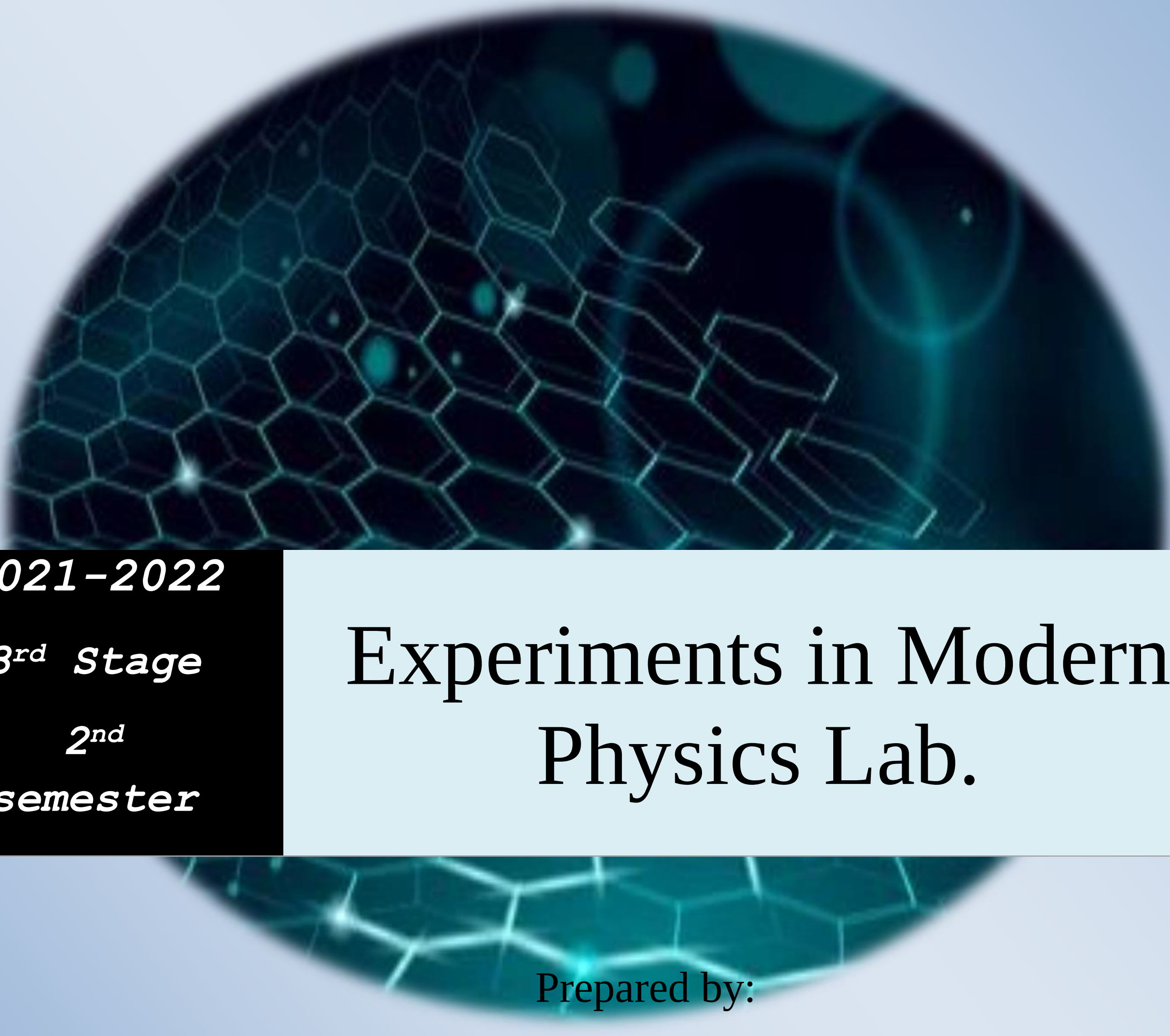
Ministry of higher education

Sallahaddin university-Erbil

Collage of education /Physics Department



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3rd Stage

2nd semester

Experiments in Modern Physics Lab.

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Experiments:

Experiment (1): Microwave power and attenuation Measurements

Aim in the experiment:

Finding the ratio of attenuated Microwave from a metal flab.

Apparatus:

MW generator, variable attenuator, detector and matched termination.

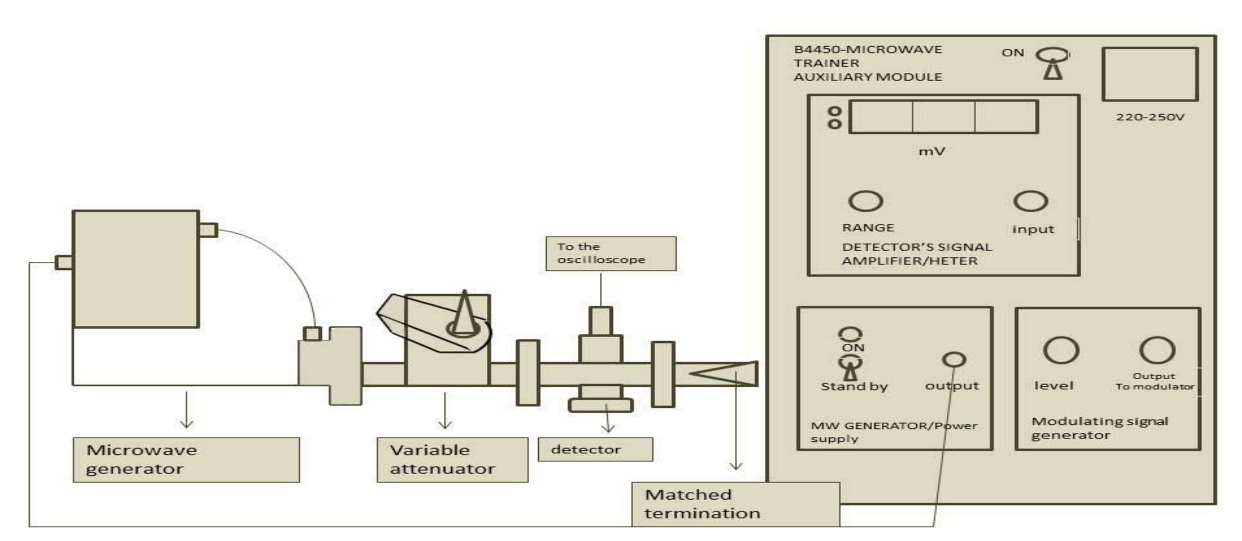


Fig (1): Microwave trainer

Theory and Calculation:-

- Microwave is a form of electromagnetic radiation with wavelengths ranging from as long as one meter to as short as 1 millimeter, with frequencies between 300 MHz (0.3 GHz) and 300 GHz.
- The microwave detector consists of a thin tungsten wire brought in contact with a small silicon wafer (diode). The whole body of the diode is exposed to the attenuated RF wave and therefore become a source of induced EMF voltage.
- Attenuation results from absorption by atmospheric molecules or scattering by aerosols in

the atmosphere between the microwave sensor on board a spacecraft or aircraft and the target to be measured. The attenuation of the microwave will take place as a function of the exponential with respect to the transmitted distance mainly due to absorption and scattering. Therefore the attenuation will increase in proportion to the distance, under homogeneous atmospheric conditions.

- The attenuation per unit of distance is called specific attenuation. Usually the loss due to attenuation can be expressed in the units of dB (decibel). The dB is a relative measure unit which always implies a reference;

$$P[dB] = 10log\frac{P}{P_0}$$

P_0: is the reference power.

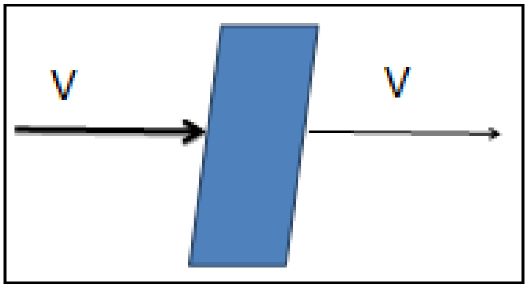
If the detector's indication is V_0 in a certain situation and V_1 in another situation, the ratio of powers shall equal the square of the detector's indication;

$$P_0 = kV_0{}^2 \;\; P_1 = kV_1{}^2$$

$$\frac{P_1}{P_2} = (\frac{V_1}{V_2})^2$$

And in (dB)

$$P_1[dB] = 10\,log\left(\frac{V_1{}^2}{V_0{}^2}\right) = 20log\,(\frac{V_1}{V_0})$$



Where V_0 is the reference voltage (without attenuator). In order to perform the experiment as show in Fig (1).

- The power levels within the mw systems is most commonly handled in Decibels (dB) , like in all communication systems .

The dB is a relative measure unit which always implies a reference;

$$P[dB] = 10 log \frac{P}{P_0}$$

P_0: is the reference power.

Note: For measuring the attenuation, first you will:

- Keep the flap of the attenuator completely extracted .in there conditions the nominal loss attenuation setting is 0 dB , however there will be an inherent and fixed insertion loss for the attenuator.
- Read the voltage indication of the detector. Increase attenuation up to reading a voltage reduced to ½ the previous value, the attenuation is:

In these conditions the power reaching the detector is 1/4than in the previous case.

$$A[dB] = 10\, log \left(\frac{P}{P_0}\right) = 20 log \left(\frac{V}{V_0}\right)$$

Data:

1- Record your values in Table (1).

A(dB)	V (mVolt)	$A(dB) = 20 \log \frac{V}{V_0}$
0 **3** **6** **9** **12** **24**		

2- Discuss the nature of the obtained value in detail.

Experiment (2): Diffraction of microwaves

Aim of experiment:

Determination of the diffraction pattern of the microwave intensity

1. behind the edge of a screen,
2. After passing through a slit,
3. behind a slit of variable width, with a fixed receiving point.

Equipment:

Microwave transmitter w. klystron
Microwave receiving dipole
Microwave power supply, 220 VAC
Screen, metal, 300x300 mm
Multi-range meter with amplifier
Barrel base -PASS-
Right angle clamp -PASS-
Adapter, BNC-plug/socket 4 mm
Connecting cord

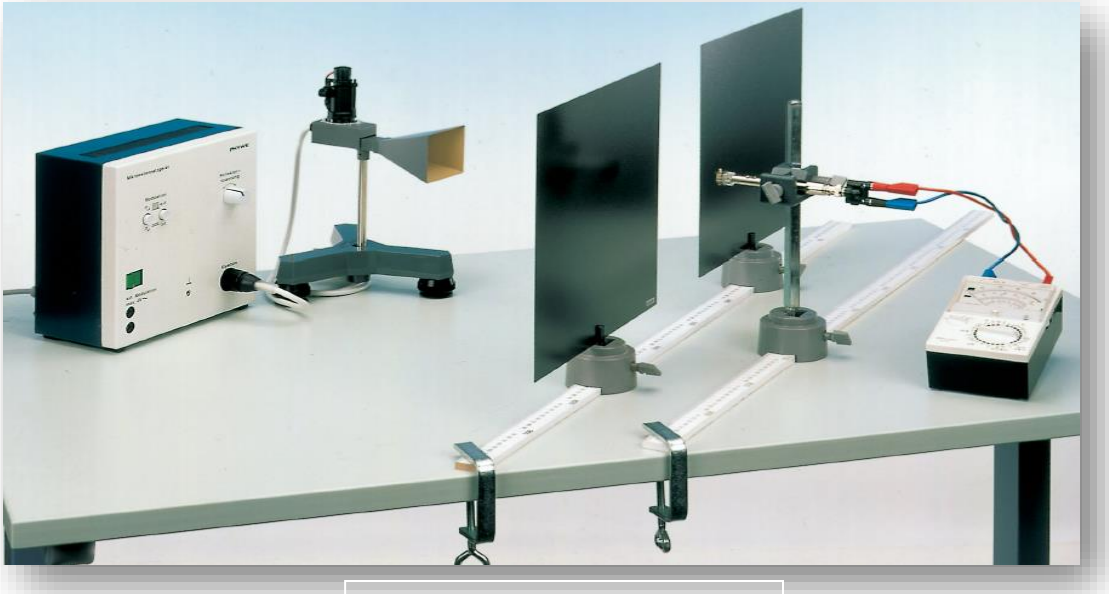


Fig -1-: Experimental setup

Principle:

Microwaves impinge on a slit and the edge of a screen. The diffraction pattern is determined on the basis of diffraction at these obstacles.

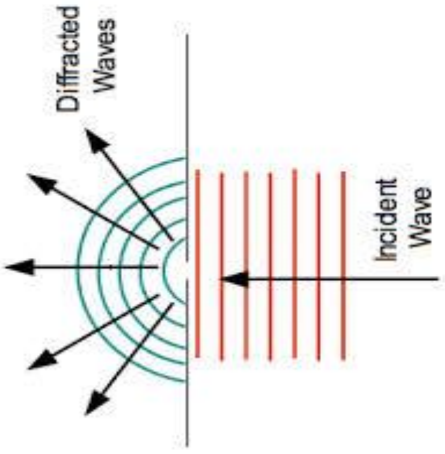
Set-up and procedure

- The experimental set up is as shown in Fig.1. The microwaves (9.45 GHz) used for detection are amplitude-modulated either internally with a frequency of 50 Hz or externally with any frequency (NF). With constant modulation (frequency, amplitude) the signal (e.g. 50 Hz), demodulated with a receiving diode, is proportional to the field strength and is measured with the measuring amplifier and the voltmeter. As it is an Ac-signal no time-constant (damping) may be switched on.

- For the diffraction at the edge, the screen is placed in the wave field so that it covers about half of the transmitter (direction receiving diode – transmitter). The receiving dipole is moved parallel to the screen.

Note: A distance of approx. 80 cm from the transmitter to the screen, and approx. 20 cm from the screen to the receiver, is recommended.

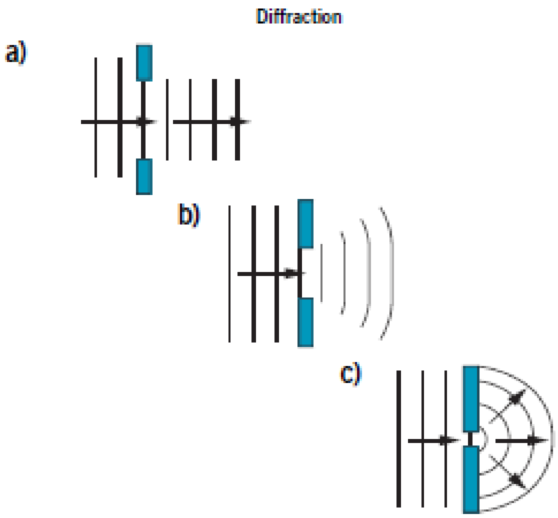
- Two metal screens, the edges of which are 3 cm apart, form a slit. The microwave beam impinges at right angles on to the slit and is adjusted parallel to the screens using the receiving diode. In task 3, the receiving diode and one screen are set up as for the diffraction at the edge. The other screen is now moved so that a slit of variable width is produced.

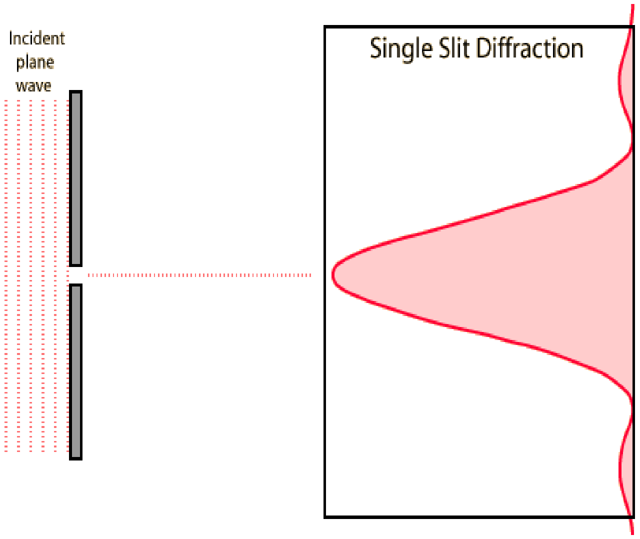


- ➢ Record your values in Table below.

d= 2 cm	
x/cm	V / mVolt
0	
1	
2	
. **.** **15**	

- ➢ Plot the graph for (V) values as a function of position of detector (X).
- ➢ Discuss the nature of the obtained curve in detail.





Experiment (3): Transmission and absorption coefficient of micro waves

You should learn…

Microwaves, EM waves, transmission, Lambert’s law and absorption coefficient.

Purpose:

- To know the mechanisms of interacting microwaves with specific frequency to the different substances.
- To find the relative microwave absorption coefficient of those various materials.

Equipments:

Transmitter with holder
Receiver with holder
Power supply with 12V DC
Three ways cable
Cable for tester
Load speaker

Multi-meter (voltmeter)
Polystyrene panel
Tray and Tray support
Paraffin prism
Metal sheet
Linear ruler

Theory and Evaluation:

Absorption and transmission of microwaves give important qualitative information about physical properties of substances that interact with electromagnetic waves. Take into account, for example, the absorption. When crossing a layer of thickness x, it is observed that the intensity of the transmitted radiation follows Lambert’s law:

$$I = I_o . e^{-kx} ---------(1)$$

Where k is the absorption coefficient of material at known frequency and I_o is the intensity of the atmospheric molecule at room temperature.

Here in experiment, we have: $V = V_o . e^{-kx} ------------- (2)$

By taking (ln) for both sides of eqn.2, we obtain: $ln\,V - lnV_o = -kx$

Hence, $$k = \frac{ln\, V_o - \ln V}{x} \quad ---------- \quad (3)$$

And for given frequency, a material has k=0, then it has zero absorption. Of course, the same material can be transport for certain frequency and absorbent for other ones.

When placing a metal body like metal sheet between the transmitter and receiver, there is no microwave passage and signal is totally absent.

Also, there is no attenuation of the signal with polystyrene panel. The Plexiglas tray without water also results no signal attenuation. The results remain the same for other electrically insulating materials (e.g. wood, cork, etc): the insulating materials let the microwaves to through. It should be noted that depending on the type of material, a partial, more or less evident, reflection of microwave may occur.

When the tray is filled with water, the signal is totally absent: the microwaves are absorbed by the water. The law that describes this phenomenon of absorption is Lambert’s law (as shown in eqn.1). This means that the water layer does not allow microwaves to reach the receiver. It is precisely for this reason that submarines and bouts use sonar not the radar system. Check if the same thing happens even when the microwaves cross the short side of tray.

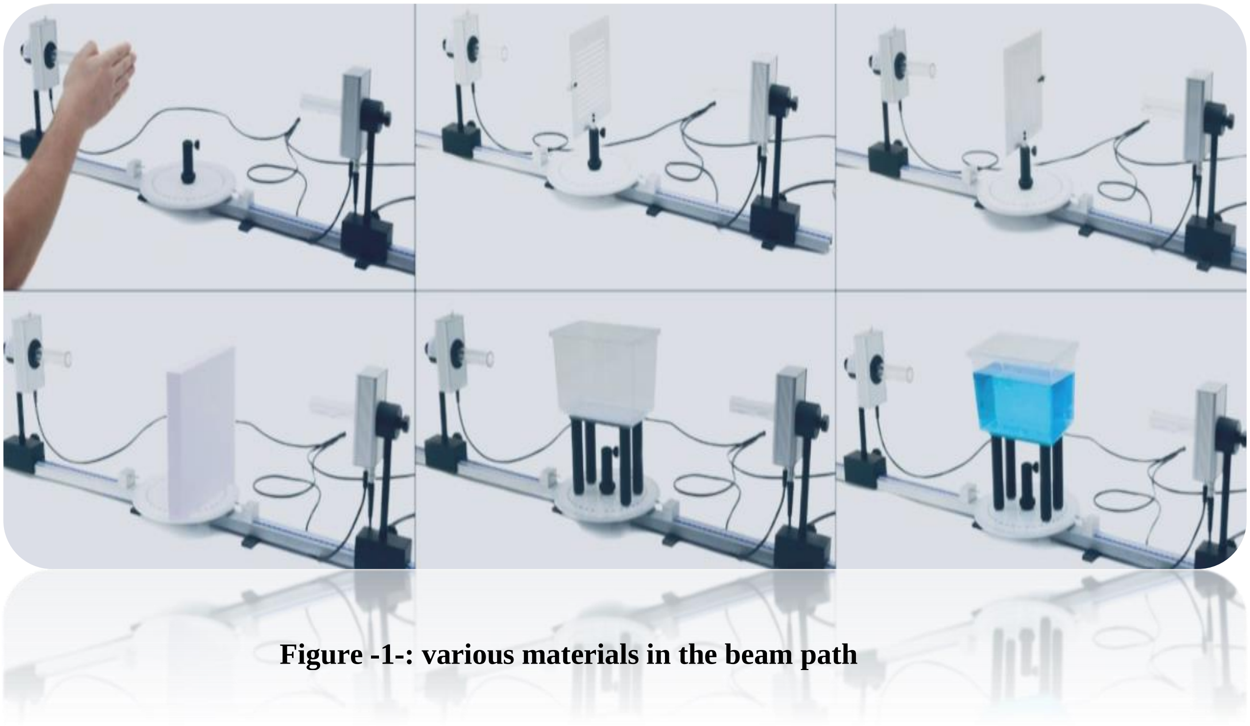


Figure -1-: various materials in the beam path

A farther confirmation that the microwaves are absorbed by the water can be seen placing the hand between the transmitter and receiver (as shown in Fig.1). Also in this case the signal is almost totally attenuated. The explanation of the phenomenon lies in the fact that the human body contains on average 75% of water. The peak of water absorption is at the frequency of 2,450 GHz.

By emitting electromagnetic energy at the same vibration frequency of the water molecule, the phenomenon of the electromagnetic resonance will be occur, in such conditions, the total absorption of electromagnetic energy by water is induced, obtaining the maximum possible heating.

The explains why a microwave oven, with a power of a few hundred watts, is able to heat in a few moments while food in a traditional oven requires at least ten minutes of heating to reach the same temperature level?

In the microwave oven the methods of diffusion of heat in the food are different, while in the traditional oven that attacks the surface of the food and then, by the conduction, the heat also spreads inside (which entails the greatest ’’burn” of the surface), with the microwave oven the heat spreads very homogeneously. In fact it is the internal matter (water in this case) to collect the electromagnetic energy and to transmit it around itself.

Set-up and procedure:

- Set the experiment as shown in figure (2). and connect the microwave transmitter, receiver, and load speaker to the power supply via three ways cable, and connect the receiver and the multi-meter which we use it to read voltage of the microwave pulses replace the intensity of microwave.

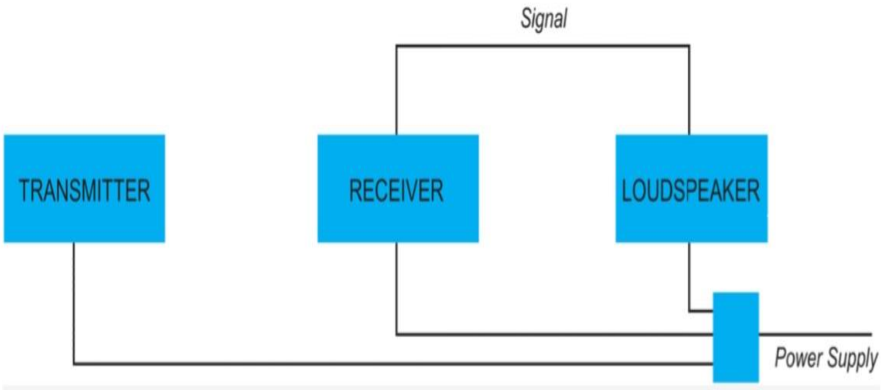


Figure -2-: Set-up experiment connection

- The transmitter and the receiver are both must be 25-30 cm far from the center of the rotation of the rail.
- At the first, you have to measure voltage value (V_O) when there is no anybody placed between the transmitter and receiver.
- After that you must be replace the polystyrene panel to measure the Voltage value (V) with its thickness (x) is measuring with the clipper Vernier at any situation.
- Repeat the previous step, by replacing each of metal sheets, Paraffin prism, an empty tray, a tray filled by water and human organ body.
- Record all related data in the table bellow, and calculate the absorption coefficient (k). by means eq.3

Materials	**x/m**	**V/ mVolt**	$k = \frac{\ln(V_o) - \ln(V)}{x}$
Air molecule		V_o	
Polystyrene panel			
Empty tray			
Paraffin prism			
Tray filled by water			
Metal sheet			
Human body			

- Discuss your result.

Experiment(4): Band gap of germanium

Aims in the experiment

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

Principle:

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

Fig.1. Experimental set-up

Equipment

Hall Effect module

Intrinsic conductor, Ge- carrier board

Power supply 0-12 V DC/ 6 V, 12 V AC

Tripod base -PASS-

Support rod -PASS-, square, l = 250 mm

Right angle clamp -PASS-

Digital multi-meter

Connecting cable

Set-up and procedure

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

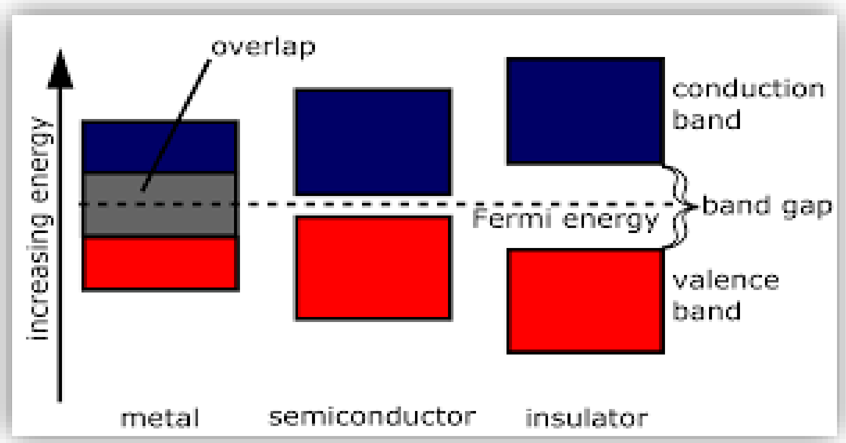
- The test piece on the board has to be put into the hall effect-module via the guide-groove.
- The module is directly connected with the12 V~ output of the power unit over the ac-input on the back side of the module.
- The voltage across the sample is measured with a multimeter.
- The current and temperature can be easily read on the integrated display of the module.
- At the beginning, set the current to a value of 5 mA. The current remains nearly constant during the measurement, but the voltage changes according to a change in temperature.
- Set the display in the temperature mode, now. Start the measurement by activating the heating coil with the ‘‘on/off”-knob on the back side of the module.
- Determine the change in voltage dependent on the change in temperature for a temperature range of room temperature to a maximum of 170°C.
- You will obtain a typical curve as shown in Fig.2.
- Record your values in Table below.

V_{th} /mVolt	$T = 273 + \left(\frac{V_{th}}{40\frac{\mu V}{K}} + T_r\right)$	I /mA	V /volt	$\sigma(\Omega) = \frac{l.I}{A.V}$	$ln(\sigma)$	$\frac{1}{T}$
4 to 0						

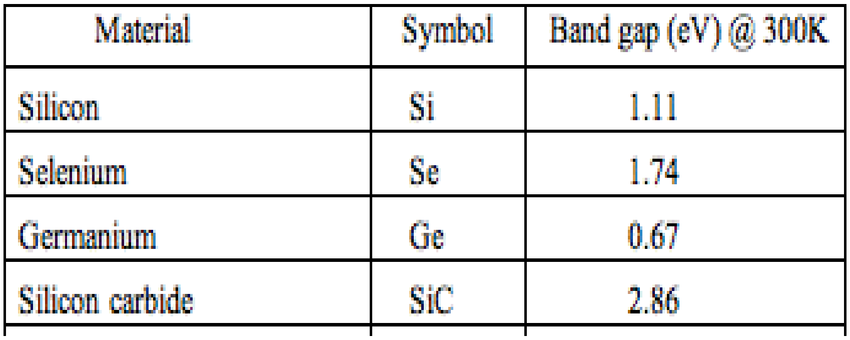
- Plot graph between the *ln (σ)* as a function of (1/T).

Theory and evaluation:

In solid-state physics, a band gap, also called an energy gap or band gap is an energy range in a solid where no electron states can exist. In graphs of the electronic band structure of solids, the band gap generally refers to the energy difference (in electron volts) between the top of the valence band and the bottom of the conduction band in insulators and semiconductors.



The band gab is different from each of famous Semi-conductors as shown in the table below:



Material	Symbol	Band gap (eV) @ 300K
Silicon	Si	1.11
Selenium	Se	1.74
Germanium	Ge	0.67
Silicon carbide	SiC	2.86

And their conductivity Ϭ is defined as following:

$$\sigma = \frac{1}{\rho} = \frac{l.I}{A.V} \left[\frac{1}{\Omega m}\right]$$

With ρ = specific resistivity, l = length of test specimen, A = cross section, I=current, U=voltage.

Note: Dimensions of **Ge-plate is** $(\boldsymbol{l} \times \boldsymbol{d} \times \boldsymbol{W})$ ***and equal to*** **(20x10x1)mm**^{3}

The conductivity of semiconductors is characteristically a function of temperature. Three ranges can be distinguished: at low temperatures we have **extrinsic conduction** (range I), i.e. as the temperature rises charge carriers are activated from the impurities. At moderate temperatures (range II we talk of **impurity depletion,** since a further temperature rise no longer produces activation of impurities. At high temperatures (range III) it is **intrinsic conduction** which finally predominates. In this instance charge carriers are additionally transferred by thermal excitation from the valence band to the conduction band. The temperature dependence is in this case essentially described by an exponential function.

$$\boldsymbol{\sigma = \sigma_o . exp^{-\frac{E_g}{2kT}}}$$

(**$\boldsymbol{E_g}$= energy gap, $\boldsymbol{k}$ = Boltzmann's constant, $\boldsymbol{T}$ = absolutetemperature**).

The logarithm of this equation: $ln\boldsymbol{\sigma} = \boldsymbol{ln\sigma_o - \frac{E_g}{2kT}}$

With the measured values from Fig. 2, the regression with the Expression:

$$ln\boldsymbol{\sigma} = \boldsymbol{ln\sigma_o - \frac{E_g}{2k} \cdot \frac{1}{T}}$$

is with y = ln σ and $x = \frac{1}{T}$ a linear equation on the type y =a + bx, where

$$\boldsymbol{b = slope} = \frac{ln\boldsymbol{\sigma}}{\boldsymbol{\frac{1}{T}}} = -\boldsymbol{\frac{E_g}{2k}}$$

Provides the slope b = (4.05 ±0.06) x 10^3 K

With the Boltzmann's constant:

$\boldsymbol{k = 8.625}$ **x** $\mathbf{10^{-5}}$**eV**

We finally obtain

$\boldsymbol{E_g}$= b x 2 $\boldsymbol{k}$ = (0.70 ± 0.01) eV.

(Literature value 0.67 eV)

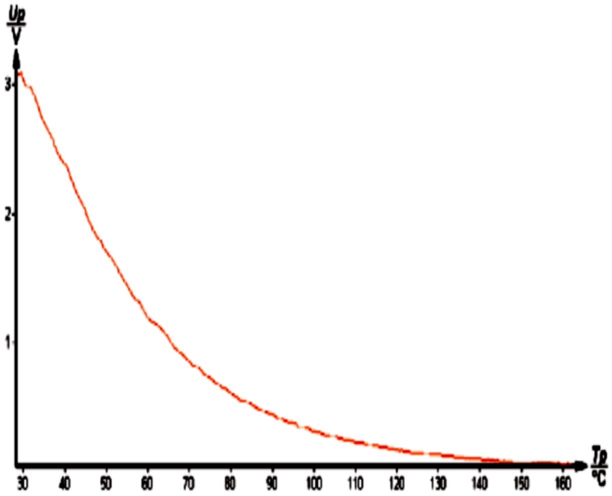


Fig.2 typical measurement of probe-voltage as a function of the temperature

Experiment (5): Hall Effect in n-germanium

Aim of experiment:

- **The Hall voltage is measured at room temperature and constant magnetic field as a function of the control current** and plotted on a graph (measurement without compensation for defect voltage).
- **The Hall voltage U_H is measured as a function of the magnetic induction B**, at room temperature. The sign of the charge carriers and the Hall constant R_H together with the Hall mobility μ_H and the carrier concentration p are calculated from the measurements.
- **The Hall voltage U_H is measured as a function of temperature** at constant magnetic induction B and the values are plotted on a graph.

Principle:

The resistance and Hall voltage are measured on a rectangular strip of germanium as a function of the temperature and of the magnetic field. From the results obtained the energy gap, specific conductivity, type of charge carrier and the carrier mobility are determined.

Fig.1. experimental set-up

Equipment

Hall effect module,
Hall effect, p-Ge, carrier board
Coil, 600 turns
Iron core, U-shaped, laminated
Pole pieces, plane, 30x30x48 mm,
Hall probe, tangent.,prot. cap
Power supply 0-12 V DC/6 V, 12 V AC
Tripod base -PASS-
Support rod -PASS-, square, l = 250 mm
Right angle clamp -PASS-
Connecting cord

Set-up and procedure

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

1st part: The Hall voltage (U_H) is measured at room temperature and constant magnetic field (B) as a function of the control current(I):

- Set the current of coils on (4 Amp.) on the power supply.
- Connect the multimeter to the sockets of the hall voltage (U_H) on the front-side of the module.
- Set the display on the module into the ‘‘current-mode”.
- Determine the hall voltage as a function of the current from 5 mA up to 30 mA in steps of nearly 5 mA.
- Record your values in Table (1).

I_{coil}= 4 Amp. At room temperature	
$I_{Semi-conductor}$ (mA)	U_H (volt)
0	
5	
10	
15	
20	
25	
30	

- Plot graph between the U_H as a function of (I).

2nd part: The Hall voltage U_H is measured as a function of the magnetic induction B, at room temperature:

- Set the control current to 30 mA.
- Connect the multimeter to the sockets of the hall voltage (U_H) on the front-side of the module.
- Determine the Hall voltage as a function of the magnetic induction. by changing the polarity of the coil-current from (0.5 – 4 Amp) and increase . in steps of nearly 0.5 Amp.
- Record your values in Table below.

$I_{Semi\text{-}conductor}$= 30 mA, at room temperature		
I_{Coil} (A)	U_H (volt)	B(mT)
0		
0.5		
1		
Till to **5**		

- Plot graph between the U_H as a function of (B).

3rd part: The Hall voltage U_H is measured as a function of temperature (T) at constant magnetic induction B :

- Set the current to 30 mA and the coil-current to (4 Amp.).
- Determine the Hall voltage as a function of the temperature.
- Set the display in the temperature mode. Start the measurement by activating the heating coil with the "on/off"- knob on the backside of the module.
- Record your values in Table below.

$I_{Semi\text{-}conductor}$= 30 mA,$I_{coil}$= 4 Amp.	
T (K)	U_H (volt)

- Plot graph between the U_H as a function of (T).

Theory and evaluation

If a current I flows through a conducting strip of rectangular section and if the strip is traversed by a magnetic field at right angles to the direction of the current, a voltage – the so-called Hall voltage – is produced between two superposed points on opposite sides of the strip. This phenomenon arises from the Lorentz force: the charge carriers giving rise to the current flowing through the samples are deflected in the magnetic field B as a function of their sign and their velocity v:

$$\vec{F} = e\,(\vec{v} \times B)$$

(F = force acting on charge carriers, e = elementary charge).

Since negative and positive charge carriers have opposite directions of motion in the semiconductor, both are deflected in the same direction.

If the directions of the current and magnetic field are known, the polarity of the Hall voltage tells us whether the current is predominantly due to the drift of negative charges or to the drift of positive charges.

With the directions of control **current und magnetic field** , the charge carriers which produce the current are deflected to the front edge of the specimen. If, therefore, the current is due mainly to electrons (as in the case of an n-doped specimen), the front edge becomes negatively charged. In the case of hole conduction (p-doped specimen) it becomes positively charged. The conductivity 60, carrier mobility μ_H, and the carrier density n are all connected by the Hall coefficient R_H:

Whereas, The ***Hall coefficient (R_H)*** is defined as the ratio of the induced electric field to the product of the current density and the applied magnetic field. It is a characteristic of the material from which the conductor is made, since its value depends on the type, number, and properties of the charge carriers that constitute the current

$$\boxed{R_H = \frac{U_H d}{BI}} \quad , \boxed{\mu_H = R_H.\sigma_o} \quad \text{and then} \quad \boxed{n = \frac{1}{e.R_H}}$$

Thus, if the thickness of specimen d = 1 · 10^{-3}m and I = 0.030 A, Then:

$$R_H = 4.8 \times 10^{-3}\,\frac{m^3}{A.s}$$

The conductivity at room temperature is calculated from the length l of the specimen, its cross-sectional area A and its resistance R_0 :

$$\boldsymbol{\sigma_o = \frac{l}{R_o . A}}$$

If each of $\boldsymbol{l = 0.02m}$, $\boldsymbol{R_o = 37.3\Omega}$ $\boldsymbol{and}$ $\boldsymbol{A = 1 \times 10^{-5} m^2}$ $\boldsymbol{then}$, $\boldsymbol{\sigma_o = 53.6\ \Omega^{-1} m^{-1}}$

The Hall mobility μ_H of the charge carriers can now be determined from the expression:

$$\mu_H = R_H . \sigma_o$$

Using the same values above, this gives

$$\boldsymbol{\mu_H = 0.257 \mp 0.005\ \frac{m^2}{V.s}}$$

The electron concentration n of n-doped specimen is given by

$$n = \frac{1}{e.R_H}$$

Taking e = elementary charge = 1.602 x10^{-19}As, we obtain n = 13.0 x10^{20} m^{-3}.

Experiment(6): Hall Effect in metals

Aims in the experiment:

- The Hall voltage is measured in thin Tungsten foils.
- The Hall coefficient is determined from measurements of the current and the magnetic induction.
- The temperature dependence of the Hall voltage is investigated on the Tungsten sample.

Principle:

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

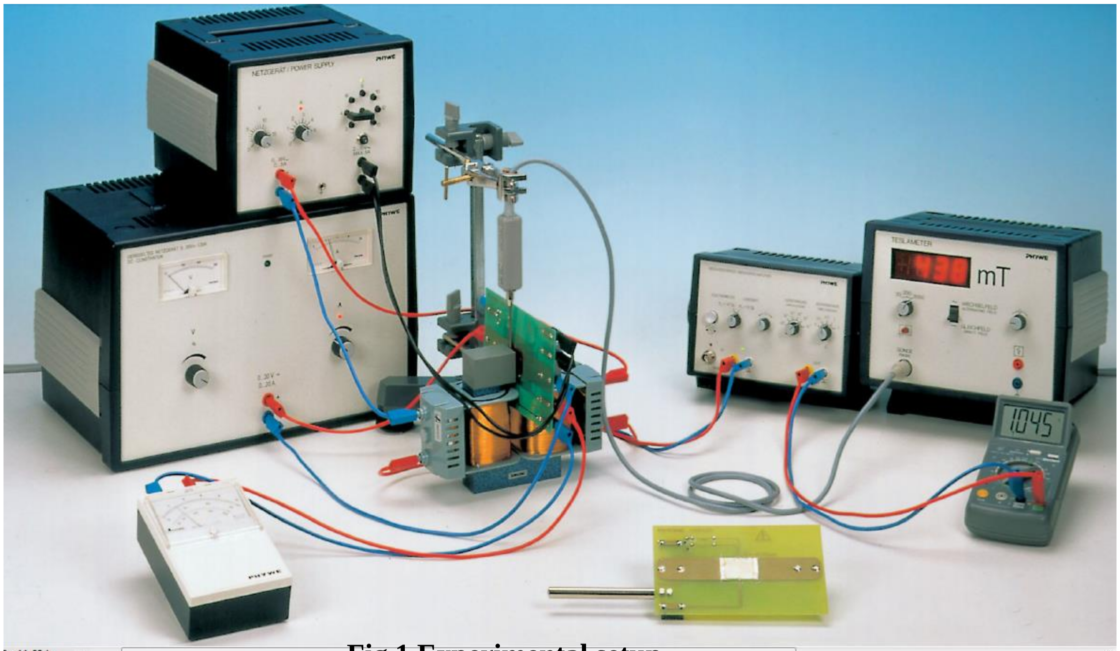


Fig.1 Experimental setup

Equipment

Hall Effect, W, carrier board

Coil, 300 turns

Iron core, U-shaped, laminated

Pole pieces, plane, 30 x 30 x 48 mm, 1 pair

Power supply, stabilised, 0...30 V- / 20 A

Power supply, universal

Teslameter, digital

Hall probe, tangential, with protective cap

Digital multimeter 2010

Meter 10/30 mV, 200°C

Tripod base -PASS-

Support rod -PASS-, square, l = 250 mm

Right angle clamp -PASS-

Connecting cable, 4 mm plug, 32 A, red, l = 75 cm

Connecting cable, 4 mm plug, 32 A, blue, l = 75 cm

Connecting cable, 4 mm plug, 32 A, black, l = 75 cm

Fig. 2 Circuit diagram for the Hall effect.

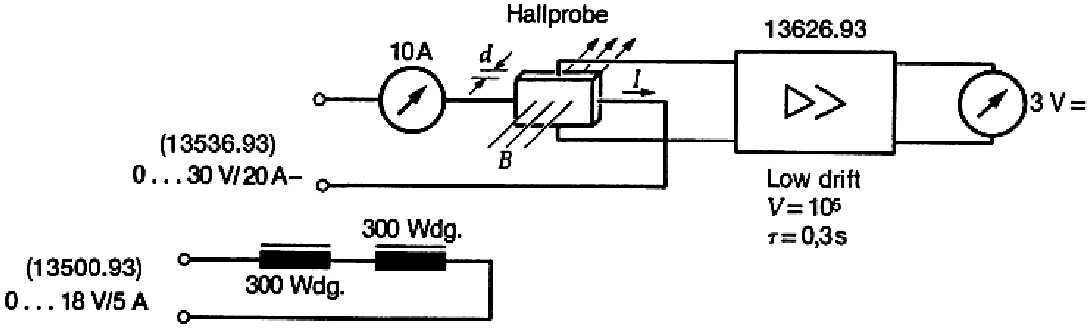


Fig.2 connection setup

Set-up and procedure:

The layout follows Fig. 1 and the wiring diagram in Fig. 2.

- Arrange the field of measurement on the plate midway between the pole pieces.
- Take the transverse current for the Hall probe from the power supply. It can be up to (15 A) for short periods. The Hall probe will show a voltage at the Hall contacts even in the absence of a magnetic field, because these contacts are never exactly one above the other but only within manufacturing tolerances.
- Adjust the compensating potentiometer, using a screwdriver, until the instrument again shows an output voltage of 1 V.
- Repeat this operation several times to obtain a precise adjustment. The determination of the Hall voltage is not quite simple since voltages in the microvolt range are concerned where the Hall voltages are superposed by parasitic voltages such as thermal voltages, induction voltages due to stray fields, etc. The following procedure is recommended:
- Set the transverse current to the desired value.
- Set the field strength B to the desired value (on the power supply).
- Set the output voltage of the measuring amplifier to about 1.5 V by adjusting the compensation voltage.

- Using the mains switch on the power supply unit, switch the magnetic field on and off and read the Hall voltages at each on and off position of the switch (after the measuring amplifier and the multi-range meter have recovered from their peak values). The difference between the two values of the voltage, divided by the gain factor 10^5, is the Hall voltage V_H to be determined.
- Record your values in Table below.

I_{coil}= 4 Amp.			
I /Amp.	V/(volt)	V_H	R=V/I
1			
2			
. **.** **.** **15**			

- Plot graph between the V_H as a function of R.

Theory and evaluation

If a current I flows through a strip conductor of thickness x and if the conductor is placed at right angles to a magnetic field B, the Lorentz force:

$$\vec{F} = Q\,(\vec{v} \times \vec{B})$$

Acts on the charge carriers in the conductor, v being the drift velocity of the charge carriers and Q the value of their charge. This leads to the charge carriers concentrating in the upper or lower regions of the conductor, according to their polarity, so that a voltage so-called Hall voltage V_H is eventually set up between two points located one above the other in the strip:

$$U_H = \frac{R_H \cdot B \cdot I}{d}$$

V_H is the Hall coefficient.

The type of charge carrier can be deduced from the sign of the Hall coefficient: a negative sign implies carriers with a negative charge (Normal Hall Effect), and a positive sign, carriers with a positive charge (Anomalous Hall Effect). In metals, both negative carriers, in the form of electrons, and positive carriers, in the form of defect electrons, can exist. The deciding factor for the occurrence of a Hall voltage is the difference in mobility of the charge carriers: a Hall voltage can arise only if the positive and negative charge carriers have different mobility.

The measurements for copper shown in Fig. 3 are related by the expression $U_H \sim B$. Linear regression using the relation $U_H = a + bB$shows these values to be represented by a straight line with the slope b= -0.0384 x 10^{-6}m^2/s from this, with $\boldsymbol{d = 5 \times 10^{-5} m}$ m and I = 10 A, we derive the Hall coefficient

$\boldsymbol{R_H}$ **= 1.18x 10^{-10} m^3/As.**

Experiment (7): The Study of X-rays Characteristics of copper

You may learn:

X-ray tube, Bremsstrahlung, Characteristic radiation, Energy levels, Crystal structures, Lattice constant, Absorption, Absorption edges, Interference, The Bragg equation, Order of diffraction

Aim of this experiment:

- Spectra of X-rays from a copper anode are to be analyzed by means of different monocrystals and the results plotted graphically.
- Find out spacing (d).

Equipments

X-ray basic unit, 35 kV 1
Goniometer for X-ray unit, 35 kV 1
Plug-in module with Cu X-ray tube. 1
Counter tube, type B. 1
Lithium fluoride crystal, 1
Potassium bromide crystal, 1
Recording equipment:

XYt recorder 1
Connecting cable, l = 100 cm, red 2
Connecting cable, l = 100 cm, blue 2
or
Software X-ray unit, 35 kV 1
RS232 data cable 1
PC, Windows 95 or higher

Fig. 1: Experimental set-up

Tasks

- The intensity of the X-rays emitted by the copper anode at maximum anode voltage and anode current is to be recorded as a function of the Bragg angle, using an LiF monocrystal as analyzer.
- Step 1 is to be repeated using the KBr monocrystal as analyzer.
- The energy values of the characteristic copper lines are to be calculated and compared with the energy differences of the copper energy terms.

Set-up and procedure:

Set up the experiment as shown in Fig. 1. Fix a diaphragm tube in the X-ray outlet tube (1 mm tube diameter using the LiF crystal and 2 mm tube diameter using the KBr crystal). With the X-ray unit switched off, connect the goniometer and the counter tube to the appropriate sockets in the base plate of the experimenting area. Set the goniometer block with mounted analyzing crystal to the middle position and the counter tube to the right stop.

The following settings are recommended for the recording of the spectra:

- Auto and Coupling mode
- Gate time 2 s; Angle step width 0.1°
- Scanning range 3°-55° using the LiF monocrystal, and 3°-75° using the KBr monocrystal
- Anode voltage U_A = 35 kV; Anode current I_A = 1 mA

When the spectra are to be recorded with an XY recorder, connect the Y axis to the analog output (Imp/s) of the X-ray basic unit and, correspondingly, the X input to the analog output for the angular position of the crystal (select the analog signal for the crystal angle with the selection button for this output). When a PC is used for the recording of the spectra then follow this short instruction for easy operation:

1) Switch on the x-ray unit

2) Open the door of the unit (check the position of the goniometer)

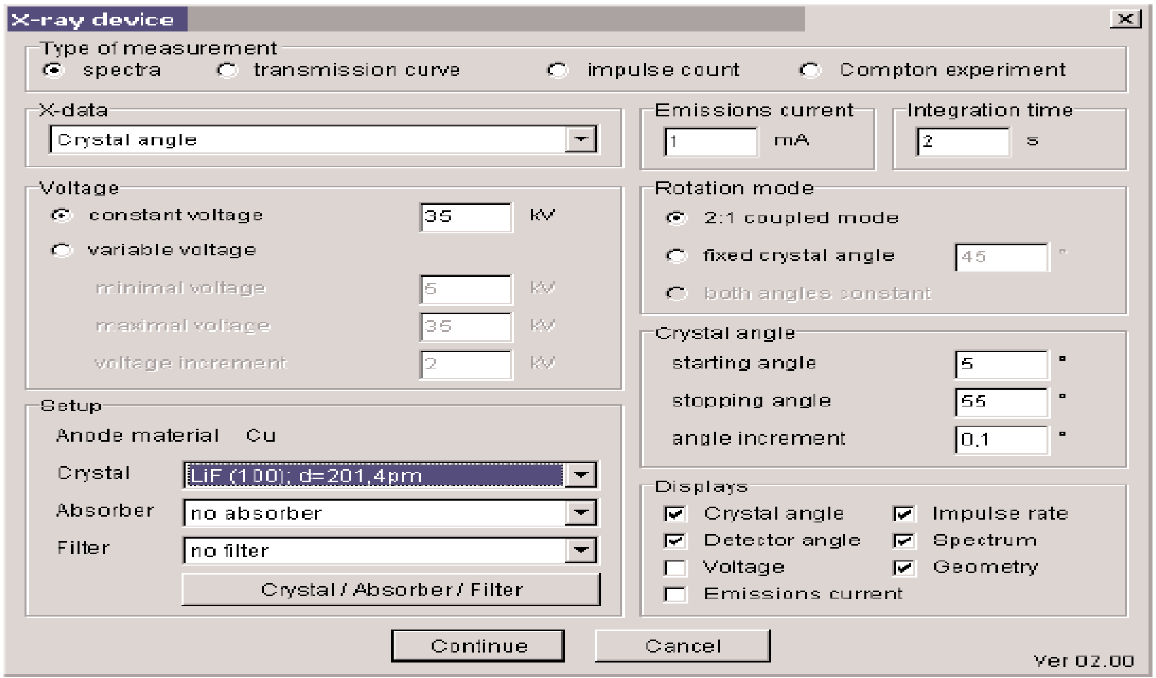
3) Connect the X-ray unit via RS232 cable to the PC port COM1, COM2 or USB port (for USB computer port use USB to RS232 Converter 14602.10)

4) Start the "Measure" program and select "Gauge" -> "X-ray Device"

5) Select the parameters shown in Fig. 1a and press continue button (select the Crystal you are using: KBr or LiF).

6) Close the door of the X-ray device

7) Start the measurement (see Fig. 2b)



X-ray device

Type of measurement: ● spectra ○ transmission curve ○ impulse count ○ Compton experiment

X-data: Crystal angle

Emissions current: 1 mA

Integration time: 2 s

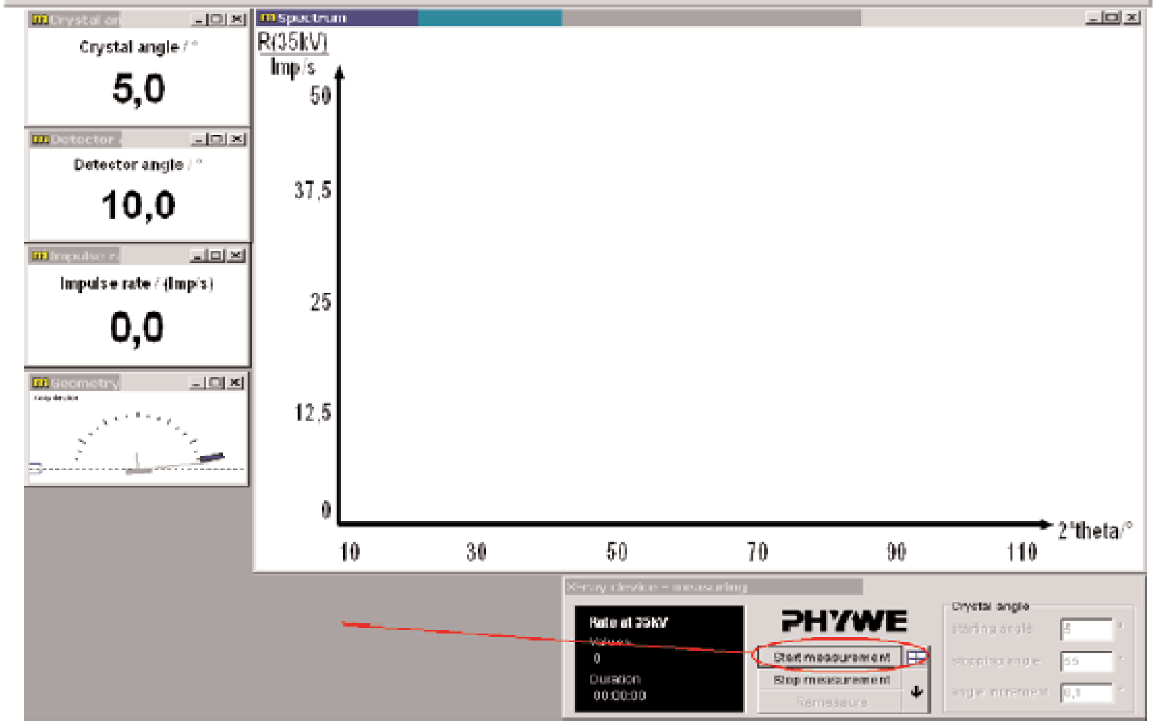
Voltage:
- ● constant voltage 35 kV
- ○ variable voltage
  - minimal voltage 5 kV
  - maximal voltage 35 kV
  - voltage increment 2 kV

Rotation mode:
- ● 2:1 coupled mode
- ○ fixed crystal angle 45 °
- ○ both angles constant

Crystal angle:
- starting angle 5 °
- stopping angle 55 °
- angle increment 0,1 °

Setup:
- Anode material Cu
- Crystal LiF (100); d=201,4pm
- Absorber no absorber
- Filter no filter

Displays:
- ☑ Crystal angle
- ☑ Detector angle
- ☐ Voltage
- ☐ Emissions current
- ☑ Impulse rate
- ☑ Spectrum
- ☑ Geometry



Crystal angle / ° 5,0

Detector angle / ° 10,0

Impulse rate / (Imp/s) 0,0

Rate at 35kV Values 0 Duration 00:00:00

Fig.2a: Measuring parameters for the recording software

Fig.2b: Graphical user interface of the "X-ray Device"-software

Note:

Never expose the counter tube to primary radiation for a longer length of time.

8) When the set up time is finished, you must have an output peak (as shown in fig 5) and be able to do the measurement.

Theory and evaluation

When electrons of high energy impinge on the metallic anode of an X-ray tube, X-rays with a continuous energy distribution (the so-called bremsstrahlung) are produced. X-ray lines whose energies are not dependent on the anode voltage and which are specific to the anode materials, the so-called characteristic X-ray lines, are superimposed on the continuum. They are produced as follows: An impact of an electron on an anode atom in the K shell, for example, can ionize that atom. The resulting vacancy in the shell is then filled by an electron from a higher energy level. The energy released in this de-excitation process can then be transformed into an X-ray which is specific for the anode atom.

Fig. 3 shows the energy level scheme of a copper atom. Characteristic X-rays produced from either the $L \rightarrow K$ or the $M \rightarrow K$ transitions are called Kα and K_β lines respectively. $M_1 \rightarrow K$ and $L_1 \rightarrow K$ transitions do not take place due to quantum mechanical selection rules.

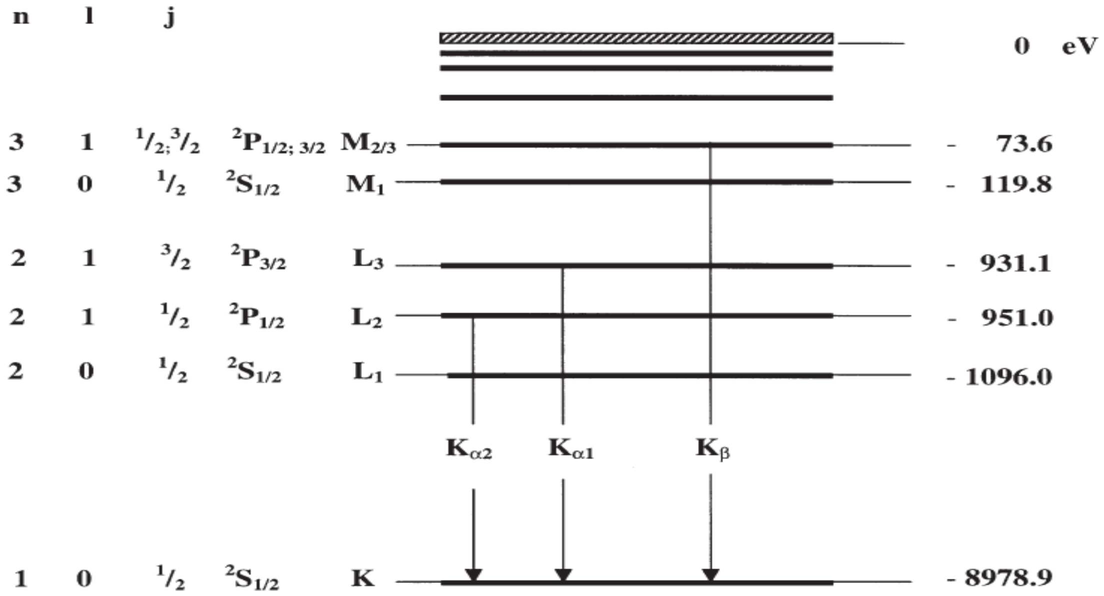


Fig. 3: Energy levels of copper (Z = 29)

Accordingly, characteristic lines for Cu with the following energies are to be expected (Fig. 3):

$$E_{K\propto^*} = E_K - \frac{1}{2}(E_{L2} + E_{L3}) = 8.038KeV \; ----------- (1)$$

$$E_{K\beta} = E_K - E_{M2,3} = 8.038KeV$$

Kα* is used as the mean value of the lines Kα1 and Kα2. The analysis of polychromatic X-rays is made possible through the use of a monocrystal. When X-rays of wavelength λ impinge on a monocrystal under glancing angle ϑ, constructive interference after scattering only occurs when the path difference Δ of the partial waves reflected from the lattice planes is one or more wavelengths (Fig. 4).

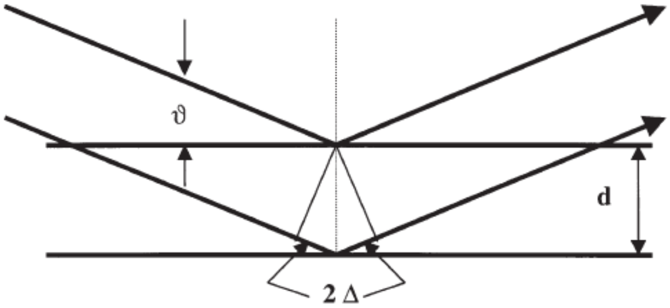


Fig. 4: Bragg scattering on the lattice planes

This situation is explained by the **Bragg equation**:

$$\boldsymbol{2d\,sin\theta = n\lambda \; ------------- (2)}$$

(d = the interplanar spacing; n = the order of diffraction) If d is assumed to be known, then the energy of the X-rays can be calculated from the glancing angle ϑ, which is obtainable from the spectrum, and by using the following relationship:

$$\boldsymbol{E = h.f = \frac{h.c}{\lambda} ------------- (3)}$$

On combining (3) and (2) we obtain:

$$\boldsymbol{E = \frac{n.h.c}{2.d.sin(\theta)} \; ----------- (4)}$$

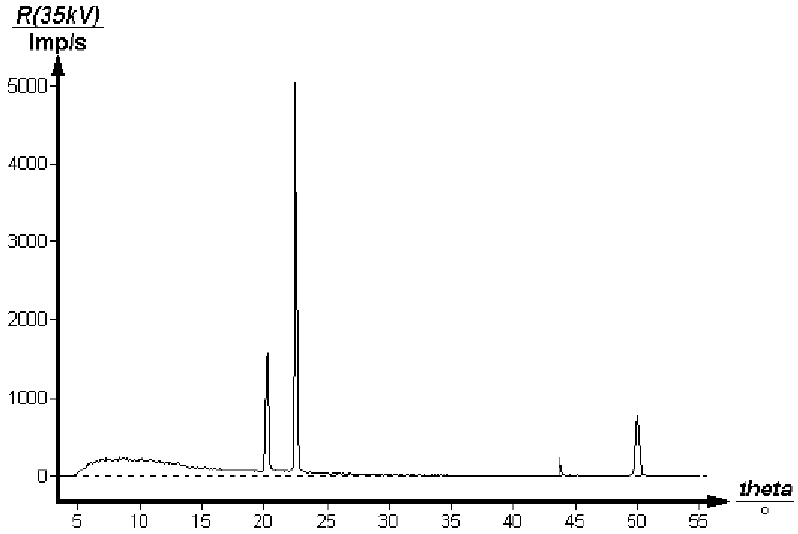


Fig. 5: X-ray intensity of copper as a function of the glancing angle; LiF (100) monocrystal as Bragg analyzer

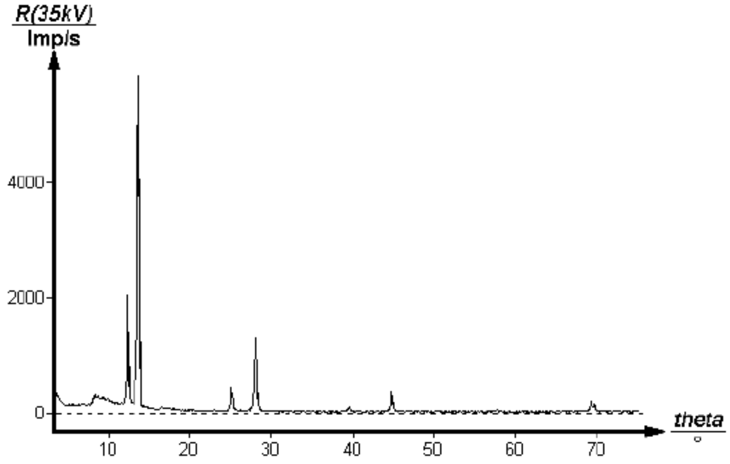


Fig. 6: X-ray intensity of copper as a function of the glancing angle; KBr (100) monocrystal as Bragg analyzer