X-ray Physics

PHYSICS | CHEMISTRY BIOLOGY | ENGINEERING | LD DIDACTIC

With the LEYBOLD X-ray Apparatus and the Computed Tomography accessories a wide range of topics on high schools and universities can be covered.

PRINCIPLES
Radiation imaging X-ray photography Ionisation and Dosimetry Attenuation of X-rays

SOLID STATE PHYSICS
Bragg: Determining the lattice constants of monocrystals Laue: Investigating the lattice structure of monocrystals
Debye-Scherrer: Determining the lattice plane spacings of polycrystalline powder samples

ATOMIC PHYSICS
Bragg: Diffraction of X-rays at a monocrystal
Investigating the energy spectrum of an X-ray tube
Duane-Hunt: Determination of h from the limit wavelength
Energy-dependent absorption, K- and L-edges
Moseley's law and determination of the Rydberg constant
Fine structure of X-ray spectra
Determining the binding energy of individual subshells by selective excitation
X-ray fluorescence Compton effect on X-rays
Digital Laue images of NaCl and LiF (exposure time < 1 min)

3D reconstruction of a frog with the LEYBOLD Computed Tomography software
TECHNICAL APPLICATIONS
Radiology Mineralogy Radiation protection X-ray fluorescence analysis Non-destructive material analysis Non-destructive testing Comput

SOON AFTER THE DISCOVERY OF X-RAYS BY W. C. RÖNTGEN, PHYSICIANS BEGAN TO EXPLOIT THE ABILITY OF THIS RADIATION TO PASS THROUGH MATTER WHICH IS OPAQUE TO ORDINARY LIGHT FOR MEDICAL PURPOSES. THE TECHNIQUE OF CAUSING A LUMINESCENT SCREEN TO FLUORESCE WITH X-RAY RADIATION IS STILL USED TODAY FOR SCREEN EXAMINATIONS, ALTHOUGH IMAGE AMPLIFIERS ARE USED ADDITIONALLY. THE EXPOSURE OF A FILM DUE TO X-RAY RADIATION IS USED BOTH FOR MEDICAL DIAGNOSIS AND MATERIALS TESTING, AND IS THE BASIS FOR DOSIMETRY WITH FILMS.

AS X-RAYS IONIZE GASES, THEY CAN ALSO BE MEASURED VIA THE IONIZATION CURRENT OF AN IONIZATION CHAMBER.

P6.3.1 DETECTION OF X-RAYS

P6.3.1.1 FLUORESCENCE OF A LUMINESCENT SCREEN DUE TO X-RAYS

THE EXPERIMENT P6.3.1.1 DEMONSTRATES THE TRANSILLUMINATION WITH X-RAYS USING SIMPLE OBJECTS MADE OF MATERIALS WITH DIFFERENT ABSORPTION CHARACTERISTICS. A LUMINESCENT SCREEN OF ZINC-CADMIUM SULFATE IS USED TO DETECT X-RAYS; THE ATOMS IN THIS COMPOUND ARE EXCITED BY THE ABSORPTION OF X-RAYS AND EMIT LIGHT QUANTA IN THE VISIBLE LIGHT RANGE. THIS EXPERIMENT INVESTIGATES THE EFFECT OF THE EMISSION CURRENT I OF THE X-RAY TUBE ON THE BRIGHTNESS AND THE EFFECT OF THE HIGH VOLTAGE U ON THE CONTRAST OF THE LUMINESCENT SCREEN.

554800 X-ray apparatus

Basic device fully assembled and adjusted for all tubes, however, without tubes and without goniometer designed for conducting a wide variety of experiments in x-ray physics. The high-voltage system, x-ray tube and experiment chamber are all within a radiation-proof housing. German type approval as school x-ray apparatus and full-protection device. The type approval is valid for all x-ray tubes (Mo, Fe, Cu, Ag, W, Au). The x-ray tubes are delivered completely adjusted and allow thus an easy and user-friendly exchange. Highest safety and operation comfort by an automatic door locking, which unlock the doors automatically, when no x-ray radiation is generated.
Two large displays show all relevant information on the current experiment. The tube voltage and tube current can be set in the ranges 0 to 35 kV and 0 to 1 mA respectively. The built-in rate meter including counter-tube voltage supply enables direct measuring in conjunction with a Geiger-Müller counter tube. The x-ray apparatus can also be connected to a PC via the USB-port (software included) for recording Bragg spectra. Alternative the two analogue outputs (counting rate and angular position) permit data acquisition using a chart recorder.
Two screened coaxial lead-ins and one free access duct provide access to set-ups in the experiment chamber, e.g. for connecting an x-ray energy detector.
Device fully assembled and adjusted, ready for operation.
Scope of delivery:
X-ray apparatus without tube
Cover for fluorescent screen
Dust cover - USB cable
Software for Windows 2000/XP/Vista/7
Technical data:
School x-ray apparatus and full-protection device with German typeapproval for school use (approval No. BFS 05/07 V/SchRöV) (suitable for the operation with the exchangeable tubes: Fe, Cu, Mo, Ag, W)
Dose rate at a distance of 10 cm: < 1 µS/h
Two independent safety circuits for doors, high voltage and emission current
Automatic door locking: doors can be opened only, when no high voltageis present i.e. no x-ray radiation can be generated
High voltage: 0 ... 35.0 kV (regulated DC voltage)
Tube current: 0 ... 1.00 mA (independent regulated DC)
Fluorescent screen for transillumination experiments: d = 15 cm
Built-in rate meter including voltage supply for GM counter tube
Loudspeaker: as an acoustic ratemeter

Two 4-digit displays (25 mm high) for displaying the following as desired: high voltage, anode current, counting rate, target/sensor angle, scanning range, step width, gate time
Exposure timer, gate time: 0.5 s ... 9999 s
Bushings in the experiment chamber: high-voltage coaxial cable, BNC coaxial cable, empty channel for e.g. tubing, cable etc.
Analog outputs: each proportional to target angle and to counting rate for chart recorder connection
USB port for connecting a PC to control the x-ray apparatus, data recording and evaluation by the delivered Windows software
LabVIEW™ driver for Windows and Linux available free of charge at http:/www.ld-didactic.com for user defined controlling and measuring
Input voltage: 230 V (±10 %) / 47 - 63 Hz
Power consumption: 120 VA
Dimensions: 67 cm x 48 cm x 35 cm
Weight: 41 kg

554862 X-ray tube Cu

Directly heated hot cathode tube with screw thread for heat sink and two-pin plug socket for cathode heating for X-ray apparatus (554 800/801).
Anode material: Copper
Characteristic radiation:
K_α = 154 pm (8.04 keV), K_β = 139 pm (8.91 keV)
Max. emission current: 1 mA
Max. anode voltage: 35 kV
Size of focal spot: approx. 2 mm^2
Minimum service life: 300 hours
Absorber foil (to generate monocromatic radiation): Nickel (Ni)
Diameter: 4.5 cm
Length: 20 cm
Weight: 0.3 kg

P6.3.1 DETECTION OF X-RAYS

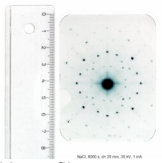
P6.3.1.2 X-RAY PHOTOGRAPHY: EXPOSURE OF FILM STOCK DUE TO X-RAYS

THE EXPERIMENT P6.3.1.2 RECORDS THE TRANSILLUMINATION OF OBJECTS USING X-RAY FILM. MEASURING THE EXPOSURE TIME REQUIRED TO PRODUCE A CERTAIN DEGREE OF EXPOSURE PERMITS QUANTITATIVE CONCLUSIONS REGARDING THE INTENSITY OF THE X-RAYS.

554838 Film holder X-ray

For x-ray apparatus 554 800/554 801, with printed scale for defined positioning of films for transillumination, Laue and Debye-Scherrer photographs; includes experiment rail with millimeter scale and pinhole diaphragm d = 1 mm for attaching to slit-diaphragm collimator. Suitable for x-ray film formats: 38 mm x 35 mm, e.g. Film-Pack 2 or 9 cm x 12 cm e.g. AGFA STRUCTURIX D7 with developer G 128 and fixer G 328.
Dimensions:
Film holder: 12 cm x 16.5 cm
Experiment rail: 25 cm x 16 cm x 6 cm

554896 X-ray film Agfa Dentus M2



X-ray film 5 cm x 7 cm, 25 per pack, welded in light proof plastic foil for use in day light. The film must be removed from the foil for development.

5548931 Changing bag with developer tank

For developing the 554 896 x-ray film and for up to two 35 mm films. Changing bag made of double-layer special material. For putting a film in the development tank during daylight hours.
Dimensions of the changing bag: 55 x 65 cm
Volume of the developer tank: 650 ml

P6.3.1 DETECTION OF X-RAYS

P6.3.1.4 DETERMINING THE ION DOSE RATE OF THE X-RAY TUBE WITH MOLYDENUM ANODE

THE AIM OF THE EXPERIMENTS P6.3.1.3 AND P6.3.1.4 IS TO DETECT X-RAYS USING AN IONIZATION CHAMBER. FIRST, THE IONIZATION CURRENT IS RECORDED AS A FUNCTION OF THE VOLTAGE AT THE CAPACITOR PLATES OF THE CHAMBER AND THE SATURATION RANGE OF THE CHARACTERISTIC CURVES IS IDENTIFIED. NEXT, THE MEAN ION DOSE RATE
[@FP6313@]
IS CALCULATED FROM THE IONIZATION CURRENT I_{ION} WHICH THE X-RADIATION GENERATES IN THE IRRADIATED VOLUME OF AIR V, AND THE MASS M OF THE IRRADIATED AIR. THE MEASUREMENTS ARE CONDUCTED FOR VARIOUS EMISSION CURRENTS I AND HIGH VOLTAGES U OF THE X-RAY TUBE.

P6.3.1 DETECTION OF X-RAYS

P6.3.1.5 INVESTIGATION OF AN IMPLANT MODEL

THE EXPERIMENT P6.3.1.5 DEMONSTRATES THE USE OF RADIOSCOPY TO DETECT HIDDEN OBJECTS. A METAL ROD INSIDE A BLOCK OF WOOD IS VISUALLY INVISIBLE, BUT CAN BE SEEN BY X-RAY FLUORESCENCE AND ITS DIMENSIONS MEASURED.

5548391 Implant model

Wood quader with inserted hidden steel pin for the transillumination in the x-ray apparatus.
Additionally required: Film holder X-ray (554 838)

P6.3.1 DETECTION OF X-RAYS

P6.3.1.6 INFLUENCE OF A CONTRAST MEDIUM ON THE ABSORPTION OF X-RAYS

THE EXPERIMENT P6.3.1.6 DEMONSTRATES THE USE OF CONTRAST MEDIUM. THE RADIOPAQUE IODINE SOLUTION IS FLOWING THROUGH CHANNELS INSIDE A PLATE AND IS CLEARLY VISIBLE IN THE X-RAY FLUORESCENCE IMAGE, BUT PURE WATER IS NOT.

554839 Blood vessel model for contrast medium

for the demonstration of the effect of contrast media.
Plastic plate with covered channels, via screw connections the contrast medium can be injected from outside the x-ray apparatus and its penetration can be observed on the fluorescence screen of the x-ray apparatus.
By variation of the distance, magnification effects can be demonstrated.
Scope of delivery:
Plate with blood vessel model on magnet support
Hose
2 Plastic syringes
2 Stoppers
necessary accessories:
672 6610 Potassium iodide, 100 g

602023 Beaker, 150 ml, low form

with graduation and spout

602295 Bottle brown glass wide treath with cap, 250 ml

602783 Glass rod, 200 mm, Ø 6 mm

6726610 Potassium iodide, 100 g

THE ATTENUATION OF X-RAYS ON PASSING THROUGH AN ABSORBER WITH THE THICKNESS D IS DESCRIBED BY LAMBERT'S LAW FOR ATTENUATION:
[@FP6320_EN@]
HERE, THE ATTENUATION IS DUE TO BOTH ABSORPTION AND SCATTERING OF THE X-RAYS IN THE ABSORBER. THE LINEAR ATTENUATION COEFFICIENT μ DEPENDS ON THE MATERIAL OF THE ABSORBER AND THE WAVELENGTH λ OF THE X-RAYS. AN ABSORPTION EDGE, I.E. AN ABRUPT TRANSITION FROM AN AREA OF LOW ABSORPTION TO ONE OF HIGH ABSORPTION, MAY BE OBSERVED WHEN THE ENERGY H · ν OF THE X-RAY QUANTUM JUST EXCEEDS THE ENERGY REQUIRED TO MOVE AN ELECTRON OUT OF ONE OF THE INNER ELECTRON SHELLS OF THE ABSORBER ATOMS.

P6.3.2 ATTENUATION OF X-RAYS

P6.3.2.1 INVESTIGATING THE ATTENUATION OF X-RAYS AS A FUNCTION OF THE ABSORBER MATERIAL AND ABSORBER THICKNESS

THE OBJECT OF THE EXPERIMENT P6.3.2.1 IS TO CONFIRM LAMBERT'S LAW USING ALUMINIUM AND TO DETERMINE THE ATTENUATION COEFFICIENTS μ FOR SIX DIFFERENT ABSORBER MATERIALS AVERAGED OVER THE ENTIRE SPECTRUM OF THE X-RAY APPARATUS.

554831 Goniometer

With two independently controllable stepping motors which move the sensor and target arm. The motion is defined using the keys in the control panel of the X-ray apparatus (554 800 and 554 801) and initiated manually or automatically. Included in the scope of supply of the X-ray apparatus (554 801).
Working principle: stepping motors for target and sensor arms, which can be electronically coupled
Angular range of target: unlimited (0°… 360°)
Angular range of sensor: approx. -10° to +170°
Angular resolution: 0.1°
Length of sensor arm: approx. 40 -110 mm
Width of sensor slit: 1 mm
Area of target platform: 25 mm x 28 mm
Sample clamping width: 3 - 9 mm
Dimensions: 13.5 cm x 22.5 cm x 12.5 cm
Weight: 3 kg

55901 End-window counter with cable

for alpha, beta, gamma, and X-rays; self-quenching Geiger counter tube in plastic case with very thin mica end window.
Gas filling: neon, argon, halogen
Avarage operating voltage: 450 V
Connection: screened cable, with coaxial plug (Amphenol-Tuchel T 3162/1)
Plateau: l = 200 V
Dead time: 100 µs
Plateau transconductance: 0.05 %/V
Service Life: > 10^{10} pulses
Background effect on the plateau: 0.2 imp/s
Sensitivity (gamma): 1 % approx.
Window: d = 9 mm
Mass per unit area: 2 mg cm^{-2}
Dimensions: 75 mm x 24 mm dia.

554834 Absorption accessory X-ray

For x-ray apparatus 554 801/811, two absorbers for quantitative investigation of the attenuation of x-rays as a function of the thickness and the atomic number of the absorber.
Thickness graduation of aluminum absorber: 0.5/1.0/2.0 /2.5 and 3.0 mm
Material and atomic number for absorbers of constant thickness (0.5 mm):
polystyrene: Z = 6
aluminum: Z = 13
iron: Z = 26
copper: Z = 29
zirconium: Z = 40
silver: Z = 47
Dimensions of diaphragm: 2.5 x 15 mm
Diaphragm spacing: 5 mm (approx. 10°)
Dimensions: 40 mm x 35 mm x 8 mm each.

P6.3.2 ATTENUATION OF X-RAYS

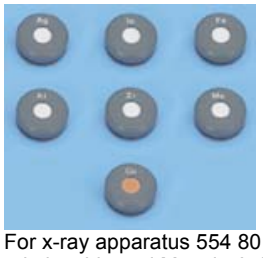
P6.3.2.2 INVESTIGATING THE WAVELENGTH DEPENDENCY OF THE ATTENUATION COEFFICIENT

THE EXPERIMENT P6.3.2.2 RECORDS THE TRANSMISSION CURVES
[@FP6322@]
FOR VARIOUS ABSORBER MATERIALS. THE AIM OF THE EVALUATION IS TO CONFIRM THE λ^3 RELATIONSHIP OF THE ATTENUATION COEFFICIENTS FOR WAVELENGTHS OUTSIDE OF THE ABSORPTION EDGES.

55478 NaCl crystal for Bragg reflection

fitting the goniometer of the X-ray apparatus (554 801), for experiments with Bragg's arrangement.
Lattice-plane spacing: 282 pm
Reflection angle for molybdenum K_α radiation (1st order): 7.24°
Crystal structure: face-centered cubic
Surface: parallel [100]
Dimensions: 25 mm x 25 mm x 4 mm

554832 Set of Absorber Foils



For x-ray apparatus 554 801/811, e.g. for experiments on the Z^4 relationship and Moseley's law; foils mounted in holder for attaching to slit diaphragm collimator or counter-tube holder.
Foil materials:
Al: Z = 13, thickness = 0.5 mm
Fe: Z = 26, thickness = 0.5 mm
Cu: Z = 29, thickness = 0.07 mm
Zr: Z = 40, thickness = 0.05 mm
Mo: Z = 42, thickness = 0.1 mm
Ag: Z = 47, thickness = 0.05 mm
In: Z = 49, thickness = 0.3 mm
Frame: 24 mm Ø x 11 mm
Foils: 10 mm Ø

ADDITIONALLY REQUIRED:
PC WITH WINDOWS 2000/XP/VISTA

P6.3.2 ATTENUATION OF X-RAYS

P6.3.2.3 INVESTIGATING THE RELATIONSHIP BETWEEN THE ATTENUATION COEFFICIENT AND THE ATOMIC NUMBER Z

IN THE EXPERIMENT P6.3.2.3, THE ATTENUATION COEFFICIENT $\mu(\lambda)$ OF DIFFERENT ABSORBER MATERIALS IS DETERMINED FOR A WAVELENGTH λ WHICH LIES OUTSIDE OF THE ABSORPTION EDGE. THIS EXPERIMENT REVEALS THAT THE ATTENUATION COEFFICIENT IS CLOSELY PROPORTIONAL TO THE FOURTH POWER OF THE ATOMIC NUMBER Z OF THE ABSORBERS.

THE RADIATION OF AN X-RAY TUBE CONSISTS OF TWO COMPONENTS: CONTINUOUS BREMSSTRAHLUNG RADIATION IS GENERATED WHEN FAST ELECTRONS ARE DECELERATED IN THE ANODE. CHARACTERISTIC RADIATION CONSISTING OF DISCRETE LINES IS FORMED BY ELECTRONS DROPPING TO THE INNER SHELLS OF THE ATOMS OF THE ANODE MATERIAL FROM WHICH ELECTRONS WERE LIBERATED BY COLLISION.

P6.3.3 PHYSICS OF THE ATOMIC SHELL

P6.3.3.1 BRAGG REFLECTION: DIFFRACTION OF X-RAYS AT A MONOCRYSTAL

TO CONFIRM THE WAVE NATURE OF X-RAYS, THE EXPERIMENT P6.3.3.1 INVESTIGATES THE DIFFRACTION OF THE CHARACTERISTIC K_α AND K_β LINES OF THE MOLYBDENUM ANODE AT AN NACL MONOCRYSTAL AND EXPLAINS THESE USING BRAGG'S LAW OF REFLECTION.

ADDITIONALLY REQUIRED:
PC WITH WINDOWS 2000/XP/VISTA

P6.3.3 PHYSICS OF THE ATOMIC SHELL

P6.3.3.2 INVESTIGATING THE ENERGY SPECTRUM OF AN X-RAY TUBE AS A FUNCTION OF THE HIGH VOLTAGE AND THE EMISSION CURRENT

THE EXPERIMENT P6.3.3.2 RECORDS THE ENERGY SPECTRUM OF THE X-RAY APPARATUS AS A FUNCTION OF THE HIGH VOLTAGE AND THE EMISSION CURRENT USING A GONIOMETER IN THE BRAGG CONFIGURATION. THE AIM IS TO INVESTIGATE THE SPECTRAL DISTRIBUTION OF THE CONTINUUM OF BREMSSTRAHLUNG RADIATION AND THE INTENSITY OF THE CHARACTERISTIC LINES.

ADDITIONALLY REQUIRED:
PC WITH WINDOWS 2000/XP/VISTA

P6.3.3 PHYSICS OF THE ATOMIC SHELL

P6.3.3.3 DUANE-HUNT RELATION AND DETERMINATION OF PLANCK'S CONSTANT

THE EXPERIMENT P6.3.3.3 MEASURES HOW THE LIMIT WAVELENGTH λ_{MIN} OF THE CONTINUUM OF BREMSSTRAHLUNG RADIATION DEPENDS ON THE HIGH VOLTAGE U OF THE X-RAY TUBE. WHEN WE APPLY THE DUANE-HUNT RELATIONSHIP
[@FP6333_EN@]
TO THE MEASUREMENT DATA, WE CAN DERIVE PLANCK'S CONSTANT H.

ADDITIONALLY REQUIRED:
PC WITH WINDOWS 2000/XP/VISTA

P6.3.3 PHYSICS OF THE ATOMIC SHELL

P6.3.3.5 EDGE ABSORPTION: FILTERING X-RAYS

THE OBJECT OF THE EXPERIMENT P6.3.3.5 IS TO FILTER X-RAYS USING THE ABSORPTION EDGE OF AN ABSORBER, I. E. THE ABRUPT TRANSITION FROM AN AREA OF LOW ABSORPTION TO ONE OF HIGH ABSORPTION.

ADDITIONALLY REQUIRED:
PC WITH WINDOWS 2000/XP/VISTA

P6.3.3 PHYSICS OF THE ATOMIC SHELL

P6.3.3.6 MOSELEY'S LAW AND DETERMINATION OF THE RYDBERG CONSTANT

THE EXPERIMENT P6.3.3.6 DETERMINES THE WAVELENGTHS λ_K OF THE ABSORPTION EDGES AS AS FUNCTION OF THE ATOMIC NUMBER Z. WHEN WE APPLY MOSELEY'S LAW
[@FP6336@]
TO THE MEASUREMENT DATA WE OBTAIN THE RYDBERG CONSTANT R AND THE MEAN SCREENING σ.

ADDITIONALLY REQUIRED:
PC WITH WINDOWS 2000/XP/VISTA

THE X-RAY ENERGY DETECTOR ENABLES RECORDING OF THE ENERGY SPECTRUM OF X-RAYS. THE DETECTOR IS A PELTIER-COOLED PHOTODIODE WHERE IN THE INCOMING X-RAYS PRODUCE ELECTRON-HOLE PAIRS. THE NUMBER OF ELECTRON-HOLE PAIRS AND THUS THE VOLTAGE PULSE HEIGHT AFTER AMPLIFICATION IS PROPORTIONAL TO THE X-RAY ENERGY. THE PULSE HEIGHT ANALYSIS IS CARRIED OUT WITH CASSY USED AS A MULTICHANNEL ANALYZER (MCA-BOX), WHICH IS CONNECTED TO A COMPUTER (PC).

P6.3.5 X-RAY ENERGY SPECTROSCOPY

P6.3.5.1 RECORDING AND CALIBRATING AN X-RAY ENERGY SPECTRUM

THE OBJECT OF THE EXPERIMENT P6.3.5.1 IS TO RECORD THE X-RAY FLUORESCENCE SPECTRUM OF A TARGET AND TO USE THE KNOWN ENERGIES FOR CALIBRATION OF THE ENERGY AXIS. THE TARGET IS MADE OF A ZINCPLATED STEEL AND EMITS SEVERAL FLUORESCENT LINES.

559938 X-ray energy detector

For the insert in the X-ray apparatus (554 801) for recording of energy dissolved X-ray spectra in connection with Sensor-CASSY (524 013) and MCA box (524 058). The detector contains a thermoelectric cold silicon PIN-detector as well as the electronics for amplification and preparation of the voltage impulses. The amount of the output impuls is proportional with the energy of the X-ray photon.
Photosensitive area: 0.8 mm Ø
Cooling of the detector: thermoelectric (Peltier element)
Entrance window (plastics): absorption equivalent to graphite with d = 40 µm
Detectable energy field: approx. 2 keV to 60 keV
Energy resolution at E = 6.40 keV (Fe Kα-line): 0.4 keV half-width value
Distribution voltage: ±15 V, +5 V (via plug-in power supply 100...250 V, 50...60 Hz, in scope of delivery)
Output: BNC socket for connection to the MCA box
Dimensions: 60 mm x 120 mm x 60 mm
Weight: 450 g

524013 Sensor-CASSY 2

Cascadable interface device for recording measurement data

- For connection to the USB-port of a computer, another CASSY module or the CASSY display (524 020USB)

- Sensor CASSY (524 010), Sensor CASSY 2 and Power CASSY (524 011USB) can be mixed cascadable
- 3-fold electrical isolation (4-mm inputs A and B, relay R)
- Measurement possible parallel at 4-mm inputs and sensor box connector sites (4 channels)
- Cascading of up to 8 CASSY modules possible (to expand the inputs and outputs)
- Up to 8 analog inputs per Sensor-CASSY retrofittable using sensor boxes
- Automatic sensor box detection (plug and play) by CASSY Lab 2 (524 220)
- Microprocessor-controlled with CASSY operating system (easily updatable via software for function enhancements)
- For use as a benchtop, console or demonstration unit (also in CPS/TPS panel frames)
- Voltage supply 12 V AC/DC via cannon plug or adjacent CASSY module
- Developper Information and LabVIEW™ driver available through our internet homepage

Technical data

- **5 Analog inputs**
  2 Analog voltage inputs A and B on 4-mm safety sockets (electrically isolated)
  Resolution: 12 bits
  Measuring ranges: ±0.1/±0.3/±1/±3/±10/±30/±100/±250 V
  Measurement error: ± 1 % plus 0.5 % of range end value
  Input resistance: 1 MΩ
  Scanning rate: up to 1 MHz per input
  Amount of measured values: nearly unlimited (dependent on PC) up to 10,000 values/s, at higher measuring rate max. 200,000 values
  Pre trigger: up to 50,000 values per input
  1 Analog current input A on 4-mm safety sockets (alternatively to voltage input A)
  Measuring ranges: ±0.03/±0.1/±0.3/±1/±3 A
  Measurement error: voltage error plus 1 %
  Input resistance: < 0.5 Ω
  Scanning rate: up to 1 MHz per input
  See voltage inputs for further data
  2 Analog inputs at sensor box connector sites A and B
  (All CASSY sensor boxes and sensors can be connected)
  Measuring ranges: ±0.003/±0.01/±0.03/±0.1/±0.3/±1 V
  Input resistance: 10 kΩ
  Scanning rate: up to 500 kHz per input
  See voltage inputs for further data
  The technical data will change depending on a connected sensor box. In this case CASSY Lab 2 automatically detects the possible measurement quantities and ranges when a sensor box is attached.
- **4 Timer inputs** with 32-bit counters at sensor box sites A and B (e.g. for GM box, timer box or Timer S)
  Counting frequency: max. 1 MHz
  Time resolution: 20 ns
- **5 LED status indicators** for analog inputs and USB-port
  Colours: red and green, according to status
  Light intensity: adjustable
- **1 Changeover relay** (switching indication via LED)
  Range: max. 250 V/2 A
- **1 Analog output** (LED switching state indicator, e.g. for holding magnet or supplying experiment)
  Variable voltage range: max. 16 V/200 mA (load ≥ 80 Ω)
- **12 Digital inputs** (TTL) on sensor box sites A and B (at present only used for automatic sensor box detection)
- **6 Digital outputs** (TTL) on sensor box sites A and B (at present only used for automatic switching of a sensor box measuring range)
- **1 USB-port** for connection to a computer
- **1 CASSY bus** for connecting additional CASSY modules
- Dimensions (WxHxD): 115 mm x 295 mm x 45 mm
- Weight: 1.0 kg

Scope of supply:
1 Sensor-CASSY 2
1 CASSY Lab 2 software, without activation code, with comprehensive help function (16 full-functionality sessions free, then usable as demo version)
1 USB cable
1 Plug-in supply unit 230 V, 12 V/1.6 A

524220 CASSY Lab 2

Improved development of the successful CASSY Lab software for recording and evaluating measurement data acquired using the CASSY family, with comprehensive integrated help functionality and many operable experiment examples.

- Supports up to 8 Sensor-CASSYs 2, Sensor-CASSYs and Power-CASSYs at a USB-port respectively at one serial interface
- Supports Pocket-CASSYs or Mobile-CASSYs at different USB-ports
- Supports Joule and Wattmeter and Universal Measuring Instruments Physics, Chemistry and Biology
- Supports all CASSY sensor boxes
- Additionally supports numerous devices via the serial interface (e.g. VideoCom, IRPD, balance)
- "Plug and play" enabled for easy use: the software automatically detects the connected CASSYs and sensor boxes and displays these graphically, inputs and outputs are activated simply by pointing and clicking and typical experiment parameters are automatically loaded (depending on the connected sensor box)
- Measurement data can be displayed in the form of analog/digital instruments, tables and/or diagrams (also simultaneously, with user-definable axis assignment)
- Measured values can be recorded manually (at keystroke) or automatically (choice of time interval, measured time, lead time, trigger or additional measurement condition)
- Powerful evaluation functions including various fits (straight line, parabola, hyperbola, exponential function, free fitting), integrals, diagram labeling, calculation of user-definable formulas, differentiation, integration, Fourier transforms
- Experiment files in XML-data format (can also import experiment files which are prepared with CASSY Lab 1)
- Convenient exporting of measurement data and diagrams via the clipboard
- "Logbook" function lets you briefly document other experiment information in the experiment file
- Complete with more than 150 experiment examples from physics, chemistry and biology with detailed descriptions
- Graphical display of CASSY, sensor box and connector allocation when the experiment file is loaded
- Free updates and demo version available through our internet homepage
- PC Requirements: Windows XP/Vista/7 (32+64 bits), free USB-port (USB apparatus) resp. free serial interface (serial apparatus), supports multicore processor

524058 MCA box

For high energy resolution measurement (spectroscopy) of radioactive radiations with Scintillation counter or Semiconductor detector. With voltage supply for the Detector output stage/Discriminator-pre-amplifier.
Resolution: from 256 to 2048 channels (8 to 11 bits) per spectrum
Storage depth: 2 • 10^9 events per channel (31 bits)
Dead time: approx. 60 µs
Energy linearity: < 3% of the final value
Coincidence window: 4 µs
Operating limit for external sensors:
0.5 V to 5 V according to the adjustment of the reductor, positive or negative. Internal reductor and polarity adjustable via software.
High-voltage measurement up to 1.5 kV in connection with the Detector output stage 559 912
Dimensions: 92 mm x 92 mm x 30 mm

50102 BNC cable, 1 m

Plug: BNC/BNC; Impedance: 50 Ohm

ADDITIONALLY REQUIRED:
PC WITH WINDOWS XP/VISTA/7

P6.3.5 X-RAY ENERGY SPECTROSCOPY

P6.3.5.2 RECORDING THE ENERGY SPECTRUM OF A MOLYBDENUM ANODE

THE EXPERIMENTS P6.3.5.2 AND P6.3.5.3 USE THE CALIBRATED DETECTOR TO RECORD EMISSION SPECTRA OF EITHER A MOLYBDENUM ANODE OR A COPPER ANODE. THE RESULTING SPECTRUM SHOWS THE CHARACTERISTIC LINES OF THE ANODE MATERIAL AND THE BREMSSTRAHLUNG CONTINUUM.

ADDITIONALLY REQUIRED:
PC WITH WINDOWS XP/VISTA/7

P6.3.5 X-RAY ENERGY SPECTROSCOPY

P6.3.5.3 RECORDING THE ENERGY SPECTRUM OF A COPPER ANODE

THE EXPERIMENTS P6.3.5.2 AND P6.5.3.3 USE THE CALIBRATED DETECTOR TO RECORD EMISSION SPECTRA OF EITHER A MOLYBDENUM ANODE OR A COPPER ANODE. THE RESULTING SPECTRUM SHOWS THE CHARACTERISTIC LINES OF THE ANODE MATERIAL AND THE BREMSSTRAHLUNG CONTINUUM.

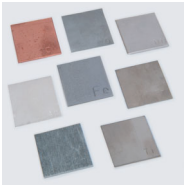
ADDITIONALLY REQUIRED:
PC WITH WINDOWS XP/VISTA/7

P6.3.5 X-RAY ENERGY SPECTROSCOPY

P6.3.5.4 INVESTIGATION OF THE CHARACTERISTIC SPECTRA AS A FUNCTION OF THE ELEMENT'S ATOMIC NUMBER: K-LINES

THE EXPERIMENT P6.3.5.4 DEMONSTRATES DIFFERENCES IN THE CHARACTERISTIC FLUORESCENT K-LINES (TRANSITIONS TO K-SHELL) WITHIN THE X-RAY SPECTRA OF DIFFERENT ELEMENTS. THESE ARE USED TO CONFIRM MOSELEY'S LAW AND SHOW ASPECTS OF MATERIAL ANALYSIS.

554844 Set of targets K-line fluorescence



For recording the X-ray fluorescence spectrum of different elements in the X-ray apparatus in connection with the X-ray energy detector, Sensor-CASSY and MCA box.
Materials: Ti, Fe, Ni, Cu, Zn, Zr, Mo, Ag
Dimensions: 25 mm x 25 mm

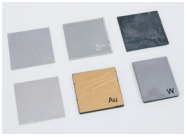
ADDITIONALLY REQUIRED:
PC WITH WINDOWS XP/VISTA/7

P6.3.5 X-RAY ENERGY SPECTROSCOPY

P6.3.5.5 INVESTIGATION OF THE CHARACTERISTIC SPECTRA AS A FUNCTION OF THE ELEMENT'S ATOMIC NUMBER: L-LINES

THE EXPERIMENT P6.3.5.5 SHOWS SIMILAR CHARACTERISTIC FLUORESCENT L-LINES FOR HEAVIER ELEMENTS, DEMONSTRATING THE X-RAY EMISSION FROM TRANSITIONS TO THE L-SHELL.

554846 Set of targets L-line fluorescence



For recording the X-ray fluorescence spectrum of different elements in the X-ray apparatus in connection with the X-ray energy detector, Sensor-CASSY and MCA box.
Materials: Ag, In, Sn, W, Au, Pb
Dimensions: 25 mm x 25 mm

ADDITIONALLY REQUIRED:
PC WITH WINDOWS XP/VISTA/7

P6.3.5 X-RAY ENERGY SPECTROSCOPY

P6.3.5.6 ENERGY-RESOLVED BRAGG REFLECTION IN DIFFERENT ORDERS OF DIFFRACTION

IN THE EXPERIMENT P6.3.5.6 USING THE X-RAY ENERGY DETECTOR IN BRAGG GEOMETRY IT IS POSSIBLE TO OBSERVE DIFFERENT X-RAY ENERGIES

SIMULTANEOUSLY, BECAUSE BRAGG CONDITION IS FULFILLED FOR DIFFERENT ORDERS.

ADDITIONALLY REQUIRED:
PC WITH WINDOWS XP/VISTA/7

THE STRUCTURE AND FINE-STRUCTURE OF X-RAY SPECTRA GIVES VALUABLE INFORMATION ON THE POSITION OF THE ATOMIC ENERGY LEVELS. THE SYSTEMATICS OF X-RAY TRANSITIONS ARE PRESENTED. STARTING WITH MOLYBDENUM AND COMPLETED WITH OTHER ANODE MATERIALS LIKE COPPER AND IRON THE K-SHELL TRANSITIONS OF LIGHT AND MEDIUM ELEMENTS ARE INVESTIGATED. IN CONTRAST TO THESE MATERIALS THE HEAVY ELEMENTS LIKE TUNGSTEN SHOW CHARACTERISTIC EMISSION FROM THE L-SHELL WITH A LOT OF DETAILS, BECAUSE THE LOWER LEVEL OF THE TRANSITION CONSITS OF SEVERAL SUBLEVELS WHICH CAN ALSO BE SELECTIVELY EXCITED.

P6.3.6 STRUCTURE OF X-RAY SPECTRUMS

P6.3.6.2 FINE STRUCTURE OF THE CHARACTERISTIC X-RAY RADIATION OF A COPPER ANODE

THE EXPERIMENTS P6.3.6.2 AND P6.3.6.3 OBSERVE THE LOW-ENERGY CHARACTERISTIC RADIATION FROM A COPPER OR IRON ANODE AND THE FINE STRUCTURE OF THE K_A LINE.

554791 KBr crystal for Bragg reflection

Designed to fit goniometer of the x-ray apparatus (554 801).
For experiments in Bragg's configuration, e.g. diffraction (up to the 6th order), x-ray spectra, wavelength determination, Duane and Hunt's displacement law, determining Planck's constant, dependence of absorption on wavelength, determination of lattice plane spacings.
Lattice-plane spacing: 330 pm
Reflection angle for molybdenum K_α-radiation (1st order): 6.2°
Crystal structure: face-centered cubic
Surface: parallel [100]
Dimensions: 25 mm x 25 mm x 4 mm

ADDITIONALLY REQUIRED:
PC WITH WINDOWS 2000/XP/VISTA

P6.3.6 STRUCTURE OF X-RAY SPECTRUMS

P6.3.6.6 DETERMINING THE BINDING ENERGY OF INDIVIDUAL SUBSHELLS BY SELECTIVE EXCITATION

IN ADDITION TO EXPERIMENT P6.3.6.5, THE EXPERIMENT P6.3.6.6 MEASURES DIRECTLY THE SPLITTING OF THE L-SHELL. AT A LOW ACCELERATION VOLTAGE ONLY THE L3 LEVEL CAN BE EXITED, WITH RAISING VOLTAGES TRANSITIONS TO L2 AND LATER L1 BECOME OBSERVABLE. THE ABSOLUTE BINDING ENERGIES OF THE L-SUBLEVELS CAN BE MEASURED DIRECTLY.

ADDITIONALLY REQUIRED:
PC WITH WINDOWS 2000/XP/VISTA

AT A TIME (EARLY 1920'S) WHEN THE PARTICLE NATURE OF LIGHT (PHOTONS) SUGGESTED BY THE PHOTOELECTRIC EFFECT WAS STILL BEING DEBATED, THE COMPTON EXPERIMENT, THE SCATTERING OF X-RAYS ON WEAKLY BOUND ELECTRONS, IN 1923 GAVE ANOTHER EVIDENCE OF PARTICLE-LIKE BEHAVIOUR OF X-RAYS IN THIS PROCESS.
COMPTON INVESTIGATED THE SCATTERING OF X-RAYS PASSING THROUGH MATTER. ACCORDING TO CLASSICAL PHYSICS THE FREQUENCY OF THE RADIATION SHOULD NOT BE CHANGED BY THE SCATTERING PROCESS. HOWEVER, A. H. COMPTON OBSERVED A FREQUENCY CHANGE FOR SCATTERED X-RAYS. HE INTERPRETED THIS IN THE PARTICLE MODEL AS A COLLISION OF THE X-RAY PHOTON AND AN ELECTRON OF THE SCATTERING MATERIAL. ASSUMING TOTAL ENERGY AND MOMENTUM TO BE CONSERVED, ENERGY IS TRANSFERRED FROM THE PHOTON TO THE ELECTRON, SO THE ENERGY OF THE SCATTERED PHOTON DEPENDS ON THE SCATTERING ANGLE ϑ.

P6.3.7 COMPTON EFFECT AT X-RAYS

P6.3.7.1 COMPTON EFFECT: VERIFYING THE ENERGY LOSS OF THE SCATTERED X-RAY QUANTUM

THE EXPERIMENT P6.3.7.1 VERIFIES THE COMPTON SHIFT USING THE ENDWINDOW COUNTER. THE CHANGE OF FREQUENCY OR WAVELENGTH DUE TO THE SCATTERING PROCESS IS APPARENT AS A CHANGE OF THE ATTENUATION OF AN ABSORBER, WHICH IS PLACED EITHER IN FRONT OF OR BEHIND THE SCATTERING BODY.

554836 Compton accessory X-ray

For x-ray apparatus 554 801/811, for investigating the Compton effect by means of wavelength-dependent transmission as a function of the placement of the Cu filter in front of or behind the aluminum scattering body; with aluminum scattering body and copper filter in frame.
Aluminum scattering body: 25 mm x 25 mm x 4 mm
Copper filter:
Frame: 24 mm Ø x 11 mm
Foil: 10 mm x 0.07 mm

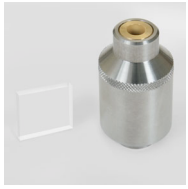
P6.3.7 COMPTON EFFECT AT X-RAYS

P6.3.7.2 COMPTON EFFECT: MEASUREMENT THE ENERGY OF THE SCATTERED PHOTONS AS A FUNCTION OF THE SCATTERING ANGLE

THE OBJECT OF THE EXPERIMENT P6.3.7.2 IS TO RECORD DIRECTLY THE ENERGY SPECTRA OF THE

SCATTERED X-RAYS WITH THE X-RAY ENERGY DETECTOR AS A FUNCTION OF THE SCATTERING ANGLE ϑ. THE ENERGY E(ϑ) OF THE SCATTERED PHOTONS AT DIFFERENT ANGLES IS DETERMINED AND COMPARED WITH THE CALCULATED ENERGY OBTAINED FROM CONSERVATION OF ENERGY AND MOMENTUM BY USING THE RELATIVISTIC EXPRESSION FOR THE ENERGY:
[@FP6372_EN@]

5548371 Compton accessory X-ray II



For investigating the Compton-effect on X-ray radiation in combination with the X-ray energy detector (559 938) and the X-ray apparatus (554 801). Consists of a circular collimator and a Plexiglas radiation body.
Dimensions: 25 mm x 25 mm x 6 mm

ADDITIONALLY REQUIRED:
PC WITH WINDOWS XP/VISTA/7

X-RAYS ARE AN ESSENTIAL TOOL TO DETERMINE THE STRUCTURE OF CRYSTALS. THE LATTICE PLANES INSIDE A CRYSTAL ARE IDENTIFIED BY THEIR MILLER IDICES H, K, L AND REFLECT THE X-RAYS ONLY IF THE LAUE OR BRAGG CONDITIONS ARE FULFILLED. THE DISTRIBUTION OF REFLEXES ALLOWS TO CALCULATE THE LATTICE CONSTANT AND CRYSTAL STRUCTURE OF THE INVESTIGATED CRYSTAL.

P7.1.2 X-RAY STRUCTURAL ANALYSIS

P7.1.2.1 BRAGG REFLECTION: DETERMINING THE LATTICE CONSTANTS OF MONOCRYSTALS

IN THE EXPERIMENT P7.1.2.1, THE BRAGG REFLECTION OF MO-K_α RADIATION (λ = 71.080 PM) AT NACL AND LIF MONOCRYSTALS IS USED TO DETERMINE THE LATTICE CONSTANT. THE K_β COMPONENT OF THE X-RAY RADIATION CAN BE SUPPRESSED USING A ZIRCONIUM FILTER

ADDITIONALLY REQUIRED:
PC WITH WINDOWS 2000/XP/VISTA

P7.1.2 X-RAY STRUCTURAL ANALYSIS

P7.1.2.2 LAUE DIAGRAMS: INVESTIGATING THE LATTICE STRUCTURE OF MONOCRYSTALS

TO MAKE LAUE DIAGRAMS AT NACL AND LIF MONOCRYSTALS, THE BREMSSTRAHLUNG RADIATION OF THE X-RAY APPARATUS IS USED IN THE EXPERIMENT P7.1.2.2 AS "WHITE" X-RADIATION. THE POSITIONS OF THE "COLORED" REFLECTIONS ON AN X-RAY FILM BEHIND THE CRYSTAL AND THEIR INTENSITIES CAN BE USED TO DETERMINE THE CRYSTAL STRUCTURE AND THE LENGTHS OF THE CRYSTAL AXES THROUGH APPLICATION OF THE LAUE CONDITION.

55488 NaCl crystal for Laue diagrams

for Laue diagrams in connection with the X-ray apparatus (554811/812)
Dimensions: 8 mm x 8 mm x 0,3 mm
Lattice-plane spacing: 282 pm
Crystal structure: face-centred cubic
Surface: parallel [100]

5548931 Changing bag with developer tank

For developing the 554 896 x-ray film and for up to two 35 mm films. Changing bag made of double-layer special material. For putting a film in the development tank during daylight hours.
Dimensions of the changing bag: 55 x 65 cm
Volume of the developer tank: 650 ml

P7.1.2 X-RAY STRUCTURAL ANALYSIS

P7.1.2.3 DEBYE-SCHERRER PHOTOGRAPHY: DETERMINING THE LATTICE PLANE SPACINGS OF POLYCRYSTALLINE POWDER SAMPLES

IN THE EXPERIMENT P7.1.2.3, DEBYE-SCHERRER PHOTOGRAPHS ARE PRODUCED BY IRRADIATING SAMPLES OF A FINE CRYSTAL POWDER WITH MO-K_α RADIATION. AMONG MANY UNORDERED CRYTALLITES OF THE SAMPLE, THE X-RAYS DIFFRACT AT THOSE WHICH HAVE AN ORIENTATION CONFORMING TO THE BRAGG CONDITION. THE DIFFRACTED RAYS DESCRIBE CONICAL SECTIONS FOR WHICH THE APERTURE ANGLES ϑ CAN BE DERIVED FROM A PHOTOGRAPH. THIS EXPERIMENT DETERMINES THE LATTICE SPACING CORRESPONDING TO ϑ AS WELL AS ITS LAUE INDICES H, K, L, AND THUS THE LATTICE STRUCTURE OF THE CRYSTALLITE.

667091 Pestle, 100 mm long

with unglazed grinding surface, suitable for mortars of 70 mm Ø

667092 Mortar, porcelain, 70 mm Ø

with spout, 35 mm high

666960 Micro powder spoon, 150 x 5 mm

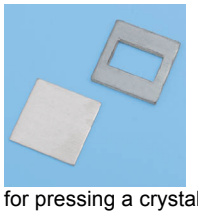
made of stainless steel

P7.1.2 X-RAY STRUCTURAL ANALYSIS

P7.1.2.4 DEBYE-SCHERRER SCAN: DETERMINING THE LATTICE PLANE SPACINGS OF POLYCRYSTALLINE POWDER SAMPLES

THE EXPERIMENT P7.1.2.4, WHICH IS ANALOGUE TO EXPERIMENT P7.1.2.3, USES AN END WINDOW COUNTER INSTEAD OF X-RAY FILM. THE DIFFRACTED REFLECTIONS OF A FINE POWDER SAMPLE ARE RECORDED AS A FUNCTION OF TWICE THE ANGLE OF INCIDENCE 2ϑ. THE INTENSITY PEAKS IN THE DIFFRACTION SPECTRUM ALLOW THE CALCULATION OF THE SEPARATIONS OF ADJACENT LATTICE PLANES.

554842 Crystal powder holder



for pressing a crystal powder and then measuring the X-ray diffraction spectrums with powder samples in the X-ray apparatus.
Dimensions: 25 x 25 x 3 mm each
Weight: 10 g

Relação dos experimentos possíveis realizados com o conjunto apresentado acima.
Total 30 experimentos:

P6.3.1 detecção de Raios X
P6.3.1.1 fluorescência de tela fluorescente provocada por Raios X
P6.3.1.2 fotografia de Raios X: escurecimento de filmes causada por Raios X
P6.3.1.3 detecção de Raios X com uma câmara de ionização
P6.3.1.4 determinação da intensidade de uma dose ionizante do tubo de Raios X com anodo de Mo
P6.3.1.5 investigação de um modelo de implante
P6.3.1.6 influencia da substancia de contraste pela absorção de Raios X

P6.3.2 atenuação de Raios X
P6.3.2.1 estudo da atenuação de Raios X em função do material e espessura do absorvedor
P6.3.2.2 estudo do coeficiente de atenuação em função do comprimento de onda
P6.3.2.3 estudo do coeficiente de atenuação em função do número atómico z

P6.3.3 física das camadas atômicas
P6.3.3.1 reflexão de bragg: difração de Raios X em um monocristal
P6.3.3.2 estudo dos espectros de energia em função da alta tensão e da corrente de emissão
P6.3.3.3 lei do deslocamento de duane-humt e determinação da constante de planck
P6.3.3.5 absorção em forma de cantos: filtros de Raios X
P6.3.3.6 lei de moseley e determinação da constante de rydberg

P6.3.5 espectroscopia energética de Raios X
P6.3.5.1 registro e calibração de um espectro energético de Raios X
P6.3.5.2 registro do espectro energético de um anodo de Mo
P6.3.5.3 registro do espectro energético de um anodo de Cu
P6.3.5.4 investigação do espectro característico em função do número atômico: linhas k
P6.3.5.5 investigação do espectro característico em função do número atômico: linhas l
P6.3.5.6 reflexão de bragg resulta energeticamente em ordens distintas de difração

P6.3.6 estrutura de espectros de Raios X
P6.3.6.2 estrutura fina dos Raios X característicos de um anodo de Cu
P6.3.6.6 determinação da energia de ligação das camadas corticales separadas l por

excitación selectiva

P6.3.7 efeito Compton em Raios X
P6.3.7.2 efeito Compton: medição da energia dos fótons dispersos em função do angulo de dispersão

P7.1.2 análise da estrutura cristalina mediante Raios X
P7.1.2.1 reflexão de Bragg: determinação de constantes de red de monocristais
P7.1.2.2 método Laue: estudo da estrutura cristalina de monocristais
P7.1.2.3 método de Debye-Scherrer: determinação da distancia reticular interplanar de amostras de polvo policristalino
P7.1.2.4 escaneo Debye-Scherrer: determinação das distancias de planos de red de pruebas policristalinas em polvo
P7.5.1 análise de fluorescencia de Raios X
P7.5.1.1 aplicação da fluorescencia dos Raios X em análise não destructivo da composição química
P7.5.1.2 determinação da composição química de uma amostra de bronze por análise de fluorescencia de Raios X

X-ray Physics

PHYSICS | CHEMISTRY BIOLOGY | ENGINEERING

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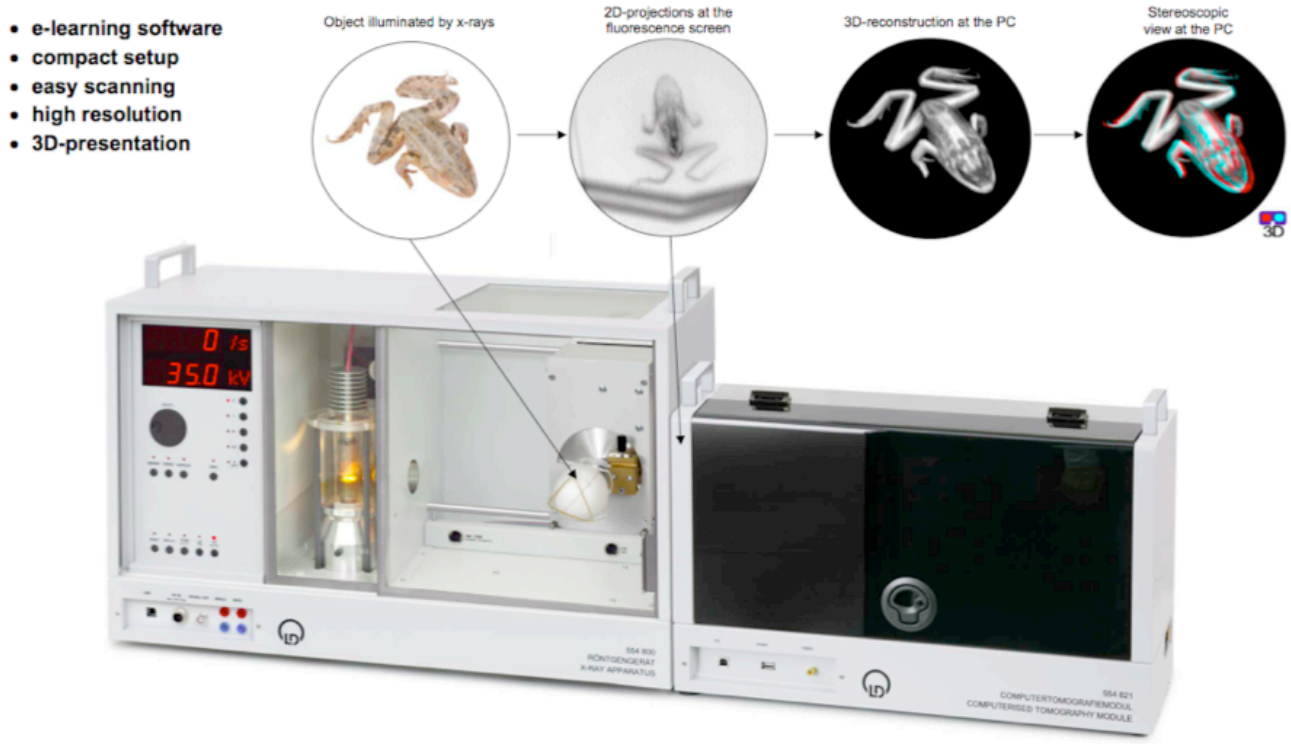


With the LEYBOLD X-ray Apparatus and the Computed Tomography accessories a wide range of topics on high schools and universities can be covered.

PRINCIPLES
Radiation imaging X-ray photography Ionisation and Dosimetry Attenuation of X-rays

SOLID STATE PHYSICS
Bragg: Determining the lattice constants of monocrystals Laue: Investigating the lattice structure of monocrystals
Debye-Scherrer: Determining the lattice plane spacings of polycrystalline powder samples

ATOMIC PHYSICS
Bragg: Diffraction of X-rays at a monocrystal
Investigating the energy spectrum of an X-ray tube
Duane-Hunt: Determination of h from the limit wavelength
Energy-dependent absorption, K- and L-edges
Moseley's law and determination of the Rydberg constant
Fine structure of X-ray spectra
Determining the binding energy of individual subshells by selective excitation
X-ray fluorescence Compton effect on X-rays
Digital Laue images of NaCl and LiF (exposure time < 1 min)

3D reconstruction of a frog with the LEYBOLD Computed Tomography software
TECHNICAL APPLICATIONS
Radiology Mineralogy Radiation protection X-ray fluorescence analysis Non-destructive material analysis Non-destructive testing Comput

SOON AFTER THE DISCOVERY OF X-RAYS BY W. C. RÖNTGEN, PHYSICIANS BEGAN TO EXPLOIT THE ABILITY OF THIS RADIATION TO PASS THROUGH MATTER WHICH IS OPAQUE TO ORDINARY LIGHT FOR MEDICAL PURPOSES. THE TECHNIQUE OF CAUSING A LUMINESCENT SCREEN TO FLUORESCE WITH X-RAY RADIATION IS STILL USED TODAY FOR SCREEN EXAMINATIONS, ALTHOUGH IMAGE AMPLIFIERS ARE USED ADDITIONALLY. THE EXPOSURE OF A FILM DUE TO X-RAY RADIATION IS USED BOTH FOR MEDICAL DIAGNOSIS AND MATERIALS TESTING, AND IS THE BASIS FOR DOSIMETRY WITH FILMS.

AS X-RAYS IONIZE GASES, THEY CAN ALSO BE MEASURED VIA THE IONIZATION CURRENT OF AN IONIZATION CHAMBER.

P6.3.1 DETECTION OF X-RAYS

P6.3.1.1 FLUORESCENCE OF A LUMINESCENT SCREEN DUE TO X-RAYS

THE EXPERIMENT P6.3.1.1 DEMONSTRATES THE TRANSILLUMINATION WITH X-RAYS USING SIMPLE OBJECTS MADE OF MATERIALS WITH DIFFERENT ABSORPTION CHARACTERISTICS. A LUMINESCENT SCREEN OF ZINC-CADMIUM SULFATE IS USED TO DETECT X-RAYS; THE ATOMS IN THIS COMPOUND ARE EXCITED BY THE ABSORPTION OF X-RAYS AND EMIT LIGHT QUANTA IN THE VISIBLE LIGHT RANGE. THIS EXPERIMENT INVESTIGATES THE EFFECT OF THE EMISSION CURRENT I OF THE X-RAY TUBE ON THE BRIGHTNESS AND THE EFFECT OF THE HIGH VOLTAGE U ON THE CONTRAST OF THE LUMINESCENT SCREEN.

554800 X-ray apparatus

Basic device fully assembled and adjusted for all tubes, however, without tubes and without goniometer designed for conducting a wide variety of experiments in x-ray physics. The high-voltage system, x-ray tube and experiment chamber are all within a radiation-proof housing. German type approval as school x-ray apparatus and full-protection device. The type approval is valid for all x-ray tubes (Mo, Fe, Cu, Ag, W, Au). The x-ray tubes are delivered completely adjusted and allow thus an easy and user-friendly exchange. Highest safety and operation comfort by an automatic door locking, which unlock the doors automatically, when no x-ray radiation is generated.
Two large displays show all relevant information on the current experiment. The tube voltage and tube current can be set in the ranges 0 to 35 kV and 0 to 1 mA respectively. The built-in rate meter including counter-tube voltage supply enables direct measuring in conjunction with a Geiger-Müller counter tube. The x-ray apparatus can also be connected to a PC via the USB-port (software included) for recording Bragg spectra. Alternative the two analogue outputs (counting rate and angular position) permit data acquisition using a chart recorder.
Two screened coaxial lead-ins and one free access duct provide access to set-ups in the experiment chamber, e.g. for connecting an x-ray energy detector.
Device fully assembled and adjusted, ready for operation.
Scope of delivery:
X-ray apparatus without tube
Cover for fluorescent screen
Dust cover - USB cable
Software for Windows 2000/XP/Vista/7
Technical data:
School x-ray apparatus and full-protection device with German typeapproval for school use (approval No. BFS 05/07 V/SchRöV) (suitable for the operation with the exchangeable tubes: Fe, Cu, Mo, Ag, W)
Dose rate at a distance of 10 cm: < 1 µS/h
Two independent safety circuits for doors, high voltage and emission current
Automatic door locking: doors can be opened only, when no high voltageis present i.e. no x-ray radiation can be generated
High voltage: 0 ... 35.0 kV (regulated DC voltage)
Tube current: 0 ... 1.00 mA (independent regulated DC)
Fluorescent screen for transillumination experiments: d = 15 cm
Built-in rate meter including voltage supply for GM counter tube
Loudspeaker: as an acoustic ratemeter
Two 4-digit displays (25 mm high) for displaying the following as desired: high voltage, anode current, counting rate, target/sensor angle, scanning range, step width, gate time
Exposure timer, gate time: 0.5 s ... 9999 s
Bushings in the experiment chamber: high-voltage coaxial cable, BNC coaxial cable, empty channel for e.g. tubing, cable etc.
Analog outputs: each proportional to target angle and to counting rate for chart recorder connection
USB port for connecting a PC to control the x-ray apparatus, data recording and evaluation by the delivered Windows software
LabVIEW™ driver for Windows and Linux available free of charge at http:/www.ld-didactic.com for user defined controlling and measuring
Input voltage: 230 V (±10 %) / 47 - 63 Hz
Power consumption: 120 VA
Dimensions: 67 cm x 48 cm x 35 cm
Weight: 41 kg

554862 X-ray tube Cu

Directly heated hot cathode tube with screw thread for heat sink and two-pin plug socket for cathode heating for X-ray apparatus (554 800/801).
Anode material: Copper
Characteristic radiation:
K_α = 154 pm (8.04 keV), K_β = 139 pm (8.91 keV)
Max. emission current: 1 mA
Max. anode voltage: 35 kV
Size of focal spot: approx. 2 mm^2
Minimum service life: 300 hours
Absorber foil (to generate monocromatic radiation): Nickel (Ni)
Diameter: 4.5 cm
Length: 20 cm
Weight: 0.3 kg

P6.3.1 DETECTION OF X-RAYS

P6.3.1.2 X-RAY PHOTOGRAPHY: EXPOSURE OF FILM STOCK DUE TO X-RAYS

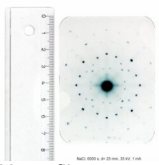
THE EXPERIMENT P6.3.1.2 RECORDS THE TRANSILLUMINATION OF OBJECTS USING X-RAY FILM. MEASURING THE EXPOSURE TIME REQUIRED TO PRODUCE A CERTAIN DEGREE OF EXPOSURE PERMITS QUANTITATIVE CONCLUSIONS REGARDING THE INTENSITY OF THE X-RAYS.

554838 Film holder X-ray

For x-ray apparatus 554 800/554 801, with printed scale for defined positioning of films for transillumination, Laue and Debye-Scherrer photographs; includes experiment rail with millimeter scale and pinhole diaphragm d = 1 mm for attaching to slit-diaphragm collimator. Suitable for x-ray film formats: 38 mm x 35 mm, e.g. Film-Pack 2 or 9 cm x 12 cm e.g. AGFA

STRUCTURIX D7 with developer G 128 and fixer G 328.
Dimensions:
Film holder: 12 cm x 16.5 cm
Experiment rail: 25 cm x 16 cm x 6 cm

554896 X-ray film Agfa Dentus M2



X-ray film 5 cm x 7 cm, 25 per pack, welded in light proof plastic foil for use in day light. The film must be removed from the foil for development.

5548931 Changing bag with developer tank

For developing the 554 896 x-ray film and for up to two 35 mm films. Changing bag made of double-layer special material. For putting a film in the development tank during daylight hours.
Dimensions of the changing bag: 55 x 65 cm
Volume of the developer tank: 650 ml

P6.3.1 DETECTION OF X-RAYS

P6.3.1.4 DETERMINING THE ION DOSE RATE OF THE X-RAY TUBE WITH MOLYDENUM ANODE

THE AIM OF THE EXPERIMENTS P6.3.1.3 AND P6.3.1.4 IS TO DETECT X-RAYS USING AN IONIZATION CHAMBER. FIRST, THE IONIZATION CURRENT IS RECORDED AS A FUNCTION OF THE VOLTAGE AT THE CAPACITOR PLATES OF THE CHAMBER AND THE SATURATION RANGE OF THE CHARACTERISTIC CURVES IS IDENTIFIED. NEXT, THE MEAN ION DOSE RATE
[@FP6313@]
IS CALCULATED FROM THE IONIZATION CURRENT I_{ION} WHICH THE X-RADIATION GENERATES IN THE IRRADIATED VOLUME OF AIR V, AND THE MASS M OF THE IRRADIATED AIR. THE MEASUREMENTS ARE CONDUCTED FOR VARIOUS EMISSION CURRENTS I AND HIGH VOLTAGES U OF THE X-RAY TUBE.

P6.3.1 DETECTION OF X-RAYS

P6.3.1.5 INVESTIGATION OF AN IMPLANT MODEL

THE EXPERIMENT P6.3.1.5 DEMONSTRATES THE USE OF RADIOSCOPY TO DETECT HIDDEN OBJECTS. A METAL ROD INSIDE A BLOCK OF WOOD IS VISUALLY INVISIBLE, BUT CAN BE SEEN BY X-RAY FLUORESCENCE AND ITS DIMENSIONS MEASURED.

5548391 Implant model

Wood quader with inserted hidden steel pin for the transillumination in the x-ray apparatus.
Additionally required: Film holder X-ray (554 838)

P6.3.1 DETECTION OF X-RAYS

P6.3.1.6 INFLUENCE OF A CONTRAST MEDIUM ON THE ABSORPTION OF X-RAYS

THE EXPERIMENT P6.3.1.6 DEMONSTRATES THE USE OF CONTRAST MEDIUM. THE RADIOPAQUE IODINE SOLUTION IS FLOWING THROUGH CHANNELS INSIDE A PLATE AND IS CLEARLY VISIBLE IN THE X-RAY FLUORESCENCE IMAGE, BUT PURE WATER IS NOT.

554839 Blood vessel model for contrast medium

for the demonstration of the effect of contrast media.
Plastic plate with covered channels, via screw connections the contrast medium can be injected from outside the x-ray apparatus and its penetration can be observed on the fluorescence screen of the x-ray apparatus.
By variation of the distance, magnification effects can be demonstrated.
Scope of delivery:
Plate with blood vessel model on magnet support
Hose
2 Plastic syringes
2 Stoppers
necessary accessories:
672 6610 Potassium iodide, 100 g

602023 Beaker, 150 ml, low form

with graduation and spout

602295 Bottle brown glass wide treath with cap, 250 ml

602783 Glass rod, 200 mm, Ø 6 mm

THE ATTENUATION OF X-RAYS ON PASSING THROUGH AN ABSORBER WITH THE THICKNESS D IS DESCRIBED BY LAMBERT'S LAW FOR ATTENUATION:
[@FP6320_EN@]
HERE, THE ATTENUATION IS DUE TO BOTH ABSORPTION AND SCATTERING OF THE X-RAYS IN THE ABSORBER. THE LINEAR ATTENUATION COEFFICIENT μ DEPENDS ON THE MATERIAL OF THE ABSORBER AND THE WAVELENGTH λ OF THE X-RAYS. AN ABSORPTION EDGE, I.E. AN ABRUPT TRANSITION FROM AN AREA OF LOW ABSORPTION TO ONE OF HIGH ABSORPTION, MAY BE OBSERVED WHEN THE ENERGY H · ν OF THE X-RAY QUANTUM JUST EXCEEDS THE ENERGY REQUIRED TO MOVE AN ELECTRON OUT OF ONE OF THE INNER ELECTRON SHELLS OF THE ABSORBER ATOMS.

P6.3.2 ATTENUATION OF X-RAYS

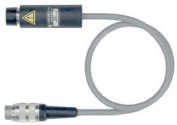
P6.3.2.1 INVESTIGATING THE ATTENUATION OF X-RAYS AS A FUNCTION OF THE ABSORBER MATERIAL AND ABSORBER THICKNESS

THE OBJECT OF THE EXPERIMENT P6.3.2.1 IS TO CONFIRM LAMBERT'S LAW USING ALUMINIUM AND TO DETERMINE THE ATTENUATION COEFFICIENTS μ FOR SIX DIFFERENT ABSORBER MATERIALS AVERAGED OVER THE ENTIRE SPECTRUM OF THE X-RAY APPARATUS.

554831 Goniometer

With two independently controllable stepping motors which move the sensor and target arm. The motion is defined using the keys in the control panel of the X-ray apparatus (554 800 and 554 801) and initiated manually or automatically. Included in the scope of supply of the X-ray apparatus (554 801).
Working principle: stepping motors for target and sensor arms, which can be electronically coupled
Angular range of target: unlimited (0°… 360°)
Angular range of sensor: approx. -10° to +170°
Angular resolution: 0.1°
Length of sensor arm: approx. 40 -110 mm
Width of sensor slit: 1 mm
Area of target platform: 25 mm x 28 mm
Sample clamping width: 3 - 9 mm
Dimensions: 13.5 cm x 22.5 cm x 12.5 cm
Weight: 3 kg

55901 End-window counter with cable



for alpha, beta, gamma, and X-rays; self-quenching Geiger counter tube in plastic case with very thin mica end window.
Gas filling: neon, argon, halogen
Avarage operating voltage: 450 V
Connection: screened cable, with coaxial plug (Amphenol-Tuchel T 3162/1)
Plateau: l = 200 V
Dead time: 100 µs
Plateau transconductance: 0.05 %/V
Service Life: > 10^{10} pulses
Background effect on the plateau: 0.2 imp/s
Sensitivity (gamma): 1 % approx.
Window: d = 9 mm
Mass per unit area: 2 mg cm^{-2}
Dimensions: 75 mm x 24 mm dia.

554834 Absorption accessory X-ray

For x-ray apparatus 554 801/811, two absorbers for quantitative investigation of the attenuation of x-rays as a function of the thickness and the atomic number of the absorber.
Thickness graduation of aluminum absorber: 0.5/1.0/2.0 /2.5 and 3.0 mm
Material and atomic number for absorbers of constant thickness (0.5 mm):
polystyrene: Z = 6
aluminum: Z = 13
iron: Z = 26
copper: Z = 29
zirconium: Z = 40
silver: Z = 47
Dimensions of diaphragm: 2.5 x 15 mm
Diaphragm spacing: 5 mm (approx. 10°)
Dimensions: 40 mm x 35 mm x 8 mm each.

P6.3.2 ATTENUATION OF X-RAYS

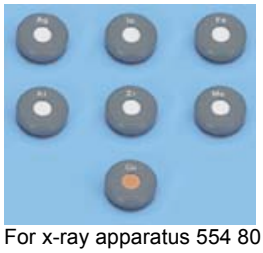
P6.3.2.2 INVESTIGATING THE WAVELENGTH DEPENDENCY OF THE ATTENUATION COEFFICIENT

THE EXPERIMENT P6.3.2.2 RECORDS THE TRANSMISSION CURVES
[@FP6322@]
FOR VARIOUS ABSORBER MATERIALS. THE AIM OF THE EVALUATION IS TO CONFIRM THE λ^3 RELATIONSHIP OF THE ATTENUATION COEFFICIENTS FOR WAVELENGTHS OUTSIDE OF THE ABSORPTION EDGES.

55478 NaCl crystal for Bragg reflection

fitting the goniometer of the X-ray apparatus (554 801), for experiments with Bragg's arrangement.
Lattice-plane spacing: 282 pm
Reflection angle for molybdenum K_α radiation (1st order): 7.24°
Crystal structure: face-centered cubic
Surface: parallel [100]
Dimensions: 25 mm x 25 mm x 4 mm

554832 Set of Absorber Foils



For x-ray apparatus 554 801/811, e.g. for experiments on the Z^4 relationship and Moseley's law; foils mounted in holder for attaching to slit diaphragm collimator or counter-tube holder.
Foil materials:
Al: Z = 13, thickness = 0.5 mm
Fe: Z = 26, thickness = 0.5 mm
Cu: Z = 29, thickness = 0.07 mm
Zr: Z = 40, thickness = 0.05 mm
Mo: Z = 42, thickness = 0.1 mm
Ag: Z = 47, thickness = 0.05 mm
In: Z = 49, thickness = 0.3 mm
Frame: 24 mm Ø x 11 mm
Foils: 10 mm Ø

ADDITIONALLY REQUIRED:
PC WITH WINDOWS 2000/XP/VISTA

P6.3.2 ATTENUATION OF X-RAYS

P6.3.2.3 INVESTIGATING THE RELATIONSHIP BETWEEN THE ATTENUATION COEFFICIENT AND THE ATOMIC NUMBER Z

IN THE EXPERIMENT P6.3.2.3, THE ATTENUATION COEFFICIENT $\mu(\lambda)$ OF DIFFERENT ABSORBER MATERIALS IS DETERMINED FOR A WAVELENGTH λ WHICH LIES OUTSIDE OF THE ABSORPTION EDGE. THIS EXPERIMENT REVEALS THAT THE ATTENUATION COEFFICIENT IS CLOSELY PROPORTIONAL TO THE FOURTH POWER OF THE ATOMIC NUMBER Z OF THE ABSORBERS.

IN 1972 THE FIRST COMPUTED TOMOGRAPHIC SCANNER WAS BUILT BY GODFREY HOUNSFIELD WHO, TOGETHER WITH ALLAN CORMACK, WAS AWARDED THE NOBEL PRIZE IN PHYSIOLOGY OR MEDICINE IN 1979. THE BASIC IDEA OF COMPUTED TOMOGRAPHY (CT) IS THE ILLUMINATION OF AN OBJECT BY X-RAYS FROM NUMEROUS DIFFERENT ANGLES.
OUR EDUCATIONAL X-RAY APPARATUS ALLOWS THE ILLUMINATION OF OBJECTS BY X-RAYS. THE RESULTING 2D-PROJECTIONS ARE VISUALISED AT THE FLUORESCENCE SCREEN.

BY TURNING AN OBJECT USING THE BUILT-IN GONIOMETER OF THE X-RAY APPARATUS, AND RECORDING THE 2D-PROJECTIONS FROM EACH ANGULAR STEP, THE COMPUTER CAN RECONSTRUCT THE OBJECT ILLUMINATED BY X-RAYS. OUR E-LEARNING SOFTWARE VISUALISES THE BACK PROJECTION (NECESSARY FOR RECONSTRUCTING THE COMPUTED TOMOGRAPHY) CONCURRENTLY WITH THE SCANNING PROCESS. THE 3D-MODEL IS THEN DISPLAYED ON THE PC SCREEN.

P6.3.8 X-RAY TOMOGRAPHY

P6.3.8.1 MEASUREMENT AND PRESENTATION OF A COMPUTED TOMOGRAM

EXPERIMENT P6.3.8.1 DISCUSSES THE BASICS OF COMPUTED TOMOGRAPHY. THE COMPUTED TOMOGRAPHIES OF SIMPLE GEOMETRICAL OBJECTS ARE RECORDED AND DISPLAYED.

554821 Computed tomography module

Records the 2D-projections of an object illuminated by x-rays within a few minutes. During the recording of the 2D-projections, the e-learning software visualises the backprojection process in two or three dimensions alternatively. After the scan the complete 3D-object is available to be viewed (rotating, zooming, transparency effects, projections, illumination similar to the Heidelberger ray-tracing model).
Well-resolved images of various objects can be obtained in spite of the simple measuring method and the low energy of the x-ray radiation (35 keV) from the educational x-ray apparatus.
The 3D-computed tomogram of various objects can be evaluated qualitatively and quantitatively. The learning involved in the preparation of the scanning process and image evaluation is emphasised.
Additionally, a suitable x-ray apparatus and a powerful computer are required.
Scope of delivery:
Computed tomography module
Computed tomography software
Object (small dried animal, e.g. frog)
Cell (e.g. for water)
Object holder including polystyrene holder
USB cable
Technical details:
Mounting of the object: at the goniometer of the x-ray apparatus
Maximum object size: approx. 8 x 8 x 8 cm^3

Object resolution: approx. 0.25 mm
Angular resolution: 1 - 360 2D-projections per computed tomogram
Size of the computed tomogram: 200 - 340 pixel per dimension
Connection of the module to the computer: USB 2.0-Port
Connection of the x-ray apparatus to the module: USB 2.0-Port
Separate Video output: Cinch (CCIR)
Mains voltage: 230 V, 50/60 Hz
Dimensions: 53 cm x 34 cm x 24.5 cm
Weight: 13.5 kg
More information and videos: http://ld-systeme.com/phk/ct.asp

ADDITIONALLY REQUIRED:
PC WITH WINDOWS XP/VISTA/7

FOR MORE INFORMATION AND DEMO VIDEOS: PLEASE VISIT
COMPUTED TOMOGRAPHY WITH THE X-RAY APPARATUS

P6.3.8 X-RAY TOMOGRAPHY

P6.3.8.2 COMPUTED TOMOGRAPHY OF SIMPLE GEOMETRICAL OBJECTS

EXPERIMENT P6.3.8.2 SHOWS THE CT OF SIMPLE GEOMETRICAL OBJECTS TO DEMONSTRATE THE BASIC PROPERTIES OF TOMOGRAPHY.

554825 LEGO® Adapter

The Lego adapter serves for the mounting of small Lego parts at the goniometer of the x-ray apparatus for the recording of computed tomography with the Computerised tomography module (554 821).
Additionally required:
Commercial Lego parts

P6.3.8 X-RAY TOMOGRAPHY

P6.3.8.4 MEASURING ABSORPTION COEFFICIENTS IN STRUCTURED MEDIA WITH COMPUTED TOMOGRAPHY

EXPERIMENT P6.3.8.4 ANALYSES THE ABSORPTION COEFFICIENT OF WATER INSIDE A PLASTIC BODY TO DEMONSTRATE THE CAPABILITIES OF CT IN DISTINGUISHING DIFFERENT KINDS OF TISSUES AND DISCUSSES HARDENING EFFECTS OF THE X-RAYS.

P6.3.8 X-RAY TOMOGRAPHY

P6.3.8.5 COMPUTED TOMOGRAPHY OF BIOLOGICAL SAMPLES

EXPERIMENT P6.3.8.5 ANALYSES THE CT OF REAL BIOLOGICAL SPECIMENS AND APPLIES TO THE RESULTS OF THE PREVIOUS EXPERIMENTS.

Relação dos experimentos possíveis realizados com o conjunto apresentado acima.
Total 13 experimentos:

P6.3.1 detecção de Raios X
P6.3.1.1 fluorescência de tela fluorescente provocada por Raios X
P6.3.1.2 fotografia de Raios X: escurecimento de filmes causada por Raios X
P6.3.1.3 detecção de Raios X com uma câmara de ionização
P6.3.1.4 determinação da intensidade de uma dose ionizante do tubo de Raios X com anodo de Mo
P6.3.1.5 investigação de um modelo de implante
P6.3.1.6 influencia da substancia de contraste pela absorção de Raios X

P6.3.2 atenuação de Raios X
P6.3.2.1 estudo da atenuação de Raios X em função do material e espessura do absorvedor
P6.3.2.2 estudo do coeficiente de atenuação em função do comprimento de onda
P6.3.2.3 estudo do coeficiente de atenuação em função do número atómico z

P6.3.8 tomografia de Raios X
P6.3.8.1 registro e representação de uma tomografía computarizada
P6.3.8.2 tomografia computarizada de objetos geométricos simples
P6.3.8.4 medida do coeficiente de absorção em medios estruturados por meio de tom. computarizada
P6.3.8.5 tomografia computarizada de amostras biológicas

Investigating the attenuation of x-rays as a function of the absorber material and absorber thickness

Objects of the experiment

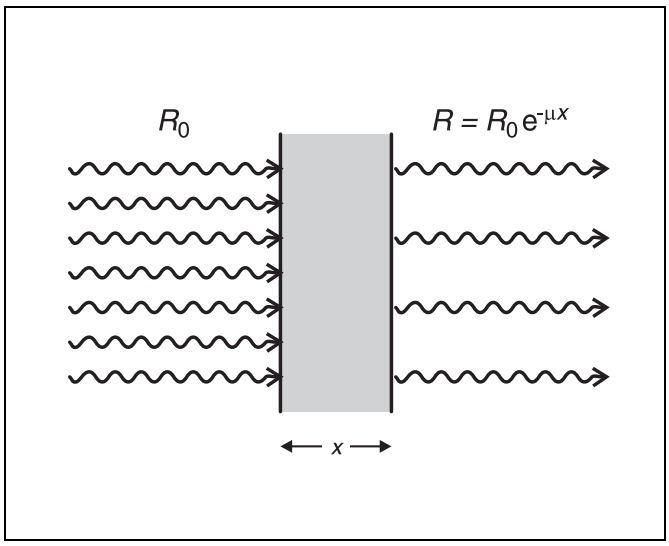
- To investigate the attenuation of x-rays as a function of the absorber thickness.
- To verify Lambert's law of attenuation.
- To investigate the attenuation of x-rays as a function of the absorber material.
- To confirme the wavelength-dependency of attenuation.

Principles

When we speak of attenuation of x-rays, we mean the decrease in intensity that occurs when the radiation passes through matter. This attenuation is caused mainly by two effects: scattering and absorption.

Although absorption and attenuation are different physical phenomena, the transilluminated object is often referred to —inaccurately— as an absorber; this should more properly be termed an attenuator. However, this description will follow the traditional usage in some places and refer to absorbers instead of attenuators.

The scattering of x-ray quanta at the atoms of the attenuator material causes a part of the radiation to change direction. This reduces the intensity in the original direction. This scattering can be either elastic or entail an energy loss or shift in wavelength, i. e. inelastic scattering.



In absorption, the entire energy of the x-ray quanta is transferred to the atoms or molecules of the irradiated material as excitation or ionizing energy.

If R_0 is the original counting rate in front of the attenuator and R is the counting rate behind it, we can quantify the transmission of the radiation to characterize the permeability of an attenuator using:

$$T = \frac{R}{R_0} \qquad \text{(I)}.$$

The greater the so-called transmittance of an attenuator is, the lower is its attenuating capacity.

The transmittance depends on the thickness of the attenuator. If we assume that the properties of the incident radiation remain unchanged in spite of attenuation, an increase in the thickness x by the amount dx will cause a decrease in the transmittance T by the amount dT. The relative reduction in transmission is proportional to the absolute increase in thickness:

$$-\frac{dT}{T} = \mu \cdot dx \qquad \text{(II)}.$$

The proportionality factor μ is referred to as the linear attenuation coefficient.

As the transmittance $T = 1$ for $x = 0$, integration of equation (II) gives us

$$T = e^{-\mu \cdot x} \qquad \text{(III)}$$

or

$$\ln T = -\mu \cdot x \qquad \text{(IV)}.$$

This relationship is known as Lambert's law of attenuation after *Johann Heinrich Lambert,* the 18th century scientist and philosopher.

The aim of this experiment is to verify Lambert's law of attenuation. It also demonstrates that the attenuation depends on the attenuating material and the wavelength of the x-rays.

Apparatus

1 X-ray apparatus	554 811
or	
1 X-ray apparatus	554 812
1 Goniometer	554 83
1 End-window counter for α, β, γ and x-ray radiation	559 01
1 Set of absorbers x-ray	554 834

Setup

Set up the experiment as shown in Fig. 1.

- Mount the collimator in the collimator mount **(a)** (note the guide groove).
- Attach the goniometer to guide rods **(d)** and connect ribbon cable **(c)** for controlling the goniometer.
- Remove the protective cap of the end-window counter, place the end-window counter in sensor seat **(e)** and connect the counter tube cable to the socket in the experiment chamber marked GM TUBE.
- Demount the target holder **(g)** of the goniometer and remove the target stage from the holder.
- Place the guide edge of the set of absorbers I **(f)** in the 90° curved groove of the target holder and carefully slide it into the target holder as far as it will go.

Safety notes

The x-ray apparatus fulfills all regulations governing an x-ray apparatus and fully protected device for instructional use and is type approved for school use in Germany (NW 807/97 Rö).

The built-in protection and screening measures reduce the local dose rate outside of the x-ray apparatus to less than 1 μSv/h, a value which is on the order of magnitude of the natural background radiation.

- Before putting the x-ray apparatus into operation inspect it for damage and to make sure that the high voltage is shut off when the sliding doors are opened (see Instruction Sheet for x-ray apparatus).
- Keep the x-ray apparatus secure from access by unauthorized persons.

Do not allow the anode of the x-ray tube Mo to overheat.

- When switching on the x-ray apparatus, check to make sure that the ventilator in the tube chamber is turning.

The goniometer is positioned solely by electric stepper motors.

- Do not block the target arm and sensor arm of the goniometer and do not use force to move them.

- Mount the target holder.
- Press the ZERO key to return the target and sensor arms to the zero position.
- Check the zero position of the empty diaphragm of the set of absorbers and the sensor and correct this if necessary (see "Adjusting the zero position of the measuring system" in the Instruction Sheet of the x-ray apparatus).
- By moving the goniometer, set a distance of approx. 5 cm between the collimator of the x-ray apparatus and the empty diaphragm, and set a distance of approx. 5 cm between the empty diaphragm and the sensor slit by moving the sensor holder **(b)**.

Carrying out the experiment

a) Attenuation as a function of the absorber thickness:

a1) Without zirconium filter:

- Set the tube high voltage to U = 21 kV.
- Set the emission current I = 0.05 mA.

Note: The counting rate should not appreciably exceed 1500/s. This avoids having to correct for dead time.

- Press the key TARGET.
- Set the angular step width $\Delta\beta$ = 0° (see "Activating an exposure timer" in the Instruction Sheet of the x-ray apparatus).
- Set the measuring time Δt = 100 s.
- Using the ADJUST knob, set the angular positions of the absorbers (approx. 0°, 10°, 20°, 30°, 40°, 50° and 60°) one after another, start the measurement with the SCAN key and display the mean counting rate R after the measuring time elapses by pressing REPLAY. Write down your experiment results (see table 1).

a2) With zirconium filter:

- Mount the zirconium filter on the collimator (this suppresses the short-wave component of the bremsstrahlung radiation generated at U = 21 kV almost entirely).
- Set the emission current I = 0.15 mA and the measuring time Δt = 200 s.
- Using the ADJUST knob, set the angular positions of the absorbers (approx. 0°, 10°, 20°, 30°, 40°, 50° and 60°) one after another, start the measurement with the SCAN key, display the mean counting rate R after the measuring time elapses by pressing REPLAY and write down your results (see table 2).

b) Attenuation as a function of the absorber material:

b1) Without zirconium filter:

- Replace set of absorbers I (absorbers of different thicknesses) with set of absorbers II (absorbers of different materials, d = 0.05 cm).
- Remove the zirconium filter.
- Set the tube high voltage to U = 30 kV (this ensures that the radiation also penetrates the thick absorbers).
- Set the emission current I = 0.02 mA and the measuring time Δt = 30 s.

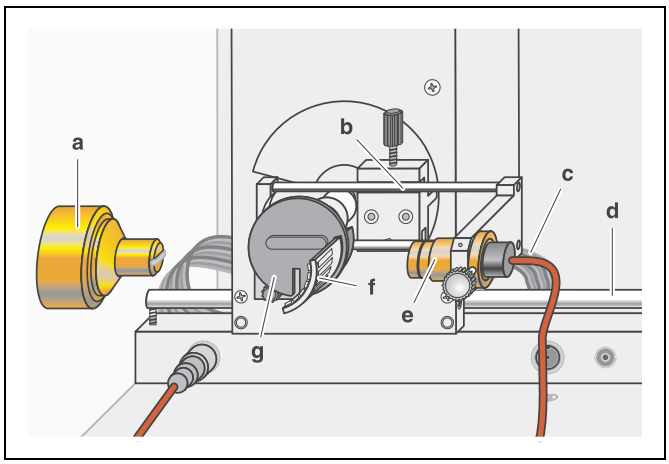


Fig. 1 Setup for investigating the attenuation of x-rays as a function of the thickness of the absorber material.

– Using the ADJUST knob, set the angular positions of the first three absorbers (approx. 0°, 10° and 20°) one after another, start the measurement with the SCAN key and display the mean counting rate R after the measuring time elapses by pressing REPLAY. Write down your results.
– Set the emission current I = 1.00 mA and the measuring time Δt = 300 s.
– Using the ADJUST knob, set the angular positions of the four remaining absorbers (approx. 30°, 40°, 50° and 60°) one after another, start the measurement with the SCAN key and display the mean counting rate R after the measuring time elapses by pressing REPLAY. Write down your experiment results (see table 3).

b2) With zirconium filter:

– Attach the zirconium filter and repeat the measurement as described for b1) (see table 4).

b3) Measuring the background effect:

– Set the parameters U = 0 kV and I = 0 mA and measure the counting rate R_1 of the background effect for a measuring time of Δt = 300 s.

Measuring example

a) Attenuation as a function of the absorber thickness:

Tab. 1: Counting rate R as a function of thickness d of the aluminum absorber (U = 21 kV, I = 0.05 mA, Δt = 100 s, without zirconium filter)

	$\frac{R}{s^{-1}}$
0	977.9
0.5	428.6
1.0	210.1
1.5	106.1
2.0	49.10
2.5	30.55
3.0	16.11

Tab. 2: Counting rate R as a function of thickness d of the aluminum absorber (U = 21 kV, I = 0.15 mA, Δt = 200 s, with zirconium filter)

$\frac{d}{mm}$	$\frac{R}{s^{-1}}$
0	969.4
0.5	426.1
1.0	197.3
1.5	84.29
2.0	40.51
2.5	19.48
3.0	9.52

b) Attenuation as a function of the absorber material:

Tab. 3: Counting rate R as a function of the absorber material (U = 30 kV, d = 0.05 cm, without zirconium filter)

Absorber	Z	$\frac{I}{mA}$	$\frac{\Delta t}{s}$	$\frac{R}{s^{-1}}$
none		0.02	30	1841
C	6	0.02	30	1801
Al	13	0.02	30	1164
Fe	26	1.00	300	93.3
Cu	29	1.00	300	16.63
Zr	40	1.00	300	194.3
Ag	47	1.00	300	106

Tab. 4: Counting rate R as a function of the absorber material (U = 30 kV, d = 0.05 cm, with zirconium filter)

Absorber	Z	$\frac{I}{mA}$	$\frac{\Delta t}{s}$	$\frac{R}{s^{-1}}$
none		0.02	30	718.3
C	6	0.02	30	698.4
Al	13	0.02	30	406.1
Fe	26	1.00	300	29.24
Cu	29	1.00	300	6.016
Zr	40	1.00	300	113.9
Ag	47	1.00	300	24.52

Background effect: R_1 = 0.243 s^{-1}

Evaluation and results

a) Attenuation as a function of the absorber thickness:

When we insert the measurement data from tables 1 and 2 in equation 1, we obtain the transmittance *T*. Fig. 2 shows how this depends on the thickness *d* of the absorber. The plotted curve conforms to the exponential function to be expected from equation (III).

Fig. 3 shows a floating-point representation in accordance with equation (IV). In this representation, the attenuation of x-ray radiation (monochromatized using the zirconium filter) can be described very well using a straight line through the origin that has a slope which corresponds to the linear attenuation coefficient μ = 15.7 cm^{-1}.

For non-monochromatic (unfiltered) x-ray radiation, the slope of the straight line through the origin fitted according to equation (IV) gives us a slightly smaller value of μ = 14.2 cm^{-1} for the attenuation coefficient. Also, we can note deviations from the linear curve. The attenuation cannot be described using a single attenuation coefficient; rather, the radiation has a larger high-energy component than the measurement with Zr filter, so that less attenuation occurs for the same absorber thickness.

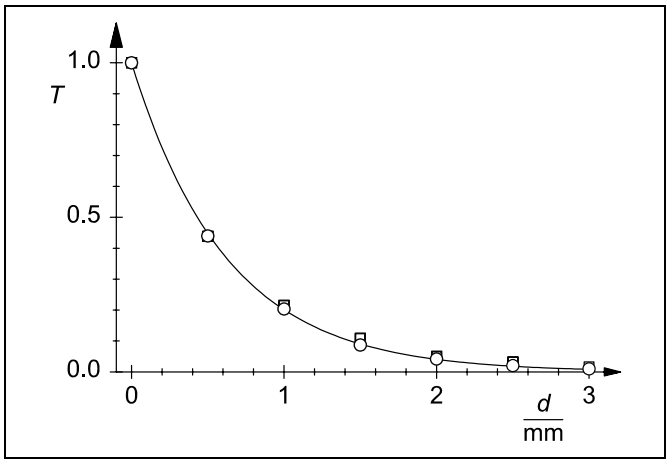


Fig. 2 Transmittance *T* as a function of the thickness d of the aluminum absorbers
Circles: measurement with zirconium filter
Squares: measurement without zirconium filter

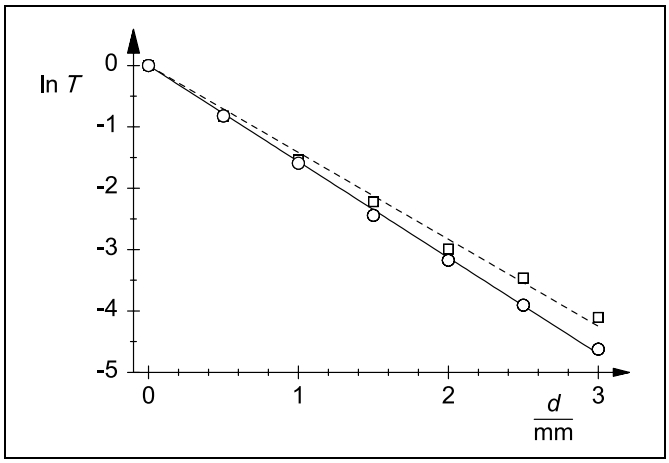


Fig. 3 Floating-point representation of transmission *T* as a function of the thickness *d* of the aluminum absorbers
Circles: measurement with zirconium filter
Squares: measurement without zirconium filter

b) Attenuation as a function of the absorber material:

Assuming that the counting rate is proportional to the emission current *I,* it is possible to scale the counting rates from tables 3 and 4 (after subtracting the background effect) to the emission current *I* = 1.00 mA.

Using the scaled data, equation (I) gives us the transmission *T* (see tables 5 and 6), which we can use to calculate the linear attenuation coefficient μ for *d* = 0.05 cm by means of equation (IV).

Fig. 4 shows the relationship between the linear attenuation coefficient μ and the atomic number *Z*. Below *Z* = 40 (Zr), the attenuation coefficient increases steeply as the atomic number rises. When *Z* reaches 40, we observe an abrupt decrease, which is more apparent for the filtered radiation. This reduction is due to the fact the certain excitations are no longer possible in Zr (binding energy of the K shell is too great, see experiment P6.3.4.5). The unfiltered radiation contains a high-energy component which can still generate this excitation, so that the decrease in μ is less.

Tab. 5: Counting rate *R* (*I* = 1.00 mA), transmittance *T* and linear attenuation coefficient μ as a function of the atomic number *Z* of the absorber material (*U* = 30 kV, *d* = 0.05 cm, without zirconium filter).

Z	$\frac{R}{s^{-1}}$	*T*	$\frac{\mu}{cm^{-1}}$
none	$92.0 \cdot 10^3$	1.000	0
6	$90.0 \cdot 10^3$	0.978	0.445
13	$58.3 \cdot 10^3$	0.634	9.11
26	93.1	$1.01 \cdot 10^{-3}$	138
29	16.4	$0.178 \cdot 10^{-3}$	173
40	194	$2.11 \cdot 10^{-3}$	123
47	106	$1.15 \cdot 10^{-3}$	135

Tab. 6: Counting rate R (I = 1.00 mA), transmittance T and linear attenuation coefficient μ as a function of the atomic number Z of the absorber material (U = 30 kV, d = 0.05 cm, with zirconium filter).

Z	$\frac{R}{s^{-1}}$	T	$\frac{\mu}{cm^{-1}}$
none	$35.9 \cdot 10^3$	1.000	0
6	$34.9 \cdot 10^3$	0.972	0.568
13	$20.3 \cdot 10^3$	0.565	11.4
26	29.0	$0.808 \cdot 10^{-3}$	142
29	5.77	$0.161 \cdot 10^{-3}$	175
40	114	$3.18 \cdot 10^{-3}$	115
47	24.3	$0.677 \cdot 10^{-3}$	146

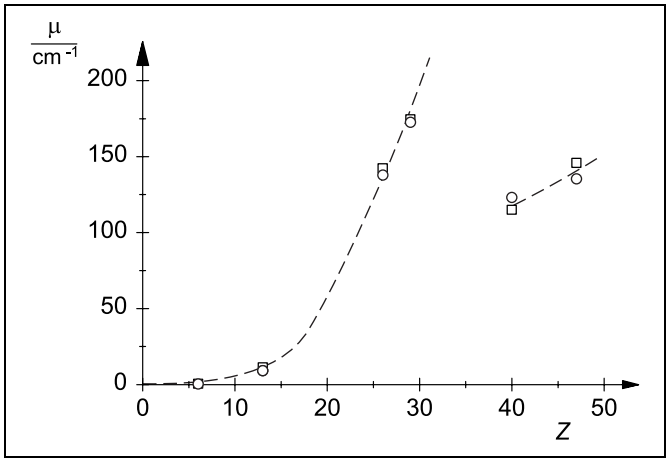


Fig. 4 Linear attenuation coefficient μ as a function of the atomic number Z of the absorber
Circles: measurement with zirconium filter
Squares: measurement without zirconium filter

Application of x-ray fluorescence for the non-destructive analysis of the chemical composition

Objects of the experiment

- Recording of fluorescence spectra for several alloys.
- Qualitative analysis of the fluorescence spectrum: determination of the elements present in the alloy.

Principle

When a sample is irradiated with high energy x-ray photons it will emit characteristic x-ray lines whose energy depends on the atomic number of the element of the sample material. This relationship (Moseley's law) has already been treated together with the x-ray fluorescence spectra of several elements in the LD Physics Leaflets P6.3.5.4 and P6.3.5.5.

If a sample consists of a chemical compound or mixture, its fluorescence spectrum will also be complex. Because the inner electron shells between which the x-ray transitions occur are not involved in the chemical bonds, the characteristic lines are largely *independent of the chemical bonds of the element*. This means that the x-ray fluorescence spectra of a chemical compound are, in a first approximation, a superposition of the spectra of its components.

For the qualitative analysis of the chemical composition of a sample, initially all peaks found in the fluorescence spectrum are correlated to the elements. This is done by means of the values for the energies of the characteristic lines found in the table. For the correlation, the "pattern" of each of the spectral series is also considered, for example, together with the $K\alpha$–line there must also be the $K\beta$–line with a lower (approx. one fifth to one tenth) intensity in the spectrum. The $L\alpha$–line appears accompanied by the $L\beta$–line of a similar intensity and the $L\gamma$–line of a lower intensity.

Information about the relative concentrations of individual elements in the compound can be gained from the relative intensities of their fluorescence lines.

Apparatus

1 set of x-ray apparatus with Mo x-ray tube and goniometer	554 811
or	
1 set of x-ray apparatus with Cu x-ray tube and goniometer	
1 x-ray energy detector	559 938
1 alloys target set	554 848
1 CASSY sensor	524 010
1 MCA box	524 058
1 CASSY Lab	524 200
1 HF cable, 1 m	501 02
1 PC with Windows 98/NT or higher	

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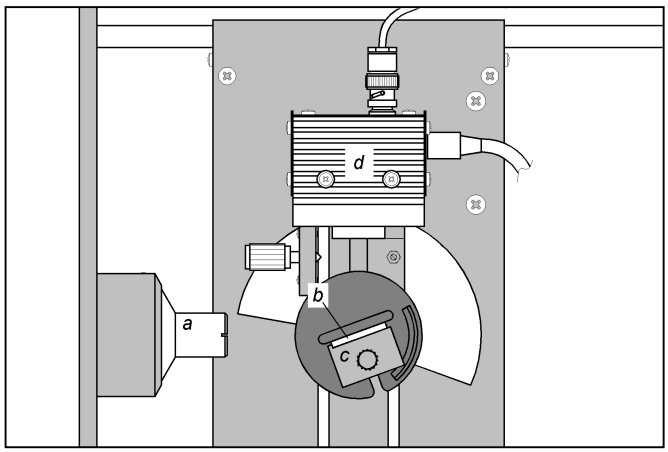

Fig. 1: Setup of the experiment: *a* – collimator, *b* – target, *c* – target table , *d* – detector.

Setup

The experimental set-up is shown in fig. 1.

- Push the connection cable for the table-top device through the empty channel of the x-ray device and connect it to the mini-DIN socket of the x-ray energy detector.
- Secure the sensor holder with the mounted x-ray energy detector in the goniometer sensor arm.
- Connect the signal output of the x-ray energy detector to the BNC socket SIGNAL IN of the x-ray device by means of the BNC cable included.

This x-ray apparatus fulfils all regulations governing the construction of x-ray apparatus for use in schools and fully protected devices for instructional use, and it is type approved for school use in Germany (NW 807 / 97 Rö).

The built-in protection and screening measures reduce the local dose rate outside the x-ray apparatus to less than 1 μSv/h, a value which is of the same order of magnitude as the natural background radiation.

■ Before commissioning the x-ray apparatus, inspect it for damage and check that the high voltage is switched off when the slide doors are opened (see the operating instructions for the x-ray apparatus).

■ Protect the x-ray apparatus from access by unauthorised people.

Overheating of the anode in the x-ray tube is to be avoided.

■ When switching on the x-ray apparatus, check if the fan in the tube chamber is rotating.

The goniometer is positioned exclusively by means of electric stepper motors.

■ Do not block the target arm and the sensor arm of the goniometer and do not use force to move them.

- Feed enough connection cable through to make complete movement of the sensor arm possible.
- Press the SENSOR button and set the sensor angle with the twist adjuster ADJUST manually to 90°.
- Connect sensor CASSY to the computer and connect the MCA box.
- Connect the SIGNAL OUT output in the connection panel of the x-ray device to the MCA box by means of the BNC cable.
- Set the distances between the slit aperture of the collimator and the axis of rotation as well as between the axis of rotation and the window of the x-ray energy detector both to 5 to 6 cm.
- Place the calibration target from the scope of delivery for the x-ray energy detector onto the table.
- Press the TARGET button and adjust the target angle manually using the twist button ADJUST to 45°.

Carrying out the experiment

- Connect the table-top device to the mains (after approx. 2 min the LED of the x-ray energy detector will glow green and the device will be ready for use).
- Call CASSY Lab and set the measuring parameters "Multi-channel measurement, 512 channels, negative pulses, amplification = -2.5, measuring duration = 180 s".
- Set the tube high voltage U = 35 kV, emission current I = 1 mA and switch the high voltage on.
- Start the spectrum recording by clicking on or pressing F9.
- Then record spectra for the targets in the alloy target set.
- Save the entire measurement under a suitable name.

Example of a measurement

The recorded spectra are shown in fig. 2a-e.

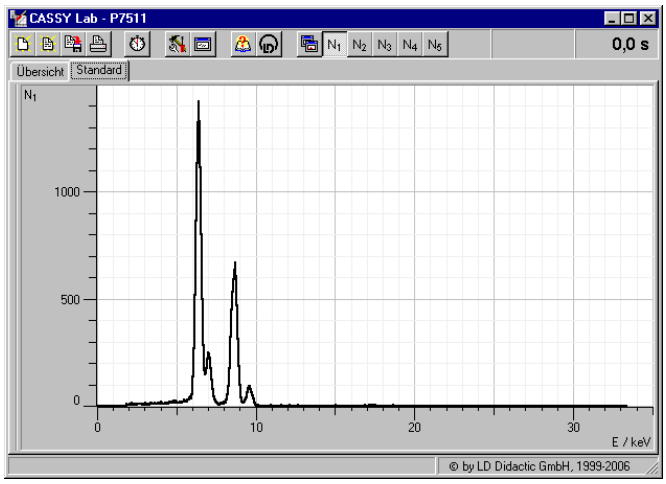

Fig. 2a: Fluorescence spectrum of the calibration target.

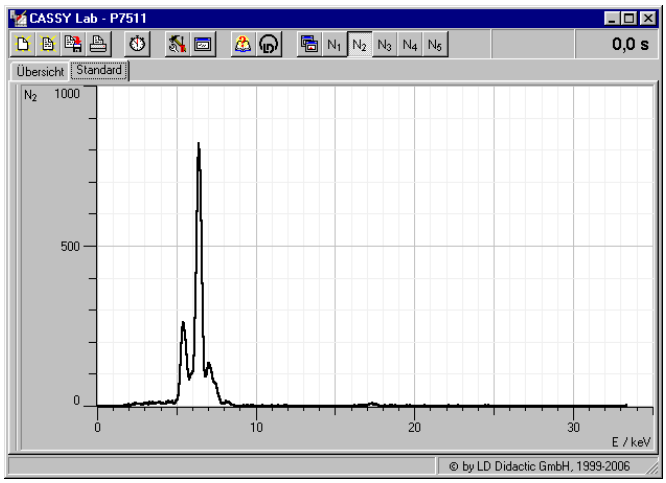

Fig. 2b: Fluorescence spectrum of target 1.

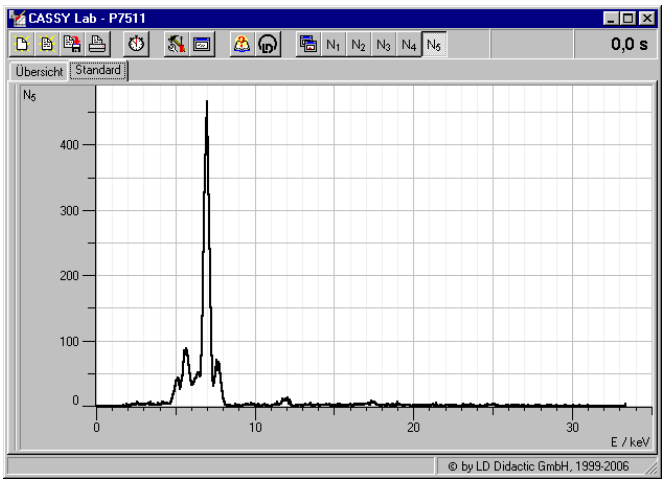

Fig. 2e: Fluorescence spectrum of target 4.

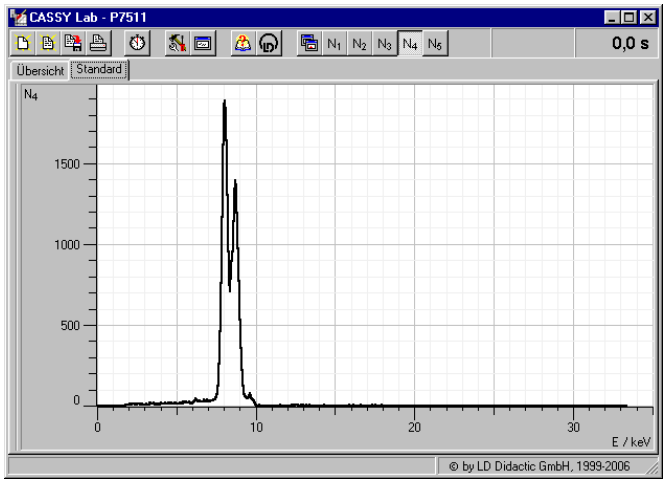

Fig. 2c: Fluorescence spectrum of target 2.

Evaluation

a) Energy calibration of the spectra

The energy calibration is made using the spectrum of the calibration target (Fe+Zn) (fig. 3a).

- Open the "Energy Calibration" dialogue window by pressing Alt+E, select "Global Energy Calibration" and enter the energies for the Fe Kα-line (6.40 keV) and the Zn Kα-line (8.64 keV).
- In the popup menu of the diagram window select the menu item "Other Evaluations" → "Calculate Peak Centre", select the Fe Kα-line and enter the result in the "Energy Calibration" dialogue window.
- Then determine the centre of the Zn Kα-line and enter it.

For identification and labelling of the lines

- In the pop-up menu of the diagram window select the menu item "X-ray Energies" and click on the element symbol Fe.

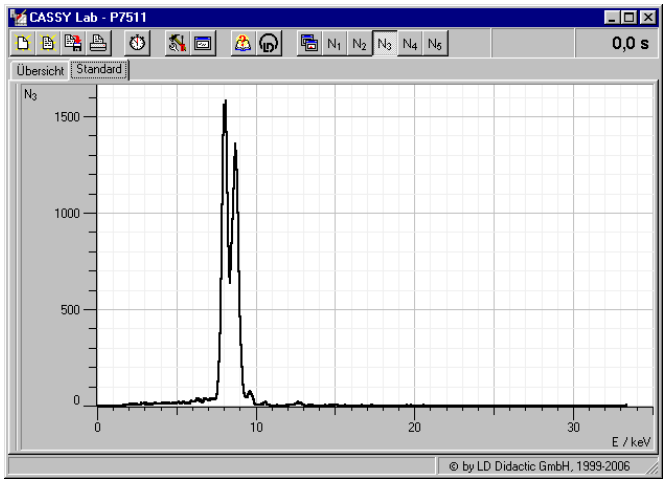

Fig. 2d: Fluorescence spectrum of target 3.

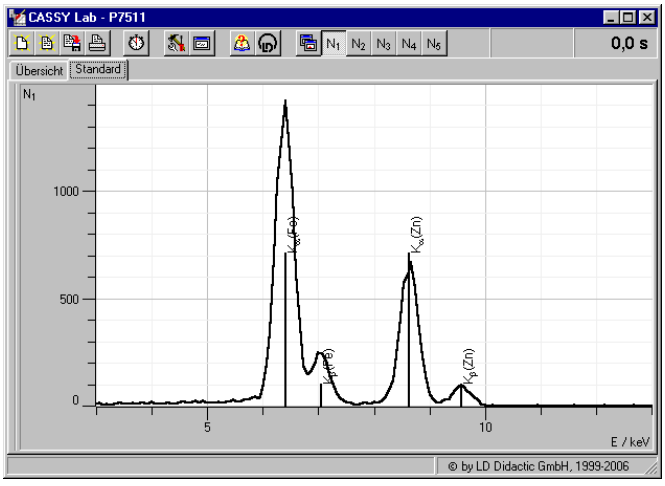

Fig. 3a Fluorescence spectrum of the calibration target with identified lines.

- Close the window by clicking the "OK" button.
- Call again the menu item "X-ray Energies" and click on the element symbol Zn.

It becomes apparent that four of the measured peaks have been caused by the fluorescence of the main components Fe and Zn of the galvanised steel plate (see fig. 3a).

b) Identification of the lines in the spectra

For the identification of the alloy components

- Select spectrum and mark a suitable section.
- In the popup menu of the diagram window select the menu item "X-ray Energies" and click on the element symbols and determine a suitable element by means of the displayed markers for the energies in the table.
- Close the window by clicking the "OK" button.
- Call again the menu item "X-ray Energies" and in this way determine further components of the alloy.

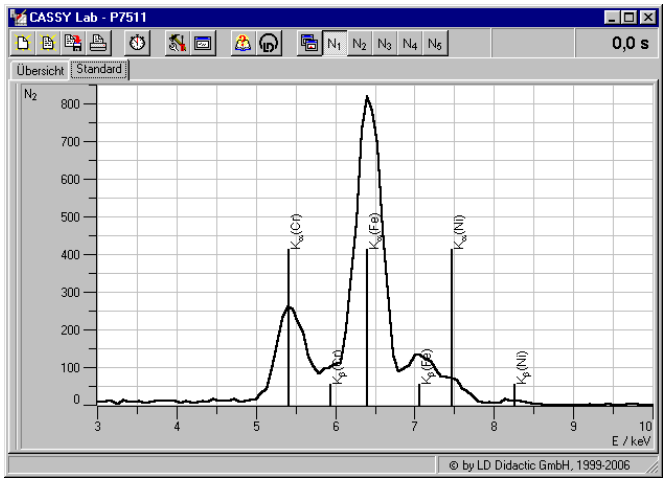

Fig. 3b Determination of the components of target 1: chromium, iron and nickel ⇒ stainless steel.

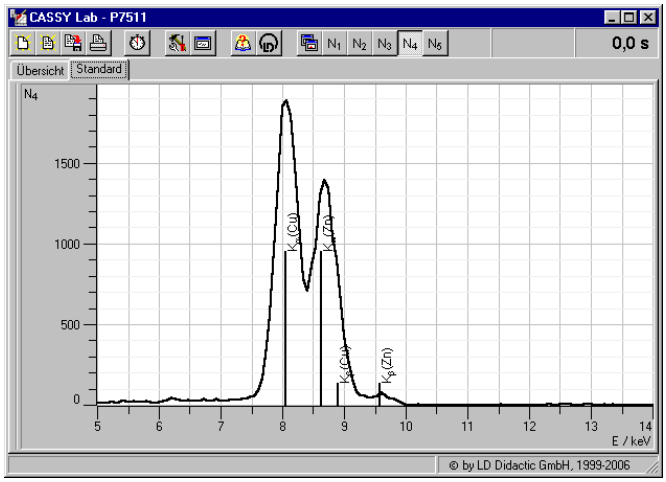

Fig. 3c Determination of the components of target 2: copper and zinc ⇒ brass.

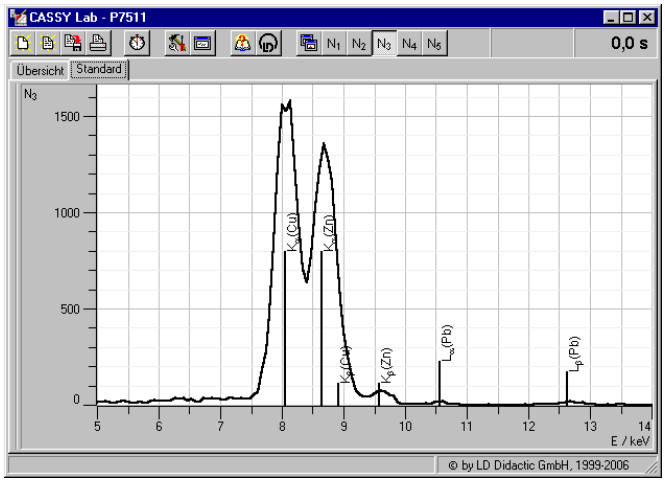

Fig. 3d Determination of the components of target 3: copper, zinc and lead ⇒ lead containing brass.

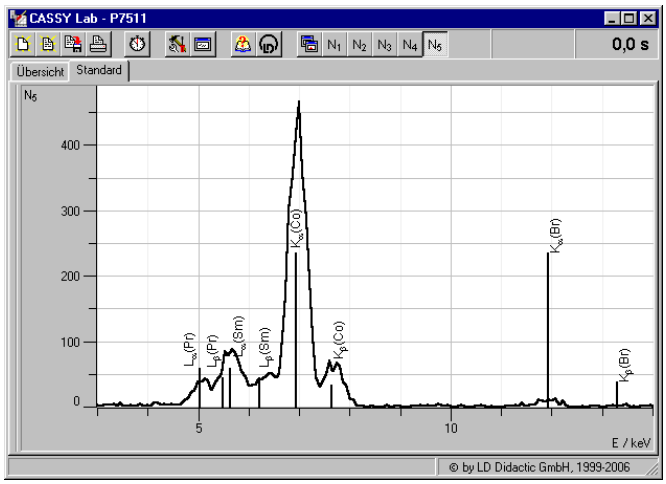

Fig. 3e Determination of the components of target 4: praseodymium, samarium, cobalt. The fluorescence lines of bromine originate from the plastic support (fire retardant)

Results

The results of the qualitative investigation of the alloys correspond well to the known chemical composition:

- Target 1: Stainless steel X5CrNi18-10 – contains 72% Fe, 18% Cr, 10% Ni.
- Target 2: Brass CuZn36 – contains 64% Cu, 36% Zn.
- Target 3: Brass CuZn39Pb3 – contains 58% Cu, 39% Zn, 3% Pb.
- Target 4: Praseodymium-samarium-cobalt magnet. These magnets can in addition to Co, Sm, Pr also contain Fe, Cu and Zr.

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Atomic and nuclear physics

X-ray physics
Physics of the atomic shell

Moseley's law and determination of the Rydberg constant

Objects of the experiment

- Measuring the K-absorption edges in the transmission spectra of Zr, Mo, Ag and In.
- Verifying Moseley's law.
- Determining the Rydberg constant.

Principles

The absorption of x-ray quanta during the passage of x-rays through matter is essentially due to ionization of atoms, which release an electron from an inner shell, e.g. the K-shell. This can only occur when the quantum energy

$$E = \frac{h \cdot c}{\lambda} \qquad \text{(I)}$$

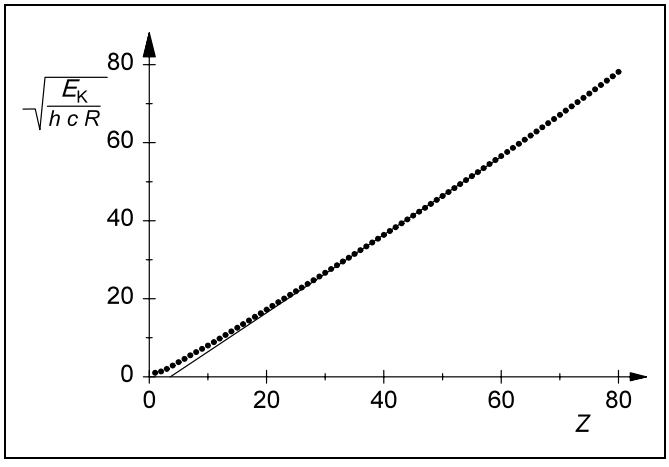
h: Planck's constant,
c: velocity of light

is greater than the binding energy E_K of the shell. The transmission

$$T = \frac{R}{R_0} \qquad \text{(II)}$$

R: intensity rate behind attenuator
R_0: intensity in front of attenuator

Fig. 1 Binding energy of the K-shell in the form $\sqrt{\frac{E_K}{h \cdot c \cdot R}}$ as a function of the atomic number Z
(see also equation (V))
Circles: Literature values from [1]
Line: best-fit straight line for Z = 30–60



of the material thus increases abruptly as a function of the wavelength at

$$\lambda_K = \frac{h \cdot c}{E_K} \qquad \text{(III)}$$

This abrupt change is known as an absorption edge, here the K-absorption edge.

In 1913, the English physicist Henry Moseley measured the K-absorption edges for various elements and formulated the law that bears his name:

$$\sqrt{\frac{1}{\lambda_K}} = \sqrt{R} \cdot (Z - \sigma_K) \qquad \text{(IV)}$$

R: Rydberg constant
Z: atomic number of absorbing elements
σ_K: screening coefficient of K-shell

A comparison with (III) gives us a value for the binding energy of the K-edge of

$$E_K = h \cdot c \cdot R \cdot (Z - \sigma_K)^2 \qquad \text{(V)}$$

We can bring this equation into agreement with the predictions of Bohr's model of the atom when we consider the following: The nuclear charge $Z \cdot e$ of an atom is partially screened from the electron ejected from the K-shell through absorption of the x-ray quantum by the remaining electrons of the atomic shell. Therefore, on average, only the charge $(Z - \sigma_K) \cdot e$ acts on the electron during ionization.

This experiment verifies Moseley's law by measuring the K-absorption edges for the atomic numbers Z between 40 and 50. In this range, the screening coefficient σ_K is largely independent of Z (see Fig. 1). Thus, (IV) is equivalent to a general, straight-line equation in the form

$$y = a \cdot x + b \qquad \text{(VI)}$$

with the atomic number Z as the x-variable. From the parameters a and b of the straight line, we can calculate the Rydberg constant R and the screening coefficient σ_K:

$$R = a^2,\ \sigma_K = -\frac{b}{a} \qquad \text{(VII).}$$

Apparatus

1 X-ray apparatus	554 811
1 End-window counter for α, β, γ and x-ray radiation	559 01
1 Set of absorber foils	554 832

additionally required:

1 PC with Windows 9x/NT

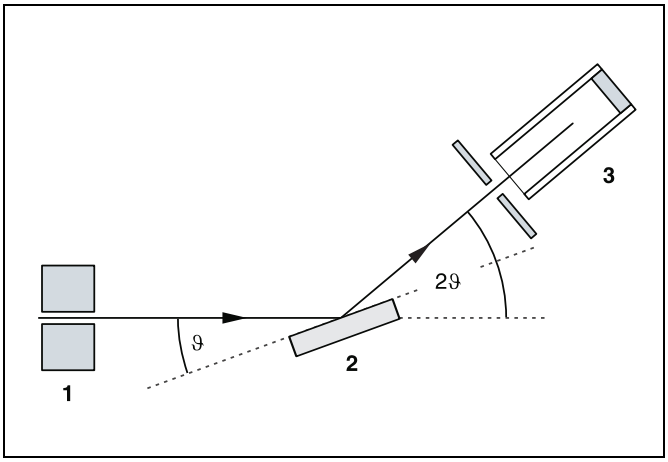


Fig. 2 Schematic diagram of diffraction of x-rays at a monocrystal and 2ϑ coupling between counter-tube angle and scattering angle (glancing angle)
1 collimator, **2** monocrystal, **3** counter tube

A goniometer with NaCl crystal and a Geiger-Müller counter tube in the Bragg configuration are used to measure the transmission T as a function of the wavelength. The crystal and counter tube are pivoted with respect to the incident x-ray beam in 2ϑ coupling, i. e. the counter tube is turned at an angle twice as large as the crystal (see Fig. 2).

In accordance with Bragg's law of reflection, the scattering angle ϑ in the first order of diffraction corresponds to the wavelength

$\lambda = 2 \cdot d \cdot \sin \vartheta$ (VIII).

d = 282.01 pm: lattice plane spacing of NaCl

Safety notes

The x-ray apparatus fulfills all regulations governing an x-ray apparatus and fully protected device for instructional use and is type approved for school use in Germany (NW 807/97 Rö).

The built-in protection and screening measures reduce the local dose rate outside of the x-ray apparatus to less than 1 μSv/h, a value which is on the order of magnitude of the natural background radiation.

- Before putting the x-ray apparatus into operation inspect it for damage and to make sure that the high voltage is shut off when the sliding doors are opened (see Instruction Sheet for x-ray apparatus).
- Keep the x-ray apparatus secure from access by unauthorized persons.

Do not allow the anode of the x-ray tube Mo to overheat.

- When switching on the x-ray apparatus, check to make sure that the ventilator in the tube chamber is turning.

The goniometer is positioned solely by electric stepper motors.

- Do not block the target arm and sensor arm of the goniometer and do not use force to move them.

Setup

Setup in Bragg configuration:

Set up the experiment as shown in Fig. 3. To set up the experiment, proceed as follows (see also the Instruction Sheet for the x-ray apparatus):

– Mount the collimator in the collimator mount **(a)** (note the guide groove).
– Attach the goniometer to guide rods **(d)** so that the distance s_1 between the slit diaphragm of the collimator and the target arm is approx. 5 cm. Connect ribbon cable **(c)** for controlling the goniometer.
– Remove the protective cap of the end-window counter, place the end-window counter in sensor seat **(e)** and connect the counter tube cable to the socket marked GM TUBE.
– By moving the sensor holder **(b)**, set the distance s_2 between the target arm and the slit diaphragm of the sensor seat to approx. 5 cm.
– Mount the target holder with target stage.
– Loosen knurled screw **(g)**, place the NaCl crystal flat on the target stage **(f)**, carefully raise the target stage with crystal all the way to the stop and carefully tighten the knurled screw (prevent skewing of the crystal by applying a slight pressure).
– If necessary, adjust the mechanical zero position of the goniometer (see Instruction Sheet for x-ray apparatus).

Notes:

NaCl crystals are hygroscopic and extremely fragile.

Store the crystals in a dry place; avoid mechanical stresses on the crystal; handle the crystal by the short faces only.

If the counting rate is too low, you can reduce the distance s_2 between the target and the sensor somewhat. However, the distance should not be too small, as otherwise the angular resolution of the goniometer is no longer sufficient to separate the characteristic K_α and K_β lines.

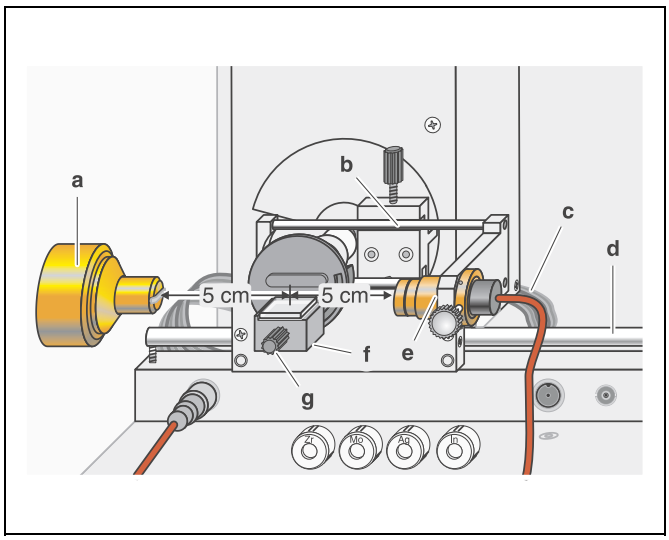


Fig. 3 Experiment setup for measuring the K-absorption edges.

Preparing the PC-based measurement:

– Connect the RS–232 output and the serial interface on your PC (usually COM1 or COM2) using the 9-pin V.24 cable (supplied with x-ray apparatus).
– If necessary, install the software “X-ray Apparatus” under Windows 9 x/NT (see Instruction Sheet for x-ray apparatus) and select the desired language.

Carrying out the experiment

– Start the software “X-ray Apparatus”, check to make sure that the apparatus is connected correctly, and clear any existing measurement data using the button or the F4 key.
– Set the tube high voltage U = 35.0 kV, the emission current I = 1.00 mA and the angular step width $\Delta\beta = 0.1°$.
– Press the COUPLED key to activate 2ϑ coupling of target and sensor and set the lower limit of the target angle to 3.7° and the upper limit to 7.5°.
– Set the measuring time per angular step to Δt = 5 s.
– Start measurement and data transfer to the PC by pressing the SCAN key.
– When the scan is finished, mount the zirconium foil on sensor seat **(e)** of the goniometer and start a new measurement by pressing the SCAN key.
– Replace the Zr foil with the Mo, Ag and In foils one after another and conduct further measurements.
– When you have finished measuring, save the measurement series under an appropriate name by pressing the button or the F2 key.
– To display the measurement data as a function of the wavelength λ, open the “Settings” dialog with the button or F5, and in the tab “Crystal”, click on the button “Enter NaCl”.

Measuring example

(see Fig. 4)

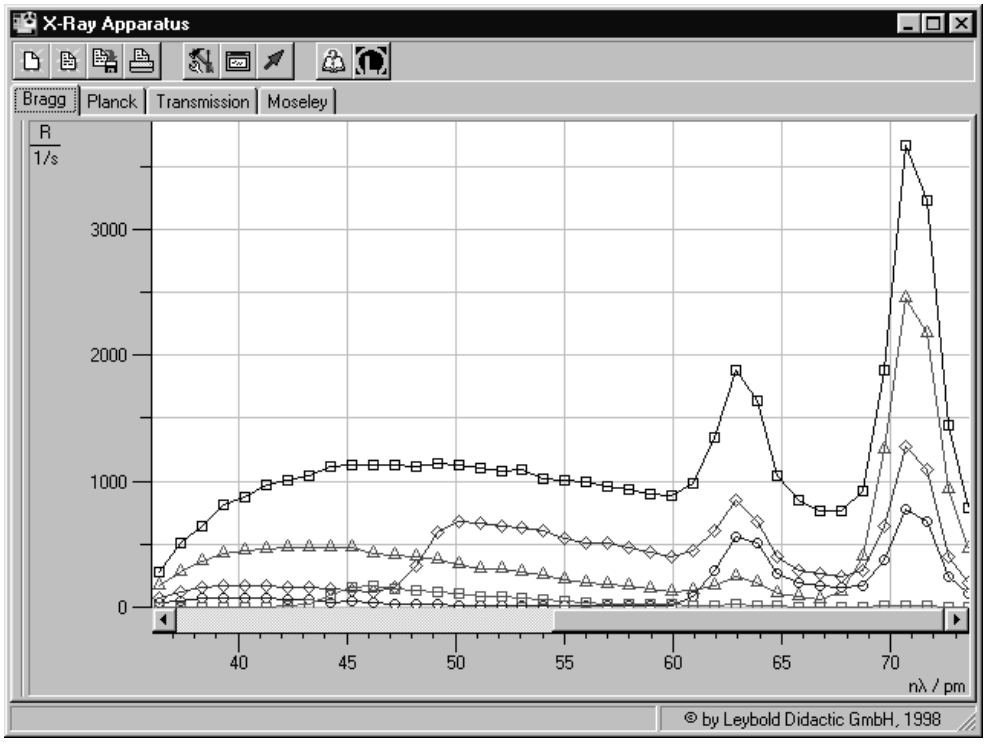


Fig. 4 Diffraction spectra of x-rays with the characteristic lines of the molybdenum anode in the wavelength range between 36 and 74 pm (U = 35 kV)
Squares:
Not attenuated
Triangles:
Attenuation in Zr foil
Circles:
Attenuation in Mo foil
Hashes:
Attenuation in Ag foil
Squares:
Attenuation in In foil

Evaluation

– Click on the “Transmission” tab in the software “X-ray Apparatus” to generate the transmission spectra (see Fig. 5) from the diffraction spectra (see Fig. 4).
– In the diagram, click the right mouse button to access the evaluation functions of the software “X-ray Apparatus” and select the command “Draw K-Edges”.
– Mark the range of each K-edge in the transmission spectra using the left mouse button.
– Click on the tab “Moseley” and enter the atomic numbers of the respective foils (Zr: 40, Mo: 42, Ag: 47 and In: 49) in the column *Z* (see Fig. 6).
– Place the mouse pointer over the diagram, click the right mouse button and select the evaluation command “Best-fit Straight Line”; then hold down the left mouse button to mark the range in the diagram to which you want to fit the line. Read off the result for the Rydberg constant *R* and the screening coefficient σ_K in the bottom left corner of the window.

Fig. 6 shows how the result should look.

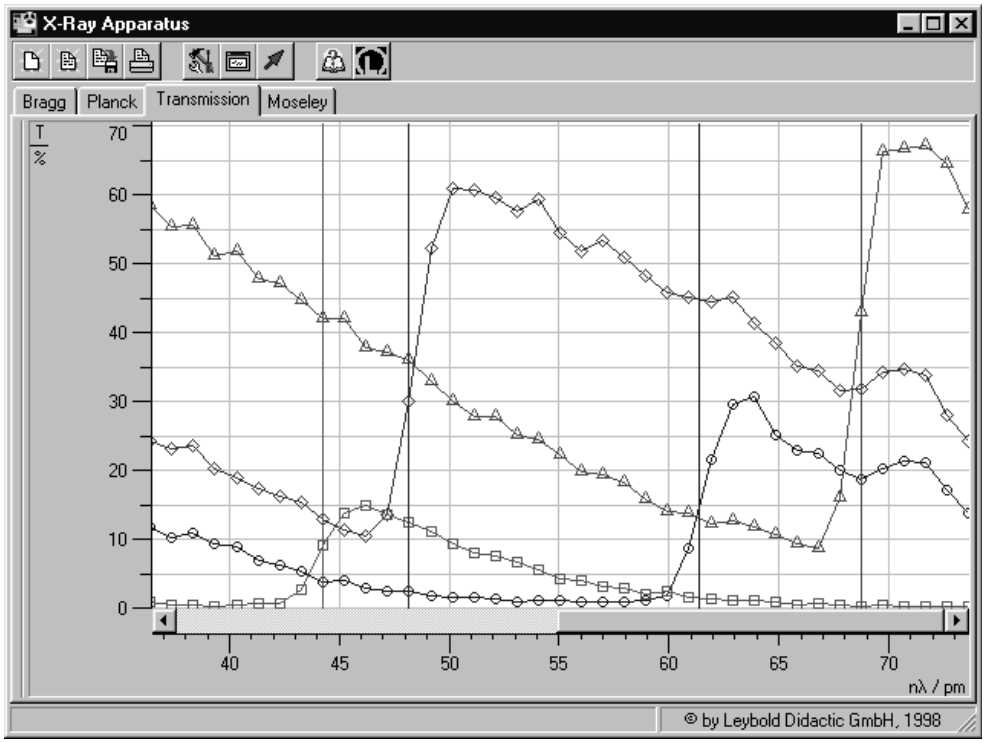


Fig. 5 Transmission spectra in the wavelength range between 36 and 74 pm
Triangles:
Attenuation in Zr foil
Circles:
Attenuation in Mo foil
Hashes:
Attenuation in Ag foil
Squares:
Attenuation in In foil

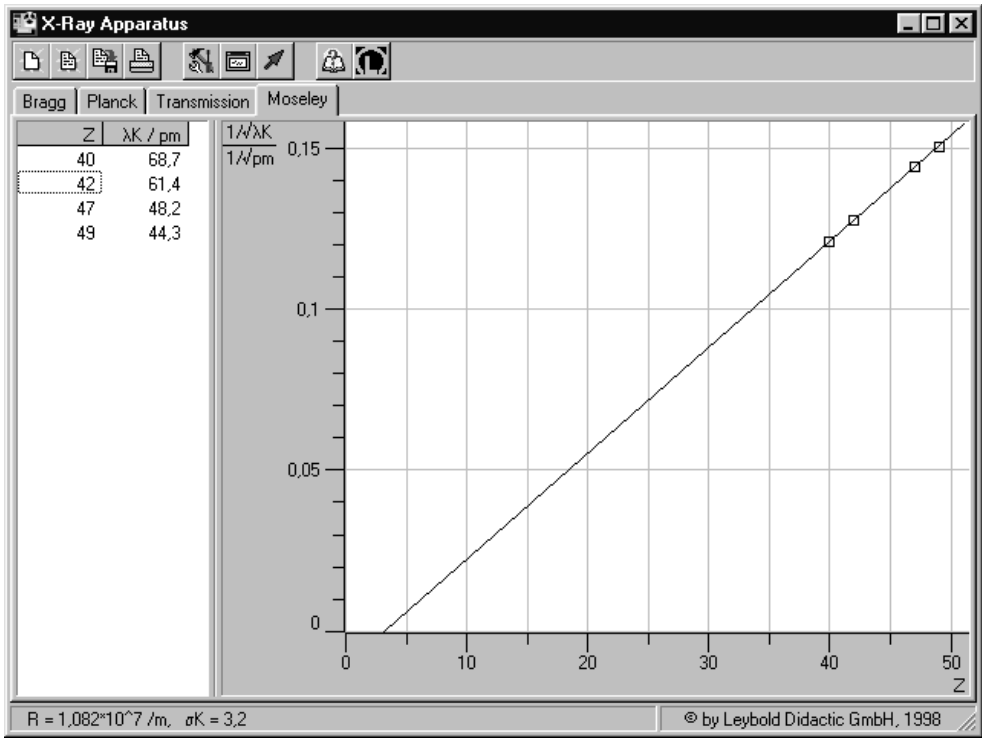


Fig. 6 Evaluation of measurement data for verification of Moseley’s law

Results

The result of the graphical evaluation is:

$R = 1.082 \cdot 10^7\ m^{-1}$, $\sigma_K = 3.2$

Literature values [1]:

$R = 1.097373 \cdot 10^7\ m^{-1}$

$\sigma_K = 3.6$ (for moderately heavy nuclei)

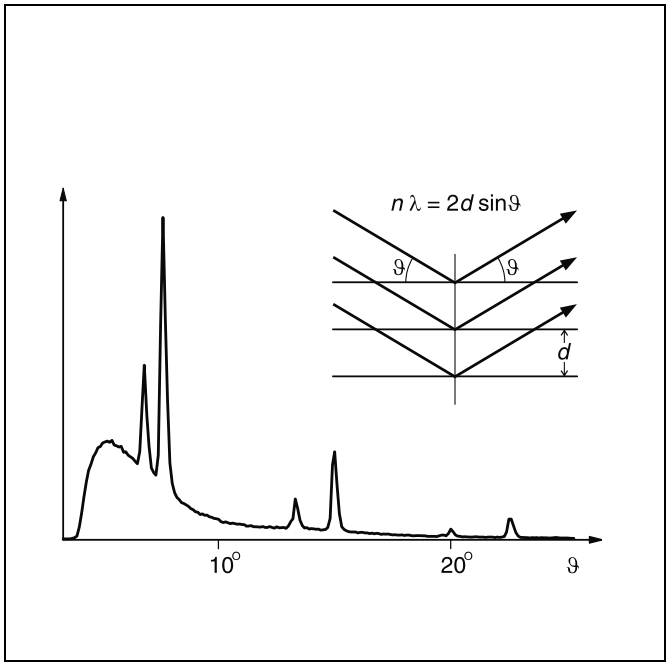
Literature

[1] C. M. Lederer and V. S. Shirley, Table of Isotopes, 7th Edition, 1978, John Wiley & Sons, Inc., New York, USA.

Bragg reflection: diffraction of x-rays at a monocrystal

Objects of the experiment

- To investigate Bragg reflection at an NaCl monocrystal using the characteristic x-ray radiation of molybdenum.
- To determine the wavelength for the characteristic K_α and K_β x-ray radiation of molybdenum.
- To confirm Bragg's law of reflection.
- To verify the wave nature of x-rays.



Principles

In 1913, *H. W.* and *W. L. Bragg* realized that the regular arrangement of atoms and/or ions in a crystal can be understood as an array of lattice elements on parallel lattice planes. When we expose such a crystal to parallel x-rays, additionally assuming that these have a wave nature, then each element in a lattice plane acts as a "scattering point", at which a spherical wavelet forms. According to *Huygens,* these spherical wavelets are superposed to create a "reflected" wavefront. In this model, the wavelength λ remains unchanged with respect to the "incident" wave front, and the radiation directions which are perpendicular to the two wave fronts fulfill the condition "angle of incidence = angle of reflection".

Constructive interference arises in the rays reflected at the individual lattice planes when their path differences Δ are integral multiples of the wavelength λ.

$\Delta = n \cdot \lambda$ with n = 1, 2, 3, ... (I)

As Fig. 1 shows for two adjacent lattice planes with the spacing *d,* we can say for the path differences Δ_1 and Δ_2 of the incident and reflected rays with the angle ϑ:

$\Delta_1 = \Delta_2 = d \cdot \sin \vartheta$

so that the total path difference is

$\Delta = 2 \cdot d \cdot \sin \vartheta$. (II)

(I) and (II) give us Bragg's law of reflection:

$n \cdot \lambda = 2 \cdot d \cdot \sin \vartheta$ (III)

The angle ϑ is known as the glancing angle.

In this experiment, we verify Bragg's law of reflection by investigating the diffraction of x-rays at an NaCl monocrystal in which the lattice planes are parallel to the cubic surfaces of the unit cells of the crystal. The lattice spacing *d* of the cubic

Apparatus

1 X-ray apparatus	554 811
1 End-window counter for α, β, γ and x-ray radiation	559 01

additionally required:

1 PC with Windows 9x or Windows NT

face-centered NaCl crystal is half the lattice constant a_0. We can thus say [1]

$2 \cdot d = a_0 = 564.02$ pm

The measurements are conducted using the built-in goniometer of the x-ray apparatus (554 811). The x-rays are detected using a GM counter tube (end-window counter) which is swiveled in tandem with the NaCl crystal in a 2_ coupling with respect to the incident light; this means that the counter tube always advances by an angle which is twice that of the crystal (cf. Fig. 2).

The x-ray radiation consists of the bremsstrahlung continuum and several sharply defined lines which correspond to the characteristic x-ray radiation of the Mo anode and which originate in the K_α and K_β transitions of the molybdenum atoms. This characteristic radiation is particularly suitable for investigating Bragg's law. Its properties are known from the literature [2] and summarized in table 1. Table 2 shows the corresponding glancing angles at which the diffraction maxima of the characteristic radiation are to be expected for scattering at an NaCl monocrystal (d = 282.01 pm) up to the third diffraction order.

Safety notes

The x-ray apparatus fulfills all German regulations governing an x-ray apparatus and fully protected device for instructional use and is type approved for school use in Germany (NW 807/97 Rö).

The built-in protection and screening measures reduce the local dose rate outside of the x-ray apparatus to less than 1 μSv/h, a value which is on the order of magnitude of the natural background radiation.

- Before putting the x-ray apparatus into operation, inspect it for damage and check to make sure that the high voltage shuts off when the sliding doors are opened (see Instruction Sheet of x-ray apparatus).
- Keep the x-ray apparatus secure from access by unauthorized persons.

Do not allow the anode of the x-ray tube Mo to overheat.

- When switching on the x-ray apparatus, check to make sure that the ventilator in the tube chamber is turning.

The goniometer is positioned solely by electric stepper motors.

- Do not block the target arm and sensor arm of the goniometer and do not use force to move them.

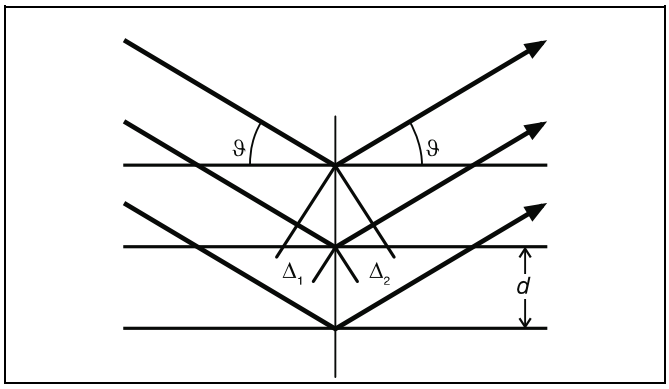


Fig. 1 Diagram of the reflection of x-rays at the lattice planes of a monocrystal.
Δ_1, Δ_2: path differences,
ϑ: glancing angle,
d: spacing of lattice planes

Table 1: Energy *E,* frequency ν and wavelength λ of the characteristic x-ray radiation of molybdenum (weighted mean values [1])

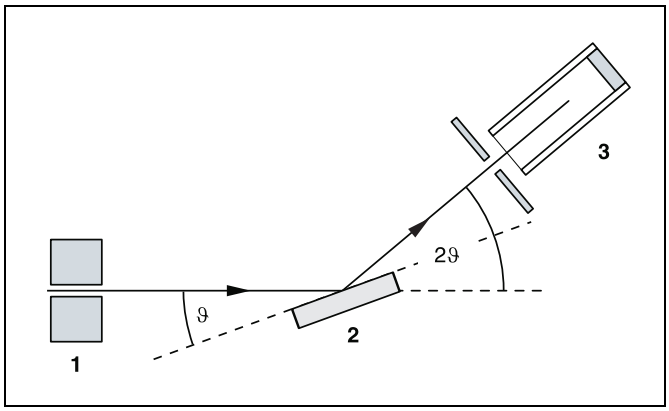
	$\frac{E}{\text{keV}}$	$\frac{\nu}{\text{EHz}}$	$\frac{\lambda}{\text{pm}}$
K_α	17.443	4.2264	71.080
K_β	19.651	4.8287	63.095

keV = 10^3 eV, EHz = 10^{18} Hz, pm = 10^{-12} m

Table 2: Glancing angle ϑ of the characteristic x-ray radiation of molybdenum for diffraction at an NaCl monocrystal up to the third order

n	$\vartheta(K_\alpha)$	$\vartheta(K_\beta)$
1	7.24°	6.42°
2	14.60°	12.93°
3	22.21°	19.61°

Fig. 2 Diagram showing the principle of diffraction of x-rays at a monocrystal and 2ϑ coupling between counter-tube angle and scattering angle (glancing angle)
1 collimator, **2** monocrystal, **3** counter tube



General remarks

In principle, you can conduct measurements in both manual scan and autoscan modes of the x-ray apparatus (see the Instruction Sheet of the x-ray apparatus). You can record the measured values manually by reading the values from the display field and writing them in a table, using a chart recorder or via a PC.

The fastest and most convenient measurement is in autoscan mode with simultaneous registration of measured values and subsequent evaluation on a Windows 9x/NT PC. This type of measurement is described in your Instruction Sheet.

The data is transmitted to the PC via the RS–232 serial interface on the x-ray apparatus. The software "X-ray Apparatus", supplied with the device, enables you to record, display and evaluate the data stream supplied by the x-ray apparatus. The program contains detailed online help which you can access by pressing F1. Please refer to the Instruction Sheet of the x-ray apparatus for details on installing the software.

The Instruction Sheet also describes recording data under Windows 3.1.

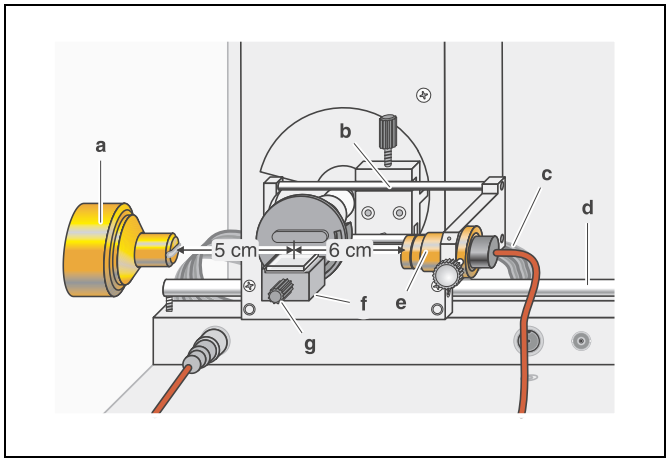
Setup

Setting up the Bragg configuration:

Fig. 3 shows some important details of the experiment setup. Specifically, you need to carry out the following steps (see also Instruction Sheet of x-ray apparatus):

– Mount the collimator in the collimator mount **(a)** (note the guide groove).
– Attach the goniometer to the guide rods **(d)** in such a way that the distance s_1 between the slit diaphragm of the collimator and the target arm is approx. 5 cm. Connect the ribbon cable **(c)** for controlling the goniometer.
– Remove the cap of the end-window counter, insert the end-window counter in the sensor seat **(e)** and connect the counter tube lead to the socket marked GM-Tube.

Fig. 3 Experiment setup in Bragg configuration



– Adjust the sensor seat **(b)** until the distance s_2 between the target arm and the slit diaphragm of the sensor seat is approx. 6 cm.
– Attach the target holder with target stage **(f)**.
– Loosen knurled screw **(g)**, lay the NaCl crystal flat on the target stage, carefully raise the stage as far at it will go and then tighten the knurled screw with care (press against the screw lightly to prevent it from stripping).
– Adjust the zero position of the goniometer measuring system as necessary (see Instruction Sheet of x-ray apparatus).

Notes:

NaCl crystals are hygroscopic and fragile. Store the crystals in a dry place. Avoid mechanical stresses on the crystal; handle the crystal by the short faces only.

If the counting rate is too low, you can reduce the distance s_2 between the target and the sensor somewhat. However, this distance must not be too small, as otherwise the angular resolution of the goniometer is no longer great enough to separate the characteristic K_α and K_β lines.

Preparing a PC-based measurement:

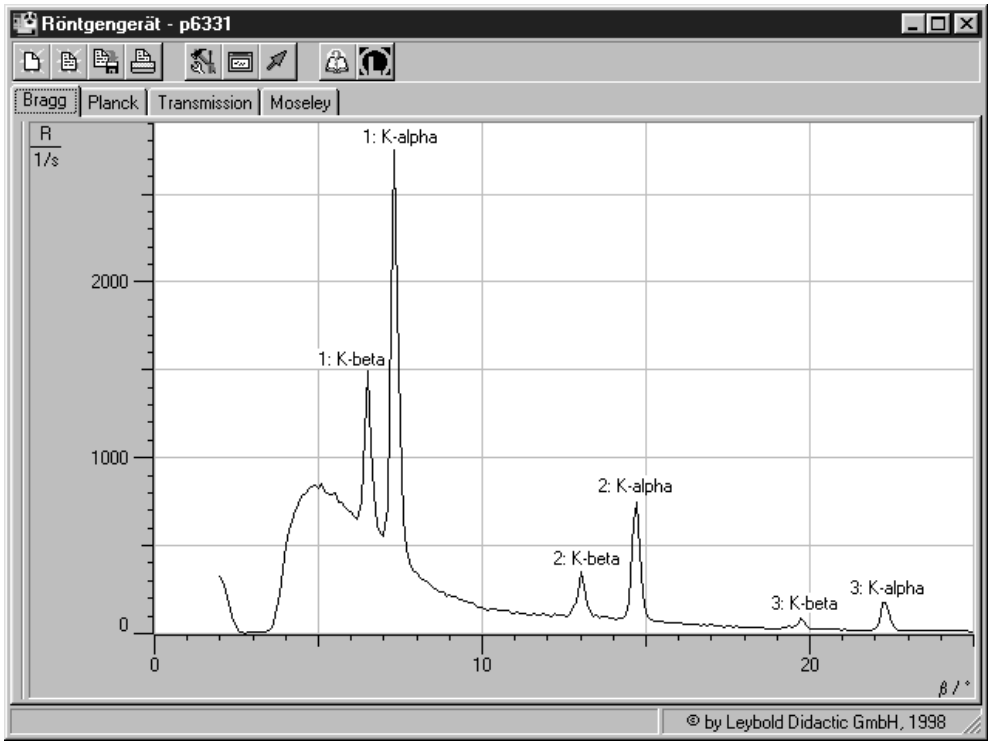
– Connect the RS–232 output to the serial interface on the PC (usually COM1 or COM2) using the 9-pin V.24 cable (included with the x-ray apparatus).
– If you have not already done so, install the software "X-ray Apparatus" under Windows 9x/NT (see Instruction Sheet of x-ray apparatus) and select the desired language.

Carrying out the experiment

– Start the program "X-ray Apparatus", check to make sure that the x-ray apparatus is properly connected and delete any existing measurement data by clicking the button or pressing F4.
– Set the x-ray high voltage U = 35.0 kV, emission current I = 1.00 mA, measuring time per angular step Δt = 10 s and angular step width $\Delta\beta$ = 0.1°.
– Press the COUPLED key on the device to enable 2ϑ coupling of the target and sensor; set the lower limit value of the target angle to 2° and the upper limit to 25°.
– Press the SCAN key to start the measurement and data transmission to the PC.
– When the measurement is finished, save the measurement series to a file under a suitable name using the button or F2.

Measuring example

Fig. 4 shows the measured diffraction spectrum.



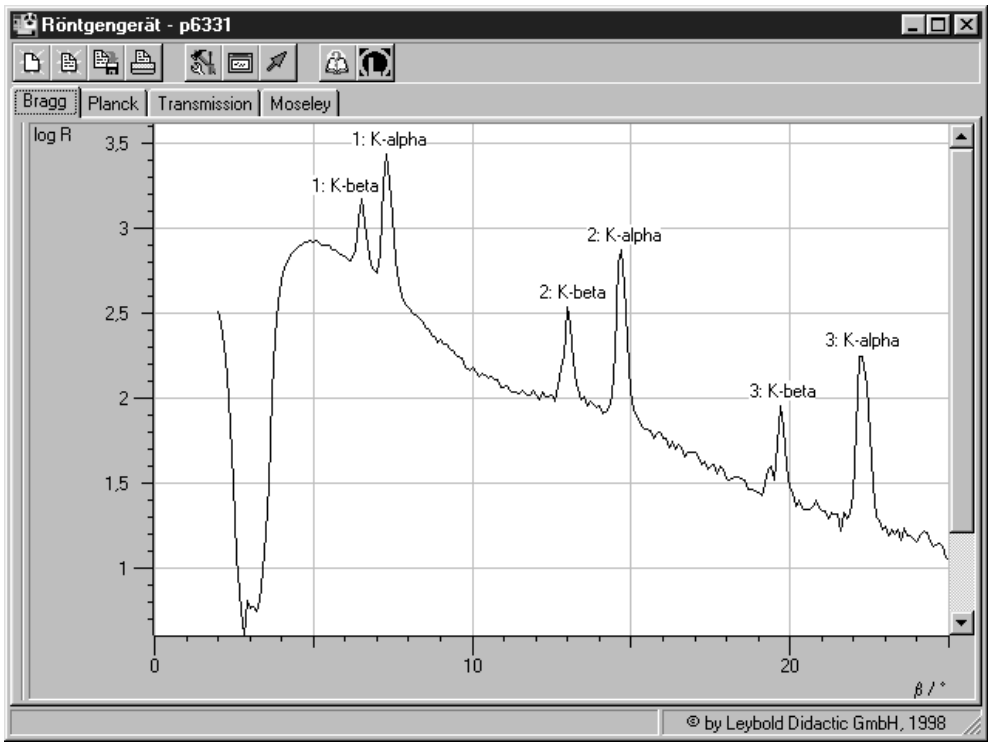


Fig. 4 Diffraction spectrum of x-ray radiation for *Bragg* reflection to the third order at an NaCl monocrystal
Top: linear representation of counting rate *R*
Bottom: logarithmic representation of counting rate *R*
Parameters of x-ray tube: *U* = 35 kV and *I* = 1 mA

Evaluation

- Access the evaluation functions of the software "X-ray Apparatus" by clicking the right-hand mouse button and select the command "Calculate Peak Center".
- Using the left mouse button, mark the "entire width" of the peaks; if desired, insert the calculated peak center β and the peak width σ in the diagram with Alt+T and note the center as the glancing angle in the measurement table (see tables 3 and 4).
- Save your measurements and evaluations to a suitably named file with the button or by pressing F2.
- Using the glancing angle ϑ and the lattice plane spacing d = 282.01 pm, calculate the wavelength λ using Bragg's law of reflection (IV) (see tables 3 and 4).
- Find the mean values for the individual diffraction orders of the measured wavelengths (see table 5).

Table 3: Measured glancing angles of the Mo K_α line and the calculated wavelengths λ for the first through third diffraction orders

n	$\vartheta(K_\alpha)$	$\frac{\lambda(K_\alpha)}{pm}$
1	7.24°	71.08
2	14.60°	71.09
3	22.20°	71.04

Table 4: Measured glancing angles of the Mo K_β line and the calculated wavelengths λ for the first through third diffraction orders

n	$\vartheta(K_\beta)$	$\frac{\lambda(K_\beta)}{pm}$
1	6.42°	63.07
2	12.94°	63.15
3	19.58°	63.01

Table 5: Mean value and literature value [2] for the characteristic wavelength λ

	$\frac{\lambda(K_\alpha)}{pm}$	$\frac{\lambda(K_\beta)}{pm}$
Mean value	71.07	63.08
Literature value	71.08	63.09

Results

The close agreement of the experimentally determined wavelengths for the characteristic lines with the literature values in table 5 verify the validity of Bragg's law. This simultaneously confirms the wave nature of x-rays, as this property was assumed in the process of deducing this law.

Additional information

The characteristic K_α and K_β lines actually consist of multiple, adjacent discrete lines, which can be observed separately at higher diffraction orders (see Physics Leaflet P 6.3.3.4). Table 1 shows the weighted mean values of the respective individual lines from this substructure.

Literature

[1] Handbook of Chemistry and Physics, 52nd Edition (1971–72), The Chemical Rubber Company, Cleveland, Ohio, USA.

[2] C. M. Lederer and V. S. Shirley, Table of Isotopes, 7th Edition, 1978, John Wiley & Sons, Inc., New York, USA.