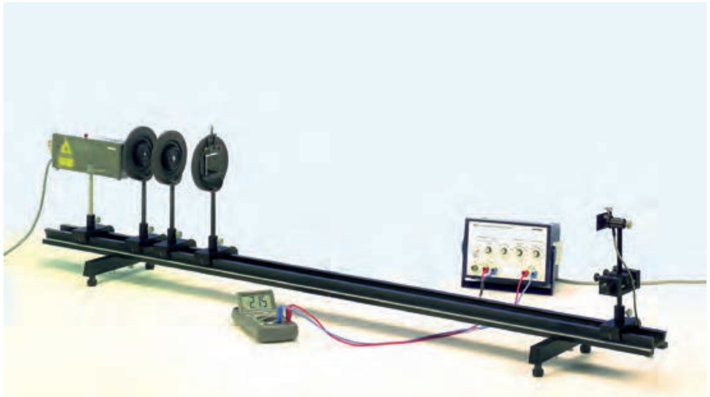
Details

Principle

Monochromatic light is incident on a slit or an edge. The intensity distribution of the diffraction pattern is determined.

Tasks
1. Measurement of the width of a given slit.
2. Measurement of the intensity distribution of the diffraction pattern of the slit and of the edge.

P2230400 Diffraction intensity due to multiple slits and grids



Details

What you can learn about
- Huygens principle
- Law of Interference
- Law of Fraunhofer und Fresnel diffraction
- Law of Coherence
- Law of Laser

Benefits
- Understand what makes an optical grid work, by approaching it via “multiple slits“
- The coherent light of a laser gives the possibility of easy observation
- Clear correlation of measurement results to the underlying theory

Principle

Multiple slits which all have the same width and the same distance among each other, as well as transmission grids with different grid constants, are submitted to laser light. The corresponding diffraction patterns are measured according to their position and intensity, by means of a photo diode which can be shifted.

Tasks

1. The position of the first intensity minimum due to a single slit is determined, and the value is used to calculate the width of the slit.
2. The intensity distribution of the diffraction patterns of a threefold, fourfold and even a fivefold slit, where the slits all have the same widths and the same distance among each other, is to be determined. The intensity relations of the central peaks are to be assessed.

P2230600 Diffraction intensity at a slit and at a wire – Babinet’s theorem

Details

What you can learn about
- Huygens’ principle
- Interference
- Fraunhofer und Fresnel diffraction
- Babinet‘s theorem
- Poissons‘ spot
- Coherence
- Laser

Benefits
- Surprisingly a slit and a wire show basically the same diffraction pattern
- Measurements prove a theorem that sounds awkward at first glance
- Sturdy setup allows good reproducability of results

Principle

An aperture consisting of a single slit and a complementary strip (wire) is illuminated with a laser beam. The corresponding diffraction patterns are measured according to position and intensity with a photocell which can be shifted.

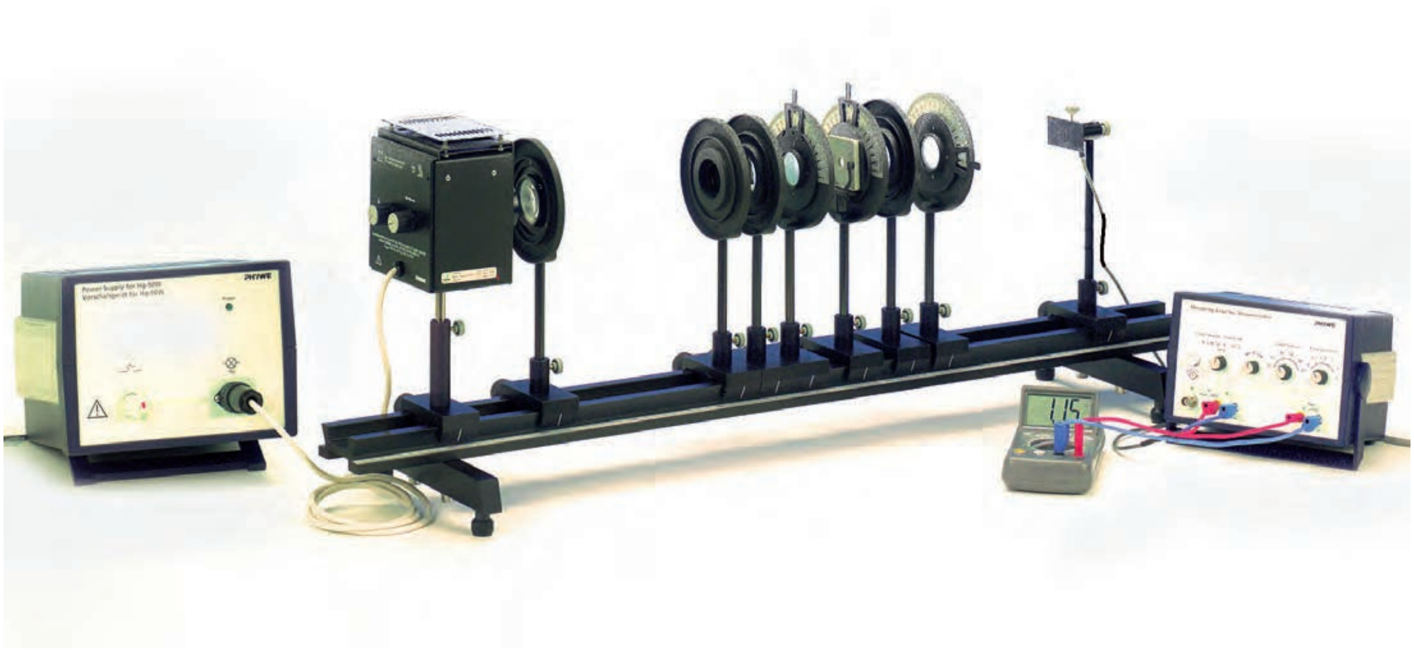
Tasks

1. Determination of the intensity distribution of the diffraction patterns due to a slit and complementary strip (wire).
2. Determination of the intensity relations of the diffraction pattern peaks for the single slit.
3. Babinet‘s theorem is discussed using the diffraction patterns of the slit and the complementary strip.

Polarisation through quarter-wave plates

P2250100

Details



Principle

Monochromatic light falls on a mica plate perpendicular to its optic axis. At the appropriate plate thickness (λ/4, or quarter-wave plate) there is a 90° phase shift between the ordinary and the extraordinary ray when the light emerges from the crystal. The polarisation of the emergent light is investigated at different angles between the optic axis of the λ/4 plate and the direction of polarisation of the incident light.

Tasks

1. To measure the intensity of plane polarised light as a function of the position of the analyser.
2. To measure the light intensity behind the analyser as a function of the angle between the optic axis of the λ/4 plate and that of the analyser.
3. To perform experiment 2. with two λ/4 plates one behind the other.

Benefits

- The principles Polaroid glasses work on
- Discover ways to modify certain attributes of light
- Make the electric vector go round and round

What you can learn about

- Plane
- Circularly and elliptically polarised light
- Polariser
- Analyzer
- Plane of polarisation
- Double refraction
- Optic axis
- Ordinary and extraordinary ray

P2250305

Fresnel's law – theory of reflection

Details

What you can learn about
- Electromagnetic theory of light
- Reflection coefficient
- Reflection factor
- Brewster's law
- Law of refraction
- Polarization
- Polarization level

Benefits
- See that reflection at a glass surface changes some properties of light
- Find out that at special angles, light can be completely polarized upon reflection
- Very versatile optical base plate

Principle

Plane-polarized light is reflected at a glass surface. Both the rotation of the plane of polarization and the intensity of the reflected light are to be determined and compared with Fresnel's formulae for reflection.

Tasks
1. The reflection coefficients for light polarized perpendicular and parallel to the plane of incidence are to be determined as a function of the angle of incidence and plotted graphically.
2. The refractive index of the flint glass prism is to be found.
3. The reflection coefficients are to be calculated using Fresnel's formulae and compared with the measured curves.
4. The reflection factor for the flint glass prism is to be calculated.
5. The rotation of the polarization plane for plane polarized light when reflected is to be determined as a function of the angle of incidence and presented graphically. It is then to be compared with values calculated using Fresnel's formulae.

P2250400

Malus' law

Details

What you can learn about
- Electric theory of light
- Polarisation
- Polariser
- Analyser
- Malus' law

Benefits
- The principle that Polaroid glasses work on
- Introductory yet quantitative experiment to polarization
- Straightforward simple setup

Principle

Linear polarised light passes through a polarisation filter. Transmitted light intensity is determined as a function of the angular position of the polarisation filter.

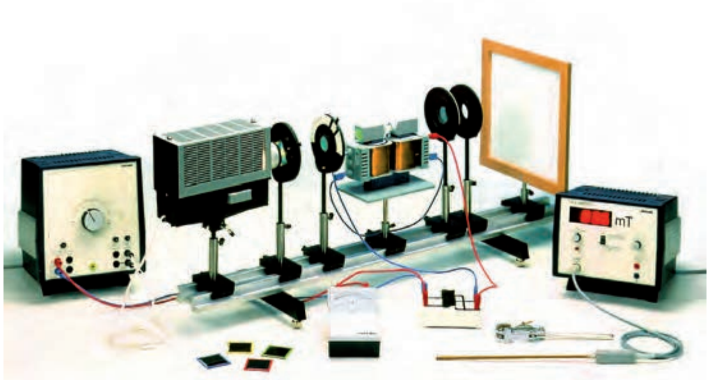
Tasks
1. The plane of polarisation of a linear polarised laser beam is to be determined.
2. The intensity of the light transmitted by the polarisation filter is to be determined as a function of the angular position of the filter.
3. Malus' law must be verified.

Faraday effect

P2260100

What you can learn about
- Electromagnetic field interaction
- Electron oscillation
- Electromagnetism
- Polarisation
- Verdet's constant
- Hall effect

Benefits
- Experience that magnetic fields can influence light by changing ist polarization properties
- Learn how wavelength and the optical medium influence the effect of the magnetic field
- Discover a bridge between the fields of optics and electromagnetism



Details

Principle
The angle of rotation of the polarisation - plane of plane polarised light through a flint glass rod is found to be a linear function of the product of the mean flux-densitiy and the length of the optical medium. The factor of proportionally, called Verdet's constant, is investigated as a function of the wavelength and the optical medium.

Tasks
1. To determine the magnetic flux-densitiy between the pole pieces using the axial Hall probe of the teslameter for different coil currents. The mean flux-density is calculated by numerical integration and the ratio maximum flux-density over mean flux-density established.
2. To determine the angle of rotation as a function of the mean fluxdensity using different colour filters. To calculate the corresponding Verdet constant in each case.
3. To evaluate Verdet's constant as a function of the wavelength.

Kinetics of the inversion of saccharose

P3050301

What you can learn about
- Reaction rate
- First order reaction
- Polarimetry
- Optical rotation

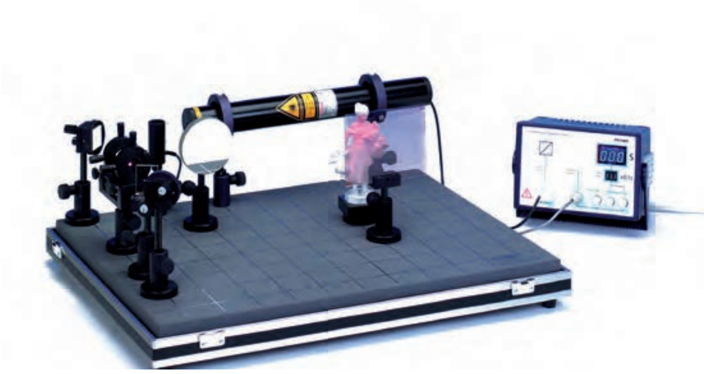
Benefits
- Easy entry into polarimetry
- Combination of methodological skills and theoretical knowledge

Details

Principle
The inversion reaction of saccharose, which is catalysed by protons, produces invert sugar, which is a mixture of glucose and fructose. The reaction is accompanied by a change in the optical rotation of the system. Glucose rotates the polarisation plane of linearly polarised light to the right, while inverted sugar rotates it to the left. A half-shade polarimeter is used for the measurement of the change in the angle of rotation of polarised light during the inversion reaction of saccharose over time.

Tasks
1. Determine the specific rotation of saccharose and lactose by measuring the rotation angle of solutions of various concentrations.
2. Determine the rate constant of the inversion of saccharose.

P2260300 Recording and reconstruction of holograms with the optical base plate



Details

What you can learn about
- Object beam
- Reference beam
- Real and virtual image
- Phase holograms
- Amplitude holograms
- Interference
- Diffraction
- Coherence
- Developing of film

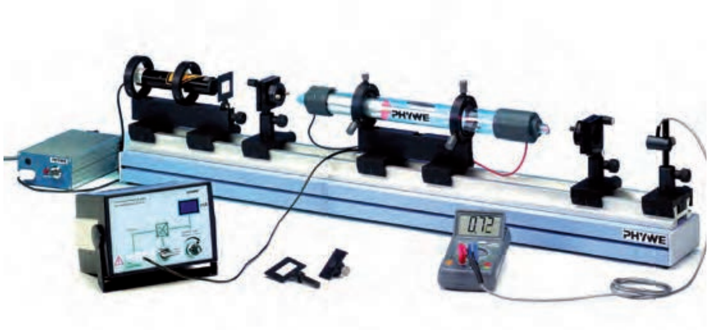
Benefits
- Experience the essence of the Nobel Prize: Michelson (1907)
- Make and see yourself a 3-D image of an object
- Grasp the essential principles of "wave front reconstruction"
- Learn about classical chemical developing of films

Principle

In contrast to normal photography a hologram can store information about the three-dimensionality of an object. To capture the three-dimensionality of an object, the film stores not only the amplitude but also the phase of the light rays. To achieve this, a coherent light beam (laser light) is split into an object and are ference beam by being passed through a beam splitter. These beams interfere in the plane of the holographic film. The hologram is reconstructed with the reference beam which was also used to record the hologram.

Tasks
1. Record a laser light hologram and process it to get a phase hologram. Reconstruct it by verifying the virtual and the real image.
2. Record a white light reflection hologram and process it to get a phase hologram. Laminate it for reconstruction by a white lightsource.

P2260701 Helium Neon laser, basic set



Details

What you can learn about
- Spontaneous and stimulated light emission
- Inversion
- Collision of second type
- Gas discharge tube
- Resonator cavity
- Transverse and longitudinal resonator modes
- Birefringence
- Brewster angle
- Littrow prism
- Fabry Perot Etalon

Benefits
- Set up and run a laser, that is by now classic, from its constituting elements
- Get a feel for the delicate adjustments necessary to achieve lasing conditions
- Discover the way many parameters can influence the output of this gas laser

Principle

The difference between spontaneous and stimulated emission of light is demonstrated. The beam propagation within the resonator cavity of a He-Ne laser and its divergence are determined, its stability criterion is checked and the relative output power of the laser is measured as a function of the tube's position inside the resonator and of the tube current.

Tasks
1. Set up the He-Ne laser. Adjust the resonator mirrors by use of the pilot laser.
2. Check the stability condition of a hemisph resonator.
3. Measure the integral relative output power as a function of the laser tube's position within the hemisph resonator.
4. Measure the beam diameter within the hemisph resonator right and left of the laser tube.
5. Determine the divergence of the laser beam.

Nd:YAG laser

P2260900

What you can learn about
- Optical pumping
- Spontaneous emission
- Induced emission
- Inversion
- Relaxation
- Optical resonator
- Resonator modes
- Polarization
- Frequency doubling

Benefits
- Experience the physics of modern solid state lasers
- Get to the point where you turn invisible IR-light into a bright green light
- Find out about the type of relationships that govern different conversion steps

Details

Principle

The rate equation model for an optically pumped four-level laser system is determined. As lasing medium, a Nd:YAG (Neodymium-Yttrium Aluminium Garnet) rod has been selected which is pumped by means of a semiconductor diode laser. The IR-power output of the Nd:YAG laser is measured as a function of the optical power input and the slope efficiency as well as the threshold power are determined. Finally, a KTP-crystal is inserted into the laser cavity and frequency doubling is demonstrated. The quadratic relationship between the power of the fundamental wave and the beam power for the second harmonic is then evident.

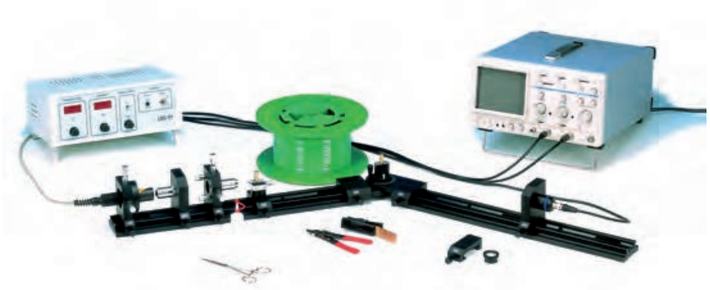
Tasks
1. Set up the Nd:YAG laser and optimise its power output.
2. The IR-power output of the Nd:YAG laser is to be measured as a function of the pump power. The slope efficiency and the threshold power are to be determined.
3. Verify the quadratic relationship between the power of the fundamental wave, with $\lambda = 1064$ nm, and the beam power of the second harmonic with $\lambda = 532$ nm.

Fibre optics

P2261000

What you can learn about
- Total reflection
- Diode laser
- Gaussian beam
- Monomode and multimode fibre
- Numerical aperture
- Transverse and longitudinal modes
- Transit time
- Threshold energy
- Slope efficiency
- Velocity of light

Benefits
- Experience the essence of the Nobel Prize: Kao (2009)
- Telecommunication and computer networking rely heavily on these techniques
- Convince yourself of the advantages and see the basic working principles of optical fiber applications
- See by your own measurements that even light takes some time to travel through a fibre



Details

Principle

The beam of a laser diode is treated in a way that it can be coupled into a monomode fibre. The problems related to coupling the beam into the fibre are evaluated and verified. In consequence a low frequency signal is transmitted through the fibre. The numerical aperture of the fibre is recorded. The transit time of light through the fibre is measured and the velocity of light within the fibre is determined.

Tasks
1. Couple the laser beam into the fibre and adjust the setup in a way that a maximum of output power is achieved at the exit of the fibre.
2. Measure the numerical aperture of the fibre.
3. Measure the transit time of light through the fibre and determine the velocity of light within the fibre.
4. Determine the relative output power of the diode laser as a function of the supply current.

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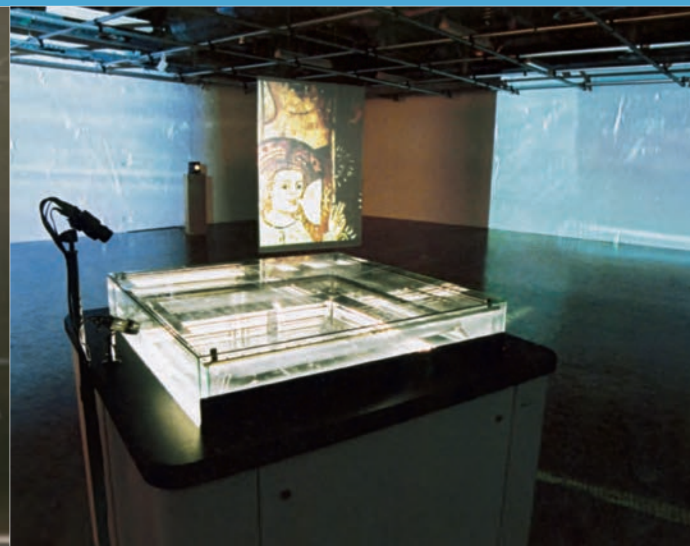
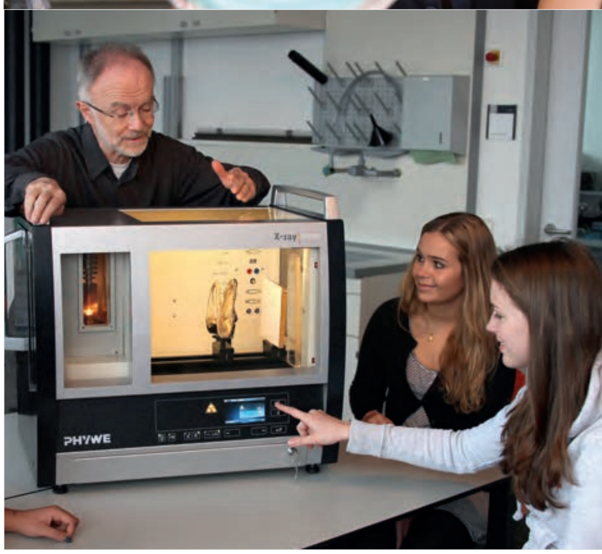
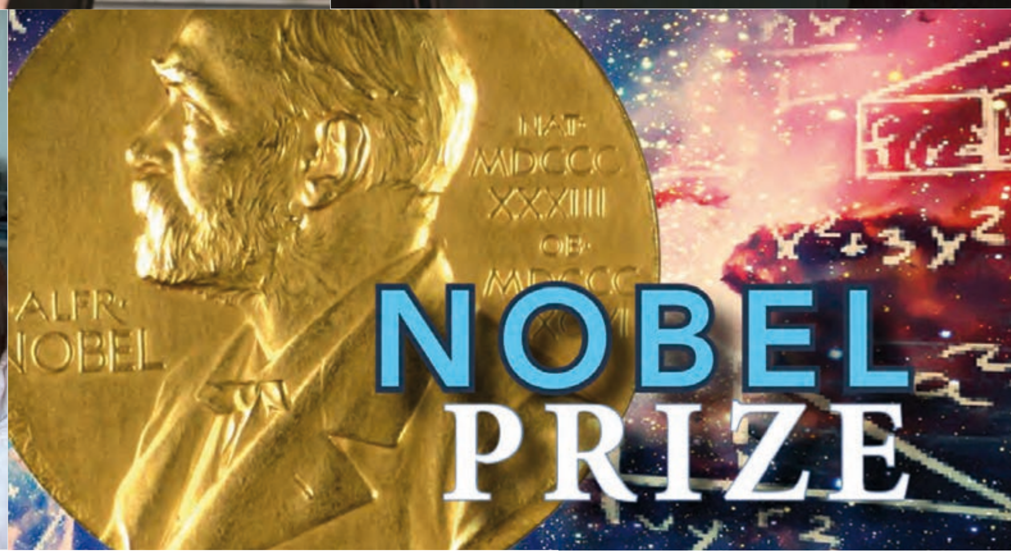






2.6 Modern Physics

P2220800 Quantum eraser with the Mach-Zehnder interferometer

Details

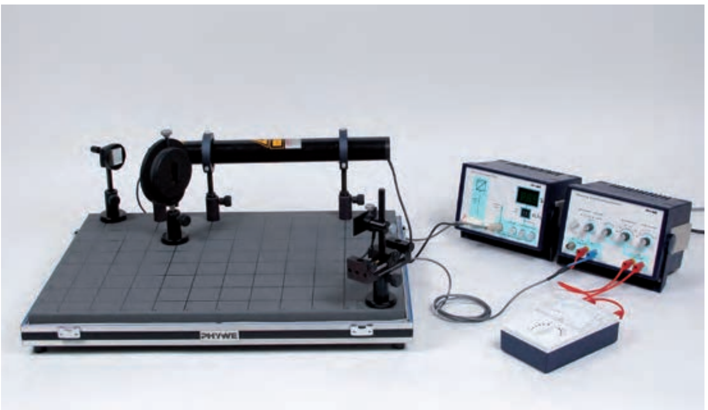
What you can learn about
- Wave-particle duality
- Wave interference
- Quantum mechanics

Benefits
- Realise that part of the information a photon carries can be erased
- Discuss the wave particle dualism of photons by interpreting the experimental outcome from different points of view
- Mach-Zehnder setup allows to follow very clearly the different path of the photons

Principle
A Mach-Zehnder-interferometer is illuminated with a laser beam. Circular interference fringes appear on the screens. If polarisation filters with opposite polarisation planes are placed in the two interferometer paths the interference patterns disappear. Placing another polariser before one of the screens causes the pattern to reappear. Electromagnetic radiation can be described both in terms of propagating waves, as well as particles (photons). The experiment illustrates this dualism by showing how interference patterns can be explained with classical wave mechanics and quantum physics.

Tasks
1. Set up the experiment and observe the interference pattern on the screen.
2. Change the polarisation of the beams with the PF1 and PF2 polarisers and observe the influence on the interference-pattern.
3. Use the third polariser PF3 to cancel the polarisation of the light in the two beams and observe the reappearance of the interference pattern.

P2230105 Diffraction at a slit and Heisenberg's uncertainty principle



Details

What you can learn about
- Diffraction
- Sharpness
- Kirchhoff's diffraction
- Formula
- Measurement precision
- Local uncertainty
- Impulse uncertainty
- Wave-matter duality
- De Broglie's relation

Benefits
- Experience the essence of the Nobel Prize: Heisenberg (1932)
- Easy setup of a Nobel Prize experiment on the optical base plate
- Experiment to verify Heisenberg's uncertainty principle
- Duality of wave – matter is shown in an impressive way

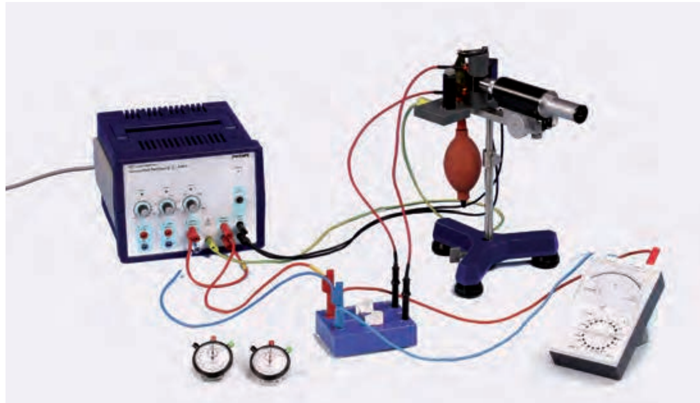
Principle
The intensity distribution in the Fraunhofer diffraction pattern of a slit is measured. Measurement results are evaluated both in the wave representation through comparison with Kirchhoff's diffraction formula and in the photon representation, in order to verify Heisenberg's uncertainty principle.

Tasks
1. The intensity distribution of the Fraunhofer diffraction pattern due to a single slit is measured. The amplitudes of the peaks and of the minima are calculated according to Kirchhoff's diffraction formula and compared to measured values.
2. Momentum uncertainty is calculated with the assistance of the diffraction patterns of simple slits of different widths and Heisenberg's uncertainty relation is verified.

Elementary charge and Millikan experiment

P2510100

What you can learn about
- Electron charge
- Electric field
- Viscosity
- Stokes' law
- Droplet method



Benefits
- Experience the essence of the Nobel Prize: Millikan (1923)
- Precise determination of the elementary charge by single and multiple charged oil droplets
- Open setup, all important parts of the Millikan apparatus are visible
- Metal base plate on stem, with capacitor distance between plates exactly 2.5 mm
- The setup includes: oil atomiser, source holder, illumination device, microscope, power supply, 0 to 600 V DC with 5 galvanic separated output voltages

Details

Principle
Charged oil droplets subjected to an electric field and to gravity between the plates of a capacitor are accelerated by application of a voltage. The elementary charge is determined from the velocities in the direction of gravity and in the opposite direction.

Tasks
1. Measurement of the rise and fall times of oil droplets with various charges at different voltages.
2. Determination of the radii and the charge of the droplets.

Specific charge of the electron – e/m

P2510200

What you can learn about
- Cathode rays
- Lorentz force
- Electron in crossed fields
- Electron mass
- Electron charge

Benefits
- Precise determination of the specific charge of the electron
- The unique fluorescent ladder for precise measurement of beam diameter without parallax error
- Modular principle where the student can set up experiment from scratch, and all parts can be used for other experiments, e.g. Helmholtz coils, power supplies
- Rotation of beam tube 360° to visualize "Lenz' rule"
- Neon as beam tube gas has longer lifetime due to its larger molecule size in comparism to He

Details

Principle
Electrons are accelerated in an electric field and enter a magnetic field at right angles to the direction of motion. The specific charge of the electron is determined from the accelerating voltage, the magnetic field strength and the radius of the electron orbit.

Tasks
Determination of the specific charge of the electron (e/m_0) from the path of an electron beam in crossed electric and magnetic fields of variable strength.

P2510311 — Franck-Hertz experiment with a Hg-tube

Details

What you can learn about

- Energy quantum
- Quantum leap
- Electron collision
- Excitation energy

Benefits

- Experience the essence of the Nobel Prize: Franck, Hertz (1925)
- Classical Version with Mercury (Hg)
- One operating unit for 2 experiments (Hg, Ne)
- Precise determination of electron excitation energy
- Direct connection to computer, no extra interface necessary

Principle

Electrons are accelerated in a tube filled with mercury vapour. The excitation energy of mercury is determined from the distance between the equidistant minima of the electron current in a variable opposing electric field.

Tasks

1. To record the counter current I in a Franck-Hertz tube as a function of the anode voltage U.
2. To determine the excitation energy E from the positions of the current strength minima or maxima by difference formation.

P2510315 — Franck-Hertz experiment with a Ne-tube

Details

What you can learn about

- Energy quantum
- Quantum leap
- Electron collision
- Excitation energy

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Benefits

- Experience the essence of the Nobel Prize: Franck, Hertz (1925)
- Version with Mercury (Ne)
- One operating unit for 2 experiments (Hg, Ne)
- Precise determination of electron excitation energy
- No heating required
- Direct visualisation of the electron exitation

Principle

Electrons are accelerated in a tube filled with neon vapour. The excitation energy of neon is determined from the distance between the equidistant minima of the electron current in a variable opposing electric field.

Tasks

1. To record the counter current I in a Franck-Hertz tube as a function of the anode voltage U.
2. To determine the excitation energy E from the positions of the current strength minima or maxima by difference formation.

Planck's "quantum of action" and photoelectric effect (line separation by interference filters)

P2510402

Details

What you can learn about

- Photon energy
- Photon absorption
- External photo effect
- Work function
- Photocell
- Quantum theory
- Plancks constant
- Anode
- Cathode

Benefits

- Experience the essence of the Nobel Prize: Planck (1918)
- Planck's "quantum of action" the most important proof in quantum physics measured directly within few hours with the photocell
- Modular setup with photocell and interference filters
- Easy determination of *h*
- No darkroom required

Principle

A photocell is illuminated with monochromatic light of different wavelengths from a filament lamp with interference filters. The maximum energy of the ejected electrons in the photocell depends only on the frequency of the incident light, and is independent of its intensity. The stopping voltage U_0 at different light frequencies is determined by the *U/I* characteristics of the photocell and plotted over the corresponding light frequency *f*. Planck's quantum of action or Planck's constant (*h*) is determined from this graph.

Tasks

To determine Planck's quantum of action from the photoelectric voltages measured at different wavelengths

Planck's "quantum of action" and photoelectric effect (line separation by a diffraction grating)

P2510502

Details

What you can learn about

- Photon energy
- Photon absorption
- External photo effect
- Work function
- Photocell
- Quantum theory
- Plancks constant
- Grating spectrometer

Benefits

- Experience the essence of the Nobel Prize: Planck (1918)
- Planck's "quantum of action" the most important proof in quantum physics measured directly within few hours with the photocell
- Modular setup with photocell on an optical bench and a different grating to produce monochromatic light
- Easy determination of *h*

Principle

The photoelectric effect is one key experiment in the development of modern physics. White light from a filament lamp is filtered by a grating spectrometer and illuminates a photocell. The maximum energy of the ejected electrons depends only on the frequency of the incident light, and is independent of its intensity. This law appears to be in contradiction with the electromagnetic wave theory of the light, but it becomes understandable in the frame of the corpuscular theory of light. The stopping voltage U_0 at different light frequencies is determined by the *I/U* characteristicsof the photocell and plotted over the corresponding light frequency *f*.

Tasks

1. Calculate the light frequency *f* in dependence on the spectrometer angle
2. Experimentally determine the stopping voltage U_0 for different light frequencies and plot it over light frequency *f*
3. Calculate Plancks constant from the dependence of the stopping voltage U_0 on the light frequency *f*

P2511101 Stern-Gerlach experiment

Details

What you can learn about

- Magnetic moment
- Bohr magneton
- Directional quantization
- g-factor
- Electron spin
- Atomic beam
- Maxwellian velocity distribution
- Two-wire field

Benefits

- Experience the essence of the Nobel Prize: Gerlach (1943)
- Only student experiment available for this essential quantum physics experiment
- First proof of the quantization of the spatial orientation of the angular momentum
- A beam of neutral potassium atoms are deflected in a non homogeneous magnetic field and can even be measured precisely

Principle

A beam of potassium atoms generated in a hot furnace, travels along a specific path in a magnetic two-wire field. Because of the magnetic moment, the non-homogeneity of the field applies a force at right angles to the direction of their motion. The potassium atoms are thereby deflected from their path. By measuring the density of the beam of particles in a plane of detection lying behind the magnetic field, it is possible to draw conclusions as to the magnitude and direction of the magnetic moment of the potassium atoms.

Tasks

1. Distribution of the particle beam density in the detection plane in the absence of the effective magnetic field.
2. Fitting a curve, to the experimentally determined distribution of the particle beam density.
3. Determining the dependence of the particle beam density in the detection plane with different values of the non-homogeneity of the effective magnetic field.
4. Investigating the positions of the maxima of the particle beam density as a function of the non-homogeneity of the magnetic field.

P2511200 Electron spin resonance

Details

What you can learn about

- Zeeman effect
- Energy quantum
- Quantum number
- Resonance
- g-factor
- Landé-factor

Benefits

- Specific operating unit guarantees a safe and easy setup
- Resonance signal can be analyzed by a simple oscilloscope
- Reproducible results guaranteed

Principle

With electron spin resonance (ESR) spectroscopy compounds having unpaired electrons can be studied. The physical background of ESR is similar to that of nuclear magnetic resonance (NMR), but with this technique electron spins are excited instead of spins of atomic nuclei. The g-factor of a DPPH (Diphenylpikrylhydrazyl) specimen and the half width of the absorption line are determined, using the ESR apparatus.

Tasks

1. Determine the g-factor (Landé-factor) of the DPPH (Diphenylpicrylhydrazyl) specimen.
2. Determine the FWHM (Full Width at Half Maximum) of the absorption line.

Zeeman effect with electromagnet

P2511005

Details

What you can learn about
- Bohr's atomic model
- Quantisation of energy levels
- Electron spin
- Bohr's magneton
- Interference of electromagnetic waves
- Fabry-Perot interferometer

Benefits
- Experience the essence of the Nobel Prize: Zeeman (1902)
- Normal and anomalous Zeeman effect with one setup
- Electromagnet secures a fine variation of the necessary magnetic field to be calculated or measured
- High precision Fabry-Perot interferometer necessary for good results
- Image analysis by specific PC capture and analysis software

Principle

The "Zeeman effect" is the splitting up of the spectral lines of atoms within a magnetic field. In this experiment the normal Zeeman effect as well as the anomalous Zeeman effect are studied using a cadmium spectral lamp as a specimen. The cadmium lamp is submitted to different magnetic flux densities and the splitting up of the cadmium lines (normal Zeeman effect 643.8 nm, red light; anomalous Zeeman effect 508,6 nm, green light) is investigated using a Fabry-Perot interferometer. The evaluation of the results leads to a fairly precise value for Bohr's magneton.

Tasks
1. Using the Fabry-Perot interferometer and a telescope the splitting up of the central line into different lines is measured in wave numbers as a function of the magnetic flux density.
2. From the results of point 1. Bohr's magneton is evaluated.
3. The light emitted within the direction of the magnetic field is qualitatively investigated.

Zeeman effect with a variable magnetic system

P2511007

Details

What you can learn about
- Bohr's atomic model
- Quantisation of energy levels
- Electron spin
- Bohr's magneton
- Interference of electromagnetic waves
- Fabry-Perot interferometer

Benefits
- Experience the essence of the Nobel Prize: Zeeman (1902)
- Normal and anomalous Zeeman effect with one setup
- Permanent magnet where the variable distance between the 2 poleshoes creates the magnetic field
- High precision Fabry-Perot interferometer necessary for good results
- Image analysis by specific PC capture and analysis software

Principle

The "Zeeman effect" is the splitting up of the spectral lines of atoms within a magnetic field. In this experiment the normal Zeeman effect as well as the anomalous Zeeman effect are studied using a cadmium spectral lamp as a specimen. The cadmium lamp is submitted to different magnetic flux densities and the splitting up of the cadmium lines (normal Zeeman effect 643.8 nm, red light; anomalous Zeeman effect 508, 6nm, green light) is investigated using a Fabry-Perot interferometer. The evaluation of the results leads to a fairly precise value for Bohr's magneton.

Tasks
1. Using the Fabry-Perot interferometer and a telescope the splitting up of the central line into different lines is measured in wave numbers as a function of the magnetic flux density.
2. From the results of point 1. a value for Bohr's magneton is evaluated.
3. The light emitted within the direction of the magnetic field is qualitatively investigated.

P2511301 Electron diffraction

Details

What you can learn about
- Bragg reflection
- Debye-Scherrer method
- Lattice planes
- Graphite structure
- Material waves
- De-Broglie equation

Benefits
- Experience the essence of the Nobel Prize: de Broglie (1929)
- Impressive visualization of a Nobel Prize experiment with various changeable parameters
- Simple setup
- Easy determination of the interplanar spacing of graphite
- Perfect demonstration of wave-particle duality

Principle

Fast electrons are diffracted from a polycrystalline layer of graphite: interference rings appear on a fluorescent screen. The interplanar spacing in graphite is determined from the diameter of the rings and the accelerating voltage.

Tasks
1. To measure the diameter of the two smallest diffraction rings at different anode voltages.
2. To calculate the wavelength of the electrons from the anode voltages.
3. To determine the interplanar spacing of graphite from the relationship between the radius of the diffraction rings and the wavelength.

P2540901 Duane-Hunt displacement law and Planck's "quantum of action"

Details

What you can learn about
- X-ray tube
- Bremsstrahlung
- Characteristic X-ray radiation
- Energy levels
- Crystal structures
- Lattice constant
- Interference
- Bragg equation

Benefits
- Experience the essence of the Nobel Prize: Röntgen (1901), Planck (1918)
- Planck's "quantum of action" the most important proof in quantum physics measured directly within few hours with the X-ray unit
- Goniometer with 2 independent or coupled (2:1) axis for sample and detector
- X-ray unit with newest technology to fulfill German safety regulations for student experiments
- No dosimeter required
- S-Lock patent pending safety feature
- Large unbreakable lead enforced acrylic glass windows (3) according to DIN safety regulations

Tasks
1. Record the intensity of the X-rays emitted by the copper anodeat various anode voltages as a function of the Bragg angle using an LiF monocrystal.
2. Determine the short wavelength limit (= maximum energy) of the bremsspectrum for the spectra obtained in (1).
3. Use the results to verify the Duane-Hunt displacement law, and to determine Planck's "quantum of action".

Fundamental principles of Nuclear Magnetic Resonance (NMR) P5942100

Details

Principle

The fundamental principles concerning the phenomenon of nuclear magnetic resonance (NMR) are demonstrated. Experiments are executed with a MRT training device giving the opportunity to investigate some small probes in the sample chamber. Investigations comprise the tuning of the system frequency to the Larmor frequency, the determination of the flip angle of the magnetisation vector, the effects of the substance quantity, the influence of particular magnetic field inhomogeneities, the measurement of a spin echo signal and an averaging procedure to maximise the signal-to-noise ratio. The adjustment of all parameters in these experiments are inevitable to obtain an adequate MR image in other experiments which can be performed with the same system without requiring any additional components.

Tasks

1. Tune the system frequency to the Larmor frequency.
2. Set the HF (High Frequency) pulse duration to determine the flip angle of the magnetisation vector.
3. Determine effects of the substance quantity on the FID signal (Free Induction Decay) amplitude.
4. Minimise magnetic field inhomogeneities via a superimposed magnetic field (shim)
5. Retrieve a relaxated FID signal via a spin echo flipping nuclear spins by 180°.

What you can learn about

- Nuclear spins
- Atomic nuclei with a magnetic moment
- Precession of nuclear spins
- Magnetisation
- Resonance condition, MR frequency
- MR flip angle
- FID signal (Free Induction Decay)
- Spin echo
- Relaxation times (T1: longitudinal magnetisation, T2: transverse magnetisation)
- Signal-to-noise ratio

Benefits

- Complete, easy to install and affordable MRT education system
- One system to cover all aspects from NMR basics to sophisticated 2D and 3D imaging sequences
- Detailed experiment guides included with the system
- Learning results guaranteed thanks to easy to manage course steps
- Can be set up at any location in the student lab

Related experiments:

Relaxation times in Nuclear Magnetic Resonance	P5942200
Spatial encoding in Nuclear Magnetic Resonance	P5942300
Magnetic Resonance Imaging (MRI)	P5942400
Magnetic Resonance Imaging (MRI) II	P5942500

P2524415 Compton effect with the gamma detector

Details

What you can learn about
- Corpuscle
- Scattering
- Compton wavelength
- g-quanta
- de Broglie wavelength
- Klein-Nishina formula

Benefits
- Experience the essence of the Nobel Prize: Compton (1927)
- Nobel Prize experiment can be performed by students within some hours
- Impressive second proof of the wave - particle dualism
- Use of a gamma detector in combination with a high precision power supply guarantees good and reproducible results

Principle
The energy of scattered gamma-radiation is measured as a function of the angle of scatter. The Compton wavelength is determined from the measured values.

Tasks
1. Calibrate the measuring set-up with the aid of a Cs-137 calibrating source (37 kBq) and a Na-22 source (74 kBq).
2. Measure the energy of the Cs-137 661.6 keV peaks scattered at different angles and calculate the Compton wavelength from the readings taken.

P2546001 Compton effect - X-ray energy dispersive measurement

Details

What you can learn about
- Bremsstrahlung
- Characteristic X-radiation
- Compton scattering
- Compton wavelength
- Conservation of energy and momentum
- Rest mass and rest energy of the electron
- Relativistic electron mass and energy
- Semiconductor detector
- Multichannel analyser

Benefits
- Experience the essence of the Nobel Prize: Röntgen (1901), Compton (1927)
- Direct measurement of the Compton effect with the X-ray energy detector (XRED) with multichannel analyzer (MCA) guarantees high counting rates without warm-up time
- X-ray unit with newest technology to fulfill German safety regulations for student experiments

Principle
Photons of the molybdenum X-ray line are scattered at the quasi-free electrons of an acrylic glass cuboid. The energy of the scattered photons is determined in an angle-dependent manner with the aid of a swivelling semiconductor detector and a multichannel analyser.

Tasks
1. Energy calibration of the multichannel analyser with the aid of the two characteristic molybdenum X-ray lines.
2. Energy determination of the photons of the Mo-line that are scattered through an acrylic glass element as a function of the scattering angle.
3. Comparison of the measured energy values of the lines of scatter with the calculated energy values.
4. Calculation of the Compton wavelength of electrons and a comparison of this value with the corresponding value of the 90°scattering.

Fine structure: one and two electron spectra P2510600

What you can learn about
- Diffraction spectrometer
- Spin
- Angular momentum
- Spin-orbital angular momentum interaction
- Multiplicity
- Energy level
- Excitation energy
- Selection rules
- Doublets
- Parahelium
- Orthohelium
- Exchange energy
- Angular momentum
- Singlet and triplet series
- Selection rules
- Forbidden transitions

Details

Benefits
- Fine structure of various elements can be determined with high precision
- Spectro- Goniometer with 30'' resolution and stable setup makes experimentation easy
- Double nonius secures good results
- Included large scales necessary for good experimental results

Principle
The well-known spectral lines of He are used for calibrating the diffraction spectrometer. The wavelengths of the spectral lines of Na, Hg, Cd and Zn are determined using the spectrometer.

Tasks
1. Calibration of the spectrometer using the He spectrum and the determination of the constant of the grating.
2. Determination of the spectrum of Na.
3. Determination of the fine structure splitting.
4. Determination of the most intense spectral lines of Hg, Cd and Zn.

Balmer series / determination of Rydberg's constant P2510700

What you can learn about
- Diffraction image of a diffraction grating
- Visible spectral range
- Single electron atom
- Atomic model according to Bohr
- Lyman-, Paschen-, Brackett and Pfund Series
- Energy level
- Planck's constant
- Binding energy

Details

Benefits
- Simple setup for high ranking experiments
- Fundamental Rydberg's constant determined within an hour
- HV power supply with high safety standard makes experimentation safe

Principle
The spectral lines of hydrogen and mercury are examined by means of a diffraction grating. The known spectral lines of Hg are used to determine the grating constant. The wavelengths of the visible lines of the Balmer series of H are measured.

Tasks
1. Determination of the diffraction grating constant by means of the Hg spectrum.
2. Determination of the visible lines of the Balmer series in the H spectrum, of Rydberg's constant, and of the energy levels.

P2510800 Atomic spectra of two-electron system: He, Hg

Details

What you can learn about
- Parahelium
- Orthohelium
- Exchange energy
- Spin
- Angular momentum
- Spinorbit interaction
- Singlet and triplet series
- Multiplicity
- Rydberg series
- Selection rules
- Forbidden transition
- Metastable state
- Energy level
- Excitation energy

Benefits
- Spectral lines of various elements can be determined with high precision
- Spectro-Goniometer with 30'' resolution and stable setup makes experimentation easy
- Double nonius secures good results
- Included large scales necessary for good experimental results

Principle

The spectral lines of He and Hg are examined by means of a diffraction grating. The wavelengths of the lines are determined from the geometrical arrangement and the diffraction grating constants.

Tasks
1. Determination of the wavelengths of the most intense spectral lines of He.
2. Determination of the wavelengths of the most intense spectral lines of Hg.

P2511500 Absorption spectra

Details

What you can learn about
- Bohr atom
- Absorption bands
- Electron gas

Benefits
- Six different metal chlorides are analyzed
- Diffraction grating is used to make a wavelength dependent analysis
- With the optical bench used a stable setup is realized

Principle

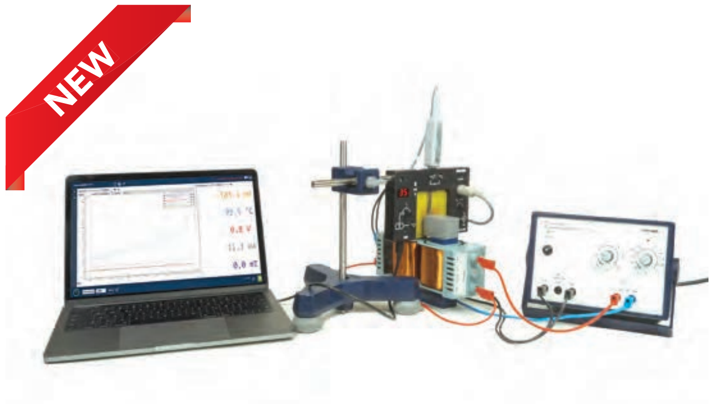
Electron shells of metal atoms in the gas phase can be elevated to an excited state by light. If light is passed through the metal vapour, various lines will be absent from its spectrum afterwards. These lines correspond to the energy levels of those electrons in the metal vapour which have been excited by the light. Spectra such as this are called absorption spectra. This experiment investigates absorption spectra of the following metals: strontium, barium,calcium, sodium, lithium, potassium, platinum, cobalt, and magnesium.

Tasks

Record the absorption spectra of the metal salts and calculate the wavelengths β.

Hall effect in n- and p-germanium (PC) P2530116

What you can learn about
- Semiconductor
- Band theory
- Forbidden zone
- Intrinsic conductivity
- Extrinsic conductivity
- Valence band
- Conduction band
- Lorentz force
- Magnetic resistance
- Mobility
- Conductivity
- Band spacing
- Hall coefficient



Benefits
- New Hall effect unit to control temperature, voltage, and supports intrinsic, p- and n-type Ge crystals
- Version with PC control and data acquisition
- Direct connection to PC via USB connection
- No extra interface necessary
- Magnetic field sensor can be connected directly with the Hall effect unit

Details

Principle
The resistivity and Hall voltage of a rectangular germanium sample are measured as a function of temperature and magnetic field. The band spacing, the specific conductivity, the type of charge carrier and the mobility of the charge carriers are determined from the measurements.

Tasks
1. The Hall voltage is measured at room temperature and constant magnetic field as a function of the control current The voltage across the sample is measured at constant control current as a function of the temperature. The band spacing of germanium is calculated.
2. The Hall voltage U_H is measured as a function of the magnetic induction B, at room temperature. The sign of the charge carriers and the Hall constant R_H together with the Hall mobility μ_H and the carrier concentration p are calculated from the measurements.
3. The Hall voltage U_H is measured as a function of temperature at constant magnetic induction B and the values are plotted on a graph.

Hall effect in n- and p-germanium (teslameter) P2530102

What you can learn about
- Semiconductor
- Band theory
- Forbidden zone
- Intrinsic conductivity
- Extrinsic conductivity
- Valence band
- Conduction band
- Lorentz force
- Magnetic resistance
- Mobility
- Conductivity
- Band spacing
- Hall coefficient

Benefits
- New Hall effect unit to control all parameters (temperature, voltage) and supports intrinsic, p- and n-type Ge crystals
- Classical Version with Teslameter
- Can also be used to study band gap of Ge

Details

Principle
The resistivity and Hall voltage of a rectangular germanium sample are measured as a function of temperature and magnetic field. The band spacing, the specific conductivity, the type of charge carrier and the mobility of the charge carriers are determined from the measurements.

Tasks
1. The Hall voltage is measured at room temperature and constant magnetic field as a function of the control current and plotted on a graph (measurement without compensation for defect voltage).
2. The voltage across the sample is measured at room temperature and constant control current as a function of the magnetic induction B.
3. The voltage across the sample is measured at constant control current as a function of the temperature. The band spacing of germanium is calculated from the measurements.
4. The Hall voltage U_H is measured as a function of the magnetic induction B, at room temperature.

P2530402 Band gap of germanium

Details

What you can learn about

- Semiconductor
- Band theory
- Forbidden band
- Intrinsic conduction
- Extrinsic conduction
- Impurity depletion
- Valence band
- Conduction band

Benefits

- New Hall effect unit to control all parameters (temperature, voltage) and supports intrinsic, p- and n-type Ge crystals
- Can also be used to study Hall effect in p and n-type Ge

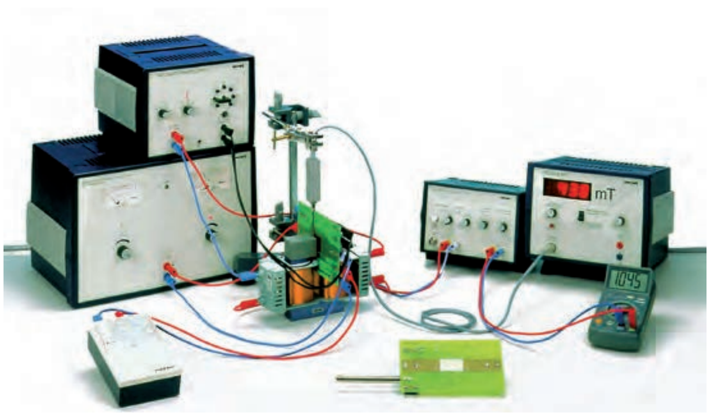
Principle

The conductivity of a germanium test sample is measured as a function of temperature. The energy gap is determined from the measured values.

Tasks

1. The current and voltage are to be measured across a germanium test-sample as a function of temperature.
2. From the measurements, the conductivity s is to be calculated and plotted against the reciprocal of the temperature *T*. A linear plot is obtained, from whose slope the energy gap of germanium can be determined.

P2530300 Hall effect in metals



Details

What you can learn about

- Normal Hall effect
- Anomalous Hall effect
- Charge carriers
- Hall mobility
- Electrons
- Defect electrons

Benefits

- Hall effect in metals for different metal foils
- High current power supply guarantees the precise results
- Clear setup where all important parts are visible
- Setup transformator to produce a high magnetic field, measured by a teslameter (included)

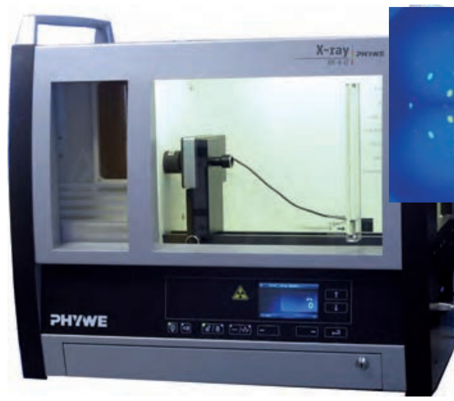
Principle

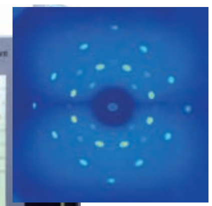
The Hall effect in thin zinc and copper foils is studied and the Hall coefficient determined. The effect of temperature on the Hall voltage is investigated.

Tasks

1. The Hall voltage is measured in thin copper and zinc foils.
2. The Hall coefficient is determined from measurements of the current and the magnetic induction.
3. The temperature dependence of the Hall voltage is investigated on the copper sample.

X-ray investigation of crystal structures / Laue method with digital X-ray image sensor (XRIS) P2541602





What you can learn about
- Crystal lattices
- Crystal systems
- Crystal classes
- Bravais lattice
- Reciprocal lattice
- Miller indices
- Structure amplitude
- Atomic form factor
- The Bragg equation

Benefits
- Experience the essence of the Nobel Prize: Röntgen (1901), Laue (1914)
- Laue pattern recording with direct X-ray image sensor XRIS within minutes
- High resolution for X-rays (48 µm)
- No dark room required
- X-ray unit with newest technology to fulfill German safety regulations for student experiments
- Large unbreakable lead enforced acrylic glass windows (3) according to DIN safety regulations

Details

Principle

Laue diagrams are produced when monocrystals are irradiated with polychromatic X-rays. This method is primarily used for the determination of crystal symmetries and the orientation of crystals. When a LiF monocrystal is irradiated with polychromatic X-rays, a characteristic diffraction pattern results. This pattern is recorded with the digital X-ray sensor XRIS.

Tasks
1. The Laue diffraction of an LiF monocrystal is to be recorded with the aid of the digital X-ray sensor.
2. The Miller indices of the corresponding crystal surfaces are to be assigned to the Laue reflections.

X-ray investigation of crystal structures / Laue method (Film) P2541601

What you can learn about
- Crystal lattices
- Crystal systems
- Crystal classes
- Bravais lattice
- Reciprocal lattice
- Miller indices
- Structure amplitude
- Atomic form factor
- The Bragg equation

Benefits
- Experience the essence of the Nobel Prize: Röntgen (1901), Laue (1914)
- Laue pattern recording with X-ray film
- X-ray unit with newest technology to fulfill German safety regulations for student experiments
- No dosimeter required
- S-Lock patent pending safety feature
- Large unbreakable lead enforced acrylic glass windows (3) according to DIN safety regulations

Details

Principle

Laue diagrams are produced when monocrystals are irradiated with polychromatic X-rays. This method is primarily used for the determination of crystal symmetries and the orientation of crystals. When a LiF monocrystal is irradiated with polychromatic X-rays, a characteristic diffraction pattern results. This pattern is photographed and then evaluated.

Tasks
1. The Laue diffraction of an LiF mono-crystal is to be recorded on a film.
2. The Miller indices of the corresponding crystal surfaces are to be assigned to the Laue reflections.

P2541401 X-ray investigation of cubic crystal structures / Debye-Scherrer powder method

Details

What you can learn about
- Crystal lattices
- Crystal systems
- Reciprocal lattice
- Miller indices
- Structure amplitude
- Atomic form factor
- Bragg scattering

Benefits
- Experience the essence of the Nobel Prize: Debye (1936)
- Debye–Scherrer diffraction patterns are recorded by X-ray sensitive film
- Analysis of other fine powders also possible
- No dark room required
- X-ray unit with newest technology to fulfill German safety regulations for student experiments
- No dosimeter required
- S-Lock patent pending safety feature
- Large unbreakable lead enforced acrylic glass windows (3) according to DIN safety regulations

Principle
When polycrystalline samples are irradiated with X-rays a characteristic diffraction pattern results. These Debye-Scherrer reflections are photographed and then evaluated.

Tasks
1. Debye-Scherrer photographs are to be taken of powdered samples of sodium chloride and caesium chloride.
2. The Debye-Scherrer rings are to be evaluated and assigned to the corresponding lattice planes.
3. The lattice constants of the sample materials are to be determined.
4. The number of atoms in the unit cells of each sample are to be determined.

P2541301 Structure of NaCl monocrystals in different orientations

Details

What you can learn about
- Characteristic X-radiation
- Energy levels
- Crystal structures
- Reciprocal lattices
- Miller indices
- Atomic form factor
- Structure factor
- Bragg scattering

Benefits
- Experience the essence of the Nobel Prizes: Röntgen (1901), W.H. Bragg, W.L. Bragg, (1914)
- X-ray diffraction analysis (XRD) of NaCl monocrystals in different orientations to teach indexing the crystals (Miller indices)
- Application of Bragg's law
- Monocrystals with other orientations also possible
- Goniometer with 2 independent or coupled (2:1) axis for sample and detector
- X-ray unit with newest technology to fulfill German safety regulations for student experiments

Principle
The spectra of the X-rays that are reflected with various different orientations by NaCl monocrystals are analysed. The associated interplanar spacings are determined based on the Bragg angles of the characteristic lines.

Tasks
1. Determine the intensity of the X-rays that are reflected by the NaCl monocrystals with the orientations [100], [110] and [111] as a function of the Bragg angle.
2. Assign the reflections to the corresponding lattice planes that are given by way of their respective Miller indices.
3. Determine the lattice constant and calculate the interplanar spacing.
4. Determine the mass of a cell and the number of atoms in the cell.

Debye-Scherrer diffraction of texture of rolled sheets P2542701

Details

What you can learn about

- Crystal lattices / Crystal systems
- Bravais-lattice
- Reciprocal lattice
- Miller indices
- Structure factor
- Atomic scattering factor
- Bragg scattering
- Characteristic X-rays
- Monochromatization of X-rays
- Fiber textures
- Sheet textures
- Annealing texture
- Recrystallization

Benefits

- Experience the essence of the Nobel Prizes: Röntgen (1901), Bragg and Bragg (1915)
- Metallurgical important examination of the texture of rolled sheets and the annealing behavior
- X-ray energy detector (XRED) with multichannel analyzer (MCA) guarantees high counting rates without warm-up time

Principle

A polycrystalline, CFC crystallizing Cu-powder sample and a copper sheet are irradiated with the Cu X-ray radiation. The Bragg diagrams are automatically recorded. The evaluation allows the Bragg reflexes to be assigned to the individual lattice planes. In contrast to the powder sample, the rolled thin sheet gives a spectrum showing an alignment of the crystallites (rolled texture).

Tasks

1. Record the intensity of the Cu X-rays back scattered by a cubic crystallizing copper powder sample as a function of the scattering angle.
2. Assign the Bragg reflexes to the individual lattice planes.
3. Record the Bragg spectrum of a thin sheet of copper.
4. Repeat the measurements made in Task 3 after the sheet of copper has been subjected to annealing.

Related experiment:
Debye-Scherrer diffraction patterns of powder samples with three cubic Bravais lattices P2542101

Quantitative X-ray fluorescence analysis of alloyed materials P2545001

What you can learn about

- Bremsstrahlung
- Characteristic X-radiation
- Energy levels
- Fluorescent yield
- Auger effect
- Coherent and incoherent photon scattering
- Absorption of X-rays
- Edge absorption
- Matrix effects
- Semiconductor energy detectors
- Multichannel analysers

Details

Benefits

- Experience the essence of the Nobel Prizes: Röntgen (1901), Siegbahn (1924)
- X-ray fluorescence analysis (XRF) of different alloys
- Other alloys also possible
- Quantitative determination of the alloy composition
- X-ray energy detector (XRED) with multichannel analyzer (MCA) guarantees high counting rates without warm-up time

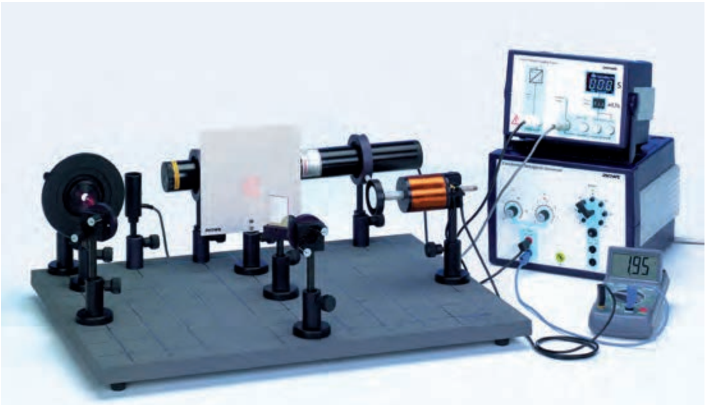
Principle

Various alloyed materials are subjected to polychromatic X-rays. The energy of the resulting fluorescence radiation is analysed with the aid of a semiconductor detector and a multichannel analyser.The energy of the corresponding characteristic X-ray fluorescence lines is determined. In order to determine the concentration of the alloy constituents, the intensity of their respective fluorescence signals is compared to that of the pure elements.

Tasks

1. Calibration of the semiconductor energy detector with the aid of the characteristic radiation of the tungsten tube.
2. Recording of the fluorescence spectra that are produced by the alloyed samples.
3. Recording of the fluorescence spectra that are produced by the pure metals.
4. Determination of the energy values of the corresponding-fluorescence lines.

P2430800 Magnetostriction with the Michelson interferometer



Details

What you can learn about

- Interference
- Wavelength
- Diffraction index
- Speed of light
- Phase
- Virtual light source
- Ferromagnetic material
- Weiss molecular magnetic fields
- Spin-orbit coupling

Benefits

- Experience the essence of the Nobel Prize: Michelson (1907)
- See that magnetic fields can change the geometry of objects
- Use a Michelson interferometer to measure quantitatively this most subtle effect
- Set up the instrument by yourself from separate components

Principle

With the aid of two mirrors in a Michelson arrangement, light is brought to interference. Due to the magnetostrictive effect, one of the mirrors is shifted by variation in the magnetic field applied to a sample and the change in the interference pattern is observed.

Tasks

1. Construction of a Michelson interferometer using separate optical components.
2. Testing various ferromagnetic materials (iron and nickel) as well as a non-ferromagnetic material (copper), with regard to their magnetostrictive properties.

P2260106 Faraday effect with optical base plate

Details

What you can learn about

- Electromagnetic field interaction
- Electron oscillation
- Electromagnetism
- Polarisation
- Verdet's constant
- Hall effect
- Virtual light source
- Ferromagnetic material
- Weiss molecular magnetic fields
- Spin-orbit coupling

Benefits

- Experience that magnetic fields can influence light by changing ist polarization properties
- Learn how wavelength and the optical medium influence the effect of the magnetic field
- Discover a bridge between the fields of optics and electromagnetism

Principle

The angle of rotation of the polarisation - plane of plane polarised light through a flint glass rod is found to be a linear function of the product of the mean flux-densitiy and the length of the optical medium. The factor of proportionally, called Verdet's constant, is investigated as a function of the wavelength and the optical medium.

Tasks

1. To determine the magnetic flux-densitiy between the pole pieces using the axial Hall probe of the teslameter for different coil currents. The mean flux-density is calculated by numerical integration and the ratio maximum flux density over mean flux density established.
2. To measure the maximum flux- density as a function of the coil current and to establish the relationship between mean flux-density and coil current anticipating that the ratio found under 1. remains constant.
3. To determine the angle of rotation as a function of the mean fluxdensity using different colour filters. To calculate the corresponding Verdet's constant in each case.
4. To evaluate Verdet's constant as a function of the wavelength.

Semiconductor thermogenerator – Seebeck effect P2410700

What you can learn about
- Seebeck effect (thermoelectric effect)
- Thermoelectric e.m.f.
- Efficiency
- Peltier coefficient
- Thomson coefficient
- Seebeck coefficient
- Direct energy conversion
- Thomson equations

Benefits
- Open design allows to fully understand function and applications
- Individual instruments for distinct functions (no "black box")
- Key products of the experiment setup can also be used for investigating the Peltier effect

Details

Principle
In a semi-conductor thermogenerator, the no-load voltage and the short-circuit current are measured as a function of the temperature difference. The internal resistance, the Seebeck coefficient and the efficiency are determined.

Tasks
1. To measure no-load voltage U_0 and short-circuit current I_s at different temperature differences and to determine the Seebeck coefficient.
2. To measure current and voltage at a constant temperature difference but with different load resistors, and to determine the internal resistance R_i from the measured values.
3. To determine the efficiency of energy conversion, from the quantity of heat consumed and the electrical energy produced per unit time.

Velocity of ultrasound in solid state material P5160100

What you can learn about
- Sound velocity
- Propagation of ultrasonic waves
- Time of flight
- Ultrasonic echography
- Thickness measurement
- Probe delay

Benefits
- Introductory experiment for echoscopy applications
- Experiment can be easily extended to perform A-scan and B-scan experiments
- With further extensions experiments with medical and materials context can be performed

Details

Principle
The velocity of sound in acrylics shall be determined by time of flight reflection technique with an ultrasonic echoscope. The measurements are done by reflection method, on three cylinders of different length. Two measurement series are carried out with ultrasonic probes of different frequencies.

Tasks
1. Measure the length of the three cylinders with the calliper.
2. Determine the time of flight of the ultrasonic reflection pulses for the three cylinders and the two ultrasonic probes.
3. Calculate the sound velocities, probe delays and use the two mean values obtained to calculate the cylinder length.

P2538000

Basic methods in imaging of micro and nanostructures with AFM (Atomic Force Microscopy)

Details

What you can learn about
- Atomic Force Microscopy (AFM)
- Lennard-Jones potential
- Imaging of nano structures
- Static Force Mode / Dynamic Force Mode
- Feedback loop
- Force and Vibrational amplitude

Benefits
- Investigation in static and dynamic mode
- Modification of numerous parameters to optimize image quality
- Perform experiment with different samples
- Custom-designed for use in teaching labs
- Microscope consists of one compact, portable instrument, no additional instruments required
- Vibration isolated for better and reproducible results

Principle
Approaching a sharp silicon tip mounted on a cantilever to a sample surface leads to an atomic scale interaction. The result is a bend of the cantilever which is detected by a laser. In static mode the resulting deflection is used to investigate the topography of the sample surface line-by-line using a feedback loop. In dynamic mode the cantilever is oscillated at fixed frequency resulting in a damped amplitude near the surface.

Tasks
1. Set-up the microscope and start up the software. Mount a cantilever (with tip) and approach the tip towards a sample.
2. Investigate the influence of the scanning parameters on the imaging quality and performance, e.g. PID gain, setpoint (force), vibrational amplitude, and scanning speed. Use both static and dynamic force mode.
3. Seven different samples supplied.

P2532000

Atomic resolution of the graphite surface by STM (Scanning Tunneling Microscope)

Details

What you can learn about
- Tunneling effect / Hexagonal structures
- Scanning Tunneling Microscopy (STM)
- Imaging on the sub nanometer scale
- Piezo-electric devices
- Local Density Of States (LDOS)
- Constant-Height-Mode / Constant-Current-Mode

Benefits
- Experience the essence of the Nobel Prize: Binnig and Rohrer (1986)
- Observe atoms within minutes
- Custom-designed for use in teaching labs
- Microscope consists of one compact, portable instrument, no additional instruments required
- Vibration-isolated for better and reproducible results
- Used for imaging of atomic resolution and spectroscopy

Principle
Aproaching a very sharp metal tip to an electrically conductive sample by applying a electrical field leads to a current between tip and sample without any mechanical contact. This so-called tunneling current is used to investigate the electronic topography on the sub nanometer scale of a fresh prepared graphite (HOPG) surface. By scanning the tip line-by-line across the surface graphite atoms and the hexagonal structure are imaged.

Tasks
1. Prepare a Pt-Ir tip and the graphite (HOPG) sample and approach the tip to the sample.
2. Investigate the topography of clean terraces and the step height between neighboring terraces in constant-current mode.
3. Image the arrangement of graphite atoms on a clean terrace by optimize tunneling and scanning parameters.
4. Measure and compare images in the constant-height and constant-current mode.

Half-life and radioactive equilibrium

P2520102

What you can learn about

- Parent substance / Daughter substance
- Rate of decay / Disintegration or decay constant
- Counting rate
- Half life
- Disintegration product

Benefits

- Experience the essence of the Nobel Prize: M. Curie, P. Curie and Becquerel (1903)
- Isotope generator produces sufficient radioactive particles ½ life law
- Versatile GM Counter can be used in many other

Details

Principle

The half-life of a Ba-137 m daughter substance eluted (washed) out of a Cs-137 isotope generator is measured directly and is also determined from the increase in activity after elution.

Tasks

1. To measure the activity of the isotope generator as a functionof time immediately after elution.
2. To measure the activity of a freshly eluted solution of Ba137m as a function of time.

Poisson's and Gaussian distribution of radioactive decay

P2520360

What you can learn about

- Poisson's distribution / Gaussian distribution
- Standard deviation
- Expected value of pulse rate
- Different symmetries of distributions
- Dead time
- Recovering time and resolution time of a counter tube

Benefits

- Fundamental mathematical Gaussian and Poisson distribution proved in physics experiments
- Wireless interface system makes data analysis with PC easy
- Stable and safe setup on a magnetic base plate

Details

Principle

The aim of this experiment is to show that the number of pulses counted during identical time intervals by a counter tube which bears a fixed distance to along-lived radiation emitter correspond to a Poisson´s distribution. A special characteristic of the Poisson´s distribution can be observed in the case of a small number of counts n < 20: The distribution is unsymmetrical, i.e. the maximum can be found among smaller numbers of pulses than the mean value.

Tasks

1. Poissons's distribution
2. Gaussian distribution of radioactive decay
3. Influence of the dead time of the counter tube on the pulse distribution

P2522015

Alpha energies of different sources

Details

What you can learn about

- Decay series
- Radioactive equilibrium
- Isotopic properties
- Decay energy / Particle energy
- Potential well model of the atomic nucleus
- Tunnel effect / Geiger-Nuttal law
- Semiconductor / Barrier layer

Benefits

- Experience the essence of the Nobel Prizes: Rutherford (1908)
- The combination of multichannel analyzer (MCA), preamplifier and alpha and photodetector leads to precise results.
- No vacuum required
- MCA and preamplifier can be used in many other experiments

Principle

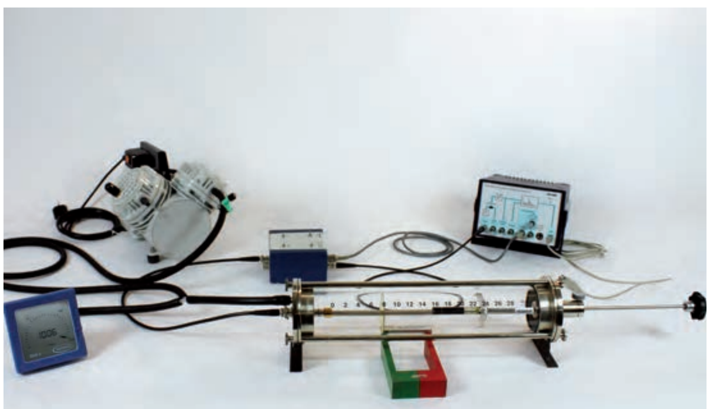
An alpha-spectrometer, consisting of a photodetector, a preamplifier, a pulse height analyser and a recording device for registration of the spectra is calibrated by means of an open alpha-emitter of known alpha energy (^{241}Am). The energy spectrum of a radium source which is in equilibrium with its decay products, is recorded and evaluated. The alpha-energies found in this way are allocated to the corresponding nuclides of the radium decay series.

Tasks

1. The Alpha-spectrum of the ^{226}Ra is recorded with multichannel analyzer.
2. The calibration spectrum of the open ^{241}Am alpha-emitteris recorded at the same settings.
3. The alpha-energies corresponding to the individual peaks of the alpha spectrum of the radium are calculated and compared to the values in the literature.

P2522115

Rutherford experiment



Details

What you can learn about

- Scattering / Angle of scattering
- Impact parameter
- Central force
- Coulomb field / Coulomb forces
- Rutherford atomic model
- Identity of atomic number and charge on the nucleus

Benefits

- Experience the essence of the Nobel Prizes: Rutherford (1908)
- Gold and Aluminum foil included
- The combination of multi channel analyzer (MCA), preamplifier and alpha detector leads to precise results.
- Transparent glass container with perfect visibility of the whole setup and good vacuum conditions, used in several experiments

Principle

The relationship between the angle of scattering and the rate of scattering of alpha-particles by gold foil is examined with a semiconductor detector. This detector has a detection probability of 1 for alpha-particles and virtually no zero effect, so that the number of pulses agrees exactly with the number of alpha-particles striking the detector. In order to obtain maximum possible counting rates, a measurement geometry is used which dates back to Chadwick.

Tasks

1. The particle rates are measured at different angles of scattering between about 20° and 90°. The measurements are compared with the particle rates calculated by means of the Rutherford theory for the measurement geometry used.
2. The particle rates are measured in the case of scattering by aluminium and gold with identical angles of scattering in each case. The ratio of the two particle rates is compared with the particle rate calculated from Rutherford's scattering equation.

Fine structure of the alpha spectrum of Am-241 / alpha spectroscopy

P2522215

What you can learn about
- Energy level diagram (decay diagram)
- Transition probability
- Excited nuclear states
- Î³-emission
- Connection between the fine structure of the Î±-spectrum and the accompanying Î³-spectrum

Benefits
- Alpha spectroscopy of the fine structure of alpha emitting Americium to understand the technique within a practical course
- The combination of multi channel analyzer (MCA), preamplifier and alpha detector leads to precise results.
- Transparent glass container with perfect visibility of the whole setup and good vacuum conditions, used in several experiments

Details

Principle
The alpha-spectrum of an open ^{241}Am-emitter is measured with a semiconductor alpha-detector. In connection with a multichannel analyzer (MCA) the main parts of the spectrum are investigated.

Tasks
1. The spectrum of an uncovered ^{241}Am-emitter is recorded with the multichannel analyzer. The energies of the two peaks preceding the principal peak are calculated. The principal peak, corresponding to a particle energy of 5.486 MeV, is used for calibration purposes.
2. The resolution capacity of the measurement layout is measured from the half-life width of the principal peak.

Study of the alpha energies of Ra-226

P2522315

What you can learn about
- Decay series / Radioactive equilibrium
- Isotopic properties
- Decay energy / Particle energy
- Potential well model of the atomic nucleus
- Tunnel effect / Geiger-Nuttal law
- Semiconductor / Barrier layer

Benefits
- The complete alpha spectrum of Radon to understand the technique within a practical course
- The combination of multi channel analyzer (MCA), preamplifier and alpha detector leads to precise results.
- Transparent glass container with perfect visibility of the whole setup and good vacuum conditions, used in several experiments

Details

Principle
An alpha-spectrometer, consisting of a silicon surface barrier-layer detector, a preamplifier, a multichannel analyser (MCA) and a PC for registration. The spectrum is calibrated by means of an open alpha-emitter of known alpha-energy (^{241}Am). The energy spectrum of a radium source which is in equilibrium with its decay products, is recorded and evaluated. The alpha-energies found in this way are allocated to the corresponding nuclides of the radium decay series.

Tasks
1. The alpha-spectrum of the ^{226}Ra is recorded, the settings of the pulse analyzer (amplification) and recorder (x and y input sensitivity) being selected so as to make best possible use of the recording width.
2. The calibration spectrum of the open ^{241}Am-emitter is recorded at the same settings.

P2522415 Energy loss of alpha particles in gases

Details

What you can learn about
- Range / Range dispersion
- Mean free path length
- Mean ionization energy of gas atoms
- Mean energy loss of a-particles per collision
- Differencial energy loss / Bethe formula
- Electron concentration in gases

Benefits
- Three different Gases (He, N2, CO2) are used to measure energy loss of alpha particles
- The combination of multi channel analyzer (MCA), pre-amplifier and alpha detector leads to precise results.
- Transparent glass container with perfect visibility of the whole setup and good vacuum conditions, used in several experiments

Principle
A study is made of the connection between the energy *E* of alpha-particles and the path x travelled by them in air at standard pressure. The measurements recorded enable the differencial energy loss dE/dx to be calculated as a function of x.

Tasks
1. The spectrum of a covered ^{241}Am source is measured at a fixed distance s as a function of the pressure p. The energy corresponding to the central points of the individual spectra are determined (after calibration of the measurement layout with an open ^{241}Am-emitter.)
2. The spectrum of the source used is measured initially under the same geometric conditions under vacuum and subsequently with the vessel filled with helium, nitrogen or carbon dioxide.
3. The mean energy with which the alpha-particles leave the covered americium source is determined by calibration against the open americium emitter (E = 5.485 MeV).

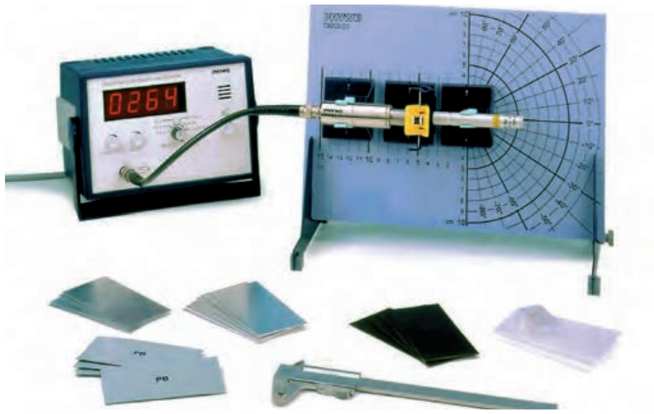
More information about the PHYWE Nobel Prize experiments can be found in the new brochure Premium experiments or in this catalogue on page 207 - 208.

Electron absorption

P2523100

What you can learn about
- Density
- Counter tube
- Radioactive decay
- Attenuation coefficient
- Mass coverage

Benefits
- Basic experiment in nuclear physics
- Different materials in various thicknesses completely covers absorption of electrons
- Classical version with GM Counter for better understanding



Details

Principle
The attenuation of an electron particle stream passing through a material layer depends both on the thickness of the layer and on the mass coverage, resp. the "mass per unit area". It will be shown that the particle flux consisting of electrons of a particular energy distribution decreases with the "mass per unit area". As electron source, a radioactive sample of ^{90}Sr is used.

Tasks
1. The beta-counting rates are measured as a function of the absorber thickness using different absorbing materials such as aluminium (AL), glass (GL), hard paper (HP) and typing paper (TP).
2. The attenuation coefficients are evaluated for the four absorbing materials and plotted as a function of the density.

Beta spectroscopy

P2523200

What you can learn about
- β_- decay
- Electron capture
- Neutrino
- Positron
- Decay diagram
- Decay energy
- Resting energy
- Relativistic Lorentz equation

Benefits
- Experience the essence of the Nobel Prizes: M. Curie, P. Curie and Becquerel (1903)
- Negative and positive charged particles are deflected in a magnetic field
- Straight forward spectroscopy by simple adjustment of the magnetic field of a coil
- GM Meter and Teslameter can be used in many other experiments

Details

Principle
The radiation of β unstable atomic nuclei is selected on the basis of its pulses in a magnetic transverse field, using a diaphragm system. The relationship between coil current and particle energy is determined for calibration of the spectrometer and the decay energy of the β transition is obtained in each case from the β_- spectra.

Tasks
1. Energy calibration of the magnetic spectrometer.
2. Measurement of the β spectra of ^{90}Sr and ^{20}Na.
3. Determination of the decay energy of the two isotopes.

P2524101 Inverse-square law and absorption of gamma or beta rays

Details

What you can learn about

- Radioactive radiation
- β decay
- Conservation of parity
- Antineutrino
- γ quants
- Half-valuethickness
- Absorption coefficient
- Term diagram
- Pair formation
- Compton effect
- Photoelectric effect
- Conservation of angular momentum
- Forbidden transition
- Weak interaction
- Dead time

Benefits

- Basic Experiment in nuclear physics
- Showing two fundamental laws: Inverse square law and absorption
- Classical version with GM Counter for better understanding

Principle

The inverse square law of distance is demonstrated with the gamma radiation from a Co-60 preparation, the half-value thickness and absorption coefficient of various materials determined with the narrow beam system and the corresponding mass attenuation coefficient calculated.

Tasks

1. To measure the impulse counting rate as a function of the distance between the source and the counter tube.
2. To determine the half-value thickness $d_{1/2}$ and the absorption coefficient of a number of materials by measuring the impulse counting rate as a function of the thickness of the irradiated material. Lead, iron, aluminium, concrete and Plexiglas are used as absorbers.
3. To calculate the mass attenuation coefficient from the measured values.

P2524715 X-ray fluorescence and Moseley's law

Details

What you can learn about

- Binding energy
- Photoelectric effect
- Shell structure of electron shells
- Characteristic X-ray radiation
- Gamma-spectrometry
- X-ray spectral analysis

Benefits

- A high ranking nuclear physics experiment can be performed by students within some hours.
- The combination of multichannel analyzer (MCA), gamma detector and high precision HV power supply leads to precise results.
- Fundamental Rydberg's constant and Mosley's law easily determined

Principle

The irradiation of iodine, barium (sulfat), silver and tin with soft gamma-radiations gives rise to K alpha radiations characteristics of these elements. The X-ray spectra are recorded with a gamma spectrometer consisting of a scintillation counter, a mlti channel analyser and a PC. After calibration of the spectrometer, the Rydberg constant is determined from the energies of the X-ray lines, using Moseley's law.

Tasks

1. Calibration of the gamma-spectrometer in the low energy range, using the Ba-resonance line Cs-137 emitter (32 keV) and the gamma-line of ^{241}Am at 59.6 keV.
2. Recording of the X-ray fluorescence spectra (Ka-lines) of different elements and determination of the corresponding energies.
3. Plotting of the measured X-ray energies according to Moseley's law against $(z-1)^2$ and determination of the Rydberg constant R; from the slope of the resulting lines.

Energy dependence of the gamma absorption coefficient / Gamma spectroscopy

P2524215

What you can learn about
- Compton scattering
- Photo effect
- Pair production
- Absorption coefficient
- Radioactive decay
- Gamma-spectroscopy

Benefits
- Gamma spectroscopy as basic knowledge for high energy physics
- The combination of multichannel analyzer (MCA), gamma detector and high precision HV power supply leads to precise results

Details

Principle
The intensity of gamma-radiation decreases when it passes through solid matter. The attenuation can be the result of Compton scattering, the photo effect or the pair production. An absorption coefficient can be attributed to each of the three phenomena. These absorption coefficients, as well as the total absorption, are highly energy-dependent. The energy dependence of the total absorption coefficient for aluminium in the range below 1.3 MeV is verified.

Tasks
1. For each of the emitting isotopes ^{22}Na and ^{241}Am the gamma-spectrum is traced and a threshold energy, E, just below the photo-peak in the high energy range determined.
2. Using the scintillation counter in conjunction with the multichannel analyser as a monochromator, the gamma-intensity is measured as a function of the thickness of different aluminium layers. The three gamma-emitting isotopes are used successively as the source, assuming that the energy of the emitted gamma-radiation is known.

Internal conversion in 137m Ba

P2524515

What you can learn about
- Gamma-radiation
- Nuclear transitions
- Transition probability
- Duration
- Metastable states
- Isotopic spin quantum Numbers
- Rules governing selection
- Multipole radiation
- Isomeric nuclei
- Photonuclear reaction
- Conversion electron
- Characteristic X-ray radiation
- Scintillation detectors

Benefits
- Decay scheme and internal conversion in one experiment
- Gamma spectroscopy as basic knowledge for high energy physics
- The combination of multi channel analyzer (MCA), gamma detector and high precision HV power supply leads to precise results

Details

Principle
The radiation emitted during the decay of the ^{137}Cs isotope is measured with a scintillation detector and the energy spectrum determined with a pulse height analyzer. The spectrum contains fractions due to a gamma-transition and fractions originating from a characteristic X-ray radiation. The areas of the fractions in question are determined and the conversion factor obtained from them.

Tasks
1. Measurement of the g-spectrum of ^{137}Cs using a scintillation detector.
2. Determination of the conversion factor of the ^{137}mBa excited nucleus.

P2524615 Photonuclear cross-section / Compton scattering cross-section with MCA

Details

What you can learn about

- Gamma-radiation
- Interaction with material
- Photoelectric effect
- Compton effect
- Pair formation
- Detection probability
- Scintillation detectors

Benefits

- Experience the essence of the Nobel Prize: Compton (1927)
- Nobel Prize experiment can be performed by students within some hours.
- Impressive second proof of the wave - particle dualism
- Use of a gamma detector in combination with a high precision power supply guarantees good and reproducible results

Principle

The radiation of ^{137}Cs and ^{22}Na is measured with a scintillation detector and the energy spectrum determined with a multi-channel analyzer. The fractions of the spectra caused by Compton scattering and those caused by the photoelectric effect are determined on the basis of their areas. The results are used for determining the ratio of the effective cross-sections and examining its energy dependence.

Tasks

1. Measurement of the gamma-spectra of ^{22}Na and ^{137}Cs, using a scintillation detector.
2. Determination of the ratio of the specific effective cross-sections due to the Compton effect and the photo-electric effect in photons having energy values of 511, 662 and 1275 keV.

P2520400 Visualisation of radioactive particles / diffusion cloud chamber

Details

What you can learn about

- α,β,γ-particles
- β-deflection
- Ionising particles
- Mesons
- Cosmic radiation
- Radioactive decay
- Decay series
- Particle velocity
- Lorentz force

Benefits

- Experience the essence of the Nobel Prize: CTR Wilson (1927)
- Only instrument to visualize natural background and cosmic radiation
- Can discriminate between different types of radiations (alpha, beta, gamma, mesons and myons)
- Qualitative and quantitative experiments described
- Permanent operation possible, no dry ice required
- Beta deflection can be visualized
- Perfect for display in science centers and museums (Size: 45x45 cm)

Principle

Radioactivity is a subject in our society which has been playing an important role throughout politics, economy and media for many years now. The fact that this radiation cannot be seen or felt by the human being and that the effects of this radiation are still not fully explored yet, causes emotions like no other scientific subject before. The high-performance diffusion cloud chamber serves for making the tracks of cosmic and terrestrial radiation visible so that a wide range of natural radiation types can be identified. Furthermore, the diffusion cloud chamber offers the opportunity to carry out physical experiments with the aid of artificial radiation sources.

Tasks

1. Determination of the amount of background radiation.
2. Visualisation of α,β,γ -particles and mesons.
3. Visualisation of the thorium (radon) decay.
4. Deflection of β-particles in a magnetic field.

XR 4.0 expert unit –
made for better education

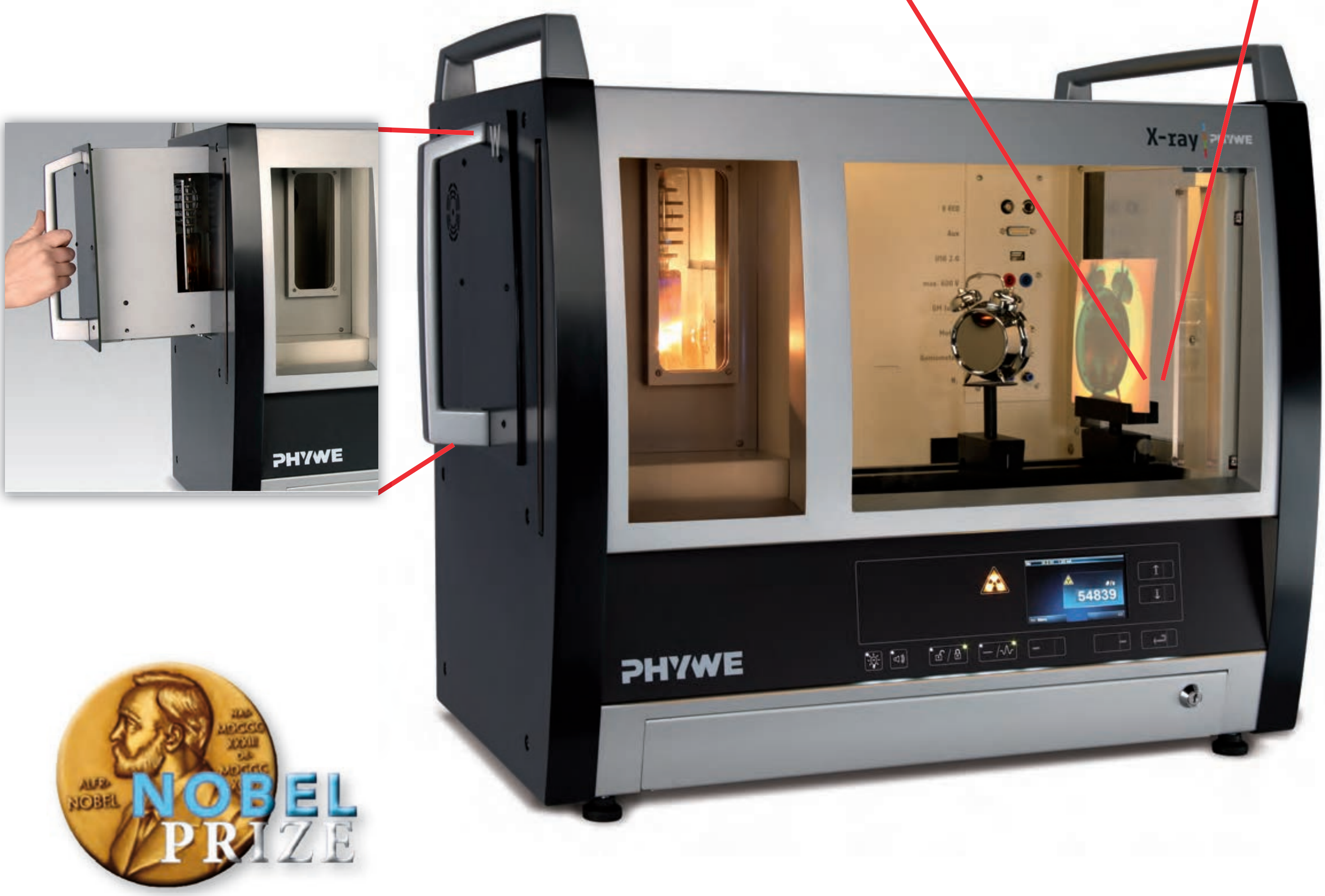
PHYWE XRE 4.0 X-ray expert set, with tungsten tube

Basic set covering the fundamental principles and areas of applications of X-rays, e.g. fluoroscopy experiments and X-ray photography. It can be extended for specific applications and topics by means of upgrade sets.

With the PHYWE X-ray XR 4.0 the physics of X-rays can be utilized in several different fields of education at universities, colleges and schools. Extension sets of the XR 4.0 product family permit custom applications in physics, chemistry, biology, medicine, material sciences and geo sciences.

The XR 4.0 is unique as it provides an abundance of uses with an excellent price/ performance ratio. Apart from its modern and innovative design the XR 4.0 excels at professional technology, a patent-pending safety system, innovative soft-ware solutions, intuitive graphical user interface as well as extensive accessories packages – **Quality Made in Germany!**

Visit: www.phywe.com/X-ray



Scope of supply

YouTube

XR 4.0 expert unit –
Sets for all applications

X-ray XR 4.0 PHYWE

Basic set	Core components	Areas of application	Application examples
XRE 4.0 expert set, W **Art. No.** 09110-88 (Basic set with tungsten tube)	■ XR 4.0 expert unit (X-ray device) ■ XR 4.0 software measure X-ray ■ Optical bench ■ TESS expert manual ■ Fluorescent screen ■ USB cable, mains cable + adaptor	Phy Che Bio Med Geo Eng	■ Basics & applications of X-radiation ■ Radiographic experiments ■ Radiology
XRE 4.0 expert set, Cu **Art. No.** 09111-88	Same as above but with copper tube		
XRE 4.0 expert set, Mo **Art. No.** 09112-88	Same as above but with molybdenum tube		
XRE 4.0 expert set, Fe **Art. No.** 09113-88	Same as above but with iron tube		

Extend the basic set with the respective extension set according to area of application

Extension sets	Core components	Areas of application	Application examples
XRP 4.0 solid-state physics Art. No. 09120-88	■ Goniometer, GM counter tube ■ LiF / KBr single crystal ■ Absorption set	Phy	■ Diffractometry ■ X-ray spectroscopy ■ Bragg reflection / bremsstrahlung ■ Characteristic lines
XRC 4.0 characterization Art. No. 09130-88	■ 3 X-ray tubes (Cu, Fe, Mo) ■ Goniometer, GM counter tube, ■ LiF / KBr single crystal	Phy	■ Radiation spectra of the anode ■ Moseley law ■ Rydberg constant ■ Duane-Hunt law
XRS 4.0 structure analysis Art. No. 09140-88	■ Goniometer, GM counter tube, ■ LiF / KBr / NaCl single crystal ■ Crystal holder ■ Powder samples	Phy Che Geo Eng	■ Structure investigations ■ Laue patterns ■ Debye-Scherrer images ■ Powder diffractometry
XRM 4.0 material analysis Art. No. 09160-88	■ Goniometer ■ X-ray energy detector ■ Multichannel analyzer ■ Sample sets	Phy Che Geo Eng	■ X-ray fluorescence spectroscopy ■ Non-destructive testing (NDT) ■ Compton effect ■ Energy-dispersive experiments
XRI 4.0 radiophotography Art.-Nr. 09150-88	■ Digital SLR camera ■ Radiographic object ■ Model loader ■ Implant model	Bio Med Geo	■ X-ray imaging ■ Radiography ■ Radiology
XRD 4.0 dosimetry and radiation damage Art. No. 09170-88	■ Parallel-plate capacitor ■ Power supply unit 600 V ■ DC current amplifier ■ Camera	Phy Bio Med	■ Dosimetry ■ Degradation ■ Damage ■ Ionization of air
XRCT 4.0 computed tomo-graphy Art. No. 09180-88	■ Direct, digital X-ray image sensor ■ Rotation unit, vertical rotation ■ Measure Tomography software package	Phy Bio Med Eng	■ 3-dimensional reconstruction ■ Cross sections ■ Direct, digital image capture

Complete systems	Core components	Areas of application	Application examples
XR 4.0 X-ray system Art. No. 09057-88	Complete set for all X-ray experiments	Phy Che Bio Med Geo Eng	All applications
XRE 4.0 X-ray expert set for schools Art. No. 09117-88	Set with copper tube ■ Goniometer, GM counter tube ■ LiF / KBr single crystal ■ Absorption set	Phy Che Bio Med Geo Eng	Same applications as for Basic set and for Solid-State Physics set

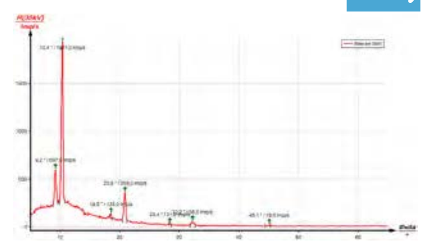
Applications of the XR 4.0 expert set – with three detectors for a wide range of experiments

Geiger-Müller counter tube

- For high-intensity signals of more than 14,000 counts per second

XR 4.0 X-ray Goniometer
- Self-calibrating
- Self-positioning

Characteristic lines and bremsstrahlung



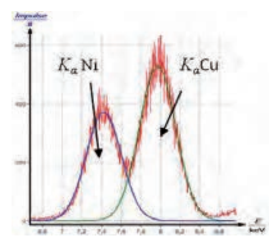
Phy

X-ray energy detector

- Measure chemical elements starting with potassium
- Use immediately, no warm-up required
- Compact and robust

XR 4.0 X-ray Goniometer
- Self-calibrating
- Self-positioning

X-ray fluorescence analysis



Phy Che Eng Geo

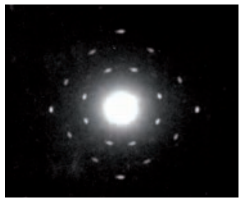
Digital image sensor

- Short exposure time at high resolution (0.5 sec. per image)
- Captures digital image directly
- Compact setup
- Can be used both for CT and for Laue images

Computed tompgraphy

Eng Med

Laue image



Che Phy

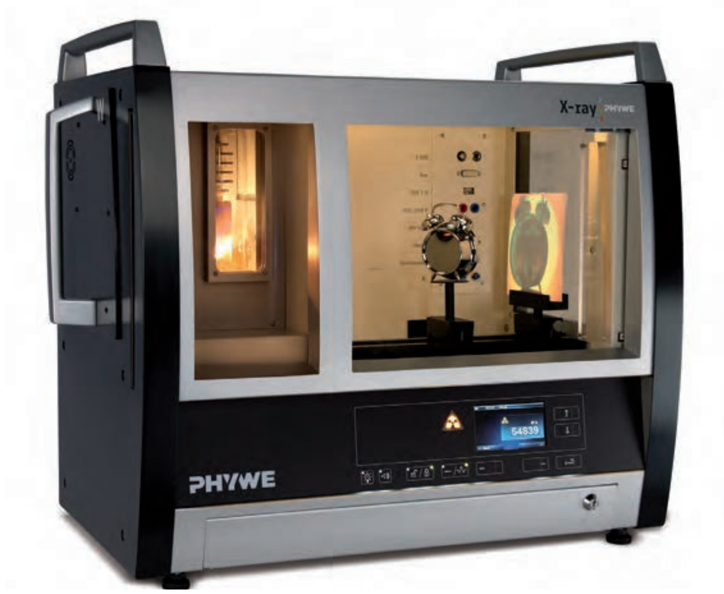
Experiment manual „X-ray experiments“

- 46 experiments

Experiment manual „Applications of X-ray Computed Tomography“

- 10 experiments

09110-88 XRE 4.0 X-ray expert set, with tungsten tube



Details

Function and Applications

Basic set covering the fundamental principles and areas of applications of X-rays, e.g. fluoroscopy experiments and X-ray photography. It can be extended by upgrade sets for specific applications and topics.

Equipment and Technical Data

The set includes the following components:

- XR 4.0 expert unit
- XR 4.0 X-ray plug-in unit with a tungsten X-ray tube
- XR measure 4.0 X software
- TESS expert manual "Experiment with X-radiation" (English and German version) with more than 50 experiments
- USB cable
- Mains cable with adaptor
- Optical bech with
- Quick-start guide
- Operating instruction
- Fluorescent screen

What you can learn about

- X-ray tube
- Absorption of X-rays
- Radiography
- Fluorescence
- Atomic number
- Fluorescence
- Lambert-Beer

Benefits

- With the PHYWE X-ray XR 4.0 the physics of X-rays can be utilized in a broad range of fields of education at universities, colleges and schools.
- Extension sets of the XR 4.0 product family permit custom applications in physics, chemistry, biology, medicine, material sciences and geo sciences.
- The XR 4.0 is unique as it provides an abundance of uses with an excellent price/performance ratio.
- Apart from its modern and innovative design the XR 4.0 excels at professional technology, a patent-pending safety system, innovative software solutions, intuitive graphical user interface as well as extensive accessories packages
- Quality Made in Germany!

Related experiments for the XRE 4.0 X-ray expert set (09110-88)

P2540020
Radiographic examination of objects

Details

P2540030
Qualitative examination of the absorption of X-rays

Details

09120-88 XRP 4.0 X-ray solid state physics upgrade set

Function and Applications

Upgrade set as an extension of the XRE 4.0 X-ray expert set (09110-88). Particularly suitable for fundamental experiments in solid-state physics with X-rays.

What you can learn about

- Geiger-Mueller counter tube
- Quenching gas
- Ionising radiation
- Characteristic X-ray radiation
- Energy levels
- Bragg equation
- Intensity of characteristic X-rays
- Bremsstrahlung
- Characteristic radiation
- Bragg scattering
- Law of absorption
- Mass absorption coefficient
- Absorption edge
- Half value thickness
- Photoelectric effect
- Compton scattering
- Pair production
- X-ray tube
- Crystal structures
- Lattice constant
- Absorption
- Absorption edges
- Interference

This set covers the following experiments and topics:

- Fluoroscopy and X-ray imaging
- Fundamental principles of X-ray spectroscopy
- Bragg reflection
- Bremsspectrum /characteristic lines
- Determination of Planck's quantum of action
- X-ray diffractometry

Equipment and Technical Data
The set includes the following components:

- XR 4.0 X-ray goniometer, 09057-10
- Geiger-Müller counter tube, type B, 09005-00
- XR 4.0 X-ray LiF monocrystal in a holder, 09056-05
- XR 4.0 X-ray potassium bromide (KBr) monocrystal in a holder, 09056-01

Benefits

- Goniometer as an essential part of the set with two independent stepper motors for rotating the sample and counter tube holders either separately or coupled in a 2:1 ratio.
- The counter tube holder of the goniometer with a slit diaphragm holder for absorption foils can be moved in order to change the angular resolution.
- Includes a light barrier system for limiting the permissible swivelling range as a function of the block position.
- Plug & measure: The goniometer can be connected during the operation and it will be automatically identified.

Related experiments for the XRP 4.0 X-ray solid state physics upgrade set (09120-88)

P2542801
Characteristic X-rays of tungsten

Details

P2540010
Counter tube characteristics

Details

P2540401
The intensity of characteristic X-rays as a function of the anode current and anode voltage

Details

P2540901
Duane-Hunt displacement law and Planck's "quantum of action"

Details

P2541101
Absorption of X-rays

Details

Basic

To perform all experiments with the XRP 4.0 X-ray solid state physics upgrade set (09120-88) you also need the XRE 4.0 X-ray expert basic set (09110-88). All details on page 136.

For all information: www.phywe.com/X-ray

09130-88 XRC 4.0 X-ray characteristics upgrade set

Details

Function and Applications

Upgrade set as an extension of the XRE 4.0 X-ray expert set (09110-88). It is used for the characterisation of the radiation spectra of various different anode materials. It is particularly suitable for studying the fundamental principles of X-ray physics.

What you can learn about

- Geiger-Mueller counter tube
- Quenching gas
- Characteristics
- Ionising radiation
- Energy levels
- Crystal structures
- Lattice constant
- Absorption
- Absorption edges
- Interference
- Order of diffraction
- Bremsstrahlung
- Characteristic radiation
- Bragg equation
- Intensity of characteristic X-rays
- Bragg scattering
- Characteristic X-ray radiation
- Selection rules
- Energy term symbols
- the Bragg equationenergy
- term symbols
- X-ray tube
- Bohr model
- Binding energy
- Moseley's law
- Rydberg frequency
- Screening constant
- Law of absorption
- Mass absorption coefficient
- Compton effect
- Compton wavelength
- Rest energy
- Absorption
- Transmission
- Conservation of energy and momentum
- X-rays

The set covers the following experiments and topics:

- Fluoroscopy and X-ray imaging
- Debye-Scherrer analyses
- Fundamental principles of X-ray spectroscopy
- Bragg reflection
- Bremsspectrum
- K and L edges
- Characteristic lines of different anode materials
- Moseley's law
- Determination of the Rydberg constant
- Duane-Hunt's law
- Determination of Planck's quantum of action
- X-ray diffractometry

Equipment and Technical Data

The set includes the following components:

- XR 4.0 X-ray goniometer, 09057-10
- Geiger-Müller counter tube, type B, 09005-00
- XR 4.0 X-ray LiF crystal in a holder, 09056-05
- XR 4.0 X-ray diaphragm tube with Ni foil, 09056-03
- XR 4.0 X-ray potassium bromide monocrystal in a holder for the Bragg reflection, 09056-01
- XR 4.0 X-ray diaphragm tube with Zr foil,09058-03
- XR 4.0 X-ray plug-in unit with an iron X-ray tube, 09057-70
- XR 4.0 X-ray plug-in unit with a molybdenum X-ray tube, 09057-60
- XR 4.0 X-ray plug-in unit with a copper X-ray tube, 09057-50
- And additional accessories

Benefits

- Plug & measure
- Quick change of the X-ray tubes in the set
- Connection of the goniometer during operation
- Automatic identification of the anode material of the X-ray tube - adjustment free.

The housings of the X-ray tubes have two safety contact pins that enable the tube operation only if the plug-in unit has been installed correctly.

Related experiments for the XRC 4.0 X-ray characteristics upgrade set (09130-88)

P2540101
Characteristic X-rays of copper
Details

P2540201
Characteristic X-rays of molybdenum
Details

P2540301
Characteristic X-rays of iron
Details

P2540801
Characteristic X-rays of tungsten
Details

P2540401
The intensity of characteristic X-rays as a function of the anode current and anode voltage
Details

P2540501
Monochromatisation of molybdenum X-rays
Details

P2540601
Monochromatisation of copper X-rays
Details

P2540701
K alpha double splitting of molybdenum X-rays / fine structure
Details

P2540801
K alpha doublet splitting of iron X-rays / fine structure
Details

P2540901
Duane-Hunt displacement law and Planck's "quantum of action"
Details

P2541001
Characteristic X-ray lines of different anode materials / Moseley's law
Details

P2541101
Absorption of X-rays
Details

P2541701
Compton scattering of X-rays
Details

P2540001
Counter tube characteristics
Details

To perform all experiments with the XRC 4.0 X-ray characteristics upgrade set (09130-88) you also need the XRE 4.0 X-ray expert basic set (09110-88).
All details on page 136.

For all information: www.phywe.com/X-ray

09140-88

Details

XRS 4.0 X-ray structural analysis upgrade set

Function and Applications

Upgrade set as an extension of the XRE 4.0 X-ray expert set (09110-88). This set is particularly suitable for the structural analysis of different types of samples in materials physics, chemical analysis, and mineralogy.

What you can learn about

- Geiger-Mueller counter tube
- Quenching gas
- Characteristics
- Ionising radiation
- Bremsstrahlung
- Characteristic radiation
- Crystal structures
- Lattice constant
- Absorption
- Absorption edges
- Interference
- Order of diffraction
- Characteristic X-ray radiation
- Energy level
- Bragg equation
- Intensity of characteristic X-rays
- Diffraction
- Bragg scattering
- X-ray tube
- Bohr's atomic model
- Atomic energy level scheme
- Moseley's law
- Rydberg constant
- Screening constant
- Miller indices
- Atomic form factor
- Structure factor
- Bragg scattering
- Crystal lattices
- Crystal systems
- Reciprocal lattice
- Structure amplitude
- Crystal classes
- Monochromatization of X-rays
- Bravais-lattice
- Atomic scattering factor
- Lorentz-polarization factor
- Multiplicity factor
- Debye-Waller factor

The set covers the following experiments and topics:

- Fluoroscopy and X-ray imaging
- Debye-Scherrer analyses and images
- Laue diffraction patterns
- Fundamental principles of X-ray spectroscopy
- Bragg reflection, Bragg-Brentano geometry
- Bremsspectrum
- Determination of Planck's quantum of action
- X-ray diffractometry
- Texture analyses of grown materials
- Monochromatisation of X-rays
- Analysis of crystals with different crystal structures: cubic, hexagonal, tetragonal, diamond, BCC, and FCC

Equipment and Technical Data
The set includes the following components:

- XR 4.0 X-ray plug-in unit copper tube
- XR 4.0 X-ray goniometer, 09057-10
- Geiger-Müller counter tube, type B, 09005-00
- XR 4.0 X-ray LiF crystal in a holder, 09056-05
- XR 4.0 X-ray NaCl monocrystals, set of 3,09058-01
- XR 4.0 X-ray set of chemicals for edge absorption, 1 set, 09056-04
- XR 4.0 X-ray diaphragm tube with Ni foil, 09056-03
- XR 4.0 X-ray potassium bromide monocrystal in a holder for the Bragg reflection, 09056-01
- XR 4.0 X-ray diaphragm tube with Zr foil, 09058-03
- XR 4.0 X-ray crystal holder for Laue images, 09058-11
- XR 4.0 X-ray universal crystal holder for the X-ray unit, 09058-02
- XR 4.0 X-ray sample holder for powder samples, 09058-09
- accessories for the structural analysis set: chemicals etc.

Computer not included.

Benefits

- Material analyses with different techniques: diffractometric and photographic analyses
- Samples of different structures: monocrystalline and polycrystalline samples, powder crystallites

Related experiments for the XRS 4.0 X-ray structural analysis upgrade set (09140-88)

P2540010
Counter tube characteristics
Details

P2540101
Characteristic X-rays of copper
Details

P2541401
The intensity of characteristic X-rays as a function of the anode current and anode voltage
Details

P2540601
Monochromatisation of copper X-rays
Details

P2540901
Duane-Hunt displacement law and Planck's "quantum of action"
Details

P2541201
K and L absorption edges of X-rays / Moseley's law and the Rydberg constant
Details

P2541301
Examination of the structure of NaCl monocrystals with different orientations
Details

P2541401
X-ray investigation of cubic crystal structures / Debye-Scherrer powder method
Details

P2541501
X-ray investigation of hexagonal crystal structures / Debye-Scherrer powder method
Details

P2541601
X-ray investigation of crystal structures / Laue method
Details

P2542101
Debye-Scherrer diffraction patterns of powder samples with three cubic Bravais lattices
Details

P2542201
Debye-Scherrer diffractions pattern of powder samples with a diamond structure (according to Bragg-Brentano)
Details

P2542301
Debye-Scherrer diffraction patterns of powder samples with a hexagonal lattice structure
Details

P2542401
Debye-Scherrer diffraction patterns of powder samples with a tetragonal lattice structure
Details

P2542501
Debye-Scherrer diffraction patterns with a cubic powder sample
Details

P2542601
Diffraction measurements to determine the intensity of Debye-Scherrer reflexes using a cubic powder sample
Details

P2542801
Characteristic X-rays of tungsten
Details

Basic

To perform all experiments with the XRS 4.0 X-ray structural analysis upgrade set (09140-88) you also need the XRE 4.0 X-ray expert basic set (09110-88).
All details on page 136.

For all information: www.phywe.com/X-ray

09150-88 XRI 4.0 X-ray imaging upgrade set

Function and Applications

Upgrade set as an extension of the XRE 4.0 X-ray expert set (09110-88). This set is particularly suitable for studying the fundamental principles of X-ray imaging in medical applications (radiography) and material science (non-destructive testing).

The set covers the following experiments and topics:

- Fluoroscopy experiments and X-ray photography
- Radiography experiments on various different models

Equipment and Technical Data

The set includes the following components:

- 09057-21 XR 4.0 X-ray optical bench, external
- 09058-06 XR 4.0 X-ray blood vessel model for contrast media experiments
- 09058-07 XR 4.0 X-ray implant model for X-ray images

What you can learn about

- X-ray radiation
- Bremsstrahlung
- Characteristic radiation
- Law of absorption
- Mass absorption coefficient
- Contrast medium
- Stereographic projection

Benefits

- Familiarisation with the radiography technology in medical applications in a technically particularly easy and intuitive way

Related experiments for the XRI 4.0 X-ray imaging upgrade set (09150-88)

P2541901
Contrast medium experiment with a blood vessel model

Details

P2542001
Determination of length and position of an object which can not be seen

Details

Basic

To perform all experiments with the XRI 4.0 X-ray imaging upgrade set (09150-88) you also need the XRE 4.0 X-ray expert basic set (09110-88). All details on page 136.

09160-88 XRM 4.0 Material Upgrade set

Function and Applications

Upgrade set as an extension of the XRE 4.0 X-ray expert set (09110-88). This set is particularly suitable for the qualitative and quantitative X-ray fluorescence spectroscopy of metallic samples in physics and material science (non-destructive testing).

What you can learn about

- Bremsstrahlung
- Characteristic X-radiation
- Energy levels
- Fluorescence radiation
- Conduction processes in semiconductors
- Doping of semiconductors
- Pin-diodes
- Detectors
- Resolution and resolving power
- Semiconductor energy
- Multichannel analysers
- Fluorescent yield
- Interference of X-rays
- Crystal structures
- Bragg's law
- Compton scattering
- Escape peaks
- Absorption of X-rays
- Bohr's atom model
- Moseley's law
- Rydberg frequency
- Screening constant
- Solubility
- Solubility product
- Auger effect
- Coherent and incoherent photon scattering
- Edge absorption
- Matrix effects
- Scattering of X-rays
- Energy detectors
- Law of absorption
- Mass attenuation coefficient
- Saturation thickness
- Semiconductor
- Energy detectors
- Photo energy
- Semiconductor detectors

The set covers the following experiments and topics:

- Various different types of samples can be analysed: powders, solids, liquids, pure metals and multi-component alloys
- Moseley's laws energy-dispersive Bragg structure analysis
- Determination of the lattice constant of monocrystals
- Duane-Hunt's law of displacement
- X-ray fluorescence analysis for layer thickness determination
- Characteristics and the special resolving power of an X-ray energy detector

Equipment and Technical Data

The set includes the following components:

- XR 4.0 X-ray goniometer, 09057-10
- XR 4.0 X-ray energy detector, 09058-30
- Multichannel analyser, 13727-99
- Software for the multichannel analyser, 14452-61
- XR 4.0 X-ray set of chemicals for edge absorption, 1 set, 09056-04
- XR 4.0 X-ray LiF monocrystal in a holder, 09056-05
- XR 4.0 X-ray universal crystal holder, 09058-02
- XR 4.0 X-ray sample holder for powder samples, 09058-09
- XR 4.0 X-ray diaphragm tube with Zr foil, 09058-03
- Balance

Benefits

- Immediate measurements possible because energy detector does not require warm-up
- Measurement data can be viewed in real-time as soon as x-ray tube is switched on
- In combination with the XR 4.0 X-ray multichannel analyser (13727-99), the entire X-ray energy spectrum (2-35 keV) of the analysed materials can be determined.
- The set includes a sensitive XR 4.0 X-ray energy detector (09058-30) with a resolution of FWHM < 400 eV, rate independent up to 20 kcps.

Related experiments for the XRM 4.0 Material Upgrade set (09160-88)

P2544001
X-ray energy spectroscopy - calibration of the X-ray energy detector
Details

P2544101
Energy resolution of the X-ray energy detector
Details

P2544201
Inherent fluorescence radiation of the X-ray energy detector
Details

P2544501
Qualitative X-ray florescence spectroscopy of metals – Moseley's law
Details

P2544601
Qualitative X-ray fluorescence analysis of alloyed materials
Details

P2544701
Qualitative X-ray fluorescence analysis of powder samples
Details

P2544801
Qualitative X-ray fluorescence analysis of solutions
Details

P2544901
Qualitative X-ray fluorescence analysis of ore samples
Details

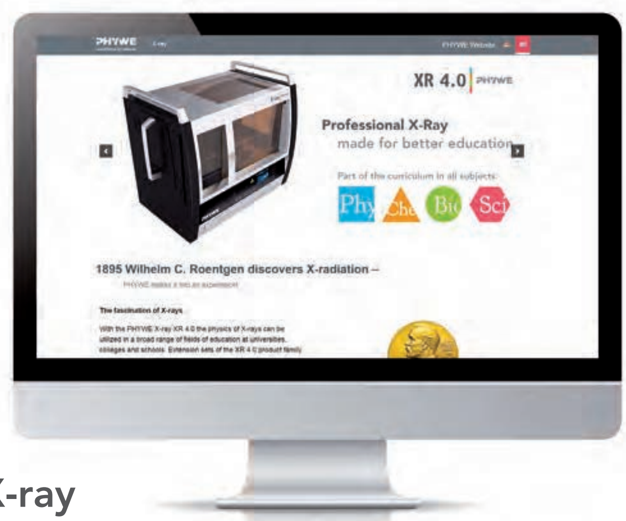
P2545001
Quantitative X-ray fluorescence analysis of alloyed materials
Details

P2545101
Quantitative X-ray fluorescence analysis of solutions
Details

P2545201
X-ray fluorescence spectroscopy – layer thickness determination
Details

P2546101
Energy-dispersive measurements of K- and L-absorption edges
Details

P2546301
Duane-Hunt displacement law
Details



Basic

To perform all experiments with the XRM 4.0 Material Upgrade set (09160-88) you also need the XRE 4.0 X-ray expert basic set (09110-88).
All details on page 136.

For all information: www.phywe.com/X-ray

09170-88 XRD 4.0 X-ray dosimetry upgrade set

Function and Applications

Upgrade set as an extension of the XRE 4.0 X-ray expert set (09110-88).

The set covers the following experiments and topics:

- Dosimetry
- Ionisation of the air by X-rays

Equipment and Technical Data

The set includes the following components:

- XR 4.0 X-ray plate capacitor for the X-ray unit, 09057-05
- Power supply unit, regulated, 0...600V-, 13672-93
- DC measuring amplifier, 13620-93
- further accessories

What you can learn about

- Geiger-Mueller counter tube
- Quenching gas
- Characteristics
- Ionising radiation
- Ionizing effect
- generation of X-radiation.
- X-rays
- Absorption inverse square law
- Ionizing energy
- Energy dose
- Equivalent dose and ion dose and their rates
- Q factor
- Local ion dose rate
- Dosimeter

Benefits

- Qualitative measurement possible with the electrocope accessory, ideal for demonstration of ionisation of air by x-rays
- Quantitative measurement using measurement equipment that can also be used for other experiments
- Experiment covers all topics relevant for teaching radiation exposure
- Ideal experiment for all students in medicine, radiology, biology, and students dealing with x-ray radiation

Related experiments for the XRD 4.0 X-ray dosimetry upgrade set (09170-88)

P2540010
Counter tube characteristics
Details

P2540040
Ionizing effect of X-radiation
Details

P2541801
X-ray dosimetry
Details

Basic

To perform all experiments with the XRD 4.0 X-ray dosimetry upgrade set (09170-88) you also need the XRE 4.0 X-ray expert basic set (09110-88). All details on page 136.

09180-88 XRCT 4.0 X-ray Computed Tomography upgrade set

Function and Applications

Upgrade set as an extension of the XRE 4.0 expert set (09110-88). Show the fundamental principles of computed tomography (CT) with the aid of a state of the art system whose technology is currently applied in medical and industrial applications. The interfaces of this method towards medicine, materials science and engineering make the "Computed Tomography Set" particularly suitable for laboratory experiments and lectures in physics, medicine, and materials science. The set covers the following experiments and topics

- X-ray imaging of biological and technical samples
- Non-destructive testing (NDT)
- Digital image processing for the generation of three-dimensional images of an object
- Digital images of Laue patterns

What you can learn about

- Crystal lattices
- Crystal systems
- Crystal classes
- Bravais lattice
- Reciprocal lattice
- Miller indices
- Structure amplitude
- Atomic form factor
- The Bragg equation
- Beam hardening
- Artefacts
- Algorithms
- Exposure time
- Detector
- Full well capacity
- Detector calibration
- Beam intensity
- Detector offset
- Pixel specific gain
- Attenuation and transmission
- Image processing
- Resolution
- Detail detectability
- Binning
- Focal spot size
- Magnification
- Saturation
- CT acquisition
- CT reconstruction
- Detector Alignment
- Rotation axis
- Tilt
- Number of projections
- Stop angle
- Image statistics
- Cupping effect
- Correction
- Metal
- Photon starvation
- Attenuation coefficient
- Hounsfield units

Equipment and Technical Data

The set includes the following components:

- XR 4.0 direct digital image sensor, 09057-41
- Active area 5 x 5 cm²
- Resolution 48 µm
- Image depth 12 bit
- USB 2.0 interface

XR 4.0 CT object Z-rotation unit, 09057-41

- Angle resolution < 1 degree
- Motorized, USB 2.0 interface
- Stepper motor with 4200 steps/360°

Benefits

- Direct acquisition of the X-ray images by a direct X-ray digital image sensor: No extra fluorescent screen is necessary
- Experimentation under daylight conditions
- High-performance image sensors for the direct digital X-ray radiography to create superior image quality, and high resolution based on CMOS technology
- Even pictures with low contrast like Laue patterns are made in less than 1 min
- Z-axis rotation of the sample to be analyzed: Movement of the sample is not influenced by gravitational effects, rigid bodies of flexible size can be analyzed on a simple way.
- Acquisition of high resolution CT scan, 360° image stack within 7 minutes (one frame per second, one degree per frame)
- Protection of Utility Patent, registered by "Deutsches Patent- und Markenamt"

Related experiments for the XRCT 4.0 X-ray Computed Tomography upgrade set (09180-88)

P2541602
X-ray investigation of crystal structures / Laue method with digital X-ray image sensor (XRIS)

P2550100
Computed tomography

P2550101
Principles of Digital X-ray Imaging

P2550200
Principles of X-ray attenuation and contrast

P2550300
Principles of beam intensity

P2550400
Principles of resolution and detail detectability

P2550500
Principles of CT scan

P2550600
Alignment of the camera

P2550700
Optimization of the CT scan quality

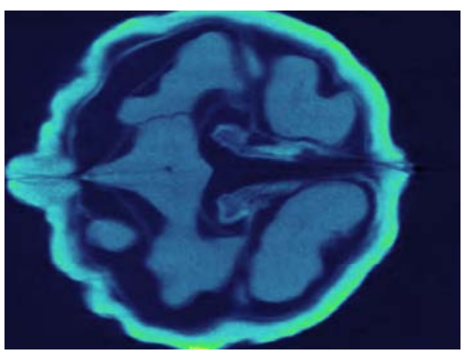
P2550800
Beam hardening and metal artefacts

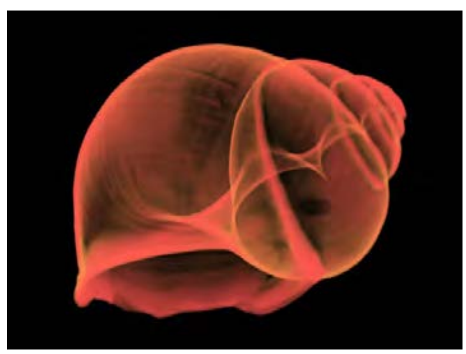
P2550900
Hounsfield units

Basic

To perform all experiments with the XRCT 4.0 X-ray Computed Tomography upgrade set (09180-88) you also need the XRE 4.0 X-ray expert basic set (09110-88). All details on page 136.

Discover our PHYWE YouTube channel:





YouTube

YouTube

YouTube

Discover the fundamental principles of Computed Tomography (CT)

PHYWE XRCT 4.0 X-ray Computed Tomography upgrade set

Upgrade set as an extension of the XRE 4.0 expert set. Shows the fundamental principles of computed tomography (CT) used in medical and industrial applications. Ease of use and speed make the Computed Tomography set particularly suitable for laboratory experiments and lectures in physics, medicine and material sciences.

The set covers the following experiments and topics:

- X-ray imaging of biological and technical samples
- Non-destructive testing (NDT)
- Digital image processing for the generation of three-dimensional images of an object
- Digital images of Laue patterns
- Complete CT scan and recontraction in less than 10 min

XR 4.0 direct digital image sensor.

Software included. Computer necessary.

Scope of supply

YouTube

3.1 Material Sciences

P2120100 — Moments

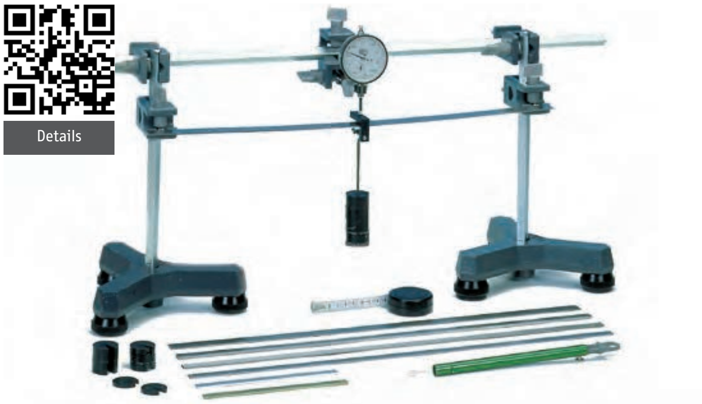
Details

Benefits
- Understand the relation and the difference between moments and force
- Smartly designed equipment that makes measurements clear and easy
- The famous quote of Archimedes in its quantitative formulation of today's physics: „Give me the place to stand, and I shall move the earth"

More Information on page 24.

P2120200 — Modulus of elasticity / Young's Modulus

Details



Benefits
- Find out the parameters that give a bar stability
- Measure the difference of elasticity in various metals with different lengths
- Learn how to determine forces with a dial gauge

More Information on page 25.

P2120300 — Mechanical hysteresis

Details

What you can learn about
- Mechanical hysteresis
- Elasticity
- Plasticity
- Relaxation
- Torsion modulus
- Plastic flow
- Torque
- Hooke's law

Benefits
- Beyond Hooke's law
- Hysteresis usually known from the field of magnetism, can be experienced in mechanics
- Learn the meaning of the words stress, relaxation and equilibrium in a physics context
- Various torsion rods made of different materials and with several diameters included

More Information on page 25.

Torsional vibrations and torsion modulus

P2133000

Details

What you can learn about
- Shear modulus
- Angular velocity
- Torque
- Moment of inertia
- Angular restoring torque
- G-modulus
- Modulus of elasticity

Benefits
- The use of eight different made out of different materials and with several diameters increase the understanding of all correlations
- Simple experimental set-up with immediate and clear results
- Extremely solid construction

More Information on page 36.

Hooke's law

P2130101

Details

What you can learn about
- Hooke's law
- Spring constant
- Limit of elasticity
- Elastic hysteresis
- Elastic after-effect

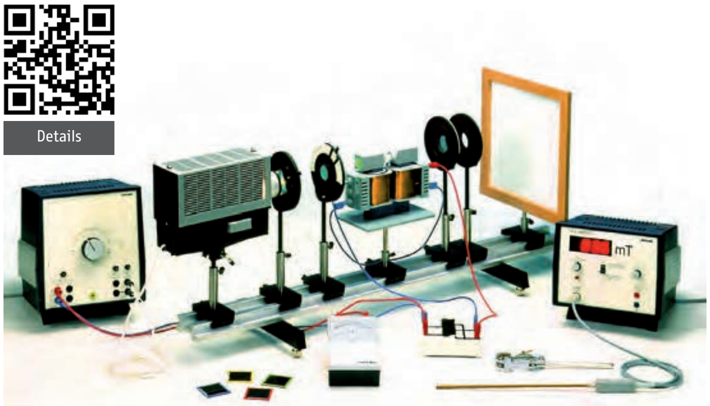
Benefits
- The law that governs the elongation of springs
- Determine the magnitude that describes the main characteristics of a spring
- Discover the main difference in the behaviour of springs and rubber bands

More Information on page 24.

P2260100

Faraday effect

Details



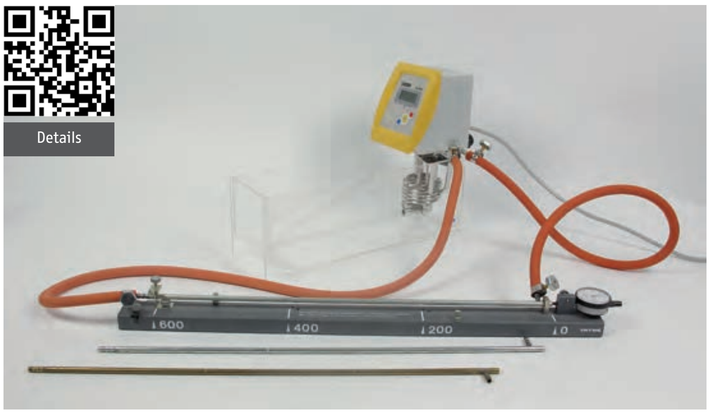
Benefits
- Experience that magnetic fields can influence light by changing ist polarization properties
- Learn how wavelength and the optical medium influence the effect of the magnetic field
- Discover a bridge between the fields of optics and electromagnetism

More Information on page 101.

P2310100

Thermal expansion in solids and liquids

Details



Benefits
- Two experiments in one

More Information on page 59.

P2330101

Heat capacity of metals

Details

Benefits
- Compact, easily transportable setup
- For both demonstration and student experiments

More Information on page 48.

P2330160

Heat capacity of metals with Cobra4

Details

Benefits
- Flexible experimenting thanks to wireless data transmission
- Data acquisition with tablets possible
- Simplified implementation: all pre-settings already prepared

More Information on page 47.

Thermal and electrical conductivity of metals

P2350200

Details

Benefits
- Measurement of electrical and thermal conductivity in one set-up
- Compact, easily transportable setup

More Information on page 56.

Temperature dependence of different resistors and diodes with a multimeter

P2410401

Details

Benefits
- One setup to measure both electrical components and semiconducting diodes, as well as the blocking voltage
- All immersion probes are mounted on one convenient heat-resistant circuit board for easy handling

More Information on page 71.

Dielectric constant of different materials

P2420600

Details

Benefits
- Supplies non-hazardous high voltage
- Easy experimental set-up due to clear and compact design

More Information on page 66.

Hall effect in n- and p-germanium (teslameter)

P2530102

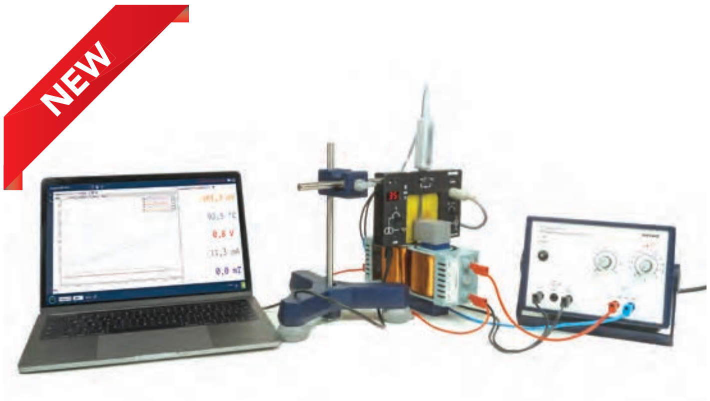
Details

Benefits
- New Hall effect unit to control all parameters (temperature, voltage) and supports intrinsic, p- and n-type Ge crystals
- Classical Version with Teslameter
- Can also be used to study band gap of Ge

More Information on page 117.

P2530116

Hall effect in n- and p-germanium (PC)



Details

What you can learn about

- Semiconductor
- Band theory
- Forbidden zone
- Intrinsic conduction
- Extrinsic conduction
- Valence band
- Conduction band
- Lorentz force
- Magneto resistance
- Neyer-Neldel Rule

Benefits

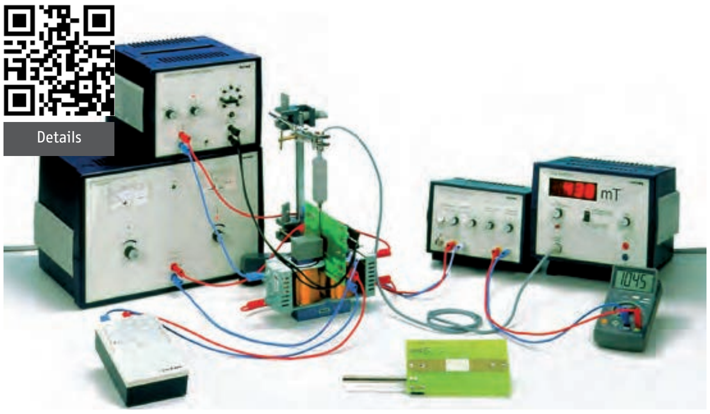
- New Hall effect unit to control temperature, voltage, and supports intrinsic, p- and n-type Ge crystals
- Version with PC control and data acquisition.
- Direct connection to PC via USB connection
- No extra interface necessary
- Magnetic field sensor can be connected directly with the Hall effect unit

More Information on page 117.

P2530300

Hall effect in metals

Details



Benefits

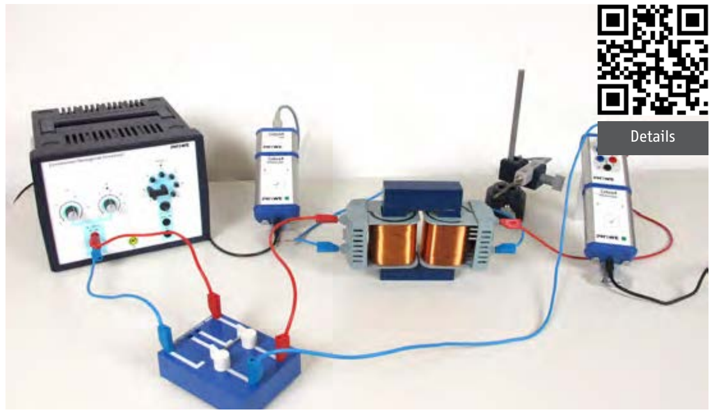
- Hall effect in metals for different metal foils
- High current power supply guarantees the precise results
- Clear setup where all important parts are visible
- Setup transformator to produce a high magnetic field, measured by a teslameter (included)

More Information on page 118.

Ferromagnetic hysteresis with Cobra4 P2430760

Benefits
- Simple experimental setup and intuitive handling of the software: Better results in less time
- Added value due to the use of datalogging: Direct visualisation of the learning objective

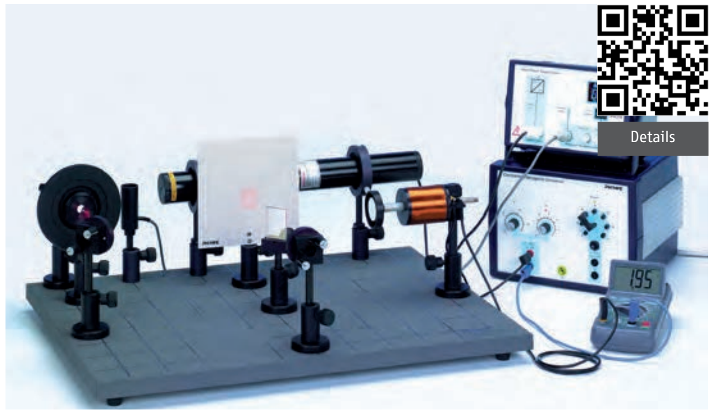
More Information on page 76.



Magnetostriction with the Michelson interferometer P2430800

Benefits
- See that magnetic fields can change the geometry of objects
- Use a Michelson interferometer to measure quantitatively this most subtle effect

More Information on page 122.



Ferromagnetism, paramagnetism and diamagnetism P2430900

What you can learn about
- Ferromagnetism
- Paramagnetism
- Diagmagnetism
- Magnetic field intensity

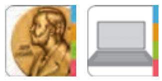
Benefits
- Compact system to study the types of magnetism
- Robust setup

More Information on page 84.

P2532000

Atomic Resolution of the graphite surface by STM (Scanning Tunneling Microscope)

Details



What you can learn about
- Tunneling effect
- Hexagonal structures
- Scanning Tunneling Microscopy (STM)
- Imaging on the sub nanometer scale
- Piezo-electric devices

Benefits
- Experience the essence of the Nobel Prize: Binning and Rohrer (1986)
- Observe atoms within minutes
- Custom-designed for use in teaching labs
- Microscope consists of one compact, portable instrument, no additional instruments required
- Vibration-isolated for better and reproducible results
- Can be used both for imaging of atomic resolution and for spectroscopy
- With interactive teaching and learning software

Principle

Approaching a very sharp metal tip to an electrically conductive sample by applying a electrical field leads to a current between tip and sample without any mechanical contact. This so-called tunneling current is used to investigate the electronic topography on the sub nanometer scale of a fresh prepared graphite (HOPG) surface. By scanning the tip line by line across the surface graphite atoms and the hexagonal structure are imaged.

Tasks
1. Prepare a Pt-Ir tip and the graphite (HOPG) sample and approach the tip to the sample.
2. Investigate the topography of clean terraces and the step height between neighboring terraces in constant-current mode.
3. Measure and compare images in the content-height and constant-current modes

P2538000

Basic methods in imaging of micro and nanostructures with AFM (Atomic Force Microscopy)

Details

What you can learn about
- Atomic Force Microscopy (AFM)
- Lennard-Jones potential
- Imaging of nano structures
- Static Force Mode
- Dynamic Force Mode

Benefits
- Investigation in static and dynamic mode
- Modification of numerous parameters to optimize image quality
- Perform experiment with different samples
- Custom-designed for use in teaching labs
- Microscope consists of one compact, portable instrument, no additional instruments required

Principle

Approaching a sharp silicon tip mounted on a cantilever to a sample surface leads to an atomic scale interaction. The result is a bend of the cantilever which is detected by a laser. In static mode the resulting deflection is used to investigate the topography of the sample surface line by line using a feedback loop. In dynamic mode the cantilever is oscillated at fixed frequency resulting in a damped amplitude near the surface. The measurement parameters (setpoint, feedback gain) play a crucial role for image quality. Their effect on the imaging quality is investigated for different nano-structured samples.

Tasks
1. Learn how to mount a cantilever (with tip) and approach the tip towards a sample.
2. Investigate the influence of the scanning parameters on the imaging quality and performance, e.g. PID gain, setpoint (force), vibrational amplitude, and scanning speed. Use both static and dynamic force mode.
3. Image 7 different samples (microstructures, carbon nano tubes, skin cross-section, bacteria, CD stamper, chip structure, glass beads) by optimizing the parameters respectively.

Determination of length and position of an object which can not be seen

P2542001

Details

What you can learn about
- X-ray radiation
- Bremsstrahlung
- Characteristic radiation
- Law of absorption
- Mass absorption coefficient
- Stereographic projection

More Information on page 194.

Debye-Scherrer diffraction measurements for the examination of the texture of rolled sheets

P2542701

Details

What you can learn about
- Crystal lattices
- Crystal systems
- Bravais lattice
- Reciprocal lattice
- Miller indices
- Structure factor
- Atomic scattering factor
- Bragg scattering
- Characteristic X-rays
- Monochromatization of X-rays
- Fiber textures
- Sheet textures
- Annealing texture
- Recrystallization

More Information on page 121.

Computed tomography

P2550100

Details

What you can learn about
- Detector calibration
- Reconstruction
- 3D imaging
- Beam hardening
- Artefacts

Benefits
- Experience the essence of the Nobel Prize: Cormack and Hounsfield (1979)
- Very fast, direct image capture
- Easy to understand linear procedure does not require training, instant results
- Integrates smoothly with software used in medical diagnostics to use additional CT software features
- All objects can be captured since object is inserted gravity-independently

Principle

The CT principle is demonstrated with the aid of simple objects. In this case only a few images need to be taken in order to achieve a good result. However, the more complex the objects are, the more images are necessary in order to show all the details. In addition, special samples are used to demonstrate how artefacts are generated and what causes beam hardening.

Tasks

1. Record a CT scan of the simple objects. While doing so, vary the number of steps.
2. Record a CT scan of the metal samples and analyse the result in view of beam hardening.

P2544501 Qualitative X-ray fluorescence spectroscopy of metals – Moseley's law

Details

What you can learn about
- Bremsstrahlung
- Characteristic X-radiation
- Absorption of X-rays
- Bohr's atom model
- Energy levels
- Moseley's law
- Rydberg frequency
- Screening constant
- Semiconductor energy detectors
- Multichannel analysers

P2544701 Qualitative X-ray fluorescence analysis of powder samples

Details

What you can learn about
- Bremsstrahlung
- Characteristic X-radiation
- Energy levels
- Fluorescent yield
- Semiconductor energy detectors
- Multichannel analyse

Benefits
- Experience the essence of the Nobel Prize: Röntgen (1901), Siegbahn (1924)
- X-ray fluorescence analysis (XRF) of different sample powders
- Other materials also possible
- X-ray energy detector (XRED) with multichannel analyzer (MCA) guarantees high counting rates without warm-up time
- Goniometer with 2 independent or coupled (2:1) axis for sample and detector
- X-ray unit with newest technology to fulfill German safety regulations for student experiments
- No dosimeter required
- Large unbreakable lead enforced acrylic glass windows (3) according to DIN safety regulations

Principle

Various powder samples are subjected to polychromatic X-rays. The energy of the resulting fluorescence radiation is analysed with the aid of a semiconductor detector and a multichannel analyser. The energy of the corresponding characteristic X-ray fluorescence lines is determined. The elements of the samples are identified by comparing the line energies with the corresponding values given in the literature.

Tasks

1. Calibrate the semiconductor energy detector with the aid of the characteristic radiation of the tungsten X-ray tube.
2. Record the fluorescence spectra that are produced by the samples.
3. Determine the energy values of the corresponding fluorescence lines and compare the experimental energy values with the corresponding theoretical values in order to identify the powder components.

Related experiments:

P2544601 Qualitative X-ray fluorescence analysis of alloyed materials
P2545101 Quantitative X-ray fluorescence analysis of solutions
P2545001 Quantitative X-ray fluorescence analysis of alloyed materials

X-ray fluorescence spectroscopy – layer thickness determination

P2545201

Principle

X-ray fluorescence analysis (XRF) is suitable for the non-contact and non-destructive thickness measurement of thin layers as well as for determining their chemical composition. When the layer on the substrate is subjected to X-rays, the radiation will penetrate the layer, if it is sufficiently thin, to a certain extent, depending on the thickness, and in turn cause characteristic fluorescence radiation in the material of the underlying substrate. The thickness of the layer can be determined based on the intensity attenuation of the fluorescence radiation of the substrate material.

Tasks

1. Calibrate the semiconductor energy detector.
2. Measure fluorescence spectrum of the iron substrate with different numbers n of pieces of aluminium foil with the same thickness placed on the substrate (including $n = 0$). Determine the intensity of the Fe-$K\alpha$ fluorescence line.
3. Plot the intensity of the Fe-$K\alpha$ fluorescence line as a function of the number of pieces of aluminium foil placed on the substrate in linear and semilogarithmic way.
4. Calculate the thickness of the aluminium foil.

Benefits

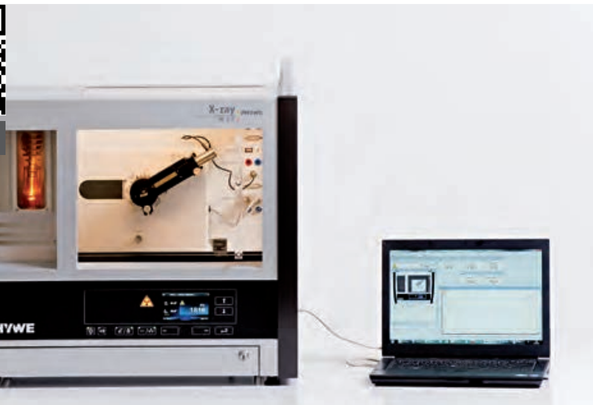
- Experience the essence of the Nobel Prize: Röntgen (1901), Siegbahn (1924)
- Technologically important thin layer thickness determination by X-ray fluorescence analysis (XRF) of different metals
- Other materials also possible
- X-ray energy detector (XRED) with multichannel analyzer (MCA) guarantees high counting rates without warm-up time
- Goniometer with 2 independent or coupled (2:1) axes for sample and detector
- X-ray unit with newest technology to fulfill German safety regulations for student experiments
- No dosimeter required
- Large unbreakable lead enforced acrylic glass windows (3) according to DIN safety regulations

What you can learn about

- Bremsstrahlung
- Characteristic X-radiation
- Fluorescent yield
- Auger effect
- Coherent and incoherent photon scattering
- Law of absorption
- Mass attenuation coefficient
- Saturation thickness
- Matrix effects
- Semiconductor
- Energy detectors
- Multichannel analysers

P2541301 Examination of the structure of NaCl monocrystals with different orientations

Details



What you can learn about

- Characteristic X-radiation
- Energy levels
- Crystal structures
- Reciprocal lattices
- Miller indices
- Atomic form factor
- Structure factor
- Bragg scattering

More Information on page 120.

P2541401 X-ray investigation of cubic crystal structures / Debye-Scherrer powder method

Details

Principle
When polycrystalline samples are irradiated with X-rays a characteristic diffraction pattern results. These Debye-Scherrer reflections are photographed and then evaluated.

What you can learn about

- Crystal lattices
- Crystal systems
- Reciprocal lattice
- Miller indices
- Structure amplitude
- Atomic form factor
- Bragg scattering

Benefits

- Experience the essence of the Nobel Prize: Debye (1936)
- Debye–Scherrer diffraction patterns are recorded by X-ray sensitive film
- Analysis of other fine powders also possible
- No dark room required
- X-ray unit with newest technology to fulfill German safety regulations for student experiments
- No dosimeter required

More Information on page 120.

Related experiment:

P2541501 X-ray investigation of hexagonal crystal structures / Debye-Scherrer powder method

P2541601 X-ray investigation of crystal structures / Laue method

Details

What you can learn about

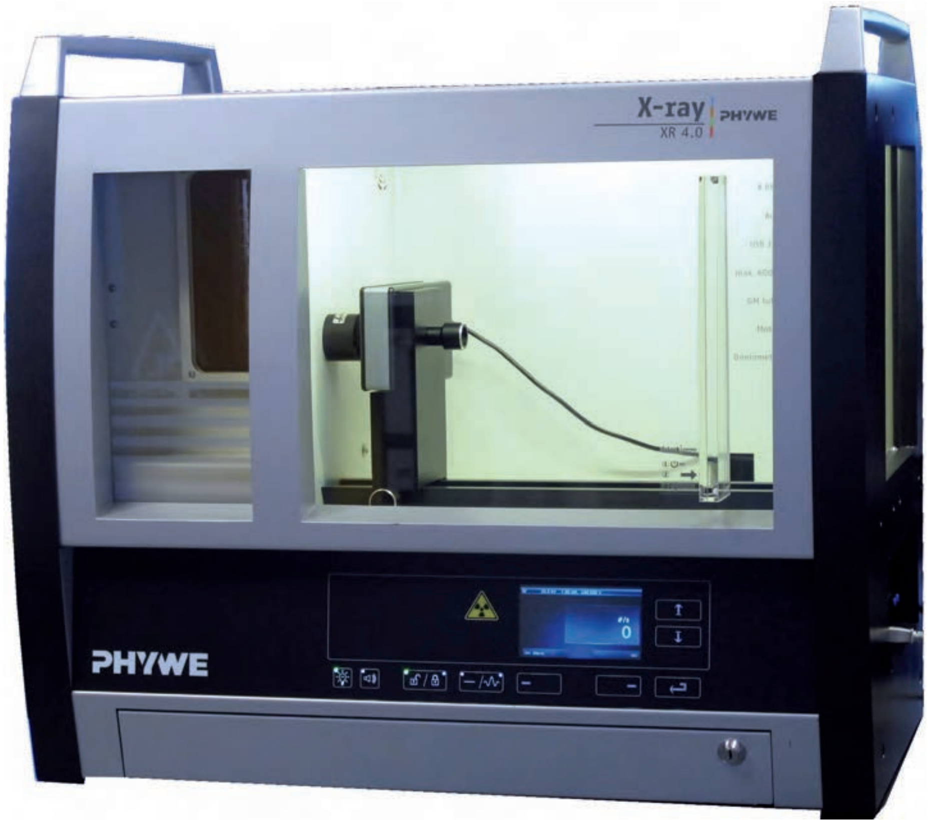
- Crystal lattices
- Crystal systems
- Crystal classes
- Bravais lattice
- Reciprocal lattice
- Miller indices
- Structure amplitude
- Atomic form factor
- The Bragg equation

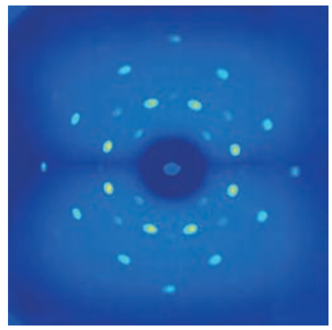
More Information on page 119.

X-ray investigation of crystal structures / Laue method with digital X-ray image sensor (XRIS)

P2541602

Details





Principle

Laue diagrams are produced when monocrystals are irradiated with polychromatic X-rays. This method is primarily used for the determination of crystal symmetries and the orientation of crystals. When a LiF monocrystal is irradiated with polychromatic X-rays, a characteristic diffraction pattern results. This pattern is photographed with a digital X-ray sensor.

Tasks

1. The Laue diffraction of an LiF monocrystal is recorded with the aid of the digital X-ray sensor.
2. The Miller indices of the corresponding crystal surfaces are to be assigned to the Laue reflections.

Benefits

- Experience the essence of the Nobel Prizes: Röntgen (1901), Siegbahn (1924)
- Laue pattern recording with direct X-ray image sensor XRIS within minutes
- High resolution for X-rays (48 µm)
- No dark room required
- X-ray unit with newest technology to fulfill German safety regulations for student experiments
- Large unbreakable lead enforced acrylic glass windows (3) according to DIN safety regulations

What you can learn about

- Crystal lattices
- Crystal systems
- Crystal classes
- Bravais lattice
- Reciprocal lattice
- Miller indices
- Structure amplitude
- Atomic form factor
- The Bragg equation

P5160100 Velocity of ultrasound in solid state material

Details

What you can learn about
- Sound velocity
- Propagation of ultrasonic waves
- Time of flight
- Ultrasonic echography
- Thickness measurement
- Probe delay

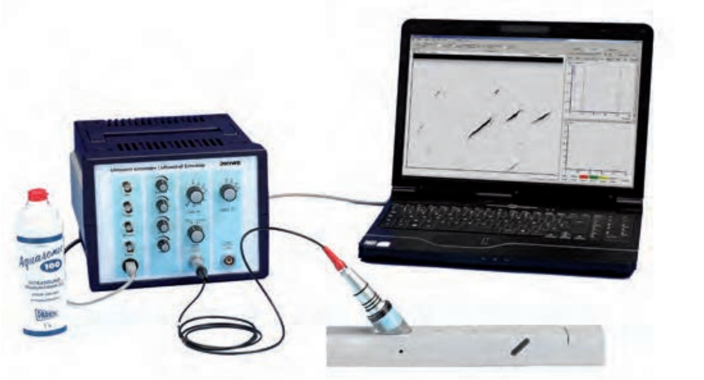
Benefits
- Introductory experiment for echoscopy applications
- Experiment can be easily extended to perform A-scan and B-scan experiments
- With further extensions more advanced experiments with medical and material sciences context can be performed

Principle

The velocity of sound in acrylics shall be determined by time of flight reflection technique with an ultrasonic echoscope. The measurements are performed by reflection method, on three cylinders of different length. Two measurement series are carried out with ultrasonic probes of different frequencies.

Tasks
1. Measure the length of the three cylinders with the caliper.
2. Determine the time of flight of the ultrasonic reflection pulses for the three cylinders and the two ultrasonic probes.
3. Calculate the sound velocities, probe delays and use the two mean values obtained to calculate the cylinder length.

P5160600 Detection of discontinuities



Details

What you can learn about
- Ultrasonic echography
- Discontinuity
- A-Mode
- Straight beam probe
- Angle beam probe
- Reflection
- Beam angle
- Signal-to-noise ratio

Benefits
- Complete echoscopy system incl. test objects to perform different NDT techniques
- With the same equipment angle beam inspection and TOFD can also be performed
- Display of measurement values as with a diagnostic system

Principle

The experiment demonstrates the application and performance of various non-destructive test methods with the aid of ultrasound. First, a test object is scanned in order to determine which detection method is suitable for which type of defect. Then, the signal-to-noise-ratio is determined for each discontinuity with a straight beam probe, angle beam probe, and a transmitter-receiver probe (TR probe).

Tasks
1. Use a straight beam probe (vertical scanning direction) to define the suitable device parameters at the ultrasonic echoscope. Produce a B-scan of the test object.
2. Assign the various defects (discontinuities) of the test object to the B-scan. Then, determine the signal-to-noise-ratio for each discontinuity in the A-mode.
3. Repeat the above-mentioned tests/measurements on the same test object with an angle beam probe and a TR probe.
4. Assess and represent the detectability of the discontinuities with the respective test methods.

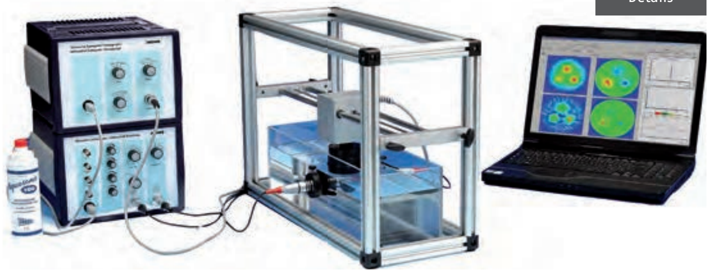
Ultrasonic computed tomography

P5161200

Details

What you can learn about
- Ultrasonic echography (A-scan)
- Tomography
- Resolution

Benefits
- Experience the essence of the Nobel Prize: Cormack and Hounsfield (1979)
- Ideal system for education: affordable compared to industrial system to demonstrate ultrasound-CT in a very comprehensible way
- With the same system mechanical scanning of an object can be performed, e.g. to create a B-scan image



Principle
This experiment explains the fundamental principles of image formation with a CT algorithm. A test object is used to create an attenuation tomogram and a time-of-flight tomogram followed by a discussion of the respective differences.

Tasks
1. Creation of several attenuation and time-of-flight tomograms
2. Variation of the device parameters
3. Discussion of the differences

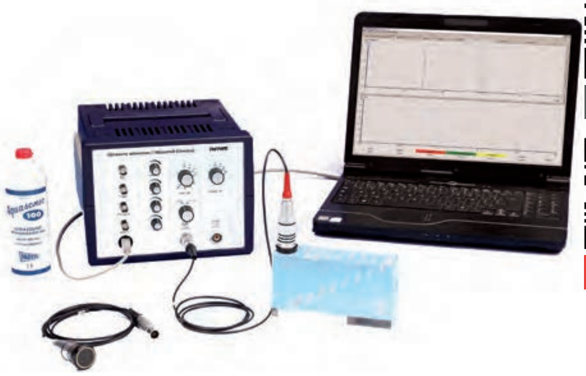
Ultrasonic echography (A-Scan)

P5160200

Details

What you can learn about
- Propagation of ultrasonic waves
- Time of flight
- Echo amplitude
- Reflection coefficient
- A-scan
- Flaw detection
- Non destructive testing (NDT)
- Ultrasonic transceiver

Benefits
- Exciting experiment to teach the basics of ultrasound imaging (echography)
- Diversified experiment with several measurement methods
- With the same setup B-scans can be performed
- Experiment setup can be upgraded for additional experiments in medical imaging and for echoscopy applications in material sciences

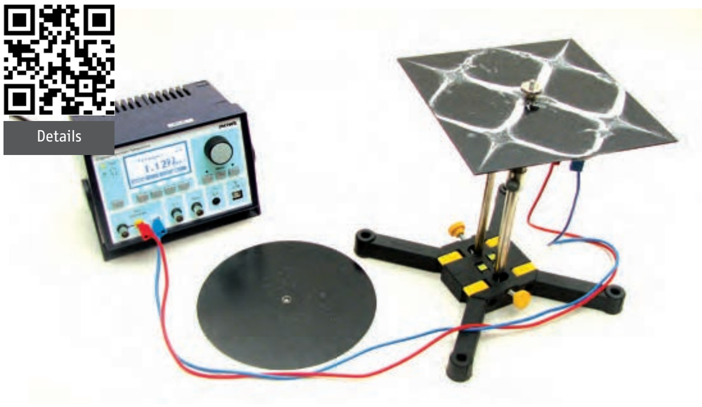


Principle
An ultrasonic wave transmitted in a sample will be reflected at discontinuities (defects, cracks). From the relationship between the time of flight of the reflected wave and the sound velocity, the distance between ultrasonic transducer and defects (reflector) can be calculated. Position and size of these defects can be determined by measuring in different directions.

Related experiment:
Ultrasonic echography (B-Scan) P5160300

P2150501 Chladni figures

Details

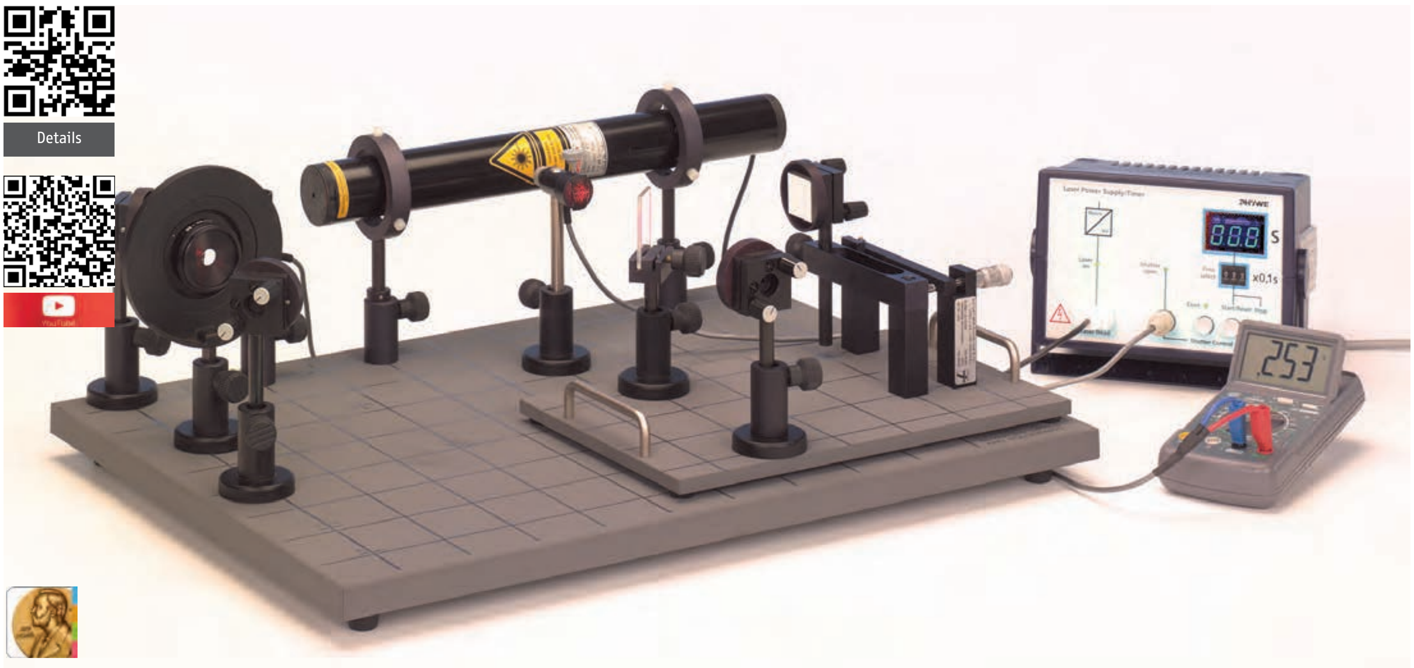


Benefits
- Experiment set-up particularly suitable to visualize resonance
- Many experiment variations possible within a short time

More Information on page 86.

P2220900 Michelson interferometer - High Resolution

Details

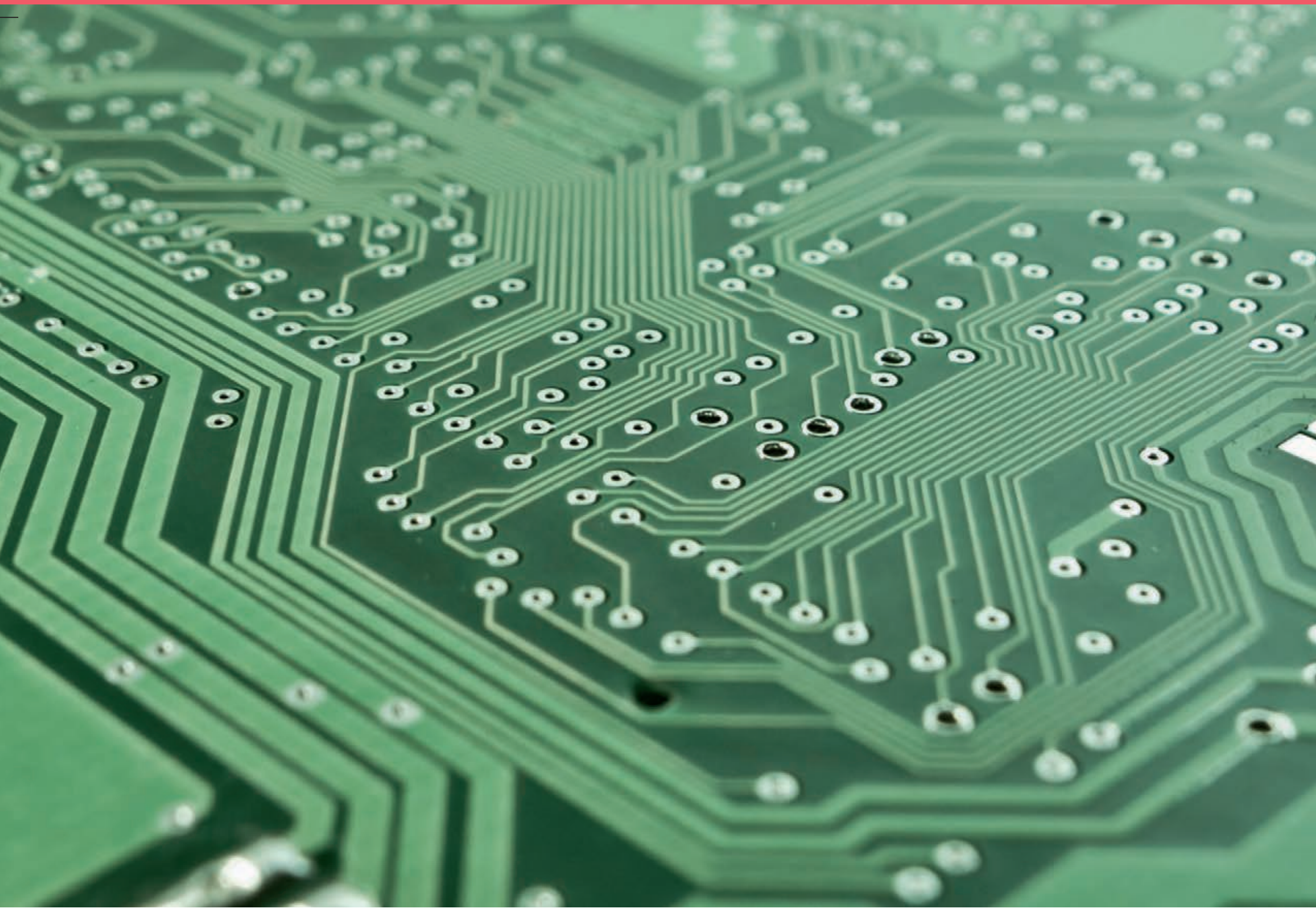


Principle
With the aid of two mirrors in a Michelson arrangement, light is brought to interference. While moving one of the mirrors, the alteration in the interference pattern is observed and the wavelength of the laser light determined.

Tasks
1. Construction of a Michelson interferometer using separat components.
2. The interferometer is used to determine the wavelength of the laser light.
3. The contrast function K is qualitatively recorded in order to determine the coherence length.

What you can learn about
- Interference
- Wavelength
- Diffraction index
- Speed of light
- Phase
- Virtual light source

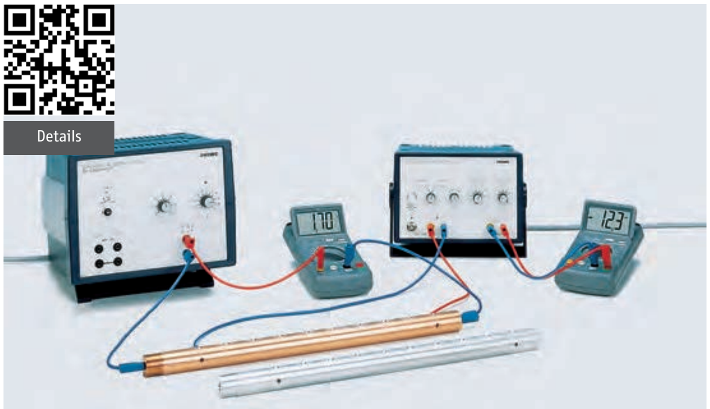
Benefits
- Experience the essence of the Nobel Prize: Michelson (1907)
- Learn about the measurement principle with which gravitational waves can be observed
- Assemble your own interferometer using invidual optical components
- Find out that even lasers have limited coherence length



3.2 Electrical Engineering

P2410101 4 Point Method / Measurement of low resistances / Ohm's Law

Details



What you can learn about
- Ohm's law
- Resistivity
- Contact resistance
- Conductivity
- Four-wire method of measurement

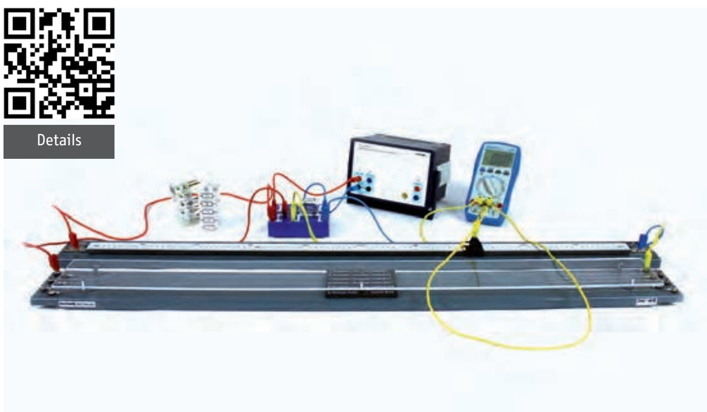
Benefits
- Measurement at two different metals possible
- Conductivity rods can be used both for electrical and thermal conductivity experiments
- Measurement amplifier can be used for both AC and DC measurements and amplifies up to 10,000 times

Principle
The resistances of various DC conductors are determined by recording the current / voltage characteristic. The resistivity of metal rods and the contact resistance of connecting cords are calculated.

Tasks
1. Plot the current / voltage characteristics of metal rods (copper and aluminium) and calculate their resistivity.
2. Determine the resistance of various connecting cords by plotting their current / voltage characteristics and calculating the contact resistances.

P2410200 Wheatstone bridge

Details

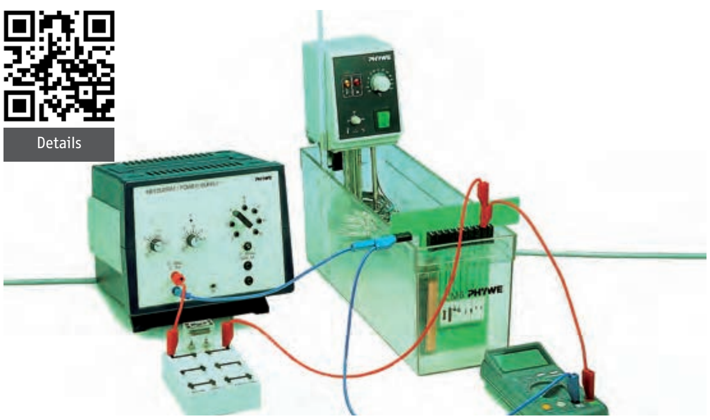


Benefits
- Highly precise and reproducible measurements possible
- Many different measurement variations possible
- Also suitable for measurement of low resistances

More Information on page 68.

P2410401 Temperature dependence of different resistors and diodes with a multimeter

Details



Benefits
- One setup to measure both electrical components and semiconducting diodes as well as the blocking voltage
- All immersion probes are mounted on one convenient heat-resistant circuit board for easy handling

More Information on page 71.

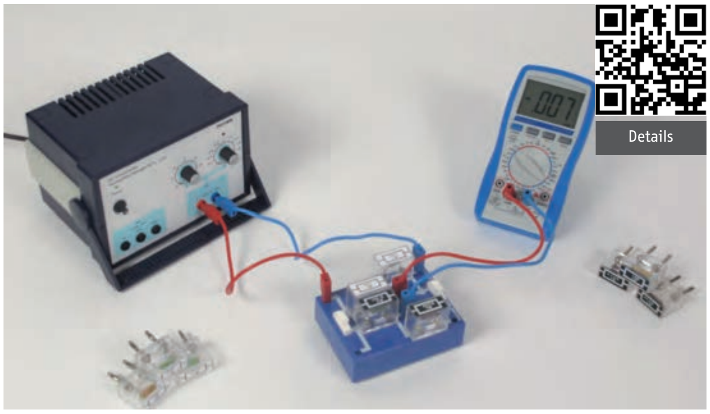
Kirchhoff's laws

P2410500

Benefits

- Setup to both measure Kirchhoff's laws and to determine unknown resistances
- Components can also be used for other basic and advanced electricity experiments

More Information on page 71.



Semiconductor thermogenerator – Seebeck effect

P2410700

Benefits

- Open design allows to fully understand function and applications
- Individual instruments for distinct functions (no „black box")
- Key products of the experiment setup can also be used for investigating the Peltier effect

More Information on page 123.

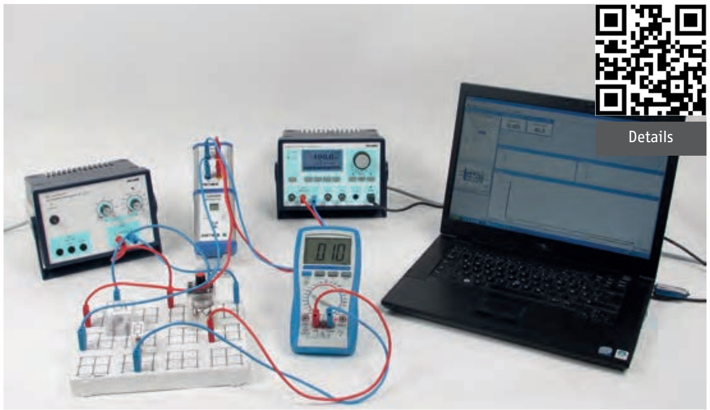
Characteristic curves of semiconductors with Cobra4

P2410960

Benefits

- Fast and easy experimenting
- Get to know the behaviour of several types of semiconductors
- Simplified implementation: all pre-settings already prepared
- Data logging reveals instantaneous results during measurement

More Information on page 69.



Electric fields and potentials in the plate capacitor

P2420100

Benefits

- Loss-less measurement of electric field strength
- Highly sensitive electric field meter also suitable for electrostatic measurement of voltages

More Information on page 62.

P2420201 Charging curve of a capacitor / charging and discharging of a capacitor

Details

Benefits
- Simple and very clear set-up: only few components required
- Further experiments in electricity and electronics can be performed with the equipment

More Information on page 64.

P2420264 Charging curve of a capacitor and switch-on behaviour of an inductance with Cobra4 Xpert-Link

NEW

Details

Benefits
- Simple and very clear set-up: only few components required
- Cost savings: Xpert-Link provides all subsidiary functions (power supply, switch, trigger)
- Extra experiment included: „Switch-on behaviour of a coil"
- Simplified implementation: all pre-settings already prepared

More Information on page 65.

P2420600 Dielectric constant of different materials

Details

Benefits
- Supplies non-hazardous high voltage
- Easy experimental set-up due to clear and compact design
- Clever investment: The included universal measuring amplifier can also be used for other applications

More Information on page 66.

P2430201 Magnetic field of single coils / Biot-Savart's law with a teslameter

Details

Benefits
- Simple setup which allows to conveniently measure magnetic flux density depending on different parameters
- No calibration needed, teslameter is calibrated up to 1 T

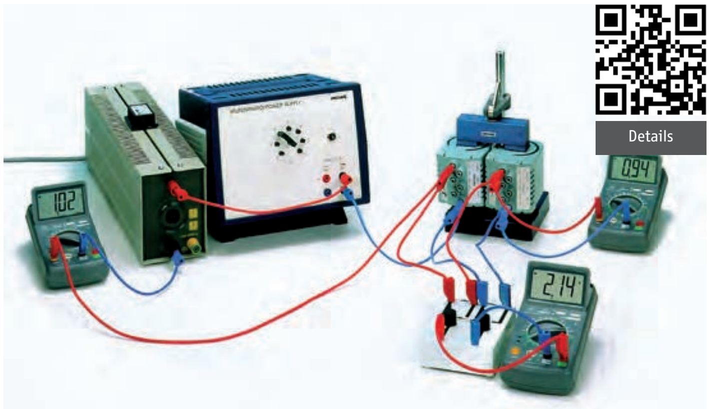
More Information on page 72.

Transformer

P2440100

Benefits
- Coils with several tappings for various combinations of winding numbers between primary and secondary coil
- Quick, easy, and neat set-up

More Information on page 77.

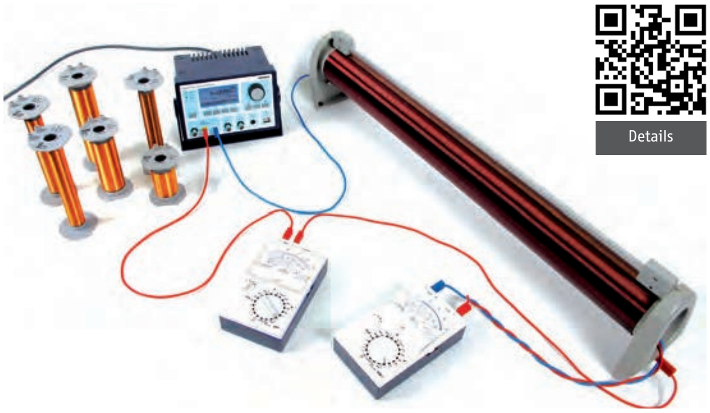


Magnetic induction

P2440201

Benefits
- Huge field coil for homogenous magnetic field
- On-the-fly switching of the numerous induction coils
- Easy frequency setting thanks to digital function generator

More Information on page 77.



Coil in the AC circuit with Cobra4 Xpert-Link

P2440464

What you can learn about
- Inductance
- Kirchhoff's laws
- Maxwell's equations
- AC impedance
- Phase displacement

Benefits
- Intuitive, touch-optimized software that controls all devices simultaneously
- Simplified implementation: all pre-settings already prepared
- Easy frequency setting thanks to digital function generator
- Fast and easy experimenting simply by switching components
- Impedance computed in real-time

Principle

The coil is connected in a circuit with a voltage source of variable frequency. The impedance and phase displacements are determined as functions of frequency. Parallel and series impedances are measured.

Tasks

1. Determination of the impedance of a coil as a function of frequency.
2. Determination of the inductance of the coil.
3. Determination of the phase displacement between the terminal voltage and total current as a function of the frequency in the circuit.
4. Determination of the total impedance of coils connected in parallel and in series.

P2440564 Capacitor in the AC circuit with Cobra4 Xpert-Link

Benefits
- Intuitive, touch-optimized software that controls all devices simultaneously
- Simplified implementation: all pre-settings already prepared
- Easy frequency setting thanks to digital function generator
- Fast and easy experimenting simply by switching components
- Impedance is computed in real-time

More Information on page 79.

P2440664 RLC circuit with Cobra4 Xpert-Link

Benefits
- Voltage and current can be measured directly and simultaneously
- Root mean square value displayed in real-time
- Impedance is computed in real-time
- Fast and easy experimenting simply by switching components
- Cost savings: oscilloscope functions integrated into the datalogging solution

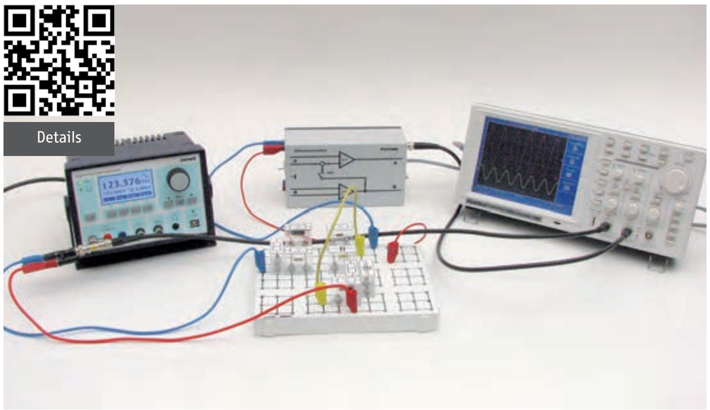
More Information on page 80.

P2440700 Rectifier circuits

Benefits
- Get to know several types of rectifier circuits
- A standard experiment for vocational education and eletrical engineering lab courses

More Information on page 80.

P2440801 RC filters



Benefits
- Investigate several types of frequency filters
- High-resistance inputs of the difference amplifier allow measurements without influencing the electrical behaviour of the circuit
- Easy frequency setting thanks to digital function generator

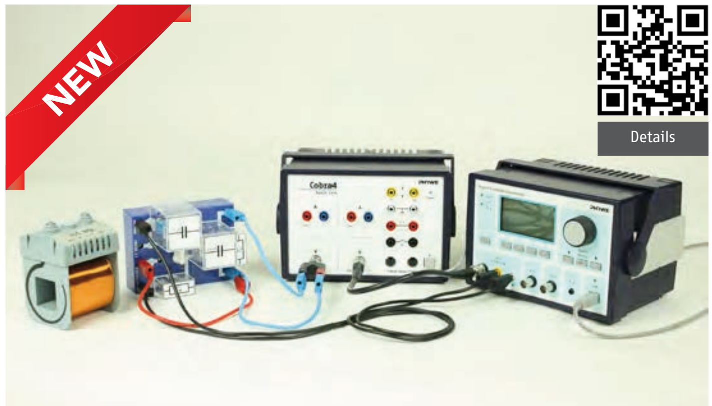
More Information on page 81.

High-pass and low-pass filters with Cobra4 Xpert-Link P2440964

Benefits

- Simple and very clear set-up: only few components required
- Cost savings: No need for an additional power supply
- Simplified implementation: all pre-settings already prepared
- The software controls all devices simultaneously
- Further experiments in electricity and electronics can be performed with the equipment

More Information on page 81.



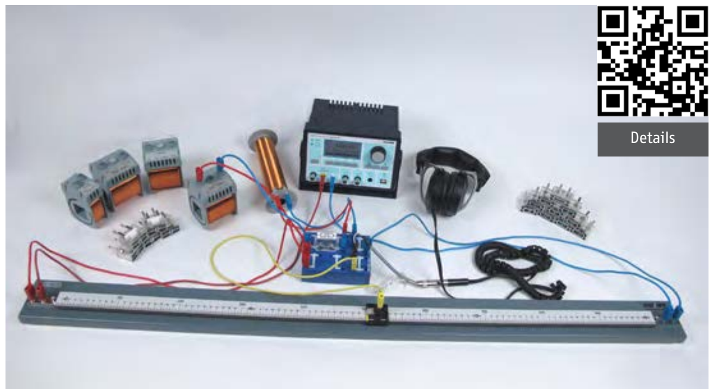
Details

RLC measuring bridge P2441005

Benefits

- Quickly obtain experiment results using the Wheatstone bridge
- Easy to tune by aural measurement relying on the sensitivity of the human ear
- Save time while switching the numerous coils, resistance and capacities on the fly

More Information on page 82.



Details

Induced voltage pulse and Faraday's law of induction with Cobra4 Xpert-Link P2441264

Benefits

- Intuitive, touch-optimized software that controls all devices simultaneously
- Simplified implementation: all pre-settings already prepared
- Coil with several tappings for quick change of winding numbers
- Investigate the influence of different falling velocities with high frequency / resolution measurements

More Information on page 83.

Details

Hall effect in n- and p-germanium (teslameter) P2530102

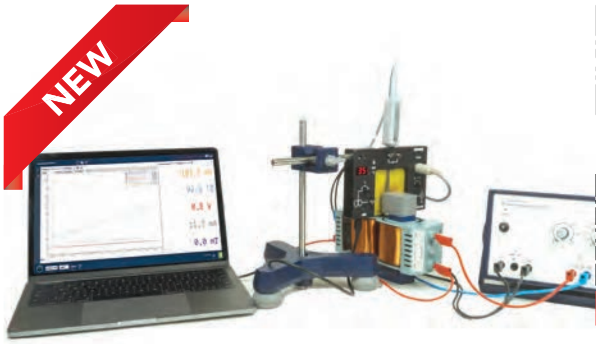
Benefits

- New Hall effect unit to control all parameters (temperature, voltage) and supports intrinsic, p- and n-type Ge crystals
- Classical Version with Teslameter
- Can also be used to study band gap of Ge

More Information on page 117.

Details

P2530116 Hall effect in n- and p-germanium (PC)



Details

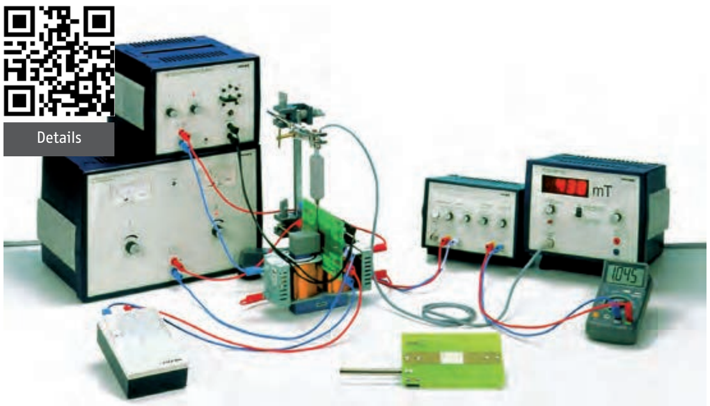
Benefits

- New Hall effect unit to control temperature, voltage, and supports intrinsic, p- and n-type Ge crystals
- Version with PC control and data acquisition
- Direct connection to PC via USB connection
- No extra interface necessary
- Magnetic field sensor can be connected directly with the Hall effect unit

More Information on page 117.

P2530300 Hall effect in metals

Details

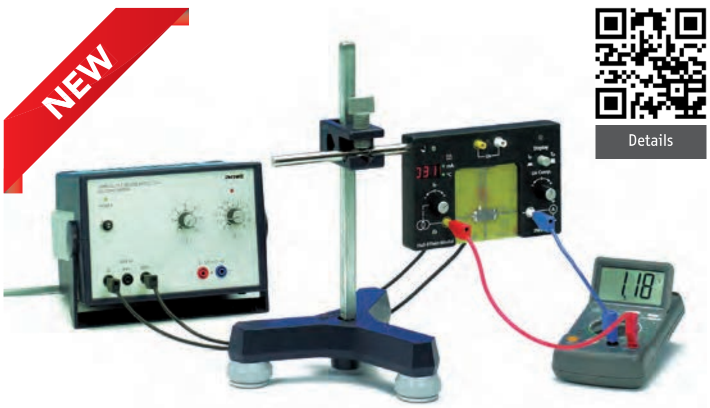


Benefits

- Hall effect in metals for different metal foils
- High current power supply guarantees the precise results
- Clear setup where all important parts are visible
- Setup transformator to produce a high magnetic field, measured by a teslameter (included)

More Information on page 118.

P2530402 Band gap of germanium



Details

Benefits

- New Hall effect unit to control all parameters (temperature, voltage) and supports intrinsic, p- and n-type Ge crystals
- Can also be used to study Hall effect in p and n-type Ge

More Information on page 118.

P3060962 Nernst equation with Cobra4

Details

Benefits

- Relevant both for electrical engineers, physicists and chemists
- Essential introductory experiment for studying battery technology

More Information on page 66.

3.3 Renewable Energy

P2320162

Equation of state for ideal gases with Cobra4 (gas laws: Gay-Lussac, Amontons, Boyle)

Details

What you can learn about
- Thermal tension coefficient
- General equation of state for ideal gases
- Universal gas constant
- Amontons' law

Benefits
- Unique system: All gas laws can be measured with the same setup
- Very compact setup, can be stored in the shelf and is always ready to use
- Very demonstrative: Volume is read off directly at the gas syringe, temperature and pressure are measured with sensors in real-time
- Heating system integrated in experiment setup

Principle

The state of a gas is determined by temperature, pressure and amount of substance. For the limiting case of ideal gases, these state variables are linked via the general equation of state.

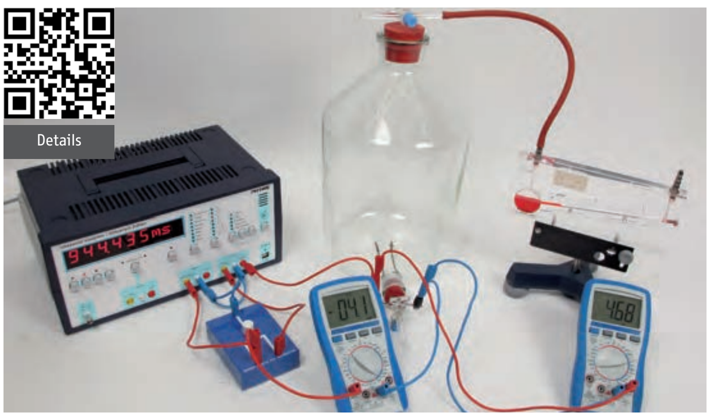
Tasks

1. For a constant amount of gas (air) investigate the correlation of
   - Volume and pressure at constant temperature (Boyle and Mariotte's law)
   - Volume and temperature at constant pressure (Gay-Lussac's law)
   - Pressure and temperature at constant volume (Charles' (Amontons' law))
2. From the relationships obtained calculate the universal gas constant as well as the coefficient of thermal expansion, the coefficient of thermal tension, and the coefficient of cubic compressibility.

P2320201

Heat capacity of gases

Details



Benefits
- Determination of cp and cv
- For both demonstration and student experiments
- Suitable for many different gases

More Information on page 45.

P2320261

Heat capacity of gases with Cobra4

Details

Benefits
- Determination of cp and cv
- For both demonstration and student experiments
- Suitable for many different gases
- Simplified implementation: all pre-settings already prepared

More Information on page 45.

Heat capacity of metals

P2330101

Details

Benefits
- Compact, easily transportable setup
- For both demonstration and student experiments

More Information on page 48.

Heat capacity of metals with Cobra4

P2330160

Details

Benefits
- Flexible experimenting thanks to wireless data transmission
- Data acquisition with tablets possible
- Simplified implementation: all pre-settings already prepared

More Information on page 47.

Mechanical equivalent of heat

P2330200

Details

Benefits
- Elegant setup to measure conversion of mechanical energy in thermal energy
- Perfect as demonstration experiment and very suitable as an introductory student experiment

More Information on page 48.

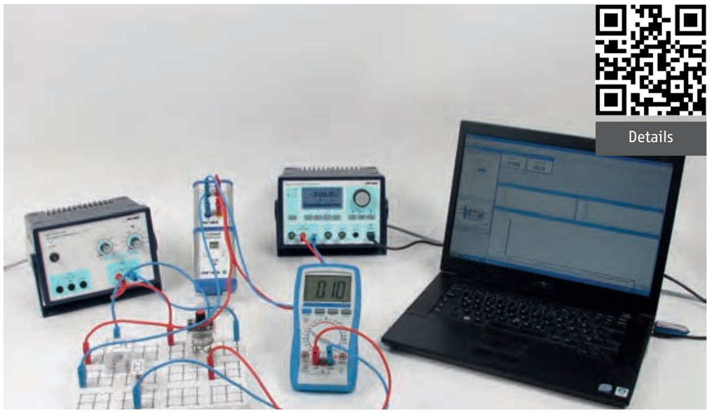
Characteristic curves of semiconductors with Cobra4

P2410960

Details

Benefits
- Fast and easy experimenting
- Get to know the behaviour of several types of semiconductors
- Simplified implementation: all pre-settings already prepared
- Data logging reveals instantaneous results during measurement

More Information on page 69.



P2420100 Electric fields and potentials in the plate capacitor

Details

Benefits
- Loss-less measurement of electric field strength
- Highly sensitive electric field meter also suitable for electrostatic measurement of voltages

More Information on page 62.

P2420201 Charging curve of a capacitor / charging and discharging of a capacitor

Details

Benefits
- Simple and very clear set-up: only few components required
- Further experiments in electricity and electronics can be performed with the equipment

More Information on page 64.

P2420264 Charging curve of a capacitor and switch-on behaviour of an inductance with Cobra4 Xpert-Link

Details

Benefits
- Simple and very clear set-up: only few components required
- Cost savings: Xpert-Link provides all subsidiary functions (power supply, switch, trigger)
- Extra experiment included: „Switch-on behaviour of a coil“
- Further experiments in electricity and electronics can be performed with the equipment

More Information on page 65.

P2420600 Dielectric constant of different materials

Details

Benefits
- Supplies non-hazardous high voltage
- Easy experimental set-up due to clear and compact design

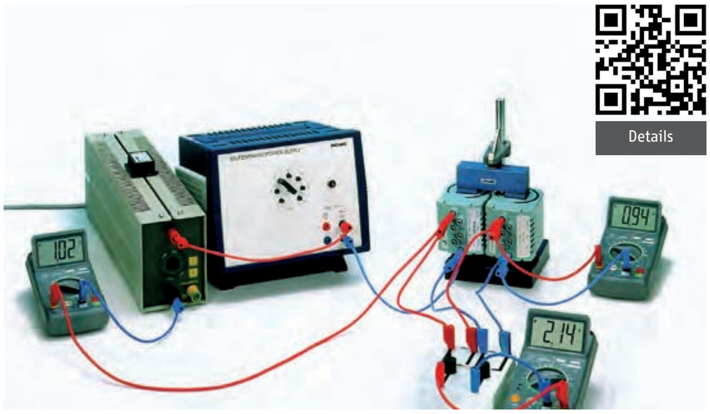
More Information on page 66.

Transformer

P2440100

Benefits
- Coils with several tappings for various combinations of winding numbers between primary and secondary coil
- Quick, easy, and neat set-up

More Information on page 77.



Hall effect in n- and p-germanium (PC)

P2530116

Benefits
- New Hall effect unit to control all parameters (temperature, voltage) and supports intrinsic, p- and n-type Ge crystals
- Version with PC control and data acquisition.
- Direct connection to PC via USB connection
- No extra interface necessary
- Magnetic field sensor can be connected directly with the Hall effect unit
- Can also be used to study band gap of Ge

More Information on page 117.

Determination of the enthalpy of combustion with a calorimetric bomb

P3021401

Benefits
- Good and reproducible results due to temperature control in the experiment
- Only a small amout of chemicals is need for the experiment due to the good heat capacity of the calorimeter

Principle
The bomb calorimeter is used to completely burn substances in an excess of oxygen. The heat of combustion released is absorbed by the calorimetric vessel in which the bomb is immersed, and results in a temperature increase ΔT.

Determination of the heating value of fuel oil and of the calorific value of olive oil

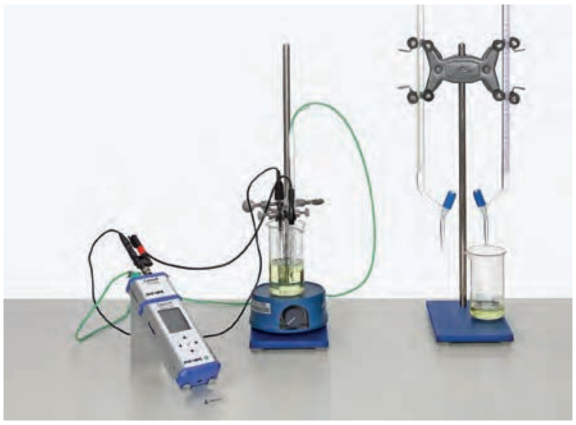
P3021701

Benefits
- No toxic or dangerous chemical is used for this experiment
- Part of a system solution – glass jacket system easily expandable

Principle
The heat of reaction generated during the complete combustion of 1000 g of solid or liquid fuel is known as the calorific value *H*. In the case of complete combustion of nutritional fats, the gross calorific value can also be determined.

P3060962 — Nernst equation with Cobra4

Details



What you can learn about
- Electrode potentials and their concentration dependence
- Redox electrodes
- Electrochemical cells

Benefits
- Relevant both for chemists and for physicists
- Essential introductory experiment for studying battery technology

More Information on page 66.

15287-88 — TESS advanced Applied Sciences Basic Set Renewable Energy basics and thermal energy

Details

Experiments
- Energy conversion (5 Experiments)
- Heat energy from solar energy (7 Experiments)
- Ambient heat (5 Experiments)

Benefits
- Complete experiment set for introductory experiments
- Add-on sets available covering solar energy, wind, water and fuel cell technology

15288-88 — TESS advanced Applied Scienes Add-on Set Renewable Energy Solar / Water / Wind

Details

Experiments
- Electrical energy from solar energy (11 Experiments)
- Wind energy (8 Experiments)
- Water energy (4 Experiments)
- Parabolic trough power plant (3 Experiments)
- Energy conversion (5 Experiments)
- Heat energy from solar energy (7 Experiments)
- Ambient heat (5 Experiments)
- Hooke's law

Electric compression heat pump

P2360200

Benefits
- Different operating modes possible
- For both demonstration and student experiments
- Simple set-up

More Information on page 53.

Details

Stirling engine with an oscilloscope

P2360401

Benefits
- Demonstration of the complete Carnot process
- Reverse Carnot process possible as well using the motor / generator unit
- All important parts are clearly visible, making their functions transparent
- Measurement device displays all relevant parameters (p, V, rpm, T)

More Information on page 53.

Details

Stirling engine with Cobra4 Xpert-Link

P2360464

Benefits
- Computer interface Xpert-Link also serves as an oscilloscope
- Demonstration of both the complete Carnot and reverse Carnot processes
- All important parts are clearly visible, making their functions transparent
- Measurement device displays all relevant parameters (p, V, rpm, T)

More Information on page 54.

Details

Semiconductor thermogenerator – Seebeck effect

P2410700

Benefits
- Open design allows to fully understand function and applications
- Individual instruments for distinct functions (no „black box“)
- Key products of the experiment setup can also be used for investigating the Peltier effect

More Information on page 123.

Details

P2410800

Peltier heat pump

Details

What you can learn about

- Peltier and Joule effect
- Heat pipe
- Thermoelectric e. m. f.
- Peltier coefficient
- Cooling capacity
- Heating capacity
- Efficiency rating
- Thomson coefficient
- Seebeck coefficient
- Thomson equations
- Heat conduction
- Convection
- Forced cooling

Benefits

- Open design allows to fully understand function and applications
- Individual instruments for distinct functions (no „black box“)
- Key products of the experiment setup can also be used for investigating the Seebeck effect

More Information on page 51.

06758-00

Solar heat set

NEW

Details

Function and Applications

This experimentation system concerning solar thermal energy conversion provides you with quantitative experiments for different collector systems for flexible and location-independent usage.

Benefits

- A cutting-edge topic: covers a broad range of solar thermal energy issues
- Multidisciplinary topic with relevance for physics, chemistry, technology (air-conditioning, heating), renewable energy, energy efficiency
- Complete set, requires no additional accessories
- Can be used everywhere since all components are provided in a transport case

Experiments

- Absorptivity and reflectivity of different materials
- Focusing of light by a Fresnel lens
- Thermal convection and layering
- Thermal conduction
- Thermal insulation
- Solar thermal collector with pump circulation
- Solar thermal collector with thermosiphon circulation
- Variation of the flow speed
- Collector circuit with heat exchanger
- Collector circuit with paraffin heat reservoir
- Parabolic trough collector with pump cycle
- Defocussing
- Qualitative demonstration of the functional principle
  Investigating the thermoelectric generator
- Quantitative determination of the electrical power

Stefan-Boltzmann's law of radiation with an amplifier

P2350101

Details

Benefits
- Classical experiment for studying black-body radiation
- High-precision measurement due to special, Moll-type thermopile

More Information on page 50.

Solar ray collector

P2360100

Details

Benefits
- Complete solution to study all aspects of thermal energy using a solar ray collector
- Covers one of the most important and highly visible technologies in renewable energy

More Information on page 57.

Characteristic curves of a solar cell

P2410901

Details

Benefits
- Set-up allows quantitative measurement which also takes light intensity into account
- Set-up allows to avoid but also to measure temperature effect quantitatively
- Determine relationship between short-circuit and light intensity

More Information on page 69.

05755-00 Hydropower set

NEW

Details

Benefits

- An important topic of renewable energy: hydroenergy
- Fast assembly thanks to the plug-in system
- Observation of the functionality of the electrical generator during the operation
- Three different types of turbines
- Fundamentals of fluid dynamics
- Complete set, requires no additional accessories
- Can be used everywhere since all components are provided in a transport case

Experiments

- Volume flow, flow velocity and power as a function of the height of fall
- Volume flow, flow velocity and power as a function of the pipe cross-section
- Comparison of the functionality of pelton turbine, crossflow turbine and waterwheel
- Comparison of the performance of the pelton turbine, crossflow turbine and waterwheel as a function of volume flow and pressure

Function and Applications

A significant percentage of power from renewable energies originates from hydropower. To familiarize students with this important topic, this experimenting kit offers both introductory experiments on hydroenergy in general as well as fundamental quantitative experiments on the physics of water turbines. Different types of turbines are used: from a simple water wheel to a modern, highly efficient Pelton turbine.

07491-00 E-mobility set

NEW

Details

Benefits

- Extensive experimentation system for battery technology used in electrical cars
- Investigate eight different storage types

Experiments

- Basics: Ohm's law, series and parallel connection of ohmic resistances, nominal voltage and capacity of voltage sources, four-terminal sensing, internal resistance of voltage sources, series connection of voltage sources
- Capacitance and energy density of a battery module
- Ri efficiency and total efficiency of a battery module
- Temperature-dependent behavior of the LiFePo cell
- Charging and discharge process of a capacitor
- I-V characteristics and charging process of different battery types: NiMH battery, NiZn battery, LiFePo battery, lead battery, lithium-polymer battery
- Discharging process of a battery module
- Hydrogen production and consumption in the reversible hydrogen fuel cell
- Characteristic curve and efficiency of the fuel cell
- Operation of the electric car with several battery modules and with the reversible fuel cell

Function and Applications

The future of road traffic belongs to battery-powered electrical cars which are about to establish themselves against other trend-setting alternatives like fuel cell-powered cars. The E-mobility set teaches the physical and technical foundations and applications of different battery technologies used in cars. Eight different battery types allow for the study of characteristics like lifespan and charging methods. Qualitative and quantitative experiments are used to explore the properties of various battery types.

66012-00 Biofuel set

Benefits
- An important topic: biotechnological generation of renewable energy
- Interdisciplinary subject with relevance in biology, chemistry, physics
- Can be used everywhere as all components are included in transport case

Experiments
- Biodiesel production
- Alcohol fermentation
- Distillation and production of bioethanol
- Ethanol fuel cell

Details

Function and Applications

The whole process of producing biodiesel is exemplified in this interdisciplinary complete experiment set. The transport case is equipped with all required components to perform the following experiments: production of bioethanol by biotechnological processes, production of biodiesel, alcoholic fermentation, distillation. Additionally with this experiment set it is possible to generate electrical energy from the produced bioethanol using the included ethanol fuel cell and measuring its yield with the potentiometer module and motor module.

TESS advanced Applied Sciences Add-on Set Renewable Energy – Fuel Cells 15286-88

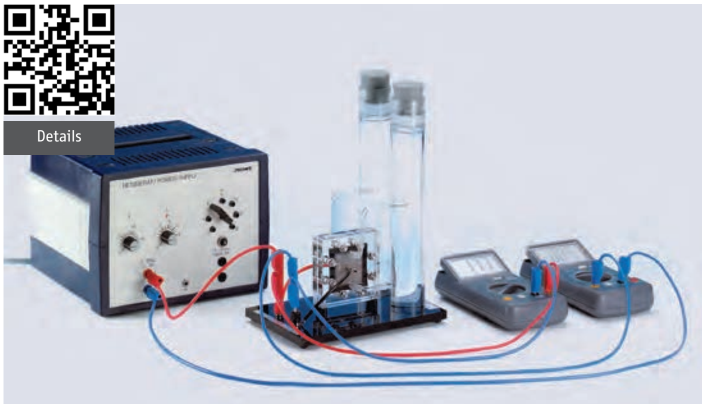
Experiments
- Generation of hydrogen and oxygen using a PEM electrolyser
- Generation of electric energy using a PEM fuel cell
- Solar-hydrogen system
- Wind-hydrogen system
- Characteristic curve of a PEM electrolyser
- Faraday efficiency and energetic efficiency of a PEM electrolyser
- Current-voltage characteristic of a PEM fuel cell
- Faraday and energetic efficiencies of a PEM fuel cell
- The efficiency of a electrolyser-fuel cell system
- current-voltage characteristic of an air breathing fuel cell

Benefits
- Experiment set for all introductory aspects of fuel cell technology
- Complementary set to the other two sets covering energy conversion, thermal energy, solar energy, wind energy and hydroenergy

Details

P2411100 Characteristic curve and efficiency of a PEM fuel cell and a PEM electrolyser

Details

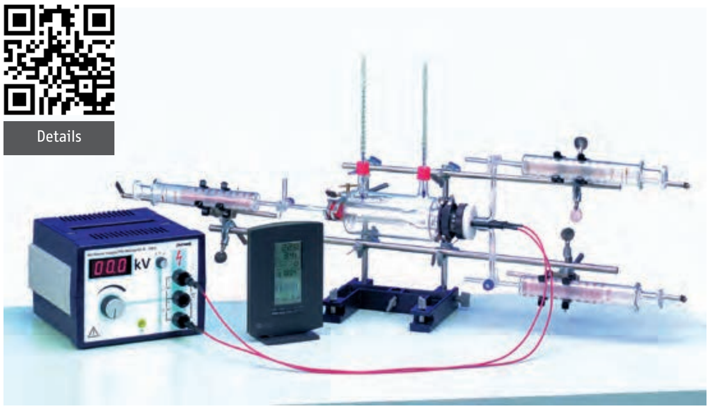


Benefits
- Quantitive determination of all relevant parameters
- Production of hydrogen and oxygen which can then be quantified
- Storage of the produced gases in a „gas bar" for reuse

More Information on page 64.

P3021501 Determination of the heat of formation of water

Details



Benefits
- Part of a system solution - glass jacket system easily expandable
- Direct determination of the enthalpy of formation

Principle
Standard molar enthalpies of formation are important compiled thermodynamics tabulation quantities for calculating standard enthalpies of reaction for any arbitrary reaction. They are defined as the heat of reaction occurring in the direct formation of one mole of the pertinent pure substance from the stable pure elements at constant pressure.

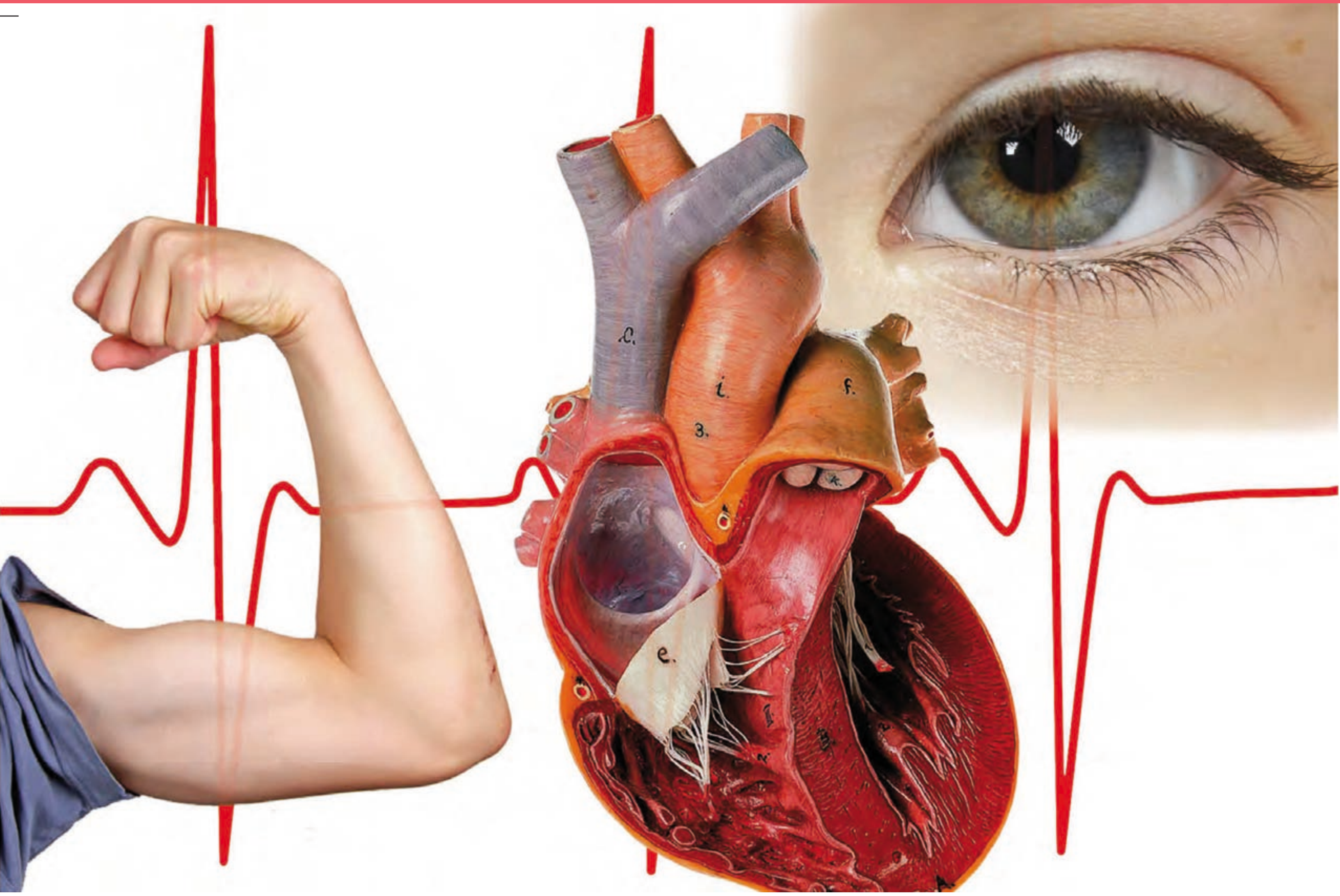
P3062101 Determination of Faraday's constant

Details

What you can learn about
- Electrolysis coulometry
- Charge
- Faraday's laws
- Avogadro's number
- General equation of state for ideal gases

Benefits
- Standard experiment in introductory physics and chemistry
- Failsafe and elegant determination of an important natural constant
- Excellent for the introduction of refractometry

More Information on page 67.



3.4 Medical Engineering

P1332760 Electrocardiography

Details

Principle

The heart is a hollow, muscular organ that comprises several secondary muscles. These secondary muscles contract and relax successively, thus pumping the blood through the heart. These muscle activities can be measured electrically as a whole at the surface of the skin with the aid of a so-called electrocardiogram (ECG). The same pattern repeats from heartbeat to heartbeat. A heartbeat is the regular sequence of electric excitations (action potentials). You can discern (record) the different partial activities of the cardiac muscle that follow each other with an electrocardiogram. This is why the ECG is also referred to as a „heart curve“. A doctor can identify various cardiac disorders by looking at the specific ECG pattern of the heart that is recorded with an ECG machine which is licensed for diagnostic purposes.

Tasks

1. Record an electrocardiogram of your own heartbeat at rest and determine the different phases of cardiac activity.
2. Compare the ECG of a „normal“ heart contraction with the ECG of a heart contraction that was caused by a pacemaker.

What you can learn about

- Electrocardiogram according to Einthoven II
- Heart rate
- Quiet and strained heart
- ECG segments
- Atria and ventricles
- AV nodes

Benefits

- No danger due to electrical energy thanks to wireless operation
- Data acquisition with both tablets and PCs possible
- Site-independent measurements possible in tablet mode
- Wireless measurement mode allows for use in sports medicine
- Tablet app easy to use, therefore appropriate for all education levels

Related experiments:

P1350360 Electromyography

Details

P1350460 Electrooculography

Details

Spirometry

P8001060

What you can learn about
- Lung
- Spirometer
- Tidal volume
- Expiratory reserve volume
- Inspiratory reserve volume

Benefits
- Uses the same spirometer design which is also used in medical diagnostics
- One-way turbine system avoids infections
- All methods used in medical diagnostics can be performed
- Wireless operation
- Can be used with iPad

Principle
Lungs are organs which enable carbon dioxide (CO_2) to be exhaled and oxygen (O_2) to be absorbed. Contraction of the diaphragm connected to the lungs causes them to stretch so that air is drawn into them from the surroundings. When the diaphragm subsequently relaxes, the lungs return to their original positions and air is passively breathed out.

In the following experiment, the lung volume, which is the volume of air which the lungs can take in, is to be determined. A spirometer is used for this measurement. Spirometers are frequently used by physicians to determine irregularities in the functioning of lungs.

Details

Tasks
1. Determine your tidal volume (TV)
2. Determine your expiratory reserve volume (ERV)
3. Determine your inspiratory reserve volume (IRV)

Related experiments:

Direct determination of lung volume from a spirogram	P8001160
Does the lung volume depend on how tall you are?	P8001260
Diagnosis of lung disease (FEV) with Cobra4	P8001360

P4010764 — The nerve cell with Cobra4 Xpert-Link

Details

What you can learn about

- Comparison between low and high threshold and stimulus levels, membrane time constant and low pass filtering, excitatory synapse, depolarisation, temporal summation, spatial summation, synaptic amplification by terminal branches, effect of decreasing stimulus, Hebbian synapse, synaptic learning and forgetting, inhibitory synapse, hyperpolarization, spacial inhibitory excitatory summation, veto synapse.

The system can be upgraded with one, two or three additional neurosimulators to perform experiments about:

- Nerve cell interactions (motoneuron signals with recurrent inhibition by Renshaw cell, motoneuron signals without recurrent inhibition, functional characteristics of Renshaw inhibition, lateral inhibition, contrast improvement, conditioned reflex, reversed stimulus succession does not bring about a conditioned reflex).
- Neural networks (transient, i.e. phasic responses: focus on visual sense, body clock, short-term memory, special anatomical circuits: cerebral cortex and sensoric learning, functional characteristic of a triad). Direction selectivity by unilateral inhibition, self-calibration of paired sensory channels.

Principle

Interactive learning and teaching system with one neurosimulator for experiments about the nerve cell.

Tasks

- Use the nerve function model to study the following aspects of a nerve cell: membrane potential, action potential, the different types of synapses.

Benefits

- Experience processes in the nerve cell „hands-on"
- Make all properties of a nerve cell easy to understand: action potential, membrane potential, functions of synapses (e.g. synaptic learning and forgetting)
- Use as a demonstration system without a computer as well
- Scale up easily to perform further experiments like nerve cell interactions (e.g. conditioned reflex) and neural networks (e.g. short-term memory)
- Ideal for lab courses in the degree course Neurobiology

Related experiments:

With 2 nerve cells:

P4010864 — Nerve cell interactions with Cobra4 Xpert-Link

With 3 and 4 nerve cells:

P4010964 — Neural networks with Cobra4 Xpert-Link

Ionizing effect of X-radiation

P2540040

Details

What you can learn about
- Ionizing effect
- Generation of X-radiation

Principle
As well as the outgoing radiation from a radioactive emitter is able to ionize air, so also X-radiation shows an ionizing effect. When air is penetrated by X-radiation, it is electrically conductive. This is tested on a charged electroscope.

Absorption of X-rays

P2541101

Details

What you can learn about
- Bremsstrahlung
- Characteristic radiation
- Bragg scattering
- Law of absorption
- Mass absorption coefficient

Principle
The polychromatic X-radiation that is emitted by an X-ray tube is filtered in terms of its energy with the aid of a monocrystal. The resulting monochromatic radiation is used as the primary radiation source for examining the absorption behaviour of various metal foils of different thicknesses.

X-ray dosimetry

P2541801

Details

What you can learn about
- X-rays
- Absorption inverse square law
- Ionizing energy
- Energy dose
- Equivalent dose and ion dose and their rates
- Q factor
- Local ion dose rate
- Dosimeter

Principle
This experiment demonstrates the principle of measurement and it explains the various units of absorbed dose, equivalent dose, and absorbed dose rate. Inside a plate capacitor, an air volume is irradiated with X-rays. The resulting ion current is used to determine the dosimetric data.

Contrast medium experiment with a blood vessel model

P2541901

Details

What you can learn about
- X-ray radiation
- Bremsstrahlung
- Characteristic radiation
- Law of absorption
- Mass absorption coefficient
- Contrast medium

Principle
When a blood vessel model is irradiated with X-rays, the blood vessels themselves are not visible at first. It is only after the injection of a contrast medium that the blood vessels become visible.

P2542001

Determination of length and position of an object which can not be seen

Details

What you can learn about

- X-ray radiation
- Bremsstrahlung
- Characteristic radiation
- Law of absorption
- Mass absorption coefficient
- Stereographic projection

Benefits

- Simulation of a real-life situation in x-ray diagnostics
- Application which trains three-dimensional thinking

Principle

This experiment provides training in determining the length and position of an object based on an X-ray image. A metal pin that is embedded in a wooden block is used as the model. This experiment is also an excellent preparatory exercise for demonstrating the principle of computed tomography.

Tasks

1. Record a bi-planar radiogram of two perpendicular planes of a metal pin which cannot be seen.
2. Determine the true length of the pin by taking into account the magnification factor which results from the divergence of the X-rays.
3. Determine the spatial position of the pin.

P2550100

Computed tomography

Details

What you can learn about

- Detector calibration
- Reconstruction
- 3D imaging
- Beam hardening
- Artefacts
- Hounsfield units

Benefits

- Experience the essence of the Nobel Prize: Cormack and Hounsfield (1979)
- Very fast, direct image capture
- Easy to understand linear procedure does not require training, instant results
- Integrates smoothly with software used in medical diagnostics to use additional CT software features
- All objects can be captured since object is inserted gravity-independently

Principle

The CT principle is demonstrated with the aid of simple objects. In this case only a few images need to be taken in order to achieve a good result. However, the more complex the objects are, the more images are necessary in order to show all the details. In addition, special samples are used to demonstrate how artefacts are generated and what causes beam hardening.

Tasks

1. Record a CT scan of the simple objects. While doing so, vary the number of steps.
2. Record a CT scan of the metal samples and analyse the result in view of beam hardening.

Magnetic Resonance Imaging (MRI) II

P5942500

Details

Principle

The Magnetic Resonance Tomograph (MRT) for teaching purposes covers all aspects from the basic principles of Nuclear Magnetic Resonance (NMR) to the high-resolution 2D and 3D MR imaging (MRI). It provides a comprehensive education experience by training with clinically relevant measuring procedures, high resolution MR imaging (2D, 3D), live visualisation of data, realtime control of experimental parameters, determination of Larmor frequency, T1/T2 measurements, all MR parameters accessible, measurement of a multitude of samples with a diameter of up to one centimeter, software-driven didactical approach and suitable for a wide range of experiments.

The aim of this experiment is to show how the spin echo technique can be used to generate 2D MR images of a slice of a well-defined thickness, orientation, and size (Localized Spin Echo 2D). These parameters determine the so-called „field of view“ (FOV) of the MR image. We will introduce a method that enables the recording of 3D MR images (Spin Echo 3D). For this purpose, an additional phase encoding will be performed in the third dimension. Both methods include the automatic calibration of the system frequency with regard to the Larmor frequency. As a result, the MR image is more stable over several averaging steps.

Tasks

1. Generation of 2D MR images with explicit slice selection (Localized Spin Echo 2D).
2. Generation of 3D MR images (Spin Echo 3D).

What you can learn about

- Nuclear spins
- Resonance condition
- MR frequency
- FID signal (Free Induction Decay)
- Magnetic gradient fields
- Spatial encoding (frequency encoding, phase encoding)
- Slice selection
- Spin echo
- Fast-Fourier-Transformation (FFT)
- T1/T2 relaxation times
- 2D and 3D magnetic resonance imaging

Benefits

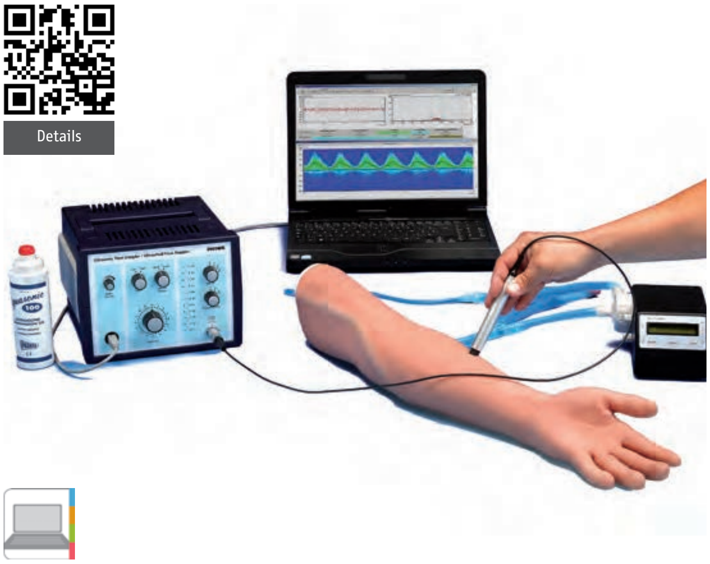
- Experience the essence of the Nobel Prizes: Lautenbur (2003)
- Complete, easy to install and affordable MRT education system
- One system to cover all aspects from NMR basics to sophisticated 2D and 3D imaging sequences
- Detailed experiment guides included with the system
- Learning results guaranteed thanks to easy to manage course steps
- Can be set up at any location in the student lab
- Experience the realistic sound of the different MR sequences

Related experiments:

Fundamental principles of Nuclear Magnetic Resonance (NMR)	P5942100
Relaxation times in Nuclear Magnetic Resonance	P5942200
Spatial encoding in Nuclear Magnetic Resonance	P5942300
Magnetic Resonance Imaging (MRI) I	P5942400

P5950100 — Doppler sonography

Details



What you can learn about
- Venous flow
- Arterial flow
- Stenosis
- Blood flow velocity tracings
- Frequency shift
- Doppler effect
- Doppler angle
- Doppler sonography
- Colour Doppler
- Continuity equation

Benefits
- Ideal experiment for medical students to learn the principles of Doppler sonography
- True to life with an arm model with blood vessels and stenosis
- Experiment components can also be used for other experiments relevant for medical students
- Display of measurement values as with a diagnostic system

Principle

This set-up shows how blood flow studies are performed using Doppler ultrasound (Doppler sonograph). On a realistic arm dummy, the differences between continuous (venous) and pulsating (arterial) flow are shown as well as the difference in flow through a normal blood vessel and a stenosis.

Tasks
1. Analyse blood flow and search for positive and negative flow components. Explain the differences.
2. Locate the built-in stenosis and compare the spectral distribution upstream and downstream of the stenosis.
3. Examine and compare the three pulse modes of the pump.

P5950300 — Ultrasonic investigation with breast dummy

Details

What you can learn about
- Breast sonography
- Tumour size
- Benign tumour
- Ultrasound imaging procedures
- Ultrasound echography
- A-mode
- B-mode

Benefits
- Ideal experiment for medical students in the preclinical phase: true-to-life breast cancer examination using a breast model
- The echoscope used in the experiment can also be used for other medically relevant experiments like A-scan, B-scan and ultrasound tomography
- Display of ultrasound image as for a diagnostic system

Principle

This experiment shows a typical application of ultrasound in medical diagnostics. A benign tumour on a realistic breast dummy has to be diagnosed, localized and measured with an ultrasound cross-section imaging method.

Tasks
1. Examine the breast dummy and search for any pathological changes. Try to characterize them as accurately as possible (size, location, mobility, strength of the change).
2. Produce an ultrasonic B-scan image of the breast dummy, especially in the regions of interest. Based on the ultrasound image, estimate the location and magnitude of the tumour.

Mechanics of flow

P5140100

Benefits
- Excellent introductory experiment for medical students to teach principles of flow
- Experiment setup can be varied and be used for other experiments
- Compact experiment setup
- Results can be read off easily from a scale

More Information on page 28.

Details

Flow Measurement / Ultrasonic Doppler effect

P5142100

What you can learn about
- Doppler effect
- Frequency shift
- Scattering
- Doppler sonography

Benefits
- Ideal for teaching the basics of the Doppler effect in fluids
- Experiment setup can be upgraded to perform experiments like flow mechanics and Doppler sonography
- Compact, easy to understand experiment setup

Details

Ultrasonic echography (A-Scan)

P5160200

What you can learn about
- Propagation of ultrasonic waves
- Time of flight
- Echo amplitude
- Reflection coefficient
- A-scan
- Flaw detection
- Non destructive testing (NDT)
- Ultrasonic transceiver

Benefits
- Exciting experiment to teach the basics of ultrasound imaging (echography)
- Diversified experiment with several measurement methods
- With the same setup B-scans can be performed
- Experiment setup can be upgraded for additional experiments in medical imaging and for echoscopy applications in material sciences

Details

Principle
An ultrasonic wave transmitted in a sample will be reflected at discontinuities (defects, cracks). From the relationship between the time of flight of the reflected wave and the sound velocity, the distance between ultrasonic transducer and defects (reflector) can be calculated. Position and size of these defects can be determined by measuring in different directions.

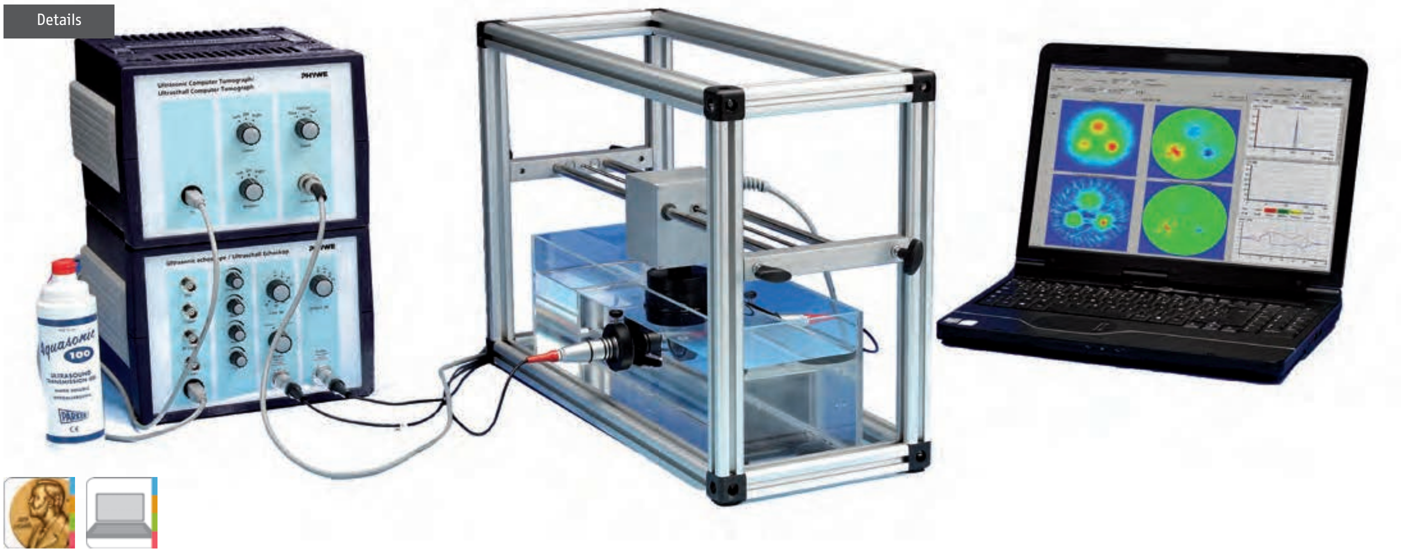
Related experiment:

Ultrasonic echography (B-Scan) P5160300

P5161200

Ultrasonic computed tomography

Details



Principle
This experiment explains the fundamental principles of image formation with a CT algorithm. A test object is used to create an attenuation tomogram and a time-of-flight tomogram followed by a discussion of the respective differences.

Tasks
1. Creation of several attenuation and time-of-flight tomograms
2. Variation of the device parameters
3. Discussion of the differences

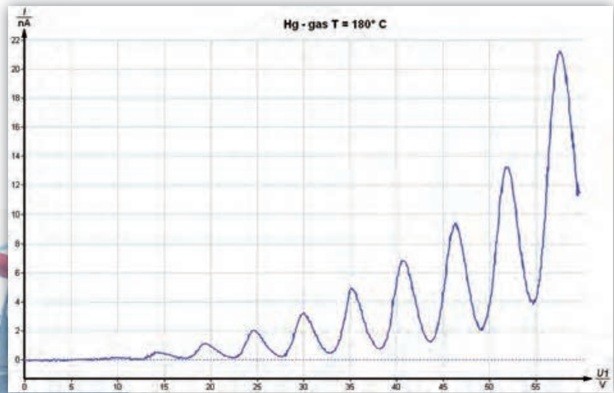
What you can learn about
- Ultrasonic echography (A-scan)
- Tomography
- Resolution

Benefits
- Experience the essence of the Nobel Prize: Cormack and Hounsfield (1979)
- Ideal system for education: affordable compared to industrial system to demonstrate ultrasound-CT in a very comprehensible way
- With the same system mechanical scanning of an object can be performed, e.g. to create a B-scan image

4 PHYWE Solutions

Impact of an electron upon an atom
Experiment: Franck-Hertz with a Hg-tube

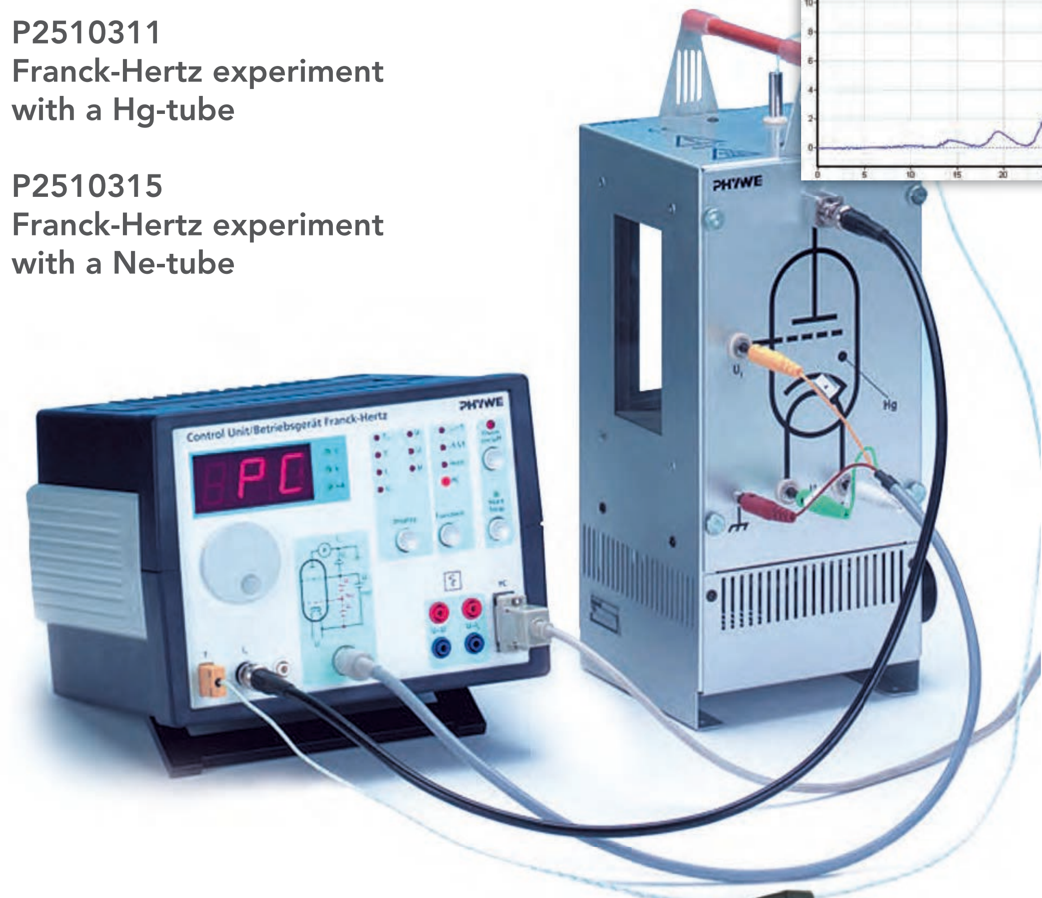
More Information on page 108.



Example of a Franck-Hertz curve for Hg-gas at T = 180 °C.

P2510311
Franck-Hertz experiment with a Hg-tube

P2510315
Franck-Hertz experiment with a Ne-tube



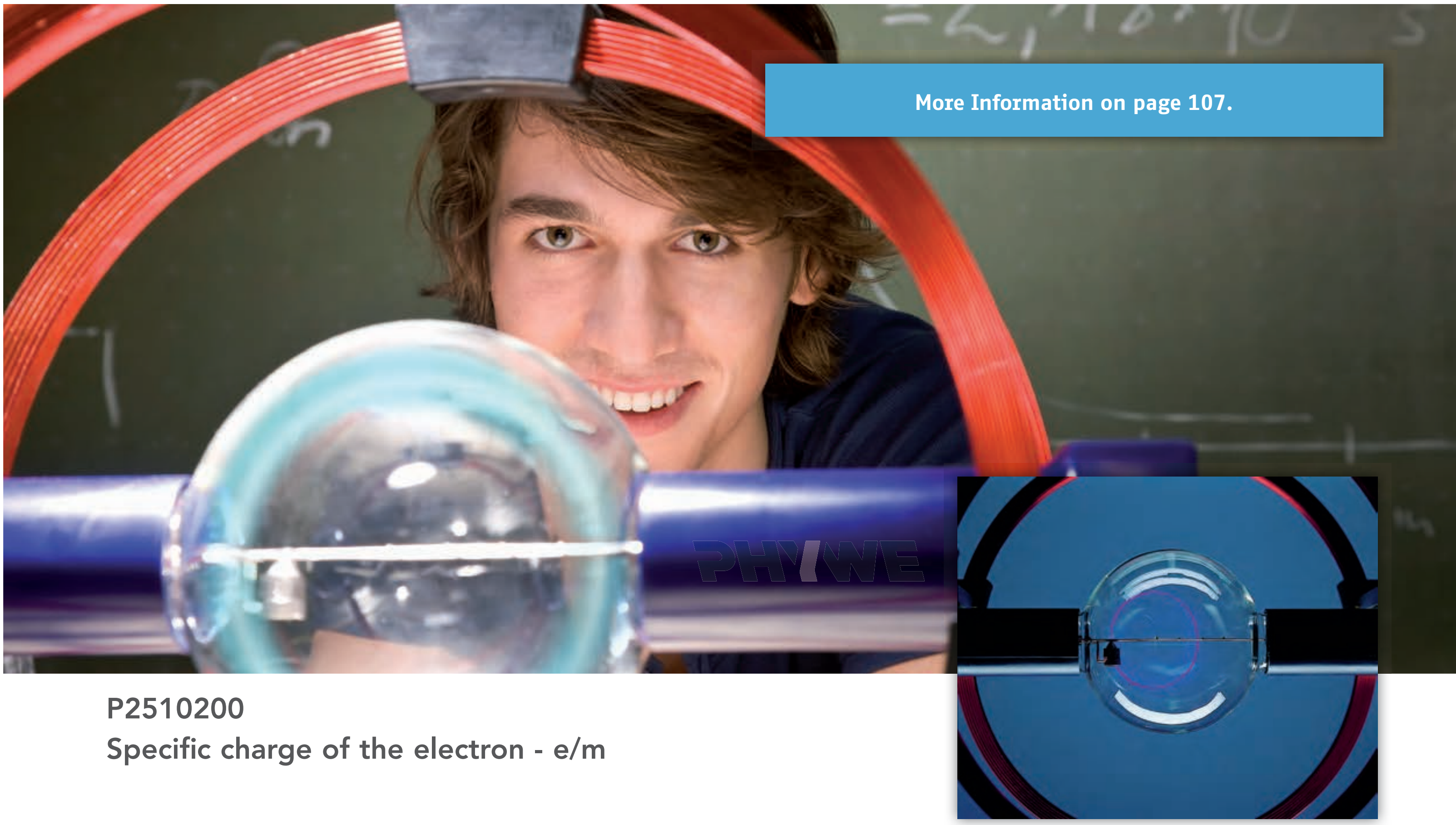
XR 4.0 expert unit –
made for better education

09110-88
XRE 4.0 X-ray expert set, with tungsten tube

More Information on page 136.

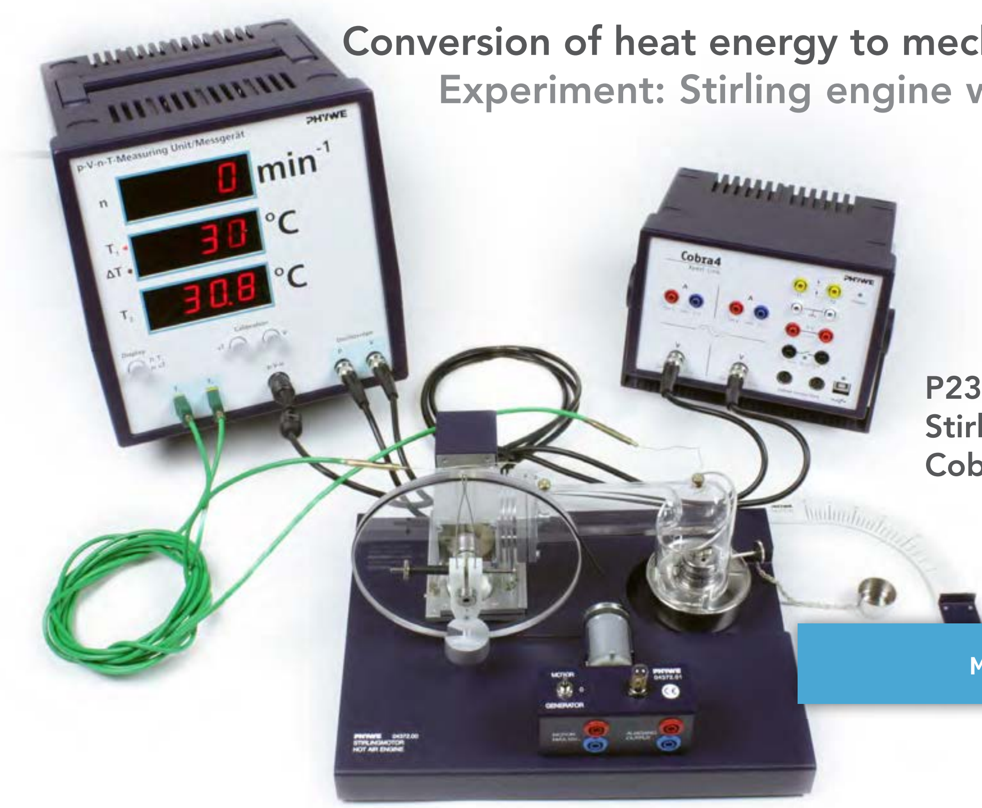
Understanding electrons

Experiment: Specific charge of the electron - e/m



More Information on page 107.

P2510200
Specific charge of the electron - e/m



Conversion of heat energy to mechanical work

Experiment: Stirling engine with Cobra4 Xpert-Link

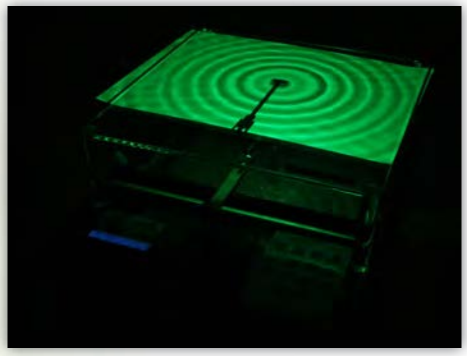
NEW

P2360464
Stirling engine with
Cobra4 Xpert-Link

More Information on page 54.

Demonstration of wave mechanics
PHYWE Ripple tank

More Information on page 38.



11260-88
PHYWE Ripple tank with LED light source, complete set

P2133500
Interference and diffraction of water waves

PHYWE Demonstration track

P2130305
Newton's 2nd law

P2130360
Newton's 2nd law with Cobra4

P2130380
Newton's 2nd law with measure Dynamics

More Information on page 15 -16.

Demonstrative and transparent – versatile modular system, easy to assemble

The PHYWE Glass jacket system

Equation of state for ideal gases with Cobra4 (gas laws: Gay-Lussac, Amontons, Boyle) (P2320162)

Steam distillation (P3031251)

The empirical formula of methane, ethane and propane (P3110900)

Avogadro's law (P3111000)

Chromatographic separation processes: Gas chromatography with Cobra4 (P3031760)

Determination of the heat of formation for CO2 and CO (Hess' law) (P3021601)

Determination of the heat of formation of water (P3021501)

Determination of the molar mass of a liquid (P3010501)

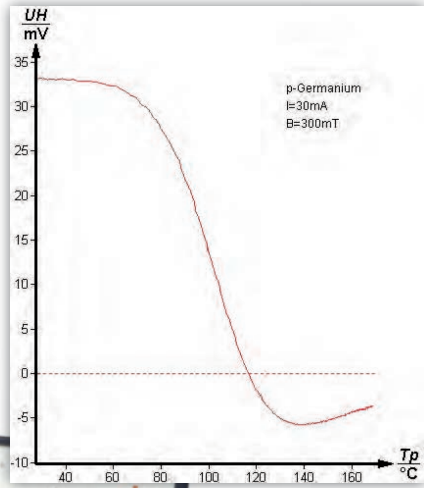
43003-88
Set gas laws with glass jacket

P2320162
Equation of state for ideal gases with Cobra4 (gas laws: Gay-Lussac, Amontons, Boyle)

More Information on page 44.

Solid-state and semiconductor physics

Experiment: Hall effect in n- and p-germanium



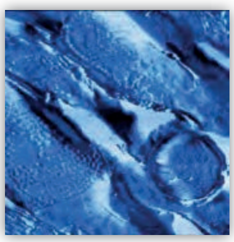
Hall voltage as a function of temperature.

More Information on page 117.

P2530102
Hall effect in n- and p-germanium (teslameter)

Visualize and image structures

PHYWE Compact AFM (Atomic Force Microscope)

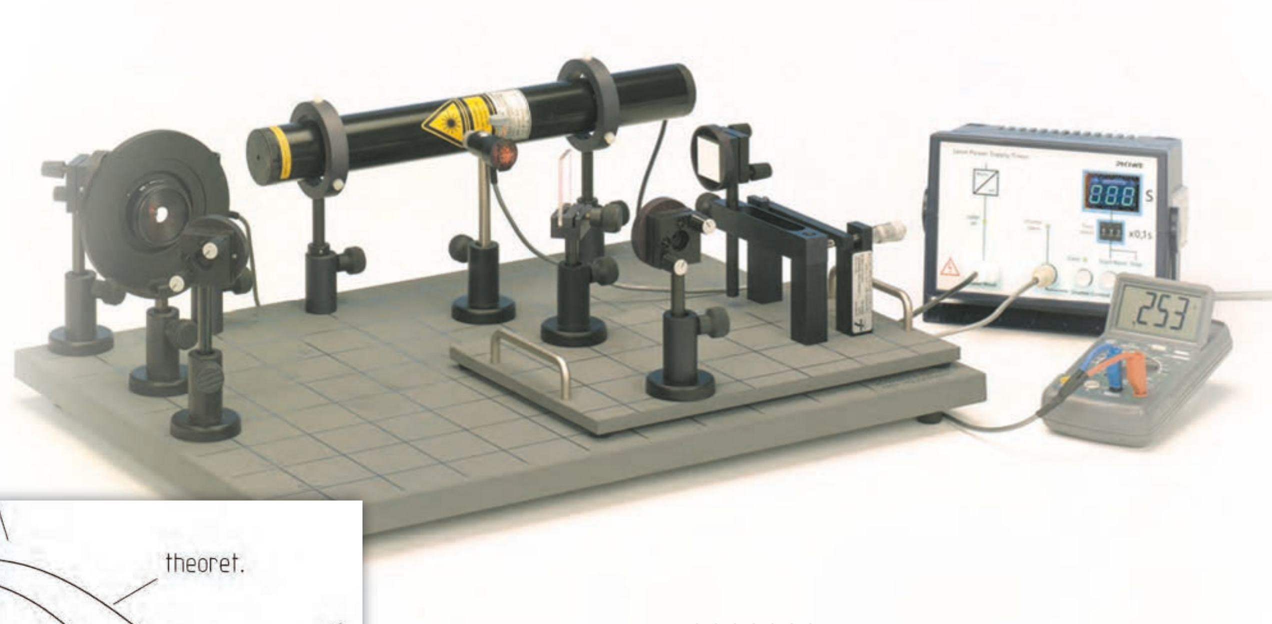


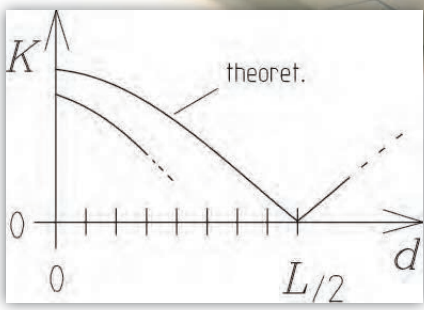
09700-99
Compact AFM (Atomic Force Microscope)

More Information on page 124.

P2538000
Basic methods in imaging of micro and nanostructures

Spectroscopic and metrological investigations
PHYWE Michelson interferometer

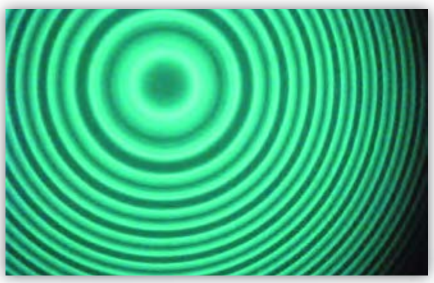




Experimentally determined contrast function in comparison to the theoretical contrast function K of a 2-mode laser.

P2220900
Michelson interferometer - high resolution

More Information on page 96.



Interference rings with the anomalous Zeeman effect.

Quantum physics at it's best
Experiment: Zeeman effect

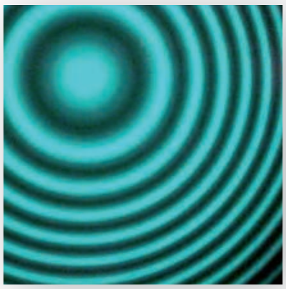
P2511007
Zeeman effect with a variable magnetic system and a CMOS camera

More Information on page 111.

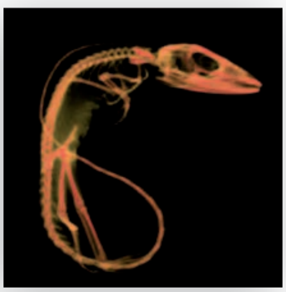
PHYWE supplies more than
50 Nobel Prize experiments

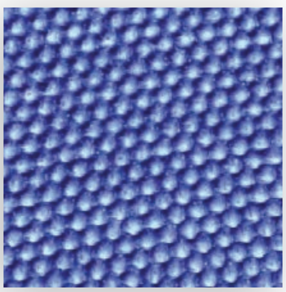
The Nobel Prize is awarded annually in the disciplines of physics, chemistry, physiology or medicine, literature and peace. For scientists and researchers, it is the highest award.

PHYWE supplies more than 50 Nobel Prize experiments. From Conrad Röntgen to Max Planck to Albert Einstein. Experiments in the footsteps of Nobel Prize winners. PHYWE makes Nobel Prize experiments understandable.



1900 ...	1910 ...	1920 ...
1901 – Wilhelm Conrad Röntgen	1910 – Johannes D. van der Waals	1921 – Albert Einstein
1901 – Jacobus Henricus van't Hoff	1911 – Wilhelm Wien	1922 – Niels Bohr
1902 – Hendrik A. Lorentz, Pieter Zeeman	1914 – Max von Laue	1923 – Robert A. Millikan
1903 – Henri Becquerel, Pierre Curie, Marie Curie	1915 – William H. Bragg, William L. Bragg	1924 – Manne Siegbahn
1907 – Albert A. Michelson	1917 – Charles G. Barkla	1924 – Willem Einthoven
1908 – Ernest Rutherford	1918 – Fritz Haber	1925 – James Franck, Gustav Hertz
	1918 – Max Planck	1927 – Arthur H. Compton
		1927 – Charles T. R. Wilson
		1929 – Louis de Broglie





More information about the PHYWE Nobel Prize experiments can be found in the new brochure Premium experiments or in this catalogue. The PHYWE Nobel Prize experiments are identified with this icon. 

1930 ...	1940 ...	1970 until today
1930 – Karl Landsteiner	1943 – Otto Stern	1971 – Dennis Gabor
1931 – Carl Bosch, Friedrich Bergius	1945 – Wolfgang Pauli	1979 – Allan M. Cormack, Sir Godfrey N. Hounsfield
1932 – Werner Heisenberg	1948 – Arne Tiselius	1986 – Heinrich Rohrer, Gerd Binnig
1936 – Victor F. Hess, Carl D. Anderson	1952 – Felix Bloch, Edward M. Purcell	2003 – Paul C. Lauterbur, Sir Peter Mansfield
1936 – Peter Debye	1954 – Max Born Walther Bothe	2009 – Charles K. Kao
1937 – Clinton J.Davisson, George P. Thomson	1964 – C.H. Townes, N.G. Basov, A.M. Prokhorov	

Computer-Assisted measurement –
for your science experiments

Cobra4 PHYWE

With computer-assisted experiments by PHYWE you rely on a system that perfectly matches the demands of modern scientific education. A great number of TESS™ and Demo expert experiments are computer-based. PHYWE offers the unique Cobra4™ system with completely new experimentation possibilities.

Combine the fast and high-precision datalogging system Cobra4™ with our proven hands-on experiments TESS™ and DEMO and discover the unbeaten solution for modern and curriculum-compliant teaching.

Benefits
- More then 50 measurerands with 28 sensors
- Fully featured data acquisition and analysis software
- High-performance interface with the Cobra4 Xpert-Link
- Compatible with the free PHYWE measureApp for tablets
- Fully automatic sensor identification (plug & play)

Sensor-Unit

Wireless/USB-Link

Available on the App Store

ANDROID APP ON Google play

The Cobra4 interfaces

12601-10

Wireless/USB-Link
for wireless or USB-based datalogging

12620-10

Mobile-Link 2*
portable measuring interface
*registered utility model

12625-99

Xpert-Link
for high-performance applications

The Cobra4 sensors

Physic Sensors

- **Timer-Counter** – Motion with light barriers
- **Motion** – Motion
- **Acceleration** – 3D acceleration
- **Electricity** – Current, voltage
- **Energy** – Current, voltage, work, power
- **Radioactivity** – Radioactivity
- **Sound level** – Sound, dBA, dBC
- **Tesla** – Magnetic field

- **Forceplate** – Force, weight (500 kg)
- **Force 40 N** – Force 40 N
- **Force 4 N** – Force 4 N
- **Temperature** – Temperature (semiconductor)
- **Temperature** – Temperature (2 x NiCr-Ni)
- **Pressure** – Pressure (7 bar)
- **Thermodynamics** – Pressure, temperature

Chemistry Sensors

- **pH** – pH value
- **Chemistry** – pH, temperature
- **Drop counter** – Titration
- **Oxygen** – Dissolved and gaseous oxygen
- **CO_2** – CO_2 content in air
- **Thermodynamics** – Pressure, temperature
- **Conductivity** – Conductivity, temperature
- **Conductivity+** – Conductivity, temperature (Pt1000)
- **Colorimeter** – Photometry

Biology Sensors

- **Oxygen** – Dissolved and gaseous oxygen
- **CO_2** – CO_2 content in air
- **Conductivity** – Conductivity, temperature
- **Weather** – Air pressure, humidity, altitude, temperature, light intensity

Sensors for Human Physiology & Medicine

- **Electrophysiology** – EKG, EMG, EOG
- **Skin resistance** – Conductance
- **Spirometry** – Respiratory volume, wind speed
- **Pulse** – Pulse

Data logging with Cobra4 Wireless/USB-Link – for modern teaching concepts with computer and tablet

Wireless data logging with the new Cobra4 Wireless/USB-Link and measureApp. Direct and operating-system-independent communication with all types of tablet and computers via Wlan.

1 Cobra4 Wireless/USB Link:
- Innovative interfaces for wireless and USB data transmission
- Compatible with all Cobra4 sensor units

2 measureLAB:
- Measure, analyze in combination with the Cobra4 datalogging interfaces
- Future-proof: Windows and MacOS
- Time-saving: Preconfigurations available
- Software oscilloscope
- Automatic identification of all Cobra4 interfaces and sensors
- Datasharing for demonstration experiments: Transfer of measurement data from teacher computer (measureLAB) to students iPads (measureApp)
- Remote operation mode: students can use their own computers in the laboratory course

curricuLAB® measureLAB PHYWE

3 measureApp:
- Data logging with the most important evaluation functions
- Record, save and send measurement data on the tablet or smartphone
- Easy and intuitive operation
- Independent of the operating system (iOS, Android), for all types of mobile devices
- Easy saving of measurement data
- Measurements can be performed with the integrated acceleration sensor of the mobile device
- For free

iOS

Available on the App Store

ANDROID APP ON Google play

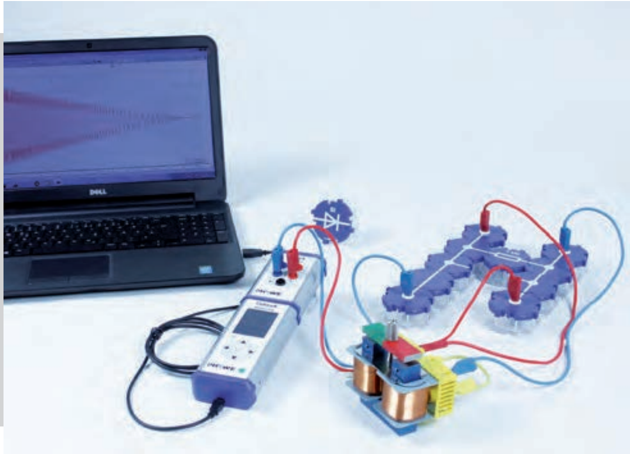
The Cobra4 Mobile-Link 2 –
3 devices in 1

You can use the Cobra4 Mobile-Link2 ...

as a hand-held measuring device

1.

- Measured values and diagrams directly on the 2.4" color display
- Battery powered - up to 9 hours
- At the lab workplace or for outdoors - with the integrated SD card no data is lost



as a live measuring device with PC

2.

- Direct transmission of the measurement data via the USB port to the software measureLAB
- Data transmission rate up to 2 kHz - for fast measurements, e.g. of current and voltage

as a demonstration measuring device

3.

- In conjunction with the Cobra4 Display-Connect (12623-88) to use the digital large display (07157-93) without using a PC

Benefits
- Compatible / usable with all Cobra4 sensors
- Robust button control panel for intuitive handling
- Integrated acceleration sensor always with you

The Cobra4 Xpert-Link – details at a glance

Cobra4 Xpert-Link PHYWE

Discover the many benefits of the new Cobra4 Xpert-Link and its new and simple experimental possibilities. Some highlights are:

Two channels for current measurement

- channels galvanically isolated
- 0.2 µA ... 10 A, 2 MHz
- ideal for the implementation of experiments which require 2 measurement channels, e.g . in induction experiments
- TrueRMS

Connectors

- up to 2 light barriers or other devices with trigger input function (TTL level) can be controlled at the same time
- for power supply of light barriers via separate jacks with 5 V / max. 2 A –
- ideal for experiments which require several light barriers, e.g. Newton's laws

Oscilloscope function

- the Cobra4 Xpert-Link completely replaces an oscilloscope
- measurement of voltages, currents, phase shifts and TrueRMS possible

Controllable relay

- relays can be easily and securely controlled via software
- max 30 V / 2 A
- ideal for experiments such as free fall

USB port

- USB connection to computer

Two channels for voltage measurement

- channels galvanically isolated
- 10 µV ... 30 V, 10 MHz
- ideal for the implementation of experiments which require 2 measurement channels
- TrueRMS

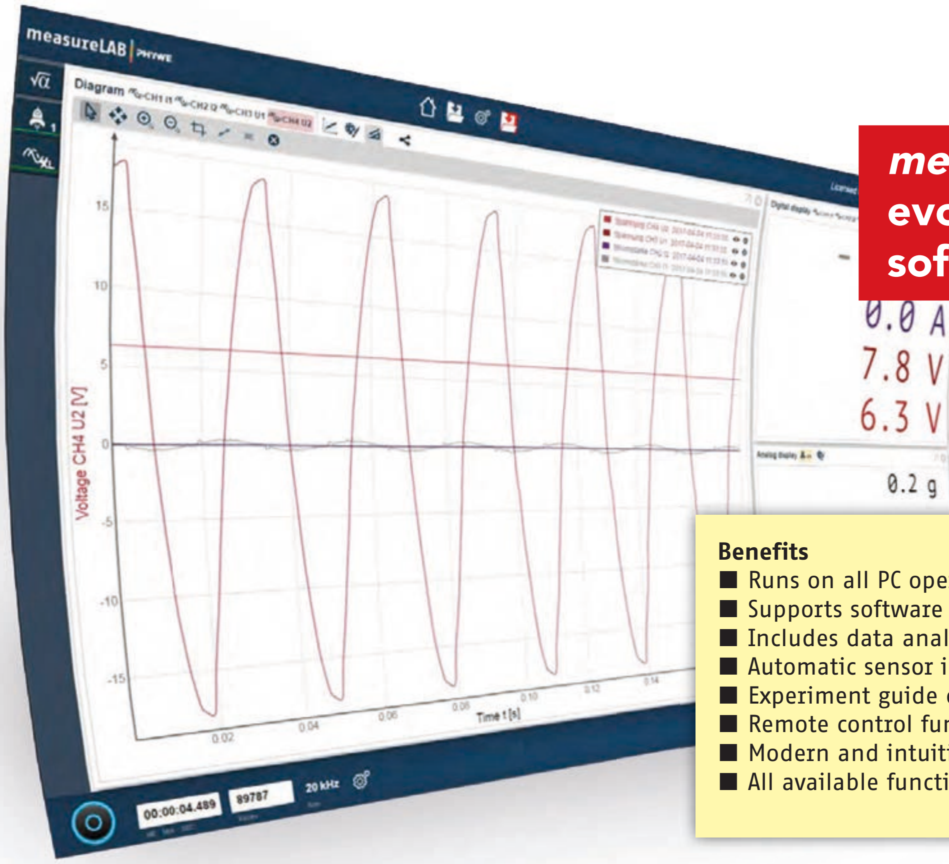
Connectors for additional sensors using Cobra4 Xpert-Connect adapters

- up to 2 Cobra4 sensors can be simultaneously connected and controlled

made in Germany

Cobra4 Xpert-Link & measureLAB –
high-performance data acquisition

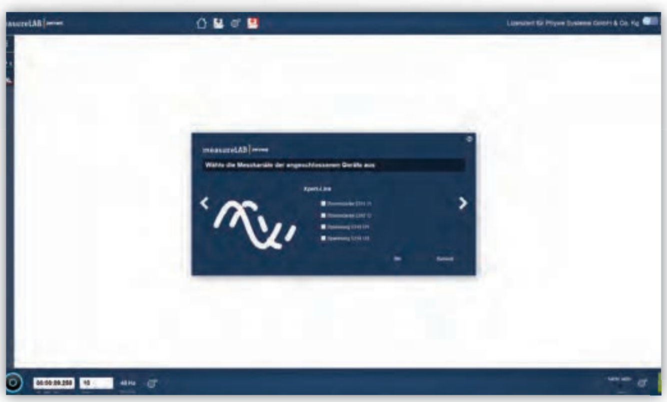
curricuLAB® measureLAB PHYWE



measureLAB* is the next evolution step of PHYWE's software *measure

Benefits

- Runs on all PC operating systems: Win, Mac, Linux (2018)
- Supports software oscilloscope function
- Includes data analysis functions
- Automatic sensor identification (plug & play)
- Experiment guide database with preconfigurations
- Remote control function
- Modern and intuitive interface
- All available functions at a glance



Preconfigurations

Automatic sensor identification

Cobra4 Xpert-Connect adapter (12625-01)

- Extends the possibilities to perform even more experiments
- Attaches 1 or 2 Cobra4 sensors to Cobra4 Xpert-Link
- More then 50 measurands with 28 sensors

Digital learning with curricuLAB® –
the new management and experimentation platform

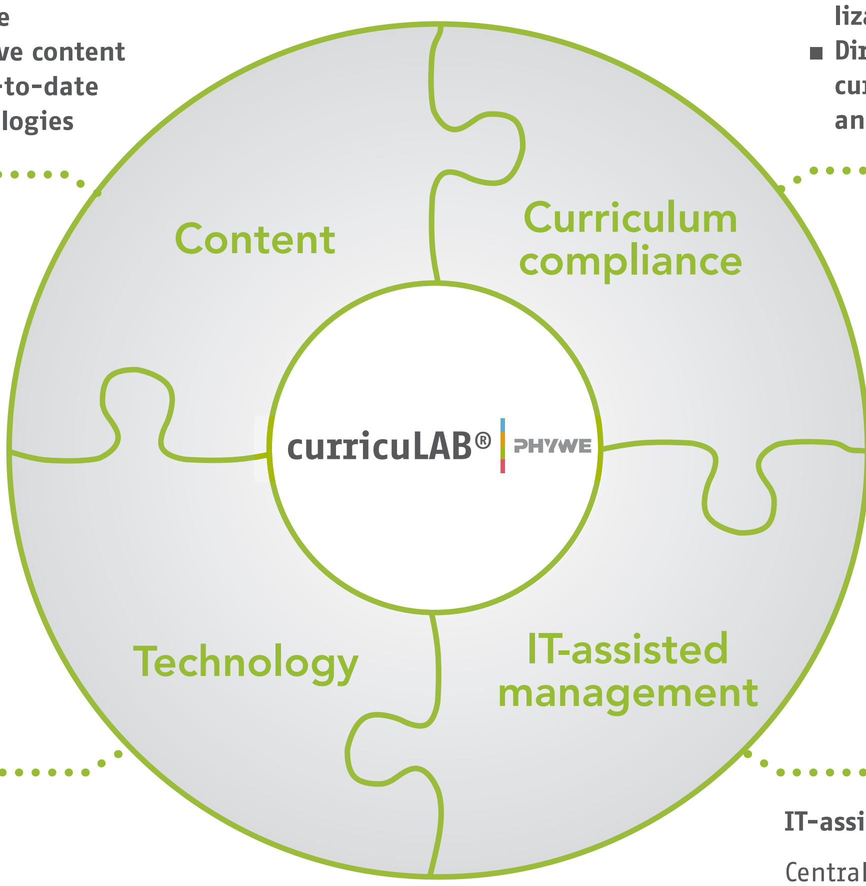
Save up to 40% of your valuable time with curricuLAB® when planning, preparing, and reviewing your science laboratory courses. **Use this extra time** for effective courses of the highest quality: interesting, captivating and conveying the joy of successful teaching and learning.

Content

- **More than 2400 detailed experiment descriptions and high didactic value**
- **Editable, interactive content**
- **Integration of up-to-date teaching methodologies**

Curriculum compliance

- **High-quality courses**
- **Didactic curriculum realization for better results**
- **Direct connection between curriculum, experiment and required equipment**



Technology

Consistent use of:

- **Internet**
- **Mobile devices**
- **Wireless datalogging**
- **Different types of operating systems**
- **Cobra4 datalogging-system**

IT-assisted management

Centralized management experimentation platform for:

- **Planning experiments**
- **Preparation and revision**
- **Optimised courses**
- **Evaluation and assessment**
- **Saving and sharing all relevant data, results and information**

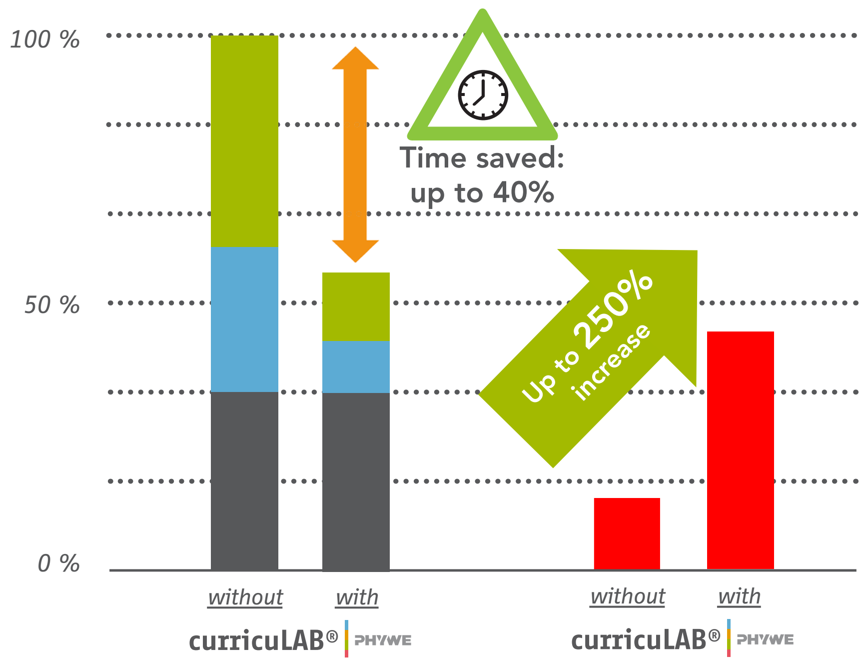
curricuLAB® supports you with all your requirements in terms of management, didactic background, integration of digital media and teaching concepts.

curricuLAB® | PHYWE

Time required by a professor or lecturer

Increasing the media competency

- Teaching
- Preparation and revision
- Management & Administration
- Media competence



Your benefits with curricuLAB®:

- Time-saving concept → higher quality, sustainability, better results and stronger motivation
- Easier and more efficient organisation and administration → lower stress level for the teaching stuff and higher focus on the courses
- Integration of mobile devices in the laboratory courses → better student motivation and enhanced media competence
- Fun in the laboratory courses → quicker achievement of learning objectives
- Attractiveness of the university
- Investment protection through sustainability and future security
- Curricula-compliant scientific content (by curricuLAB® from PHYWE)
- Safety Conformity

curricuLAB® assists you particularly in following fields:

1 Teaching

2 Preparation and revision

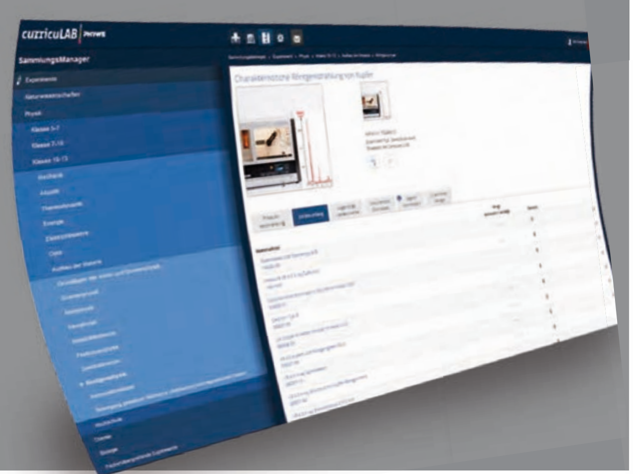
3 Knowledge management

The curricuLAB®-platform with his modules –
time-saving, intuitive, motivation-enhancing and future-proof

	curricuLAB® LabManager PHYWE	curricuLAB® ActivityManager PHYWE
1 Teaching		✓
2 Preparation and revision	✓	✓
3 Knowledge management	✓	✓

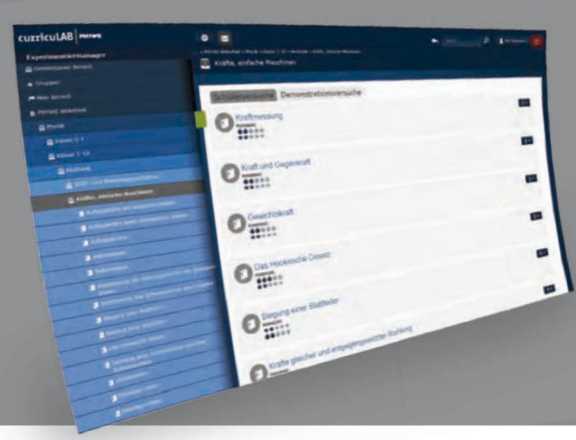
Excellent preparation.

- Inventory of new and already existing equipment
- Curricula-compliant overview of more than 2.400 PHYWE experiments, including all experiment descriptions as PDF
- Approximately 6.000 items linked to suitable experiments - optimum use of your equipment
- All operating instructions for all PHYWE devices and experiments included
- Can be combined with the PHYWE allocation and inventory service
- Hazard assessments and safety data sheets
- List of hazardous substances at the push of a button



Excellent lessons.

- Access to more than 2.400 curricula-compliant experiments made by PHYWE with all related information
- Interactive instructions for student and demonstration experiments, prepared under didactic aspects
- All experiments can be edited and filled, combined and shared with own multimedia content (comments, documents, videos, pictures, etc.)
- Create teaching modules in groups and courses for your lessons and share them with your colleagues
- Manage your own calendar
- Use any type of device for planning your lessons, in particular laptops, tablets or smartphones

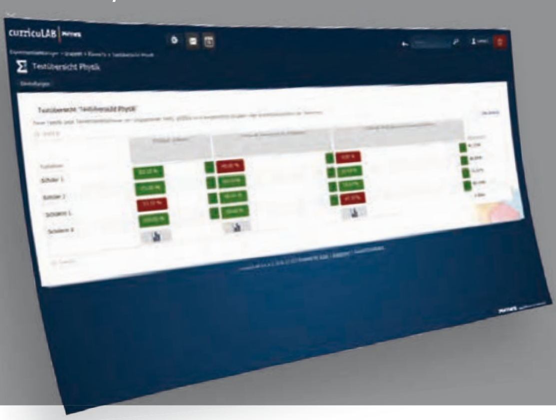


iOS

curricuLAB® ActivityManagerPRO PHYWE	curricuLAB® DataManager PHYWE	
✓	✓	Teaching
✓	✓	Preparation and revision
✓	✓	Knowledge management

Excellent network.

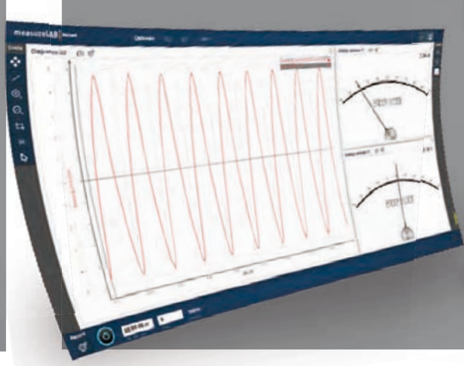
- Contains all functionalities of the ActivityManager
- The ideal solution for networked natural sciences laboratory courses with tablets and also with computers
- Create groups for your laboratory courses
- Central storage and use of teaching contents, including working with your colleagues
- Interactive exams, including logs on the student device
- Data exchange between students and teacher devices
- Simple assessment: evaluation of all relevant results
- Quick overview of the students learn progress
- All sensitive student data can remain on your university server



curricuLAB® measureLAB PHYWE curricuLAB® measureAPP PHYWE

Excellent results.

- The DataManager is the perfect tool for the operating system-independent recording of measurement data during student and demonstration experiments
- The datalogging process is embedded in the experiment so that the measurement results can easily be transferred into the interactive experiment report
- Use any type of devices: for tablets you can use measureApp and for PCs and Macs you can use measureLAB
- Automatic recognition of the Cobra4 measurement sensors
- Intuitive and touch-optimised user interface
- Data sharing between teacher computer and iPads



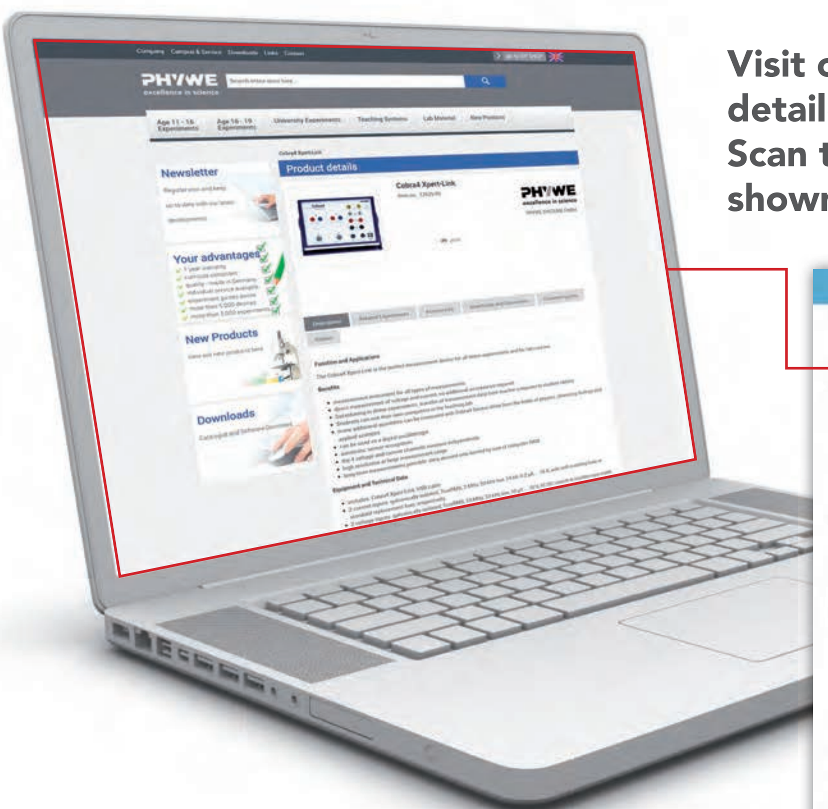
YouTube

Subscribe to our channel!

https://www.youtube.com/user/phywe

Take a look at our PHYWE YouTube channel and watch our latest experiment and product videos

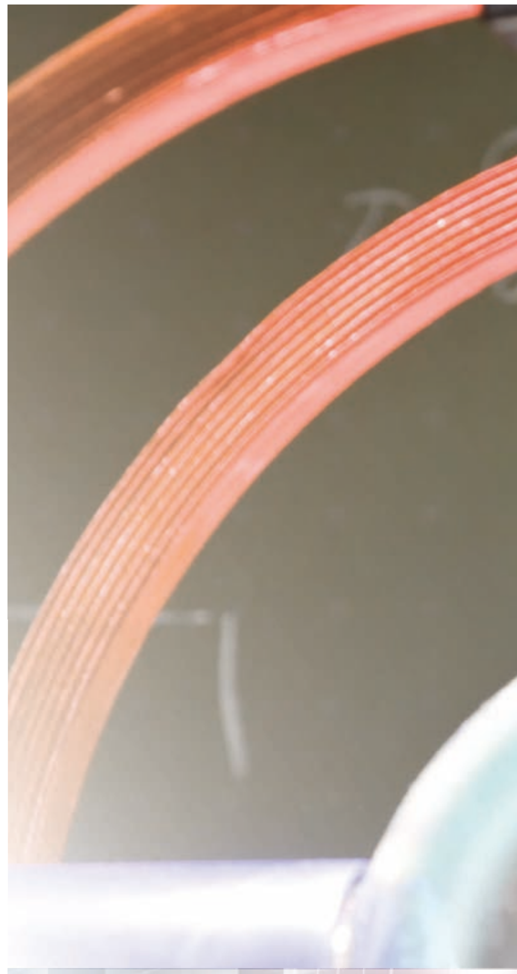
YouTube



Visit our PHYWE website for all detailed information. Scan the QR codes which are shown by the experiments

5 About PHYWE

Traditional yet modern –
more than 100 years of quality



> Those who know nothing must believe everything.
>
> Marie von Ebner-Eschenbach

With a more than 100-year tradition of excellence, PHYWE Systeme GmbH & Co. KG stands for technical acumen, innovation, quality and customer satisfaction. As a leading supplier of premium quality teaching and learning materials, PHYWE is one of the world's largest providers of system solutions for the teaching of the natural sciences.

The product range comprises scientific equipment, experiments and solution systems along with modern computer-assisted measurements and wireless data logging systems, experiment guides and software in the areas of physics, chemistry, biology, medicine, material sciences and earth sciences. A broad spectrum of services such as training programmes, installation and comprehensive consulting services completes the portfolio.

PHYWE solutions can be individually adapted to the specific curricula in each country and provide ideal coverage for the full spectrum of performance specifications and requirements. Ask us to prepare a customised equipment offering to suit your specific needs!

made
in
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curricuLAB
measureLAB

Service at PHYWE – individual and reliable

By choosing a PHYWE product, at the same time you decide in favour of a comprehensive service. We support you with our multi-level service concept. From planning through to installation and up to our extensive after-sales service. Rely on our strengths: rugged and long-lasting products made in Germany, customized for your needs.

Consultancy

From your vision in mind, we consult you competently:

- Proposals for new acquisition, expansion or modernization of your teaching materials
- Suggestions for integrating the PHYWE LabManager – the organization platform for your new or already existing equipment

Project definition

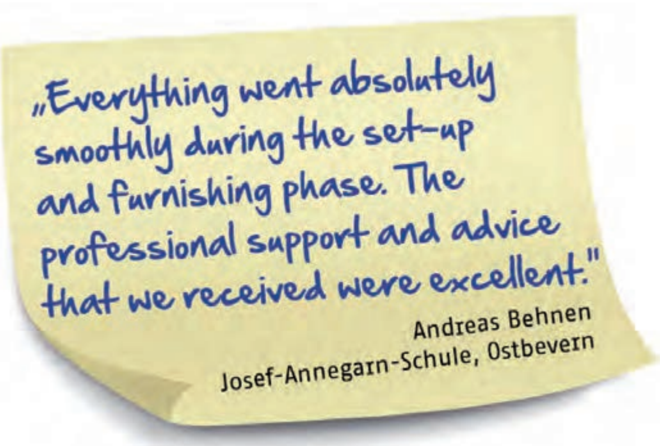
Complete project definition according to your curriculum topics, including:

- Solution for science experiments in your laboratory courses
- Solution for infrastructure & furniture
- Additional services, e.g. assistance in tendering

Delivery & Installation

Save time by:

- Fast, on-time delivery
- Service for unpacking or granting
- Check for completeness
- Installation of hardware and software
- Training (on location or at PHYWE)



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Service PHYWE

Training

Hotline & Maintenance

For successful use:

- Training of how to set up and operate instruments and experiments, explanation of device-specific
- Training for maintenance and handling

We are also available after the purchase:

- Hotline service – write an e-mail or call our experts:
  E-mail: hotline@phywe.de
  Phone: +49 (0) 551 604-196
- Repair service / spare parts

Services

Description	Article No.
On-site training per day: Hands-on training of PHYWE equipment, technology and handling with the available products / experiments, information on equipment-specific characteristics at your location.	
On-site training	03333-02
Training, presentation per day at the PHYWE site: Topic-related training courses on PHYWE equipment. Technology, handling and didactical use of equipment and experiments in the PHYWE Information Centre.	
Training at the PHYWE site	03333-03
On-site placement service per day: Unloading the delivery into the special areas provided by you. Unpacking the devices and completeness check. Placement of the devices into your storage / filing systems and cabinets. Labeling of the storage systems. Explanation of specific characteristics of the devices. Preparation of an inventory sheet (Excel) with storage location.	
On-site placement service per day	03333-05
Commissioning per day: Unpacking of equipment and completeness check. Installation, commissioning and functional test of the supplied material.	
Commissioning per day	03333-06
Online training per experiment: Interactive training via video conference, most suitable for single experiment support, troubleshootings or small orders. Perfect addition to offers and for recapitulating specific topics.	
Online training per experiment	03333-09

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General notes on safety

Notes on safety

The regulations for dealing with electrical devices, lasers, radioactive materials and hazardous materials are not uniform worldwide. Before any experimentation, it is essential that you become familiar with the national and local laws, directives and ordinances regarding the handling of these appliances and materials, as well as their storage and transport.

You can refer as an example to our notes on safety, which correspond to the high German and EU standards. The laws in the respective country are binding, however.

1.) Experiments using electrical energy

The utilisation of the electrically operated devices (mains power supply) that are offered herein is only allowed in science rooms of educational institutions, schools, universities, and laboratories, but NOT in residential areas.

Experiments at school usually use non-hazardous extra-low voltages (< 25 V~/< 60 V-). The following safety notes provide information about the existing legal regulations. In addition, they include rules of conduct for the responsible teacher for the execution of experiments with hazardous voltage levels.

When performing experiments with electrical energy, it must be absolutely sure that the persons involved in the experiment cannot come into contact with hazardous voltage. The professional (teacher) who supervises/conducts the experiment is responsible for this.

In the “Safety requirements for electrical equipment for measurement, control, and laboratory use” (DIN EN 61010-1, VDE 0411 part 1) of the European Union, non-hazardous voltage is defined as voltage < 33 V~ or < 70 V- or, in the case of higher voltage, with a limited current of 0.5 mA~ and 2 mA- maximum.

Other restrictions for schools providing general education have been decreed by the standing conference of the minister of education and cultural affairs of Federal Republic of Germany in the “Directives concerning safety during lessons” (GUV-SI 8070) with reference to the standard VDE 0105 part 12 (“Operation of power installations - Particular requirements for experiments with electrical energy in lecture rooms”). In these directives, the voltage limits for students up to the German class level 10 (age approximately 16 years) have been fixed at 25 V~ and 60 V- maximum.

Professionals (usually teachers) and students of class levels higher than level 10 may work with hazardous voltages in exceptional cases, if the teaching objective cannot be reached with non-hazardous voltage. In this case, the teacher must be present during the experiment.

The following rules and regulations should be observed:

1. **Electrical safety**
   (DIN EN 61010-1, VDE 0105 part 12, GUV-SI-8070)

Prior to the first experiments of students, trainees, or apprentices with electrical energy in a laboratory or classroom, the students, trainees, and apprentices must be informed in detail about the hazards of the electrical current and about the applicable safety instructions.

Prior to using the electrical devices, they must be checked for signs of damage! Do not use the device if it is damaged!

The operating instructions of the equipment that is used for the experiment must be followed!

Do not use hazardous voltages (> 25 V~ and > 60 V-) in student experiments!

The professional must re-check the experiment set-up (circuit) prior to the start of the experiment and inform the user of any potential hazards!

Modifications of the experiment set-up (set-up, conversion, and take-down) must only be performed when the set-up is completely disconnected from the power supply and when all poles of the supply voltage are switched off!

If measurements or adjustments are unavoidable during an experiment with hazardous voltage, work only with one hand and hold the other behind the back or put it in a pocket!

Ensure that there is a sufficient number of emergency OFF switches in the laboratory.

Use only 4-mm safety cables that are protected against accidental contact (e.g. PHYWE ref. no. 07336-01) when performing experiments with hazardous voltages!

After the completion of the experiment, it should be taken into consideration that component parts, such as capacitors, may supply hazardous voltage even some time after the equipment has been switched off!

Experiments with set-up transformers require special safety measures. Even if the primary side of the transformer is supplied with extra-low voltage (< 25 V~), very high hazardous voltages may be generated on the secondary side by the transformation, e.g. if the coils get mixed up!

If demonstration experiments are performed with hazardous voltages, the teacher or lecturer must ensure a sufficient safety distance from the students. In addition, these kinds of experiments must be marked with the danger sign "High voltage!" (PHYWE ref. no. 06543-00)!

Experiments that are directly supplied with mains power must not be performed unless a residual current circuit breaker (< 30 mA), e.g. a safety plug/socket assembly (PHYWE ref. no. 17051-93) or a variable isolating transformer (PHYWE ref. no. 13535-93), has been installed before the set-up. Do not plug the 4-mm connecting cables directly into the earthing contact socket outlet (SCHUKO socket)!

If power supply units (e.g. power supply unit for students, PHYWE ref. no. 13505-93) are used that do not produce hazardous voltages (extra-low voltages < 25 V~ and < 60 V-), simple, unprotected 4-mm connecting cables and other non-insulated components may also be used for student experiments.

2. **EMC (electromagnetic compatibility) (Technical recommendation concerning the application of the EMC Act on electrical teaching equipment, Reg TP 322 TE01)**

Experiment set-ups for the demonstration of physical processes must only be used in science rooms at schools, universities, and other educational institutions!

The teacher (expert) who sets up and performs the experiments is responsible for the compliance with the requirements for the EMC Act on the electromagnetic compatibility of equipment! The experiment set-ups do not require a CE mark or declaration of conformity, but the teacher as an expert must take all the necessary measures in order to avoid interferences in the environment!

Possible EMC measures:

- Ensure shielding and equipotential bonding!
- Keep a sufficiently large distance from sensitive equipment!
- Use short connecting cables (in order to reduce RF emission)!
- Floor coverings that my lead to static charges should be avoided and the body should be discharged prior to touching any sensitive experiment equipment!
- RF emitters, e.g. mobile phones, should be not be used in close vicinity of the experiment set-up!
- Critical experiment set-up and devices (e.g. Van de Graaf generator, Ruhkorff induction coil, transmitter), which can cause interferences even at a distance of several 100 metres should be switched on as briefly as possible.

2.) Experiments using lasers

In general, the "Directives concerning safety during lessons" (GUV-SI 8070) are applied at schools. In accordance with these directives, the following points must be observed when working with lasers:

1. Only lasers of class 1, 1 M, 2, and 2 M1 in accordance with DIN EN 60 825 may be used at schools.
2. Lasers of class 1 M, 2, and 2 M must be kept under lock and key.
3. Prior to setting up and performing experiments with lasers of class 1 M, 2, and 2 M, the students who observe or are involved in the experiment must be informed as to the risk to the eyes that is caused by the laser light. These lasers must only be used under the supervision of the teacher.
4. The area in which experiments with lasers of class 1 M, 2, and 2 M are performed must be marked with laser warning signs during the operation of the laser. This laser area of experiment set-ups must be secured against accidental access by some form of delimitation.
5. The set-up and performance of experiments with lasers of class 1 M, 2, and 2 M must ensure that looking into the direct laser beam or into the reflected beam is avoided, e.g. with the aid of some kind of screening. If lasers of class 1 M and 2 M are used, the beam cross-section must not be reduced, i.e. these lasers must not be used

in combination with converging components (e.g. magnifying glasses).

6. The use of laser devices of class 3 B or 4 in other educational institutions (universities etc.) must be reported to the responsible accident insurer and to the responsible occupational safety and health authority prior to the first start-up of the lasers.

For the use of laser systems of class 3 B or 4, a competent person must be appointed the laser safety officer in writing.

Additional information concerning the use of lasers can be found in the documents of the German Social Accident Insurance "GUV-V B – Laser radiation" and "GUV-I 832 – Use of laser systems". These documents are mainly based on the EU standard "DIN EN 60825-1 – Safety of laser products".

3.) Handling of radioactive products

In Germany, the handling of radioactive substances is controlled by the German Radiation Protection Ordinance (Strahlenschutzverordnung, StrlSchV). The legal bases of this ordinance are articles 25 to 27 combined with appendix V of the ordinance dated 20 July 2001, last amended by article 2 of the law of 02/08/2008. Substances within the exemption limits (see Appendix V of the German Radiation Protection Ordinance (StrlSchV) for the exemption limits) can be supplied to schools without any conditions. If the exemption limits are exceeded, the school will need a special handling permit issued by the responsible supervisory authority prior to purchasing the substances.

If several substances within the exemption limits are owned and/or purchased, the sum formula that is stated in the German Radiation Protection Ordinance must be observed.

Radioactive substances must be protected against unauthorised persons, which is why they must be stored in a theft-proof manner. In addition, the handling regulations of the German Radiation Protection Ordinance must be observed. Substances that have become unusable must be handed over directly to the responsible collection centre or to a disposal company.

4.) Safety instruction for handling hazardous materials

Before any experimentation with hazardous materials, it is essential that you become familiar with the national and local directives and ordinances concerning the handling of hazardous materials, their storage and transport. The basic principle is that all hazardous materials must be dealt with cautiously and carefully. It is of course required that, in case of experiments, neither the students nor the teachers be exposed to any unnecessary dangers to health. The instructions of the safety data sheets for the individual materials, in the most current version in each case, are to be considered, as well as the accident-prevention specifications and the respective workplace-related operating instructions. The waste disposal of used hazardous materials must be implemented according to recognized methods. The local specifications for the proper removal of chemical residues are to be considered in this case.

General Terms and Conditions (GTC)

of PHYWE Systeme GmbH & Co. KG

§ 1 Application of Conditions

1. These General Terms and Conditions (hereinafter referred to as GTC) shall apply for all goods, services and offers of PHYWE Systeme GmbH & Co.KG (hereinafter referred to as PHYWE) for its customers (hereinafter referred to as Customer). They shall apply equally for all future business between the contract parties without requiring a repeated reference. General Terms and Conditions of the Customer shall apply only if expressly approved by PHYWE in writing.
2. All deviating agreements between PHYWE and the Customer shall be set down in writing; a waiver of the written form does not have any effect on the agreement's validity. In the event of such an agreement these GTC shall be of lesser importance and shall supplement the agreement.
3. PHYWE reserves all rights to PHYWE operational and offer documents. If no order is placed, all documents shall be returned immediately of the Customer's own accord. All information in them and from other transactions shall be treated as strictly confidential.
4. All offers, samples and test products as well as their technical data and descriptions in the respective product information and promotional materials on the PHYWE website are for information only and are not binding. They do not represent a warranty of quality or application.
5. Insofar as PHYWE considers it necessary for the completion of its performances, PHYWE is authorized to exchange job-related data with assistants or trading partners. If the Customer does not desire such an information exchange, the Customer may object to it in writing at any time.

§ 2 Offer and Contract Conclusion

PHYWE's offers are not binding. PHYWE reserves an acceptance period of two weeks from receipt at PHYWE regarding the Customer's binding orders. Verbal statements of acceptance (by phone) and all Customer orders shall be confirmed by PHYWE in writing or by telex; a waiver of the confirmation does not affect the effectiveness of verbal statements of acceptance and orders (by telephone).

§ 3 Prices

1. The prices given in the PHYWE price list or the PHYWE order confirmation, exclusive of the relevant applicable value-added tax in the respective country, shall be binding. Additional goods and services are charged separately.
2. The prices are "ex work PHYWE" and include PHYWE standard packaging. Special packaging or other requests from the Customer, such as packaging in certain lots, are charged separately. Deviating provisions may be agreed between PHYWE and the Customer or by PHYWE for a region or a country in writing from time to time.

§ 4 Delivery and Performance Terms

1. Delivery dates or terms that may be agreed upon, both binding and unbinding, shall be set down in writing. Non-binding delivery terms may be exceeded by up to 8 weeks by PHYWE; only after expiration of this term we shall fall into arrears by reminder of the Customer. Delivery terms shall start as of contract conclusion and acceptance of payment details by PHYWE. In the event that changes to the contract are agreed upon, it is subsequently required to agree on a new delivery date at the same time. Claims for damages or recourse of the Customer towards PHYWE shall be excluded in any case.
2. In the event of delivery and performance delays due to force majeure, natural disasters as well as due to labour disputes, traffic or operation disturbances, lack of material through no fault of their own and similar reasons on PHYWE and its suppliers' part, the Customer is not entitled to withdraw from the contract or to assert claims towards PHYWE. The Customer is entitled to withdraw from the contract if the aforementioned reasons cause an extension of the delivery date by more than four months. PHYWE is entitled equally to withdraw from the contract. Claims for damages or recourse of the Customer towards PHYWE shall be excluded in any case.
3. PHYWE is entitled to make partial deliveries and partial performances at any time unless the deliveries and performances are to be made fully and completely in accordance with the contractual arrangements.
4. PHYWE's compliance with delivery and performance obligations requires the Customer's timely and proper compliance with its obligations.
5. If the Customer falls into arrears, PHYWE is entitled to demand reimbursement of the additional expenses it had to make for the unsuccessful offer and storage and maintenance of the owed object; with commencement of default of acceptance the risk of incidental deterioration and accidental loss is transferred to the Customer.

§ 5 Export Business

PHYWE is entitled to withdraw from the contract regarding delivery of such products (partial withdrawal) that require approval of the federal ministry for economics and export control, the Federal Institute for Medicaments and Medical Products or a similar governmental institution for their export from Germany or their import in their country of destination pursuant to legal provisions in the event that the approval is not issued or probably may not be obtained until the agreed delivery date. PHYWE shall immediately advise the Customer of this and possibly reimburse a compensation for the part of the performance affected by the withdrawal.

§ 6 Shipping and Transfer of Risk

1. Place of performance is Göttingen. The delivery condition is "ex works PHYWE". Other agreements must be made in writing.
2. The Customer may request PHYWE to ship the goods. It shall bear the costs and risk for it. In the case of a forwarding order the risk is transferred to the Customer as soon as the shipment had been handed over to the person executing the transport. If PHYWE is able to ship the goods at the time determined by contract and the shipment is delayed at the Customer's request the risk is transferred to the Customer at notice of readiness for shipment.
3. At the Customer's request shipments shall be insured in its name and on its account.

§ 7 Claims for Defects/Guarantee

1. PHYWE is working pursuant to the guarantee claims typical in Germany and the EU. If a PHYWE product shows any other defect already present at delivery, the Purchaser shall advise it immediately and provide evidence. In such an event PHYWE shall repair the defect or deliver a product free of defects (supplementary performance) pursuant to legal provisions. PHYWE shall bear the expenses required for the purposes of supplementary performance, including but not limited to transport, labour and material cost. Additional expenses caused by the sold product being brought to a place other as the domicile or the branch office of the Customer shall not be borne by PHYWE.
2. Insignificant or commercial deviations of the delivered goods in size, shape and colour being in the material's nature do not establish claims for defects by the Customer. Article 377 German Commercial Code applies.
3. PHYWE reserves the right to changes to the PHYWE products required for technical or other reasons not affecting usability and not reducing the service's value and for technical improvements. They do not establish claims for defects, abatement or withdrawal from the transaction by the Customer.
4. If PHYWE's operation or maintenance instructions are not adhered to, changes to the products are made, parts are exchanged or consumables not complying with the original specifications are used, the Customer may not assert claims for defects if the Customer does not refute a substantiated claim to the effect that it was only one of those circumstances that had caused the defect.
5. The Customer must immediately inform customer service management/PHYWE's technical hotline of visible defects in writing, however, the latest within one week after receiving and/or accepting the

delivered goods. Defects that can not be discovered within this period even with careful examination shall be communicated and proven to PHYWE in writing immediately upon discovery.

6. Claims for defects for regular wear and tear are excluded.
7. Only the immediate Customer is entitled to claims for defects towards PHYWE and may not transfer them to third parties.
8. Claims for defects fall under the statute of limitations after 12 months as of delivery of the goods under contracts with the Customer. Retaining payments by the Customer is only admissible if the proportion of the occurred defect is appropriate.

§ 8 Repairs

If the Customer is not entitled to claims for defects pursuant to § 7 or if the statutory period of limitation pursuant to § 7.8 is expired and PHYWE and the Customer agree on a repair of the products § 7.8 applies equally to the limitation of a defect of the repair.

§ 9 Reservation of Title

1. PHYWE reserves title to the goods until fulfilment of all claims from the business relation for whatever legal reason including the claims arising in the future or conditional claims. If the realisable value of existing securities (goods subject to reservation of title pursuant no. 3 below and transferred accounts receivable pursuant no. 5 below) exceeds the secured claims by more than 10 % in total PHYWE is obliged insofar to release securities at the seller's discretion at the Customer's request.
2. Joint ownership rights arising from combination or mixing are deemed goods subject to reservation of title. PHYWE has an appropriate right to the reservation of title on these goods as well.
3. The Customer is entitled to process and sell the goods subject to reservation of title in the course of normal business unless it falls into arrears. Pledging or protective conveyance is inadmissible. By way of security the customer shall immediately transfer to PHYWE all claims (including any outstanding balance claims from the current accounts) arising from the resale or another legal reason (insurance, inadmissible action) in connection with the goods subject to reservation of title to their full extent. PHYWE shall give it the revocable authorization to collect the claims transferred to PHYWE for its account in its own name. This authorization for collection may only be withdrawn if the Customer does not properly fulfil its payment obligations.
4. In the event that the Customer behaves contrary to the contract – including but not limited to falling into arrears – PHYWE is entitled to take back the goods subject to reservation of title after expiration of an appropriate additional respite or demand the transfer of the Customer's claims for return towards third parties as the case may be. PHYWE taking back the goods subject to reservation of title does not constitute a withdrawal from the contract unless PHYWE has expressly stated such withdrawal.

§ 10 Payment

1. All payments exceeding the credit limit of the Customer with PHYWE confirmed by PHYWE in writing shall be made for payment in advance or confirmed with an irrevocable letter of credit from a large European bank accepted by PHYWE or an equivalent bank guarantee.
2. Within or above credit limit invoices shall be payable without deducting a cash discount or other discounts with PHYWE receiving the payment within 20 days as of contract conclusion and receipt of the invoice or an equivalent payment listing by the Customer.
3. In the event of orders with a purchase price surpassing € 25,000.00 the Customer shall make an advance payment of 40% of the purchase price for PHYWE products and 60% of the purchase price for third party products. The advance payment is due on contract conclusion and receipt of an invoice or equivalent payment listing.
4. A payment is only deemed made when PHYWE has the amount at its disposal. In case of cheques the payment is only deemed made when the cheque has been cashed.
5. The Customer shall fall into arrears 3 days after maturity of the claim by PHYWE and receipt of an invoice or delivery without it requiring a written reminder. If the Customer falls into arrears PHYWE is entitled to demand interest of 8% above the relevant basic interest rate of the European Central Bank at the respective point in time. PHYWE may submit evidence of a greater damage
6. If PHYWE becomes aware of circumstances calling the Customer's financial standing into question, including but not limited to not cashing its cheque or stopping its payments, or if PHYWE becomes aware of other circumstances calling the Customer's financial standing in question, PHYWE is entitled to call the complete outstanding debts even if it had accepted cheques.
7. The Customer is only entitled to set off its debts if the counterclaims have been established as final and absolute or are undisputed. The same shall apply for the right of retention pursuant to article 273 German Civil Code, the commercial right of retention pursuant to article 369 German Civil Code and the right of refusal of services pursuant to article 320 German Civil Code.

§ 11 Copyright Infringements

1. PHYWE shall exempt the Customer and its customers from claims arising from infringements of copyrights, trade marks or patents unless the design of a delivery object had been made by the Customer. PHYWE's exemption obligations shall be limited to the amount of the predictable damage. An additional requirement for exemption is that in case of a legal dispute (article 72 German Code of Civil Procedure) the Customer informs PHYWE of the dispute and that the alleged legal infringement may be ascribed to the construction of PHYWE's delivery items without combination or use with other products.
2. Optionally PHYWE has the right to free itself from the obligations assumed in clause 1 by either

a) obtaining the required licences regarding the alleged infringed patents, or

b) providing the Customer with a changed delivery item or part of it that rectifies the infringement reproach concerning the delivery item by exchanging it for the infringing delivery items or their parts unless the changed delivery item (or parts of it) falls behind the original performance regarding the usability and/or its value.

§ 12 Liability

1. PHYWE shall be liable for breaches of contractual and non-contractual obligations, including but not limited to impossibility, delay and unlawful acts, only in cases of malicious intent and gross negligence – of its executive employees as well – limited to damages foreseeable at contract conclusion.
2. Claims for damages of material defects shall fall under the statute of limitation after 12 months as of delivery of the goods – with exception of personal injury or wilful or grossly negligent breaches of duty. The limitation of legal regress claims remains unaffected. The relevant legal provisions apply for claims for damages on account of other legal reasons.

§ 13 Applicable law, jurisdiction, partial invalidity

1. In addition to these provisions German law with exemption of the provisions of the UN Convention on Contracts for the International Sale of Goods dated 11/04/1980 (CISG) applies.
2. Place of jurisdiction is Göttingen
3. If a provision in these General Terms and Conditions or a provision under other agreements is or becomes ineffective the validity of all other provisions or agreements shall remain unaffected.

General Terms and Conditions of PHYWE Systeme GmbH & Co. KG, last updated on 01/08/2010

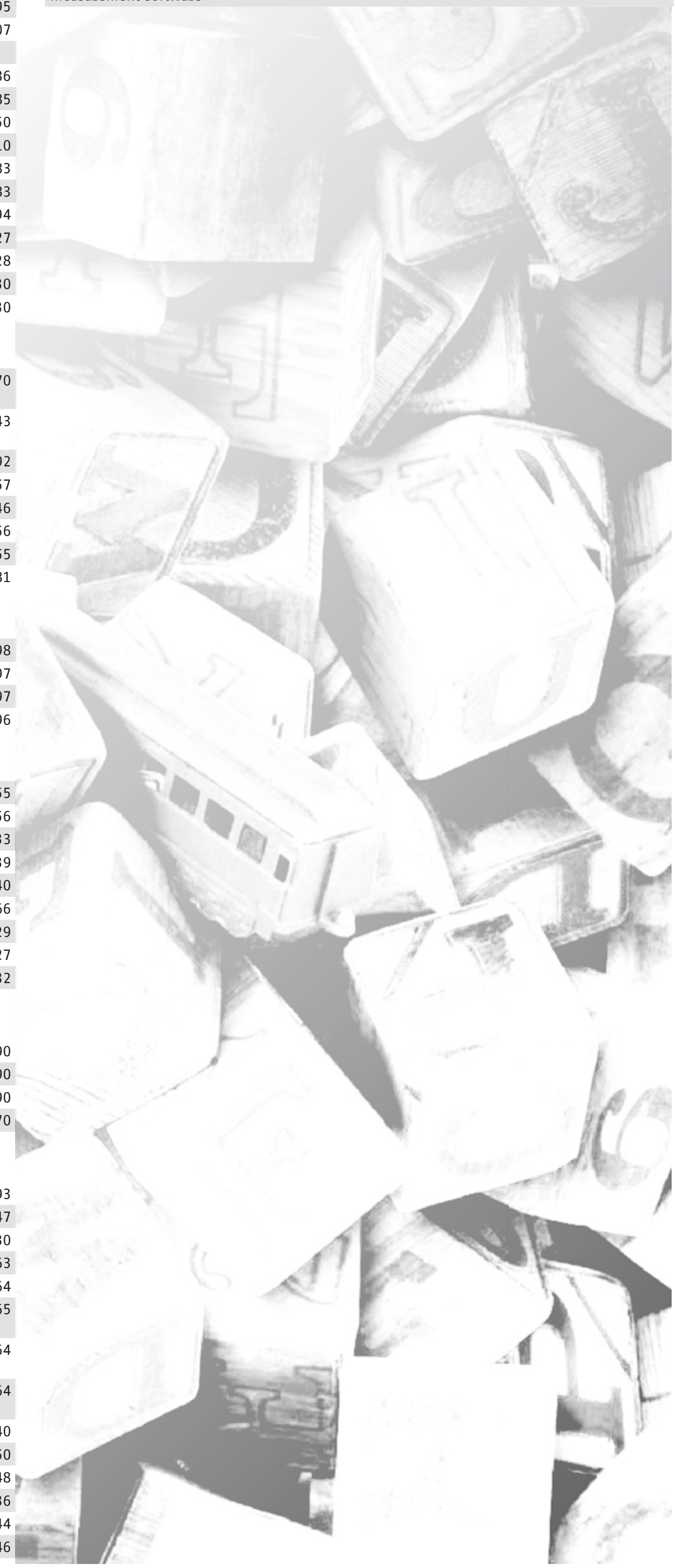
After announcement of new General Terms and Conditions all previous General Terms and Conditions loose their validity.

6 Indices

Numerical Index

6.1 Numerical Index

Alphabetical Index



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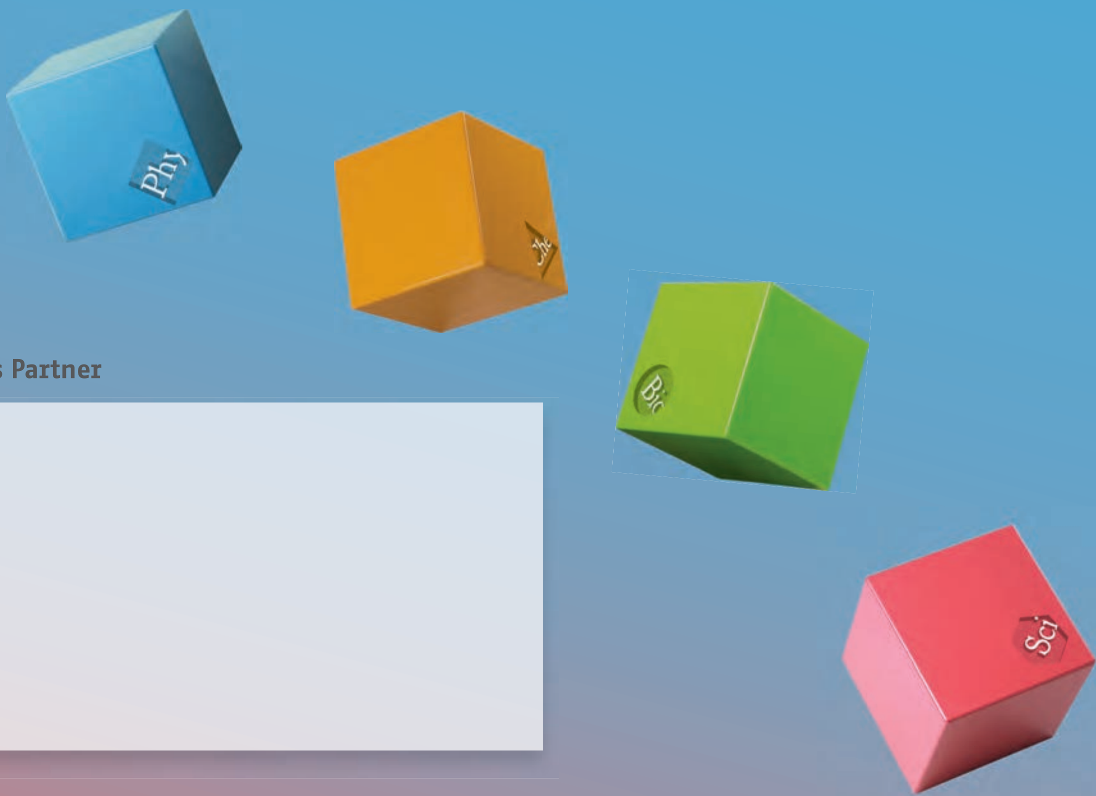
PHYWE Systeme GmbH & Co. KG
Robert-Bosch-Breite 10
37079 Göttingen / Germany

Phone +49 (0) 551 604 - 0
Fax +49 (0) 551 604 - 107

info@phywe.com



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