Solid state physics laboratory

The fourth stage

First semester

صباحي + مسائي

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<u>*Expt. 1*</u>

Forbidden Energy Gap of Semiconductor

A. Introduction:

In this experiment we shall measure the forbidden energy gap of semiconductor sample. The forbidden gap**-the gap between the bottom of the conduction band and the top of valance band- is actually the energy required for an electron -hole pair generation.** One of the simplest ways for the determination of the forbidden energy gap is to measure conductivity or resistivity of the sample versus temperature.

The conductivity, **σ**, of semiconductors is given by the formula

$$\sigma = e(\mu_n\, n + \mu_p\, p) \qquad \dots (1)$$

Where e is the electronic charge**,** μ_n , μ_p are mobilities of electrons ad holes respectively, and **n, p** are volume concentrations of free charge carriers: electrons and holes respectively.

The effect of temperature on semiconductor conductivity can be explained the diagram of Fig.1. In region 1, the conductivity increases with temperature since donor and accepter atoms are ionized. In region 2, the number of charge carriers is constant, but the mobility decreases. In this region, the conductivity decreases, like metals. The high temperature region, region3, is suitable for the forbidden gap measurement. In this region, Eq.1 takes the form

$$\sigma = Const.\,exp.\left(-\frac{E_g}{2kT}\right) \qquad \dots (2)$$

Where E_g is the forbidden energy gap, and k is the Boltizman constant.

For resistivity, $\rho = \frac{1}{\sigma}$ we can write

$$\rho = Const.\,exp.\left(\frac{E_g}{2kT}\right) \qquad \dots (3)$$

The resistance of a given sample, **Rs**, is proportional to its resistivity,

We can, therefore, write:

$$R_s = C.\,exp.\left(\frac{E_g}{2kT}\right) \qquad \ldots (4)$$

Or

$$lnR_s = lnC + \left(\frac{E_g}{2k}\,\frac{1}{T}\right) \qquad \ldots (5)$$

Where **C** is constant.

The idea of our experiment is to measure the resistance of a given semiconductor sample versus temperature in region 3.the high temperature region, Fig1.and calculate E_g from the slope of linear plot of lnR_s versus $1/T$ (Eq.5). In this experiment, high measurement is necessary to obtain good results.

Figure 1
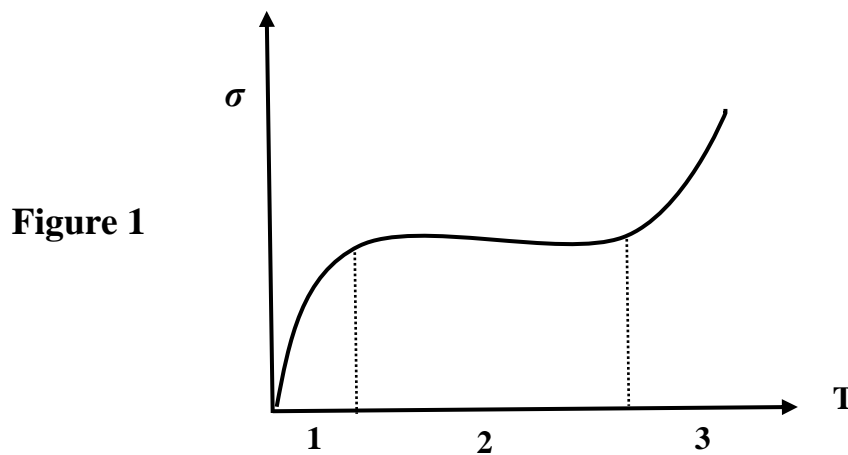
B. Experiment:

a. Measurement of the semiconductor sample resistance:

The resistance can be measured by measuring the potential drop across the sample using a precise potentiometer, is in elimination of the lead's resistance (no current flows to the potentiometer), and the elimination of the effect of

contacts to the sample. The current through the sample is heat constant during the whole experiment.

b. Temperature measurement:

A calibrated thermistor will be used for temperature measurement. Its resistance varies with temperature according to the formulas:

$$T = 3257.6/(\ln R + 3.5976) \qquad \ldots (6)$$

Where T in $^{\circ}$K and R in Ohms. For correct use of this formula read R to five significant figures and calculate lnR to five significant figures too.

Thermistor resistance is measured by reading the voltage drop across the thermistor using potentiometer to eliminate leads resistance. The semiconductor sample and thermistor are connected in series and placed close to one another in an oven. Temperature, which can be set roughly by a dial, is kept constant automatically.

C.Procedure:

1. Contacted the circuit as shown in Fig.2.By resistance box set the current to 200µA.Keep carefully the value of the current constant during the measurements.
2. Balance the potentiometer for A and then for B inputs.
3. Set the temperature control to 30 °C. After about 15 minutes take reading of both A and B inputs.
4. .Repet step3 for 40.50,60,70,80,90, and100°C.
5. Calculate the valuer of R_s and Rand fined T from Eq.6.
6. Plot a graph of ln R_s versus1/T. Calculate E_g from the slope of the linear part (see Eq.5).
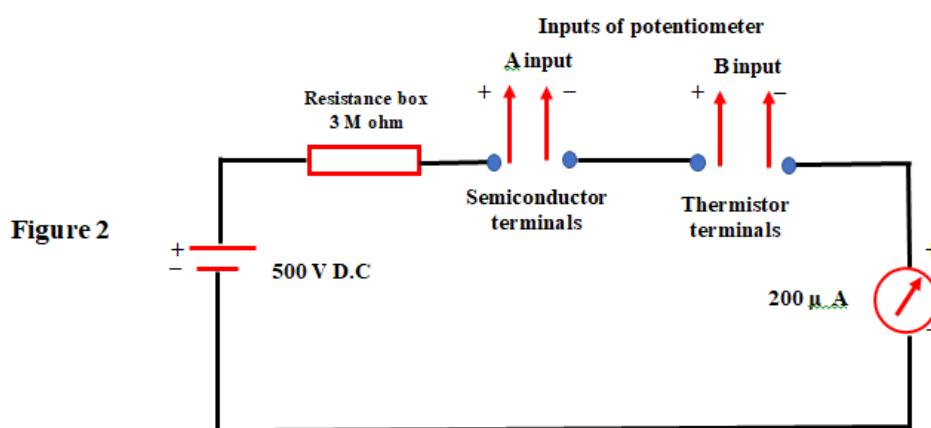
Figure 2

Measurement of the principal value of thermos-electric e.m.f.s. In crystal

Introduction

When two dissimilar metal wires are joined at two point and one junction is heated relative to the other a thermos-electric electro- motive force (e.m.f.) is generated.

A current circulates round the two wires so long as the difference in temperature is maintained. The same phenomenon occurs when a block of a conducting crystal is held in contact with two pieces of the same metal which are at different temperature and are joined by a wire of the same material. The magnitude of the e.m.f. generated in this way depends on the orientation of the crystal relative to the direction of heat flow, we are here concerned with the relation between two vector quantities, namely, the temperature gradient and the flow of electric current. As in all cases where two vector quantities are related in a crystal the coefficients relating these quantities from a second order tensor. Thus the surface which may be constructed by drawing lines from a given point of length proportional to the ratio of the electric current (or potential) to the temperature gradient in the same direction , is an ellipsoid , further it is a triaxial ellipsoid for triclinic monoclinic and orthorhombic crystal , an ellipsoid of revolution for hexagonal, trigonal and tetragonal crystals and a sphere for cubic crystals.

Just as is the case with thermal conductivity the direction of maximum temperature gradient and of electric current flow does not in general coincide.

Only along directions parallel to the principal axes of the ellipsoid is this the case. Thus, in hexagonal and trigonal crystals the direction of the trigonal axis is one such direction and all direction perpendicular to this axis there are also characterized in the same way. thus, for pieces of crystal cut in directions inclined to the principal axis there are transverse thermos-electric e.m.f.s. with which, however we shall not.

Experimental arrangement:

Crystal are cut so that they may be clamped between two brace blocks of which is heated and the other cooled. The blocks are joined to millivoltmeter for reading the potential difference between the two blocks. Holes in the blocks permit the insertion of a thermometer for reading the temperatures. If v is the voltage measured across the crystal and t is the temperature difference between the two blocks, the thermoelectric power of the crystal under test is v/t or volt/ ºC .

Procedure.

Crystals of bismuth and tellurium are provided. The bismuth block has a cleavage face which is perpendicular to the trigonal axis. The face can be recoginsed by its smoothness. The crystal is clamped between the blocks. The measurement carried out as described above given the thermoelectric power in a direction parallel to the trigonal axis. The crystal is now turned so that the trigonal axis is parallel to the surface of the block and the measurement is repeat.

Expt (3)

## Crystal Systems and Bravais Lattices

Theory:-

Crystalline Solid: A crystalline solid is formed by regular repetition of its building blocks (atoms or molecule) in a three dimensional periodic array. The examples of crystals are table salt (NaCl), diamond, snowflakes, metals, ice, ceramics etc.

Amorphous solid: materials in which constituents (atoms or molecules) are not arranged in a regular manner over a long range. There is no periodicity in structure, if periodicity occurs, it must be over a short distance . The examples of crystalline solid are glass, plastic, rubber etc.

Crystal system is a method of classifying crystalline substances on the basis of their unit cell. There are seven unique crystal systems. The simplest and most symmetric, the cubic system, has the symmetry of a cube. The other six systems, in order of decreasing symmetry, are hexagonal, tetragonal, trigonal (also known as rhombohedra), orthorhombic, monoclinic and triclinic. Lattice: defined as a regular periodic array of point in space. Each point in a lattice has identical surrounding everywhere. Lattice is basically imaginary points on space with a periodic manner.
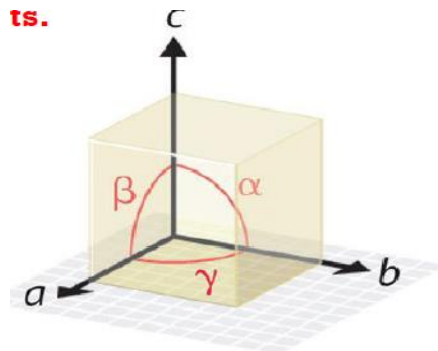
• Basis: atoms or molecules which are constituents of a crystal material. For example in NaCl crystal, NaCl molecule, group of one Na and one Cl atoms form basis.

# Crystal structure = lattice + basis

Lattice + Basis = Crystal
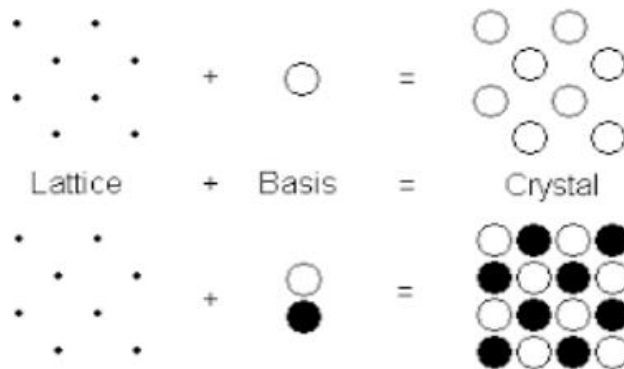
Crystal as combination of lattice and basis.

Unit cell can be considered as the building block of a crystal and is the smallest unit of volume that permits identical cells to be stacked together to fill all space. By repeating the pattern of the unit cell over and over in all directions, the entire crystal lattice can be constructed.
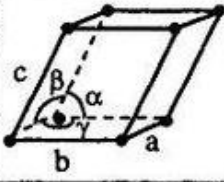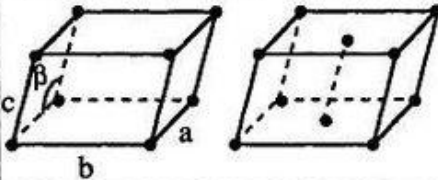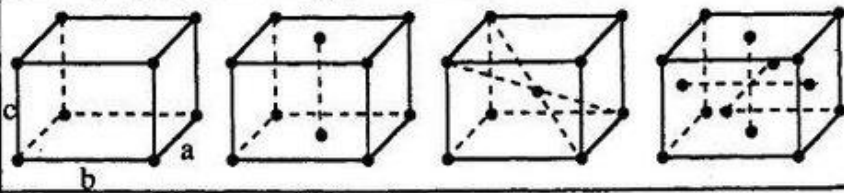
Unit cell

Unit Cell | Translation along y axis | Translation along x axis | Translation along z axis
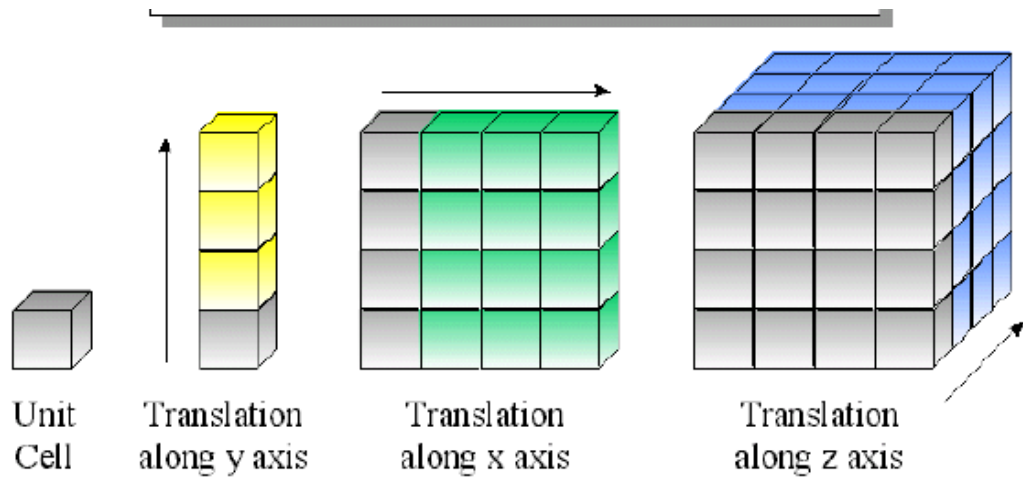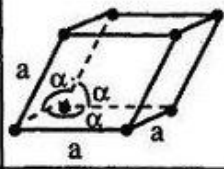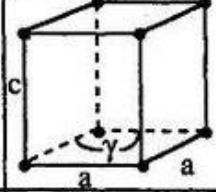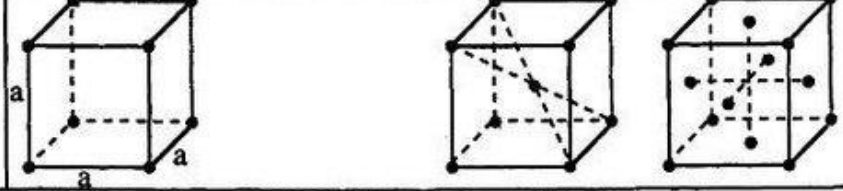
Bravais lattice is a set of points constructed by translating a single point in discrete steps by a set of basis vectors. In 1848, the French physicist and crystallographer Auguste Bravais established that in three-dimensional space only fourteen different lattices may be constructed. The fourteen Bravais lattice differ from each in term of ;

1-   unit cell shape

2-   Types of symmetry. It's divided into seven systems.

crystal system are divided into seven groups or seven types crystal system based on condition of lattice three vectors and three interfacing angles between them.

seven types of Crystal system which contains total 14 types of lattice named as cubic, tetragonal, orthorhombic, monoclinic, triclinic, triangular (rhombohedra) and hexagonal.

Crystal system	Bravais lattices			
	primitive	base-centered	body-centered	face-centered
Triclinic $a \neq b \neq c$ $\alpha \neq \beta \neq \gamma$				
Monoclinic $a \neq b \neq c$ $\alpha = \gamma = \frac{\pi}{2} \neq \beta$				
Orthorhombic $a \neq b \neq c$ $\alpha = \beta = \gamma = \frac{\pi}{2}$				
Trigonal $a = b = c$ $\alpha = \beta = \gamma \neq \frac{\pi}{2}$				
Tetragonal $a = b \neq c$ $\alpha = \beta = \gamma = \frac{\pi}{2}$				
Hexagonal $a = b \neq c$ $\alpha = \beta = \frac{\pi}{2}$ $\gamma = \frac{2\pi}{3}$				
Cubic $a = b = c$ $\alpha = \beta = \gamma = \frac{\pi}{2}$				

Cubic crystal system

• The simplest and easiest structure.

• Three types of possible crystal structure under this family named as simple cubic, body centered cubic and face centered cubic.

1- Simple cubic crystal (sc)

• Lattice points are arranged at each 8 corner of cube.

• At each corner of cube, an atom is shared by 8 nearby unit cells.

• one unit cell contains 1/8×8=1 atoms.

• Each atom is surrounded by 6 nearest neighbors atoms. The number of nearest neighbors of a lattice point (or atom) in a crystal lattice is called coordinate number. • Example Cu, Ag, Au are this types of structure.

2-Body centered cubic (bcc)

• In this case of cubic crystal, one atom is arranged inside the cube additional to eight atoms at eight corners this structure

• one atom is inside the unit cell entirely, and eight corners of lattice cube share1/8 part of each atoms. Therefore the number of atoms in a bcc unit cell =1+1/8=2.

• Many metals a like Li, Na, K, Cr exhibit bcc.

3- Face centered cubic crystal

• 8 atoms are arranged at eight corners of the cubic lattice and 6 atoms are arranged at the centre of eight faces of cube

• Each atom of 8 corners is shared by 8 neighbor unit cells therefore one corner of cube share 1/8 atom; each atom at the faces of cube is shared by 2 unit cell and each face shared 1/2 atom and total 6 faces share 6×1/2=3 atoms. Therefore net atoms inside a unit cell is equal to 1/8×8+½×6=4.

• coordinate number of fcc crystal is 12.

• example of fcc Crystal are Al, Cu, Au, Ag etc
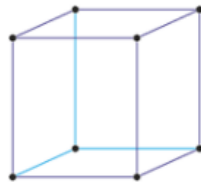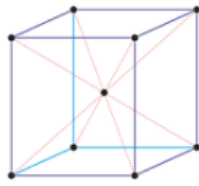
primitive (cP)   body-centered (cI)   face-centered (cF)
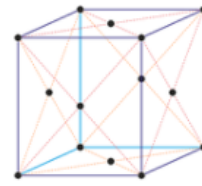
Atomic Packing Factor or (Filling Factor):-

It may be defined as the fraction of volume occupied by spherical atoms as compared to the total available volume of the structure.

A.P.F. = number of atoms × volume of atoms in a crystal / volume of unit cell

$$A.P.F = N \times V_{atom} / V_{unit\ cell}$$

Measurements

1- Measure the atomic packing factor for three types of the cubic.

Crystal system

1- Sodium Chloride (NaCl) Structure

Rock salt (NaCl) structure type is fcc, here the cation number is 6, anion is 6. A basis consist one Na and one Cl. position of Cl and Na atoms are: Cl : 0, 0, 0; 1/2,1/2, 0; 1/2, 0, 1/2; 0, 1/2, 1/2; Na : 1/2, 1/2, 1/2; 0,0, 1/2; 0; 0, 1/2, 1/2; 1/2,0,0 The coordinate number of each Na and Cl atom in this structure is 6. Other examples of NaCl type structure are KBr, KCl, MgO, AgBr.
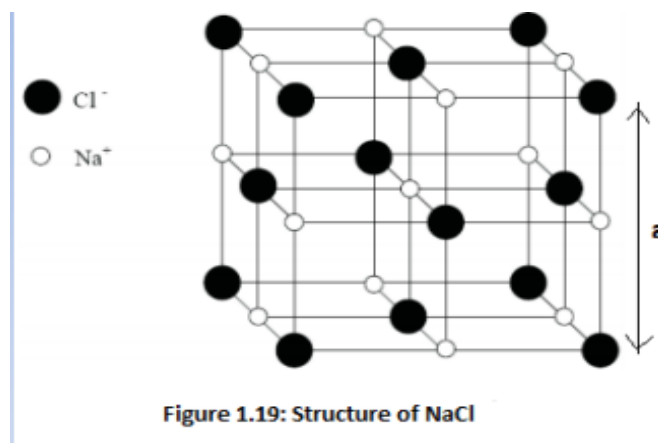

Figure 1.19: Structure of NaCl

Diamond Structure

• The diamond structure is face centered cubic with four additional atoms in the body diagonals. Out of four additional atoms, two atoms are placed at ¾ length of first and second diagonal, remaining two atoms are placed at ¼ lengths of 3rd and 4th body diagonals

• Total number of C atoms is 18.T

• he whole appearance seems complicated thus for simplicity, we draw the projection of atoms on a plane (say XY plane) as shown in scond figure.

• In XY pane, only five atoms are at the face (base of cube) ABCD in actual and other atoms are projections of atom near to face.

• Points E, G, M, K show the projection of atoms at vertical faces of cube and z coordinate of actual position of these atoms are ½ as shown in figure. We write only z coordinates of projected atom explicitly. Now point F,H,J,L shows the projection of atoms situated at 4 body diagonals and z coordinates of these atoms are ½, 3/2, ½, 3/2.

• The coordinate number (number of nearest neighbours) is 4 and each group of 4 C atoms make a tetrahedral bond arrangement.

• The packing fraction of diamond structure is 0.34 ,considerably small than fcc structure (PF 0.74) and shows relatively empty space in the crystal.
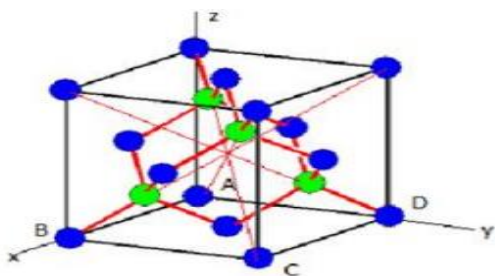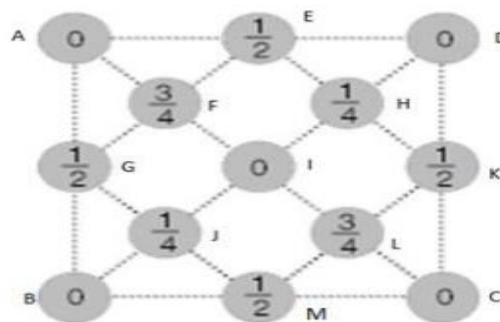

Figure 1.21: Dimond Structure

Figure 1.22: Projection on atoms on face ABCD

Expt (4)

X-ray diffraction

Introduction

X-ray are electromagnetic radiation of exactly the same nature as light but of very such shorter wavelength lying in the rang 0.5-2.5 A°. Thus X-ray occupies the raging between gamma and ultraviolet rays in the electromagnetic spectrum. X-ray are produced when electrically charged particles of sufficient kinetic energy is rapidly delectated. Electrons are usually used x-ray are produced at the point of impact of high speed electrons with metal target. If (e) is the charge of the electron, (U) is the accelerating voltage between anode and the source of the electron, then K.E of electron:

$$\text{K.E} = eU = \frac{1}{2}mv^2.$$

When the rays coning from the target are analyze, they are found to consist of a mixture of different wavelengths and the variation of intensity with wavelength is found to depend on the tube voltage. The intensity is sore up to a curtain wavelength, called cut off wavelength (λ_c).

Increases rapidly to a maximum and then decreases, not very electron is decelerated in the same way, however, some are stopped in one impact and give up all their energy at once, while others successively losing fraction of their total kinetic energy until it is all spent, these electrons which are stopped in one impact will give rise to photons of maximum energy i.e. X-ray of minimum wavelength. Such electrons transfer all their energy , eU, into photon energy and we may write :

$eU = hV_{max} = hc/ \lambda_c$ or $\lambda_c = hc/eU$

when the voltage on the x-ray tube is raised above a critical value, characteristic of the target metal, lines of sharp intensity appear at certain wavelength. They are denoted as K, L, K, and etc. lines in the order of increasing wavelength. Ordinarily only the k lines are useful in the x-ray differential. The longer wavelength lines are easily absorbed. There are several lines in the k set, ones are observed in normal diffraction work,

these are k_α, k_β and k_γ. k_α is usually the most strong line which make diffraction by crystal possible.

In 1992 the German physicist von Laue took up the problem of diffraction he reasoned that if crystals were composed of regularly spaced atoms which might act as scattering centers for x-ray , and if x-ray were e.m. waves of wavelength about the interatomic distances in crystals , then it should be possible to diffract x-ray by means of crystals. The account of Laue experiment was read with great interest by two English physicists, H. H. Bragg and his son W. L, Bragg. The Later could successfully determine the structure of Na Cl, Kcl, KBr, and K crystals, all of which have the NaCl structure. Thus N.L. Bragg relation was determined and concluded as:

$$n\lambda = 2d \sin$$

where **n** = 0,1,2,….. order of recpection and λ wavelength of x-ray, **d** is lattice plane spacing Θ is Bragg angle

when a narrow beam of monochromatic X-ray falls at different anglos upon the mutually parallel lattice plances separated by distance d is reflected by the planes as shown in fig.(1)
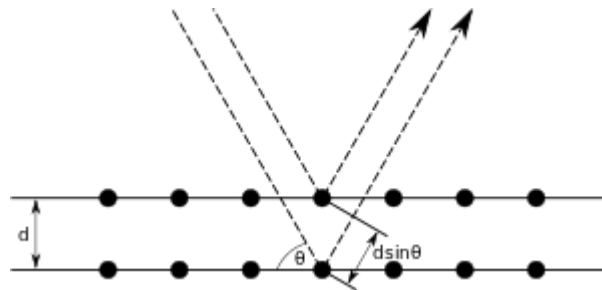
Baragg reflection occurs only intensification by construction interference of all the reflected components a_1, a_2 , … take place. it is not possible to obtain reflection from all lattice planes. The possible reflection from certain crystal could be determined by the stricter factor S (hkl) .if s=0 there is no possible reflection. s≠0 there is possible reflection.

Where **h,k,l** is called Miller indices.

The structure factor for bcc lattice, for example, could be writer as:

S(hkl) = f (1+exp-i(h+k+l)л)where f is the seattering

Power of an atom. Thus s=0 whenever the expontial has the value (-1) in bcc the unit cell has identical atoms located at (000), and $(\frac{1}{2}\frac{1}{2}\frac{1}{2})$ so

S=0 when (h+k+l) is an odd integer.

S=2f (non-zero) when (h+k+l) is an even integer.

The Lif crystal. Has (fcc) structure, the diffraction spectrum does not contain lines such as (100), (100),(110) and (221) … , however lines such as (200), (111), (222), …, are possible .

Experimental A

Determation of d spacing of cubic crystal diffraction experiment could be carried on and (d) spacing or (a) lattice constant , could be determined either by production of Laue pattern on photographic plate or by using counter to detect the maximum intensity of reflection. The latter method will be used in our laboratory.

Procedure

1- Set the center tube voltage to 460v dc.
2- Push the zirconium filter into place in front of the collimator slit.
3- Switch on the scalar, and the x-ray apparatus. Set the emission current to 0.8 mA, and high tension to its minimum.
4- Select the Bragg angle Ө (3°) between the incident x-ray and the crystal surface by adjusting the pointer which is attached to the crystal,
   Set the counter tube in the direction of the reflected beam by means of the pointer attached to the counter. This angle should be 20 on the scale which must give the maximum count. However due to disorientation of the crystal or misalignment of the beam, it will be found that the angle of the maximum may be greater or smaller than 2Ө. Thus it is advisable to take count for the positions 2Ө, 2Ө-(Ө₂-Ө₁), and 2Ө +Ө, where Ө is the error in the angle due to the set of the apparatus.
5- Take number of count per 10 sec. Repeat three times ad find the average no. of count N. increase the angle Ө in stupe of 1° up to maximum angle of 25°.
6- Draw a graph of N against Ө, and then calculate (d) spacing for specific planes.

7- Calculate lattice constant (a) for specific planes (hkl).
Not that for cubic crystal $d = a/(h^2+k^2+l^2)^{1/3}$
compare with the given value of (a) for LiF crystal.

8- Calculate d using the relation $d = (M/2\rho NA)1/3$ where M: molecular weight of the sample (25.94gm/mol for LiF)., ρ : density (2.6gm/cm3), NA : Avogadro no. (6.02*1023 par/gm.mol).

Experiment:

Determination of (h) using X-ray continuous spectrum

Procedure:

Use the same set up of Exp, (A) but remove the zircon filter.

1- Switch on the X-ray apparatus. Set the emission current to 0.8 mA, and the primary potential U_{prim} applied to the high tension transformer to its maximum value.

2- Set the crystal plane at Bragg angle $=3°$ take no. of count three times and find the verge N which represent the reflected intensity of the beam. Increase Θ by $\frac{1}{2}°$ each step up to about 17°

3- Calculate λ using Bragg relation taking n= 1.

4- Plot a graph of N against λ. Find the value of $\lambda_{\circ}$ by extrapolating

5- To λ-axis , the intercept gives $\lambda_{\circ}$ determine the value of plank constant, h , from the equation :

$h = e\,\lambda_{\circ}\,U/c$

Note: to determine the applied voltage, u, measure the primary voltage U_{prim}(r.m.s), then:

$U = 1000\sqrt{2}\ U_{prim}$

Expt (5)
Electron Diffraction

Principle:

Fast acceleration electron is diffraction from a polycrystalline layer of graphite, and then strike a florescent screen. Interference rings are produced on the screen. The inter planer spacing in graphite cam them be determined the diameter of the rings and the accelerating voltage.

Theory:

To explain the interference phenomenon produced by electrons, a wavelength λ, which depend on momentum, is assigned to the electrons in a accordance with the de Bragg equation:

$\lambda = \dfrac{h}{\rho}$ ………. (1)

Where h = 6.625 $*10^{-34}$ j.s Planck constant.

That the acceleration esquire under accelerating voltage V_A as follows $\frac{1}{2}mv^2 =$ $p^2/2m = eV_A$ …..(2)

The wavelength is then given by

$\lambda = h/\sqrt{2mev}$ …………… (3)

Where e = 1.602 $*10^{-19}$ C the electron charge, and m= 9.109$*10^{-31}$kg the rest mass of the electron. At the voltages V_A used, the relativistic mass can be replaced by the rest mass with an error of only 0.5%. using these values in eq (3) one finds,

$\lambda = 1.2263*10^{-19} /\sqrt{V}$ (M.K.S)…… (4)

When the accelerated electron beam strikes a poly crystalline graphite film deposited in a copper grating, it will be reflected in accordance with the Bragg condition.

$n\lambda = 2\ dsin\Theta$ $\qquad$ n= 0,1,2,3,…. $\qquad$ (5)

Where d is the space between the planes of the carbon atoms, and the Θ is Bragg angle (the angle between electron beam) and the lattice.

The electron beam is the reign spaced out in the form of a cone and produce interference rings on the florescent screen.

The Bragg angle Θ can be calculated from the reduce of the interference ring but it must be remembered that the angle of deviation α (fig2)

$$\alpha = 2\Theta \ldots\ldots\ldots\ldots (6)$$

From fig 2 we read off

$$\sin 2\alpha = r/R = \frac{D}{2R} \ldots\ldots\ldots (7)$$

where D=2r, and R=65mm, the radius of the glass tube. From the eq 6 and 7 one can write

$$\sin 4\Theta = \frac{D}{2R} , \text{ or } \Theta = \frac{1}{4} \sin^{-1}(\frac{D}{2R}) \ldots\ldots (8)$$

The tow inner interference ring occurs through reflection from the lattice planes of the spacing d_1, and d_2 (fig3).

Procedure:

1. Set up the experiment as screen in fig4. Connect the terminals of the diffraction tube to the power supply as shown in fig2 connect the light voltage to the anode through a 10 M ohm protecting resistance.
2. Adjust the anode voltage V_A to a value of 4 kv , the anode voltage at the anode plugs measured with a light voltage probe and a digital millimeter the probe head contains voltage divider which reduces the voltage to be measured in a ratio1000:1
3. Adjust the voltage at G_4 and G_1 so that setup well depended diffraction rings appear usually the live of ringer tube.
4. Measure the diameters of the tow rings D_1 (the smaller), and D_2 (in a darkened room) by measuring the diameters of the inner and outer edges of the each ring with a veneer caliper and then taking the overage.
5. Increase the anode voltage V_A by about 1 Kv and measure the corresponding diameters D_1 and D_2
6. Repeat setup (5) till a value of about 7.5 Kv of V_A .

Calculation :

1. Calculated the values of de Bragg wavelength λ of the electron from anode voltage V_A using eq (4). Calculated the corresponding values of the Bragg

angle Ө from eq (8) using the measured value of diameters D_1 and D_2. Determine the value of the inter planer spacing d_1 and d_2 from the eq (5) for each value of V_A, taking n=1, and then find the average

2. Tabulate your results as showed in table (1). Compare the average value of d_1 and d_2 with the literature value (d_1= 2.13A°, and d_2 =1.23A°).

3. **Table (1)**

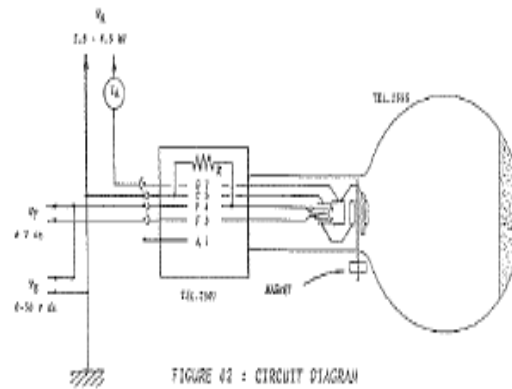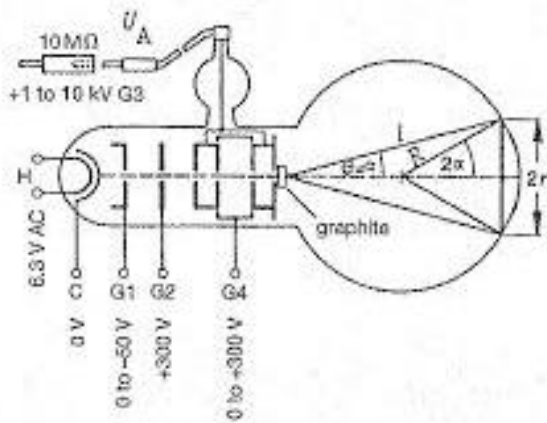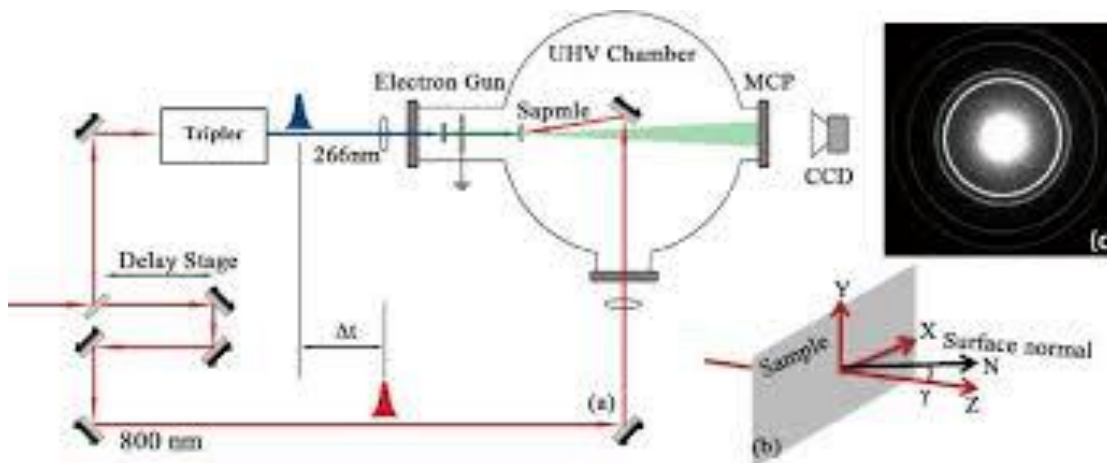| V_A (Kv)	λ	D_1	D_2	$Ө_1$	$Ө_2$	d_1	d_2
4 . . . . 7.5							

FIGURE 42 : CIRCUIT DIAGRAM

The Normal Zeeman Effect

Introduction:

The "Zeeman effect" is the splitting up of the spectral lines of atoms within a magnetic field. The simplest is the splitting up of one spectral line into three components called the "normal Zeeman effect". The normal Zeeman effect is studied using a cadmium spectral lamp as a specimen. The cadmium lamp is submitted to different magnetic flux densities and the splitting up of the red cadmium line (643.8 nm) is investigated using a Fabry-Perot interferometer. The evaluation of the results leads to a fairly precise value for Bohr's magneton.

In the normal Zeeman effect three components are observed, whereas when more than three components may be seen the effect is known as **anomalous.**
The electron might be pictured as moving in a particular orbit, corresponding to its permitted orbital angular momentum. the motion of the electron in an orbit is equivalent to a current in a loop wire. If a current carrying loop of wire is placed in magnetic field , it experiences a torque and the potential energy of the system depends on the orientation of the loop with respect to the magnetic field. The correct energies are obtained if the component of the orbital angular momentum of the electron along the direction of the magnetic fields restricted to the values **m$\hbar$** where m= 0,±1, ±2, ±3, ±4 …… **, L**, the electrons orbital angular momentum now may be said to be space-quantized , this result in a splitting of the energy levels corresponding to the various value of **m**, Hance for each frequency of radiation emitted by the atom in the absence of a magnetic field , there are now several possible frequencies. That is why the quantum number **m** is often referred to as the magnetic quantum number.

The solution of the Schrodinger equation (for Hydrogen like atom)

Yields state labeled by three integer indices **n , L, m**, where L< n and **m**= -L, -L+1, ….., L-1. The energy of these states depends om n and L but not on m , thus we may say that the (2L +1) states with same **n** and **L** index are degenerate in the **m** quantum number. If a magnetic field **H** is switched on in the region of the atom, we should expect that the electrons will interact with it. We need only to consider the electrons outside closed shell, and let us assume

there is one such electron. The interaction of the magnetic field with this electron yields for each state an additional energy ΔE given by

$$\Delta E = m\, \mu_o\, H \ldots\ldots 1$$

Thus the energy of a particular state **n, L,m** in the presence of a a magnetic field will be given by

$$\mathbf{E_{n,\,L,m}} = \mathbf{-E_{n,\,L} + mH\mu_o}$$
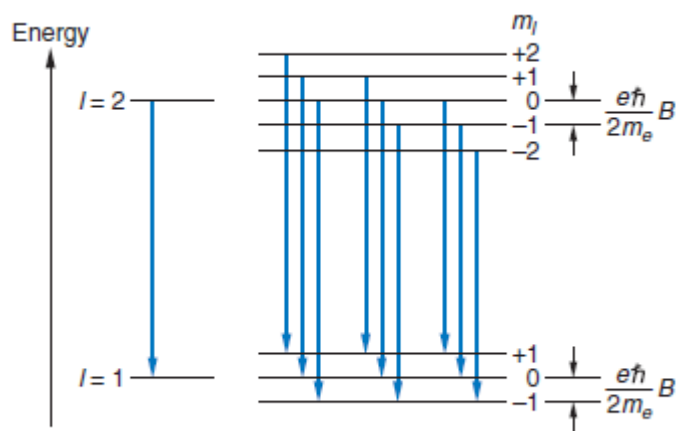
$$\mathbf{\mu_o = e\hbar/\, 2m_o c}$$

figure 1: Energy-level splitting in the normal Zeeman effect for singlet levels $l = 2$ and $l = 1$. Each level is split into $2l + 1$ terms. The nine transitions consistent with the selection rule $\Delta m = 0, \pm1$, give only three different energies because the energy difference between adjacent terms is $e\hbar B/2me$ independent of l.

Set-up

The electromagnet is put on the rotating table for heavy loads and mounted with the two pole-shoes with holes in such a way that a gap large enough for the Cd-lamp (9-11 mm) remains for the Cd-lamp. The pole-shoes have to be well tightened in such a way that they cannot move later on when the magnetic flux is established. The Cd-lamp is inserted into the gap without touching the pole-shoes and connected to the power supply for spectral lamps. The coils of the electromagnet are connected in parallel and via an ammeter connected to the variable power supply of up to 20 VDC, 12 A. A capacitor of 22000 mF is in parallel to the power output to smoothen the DC-voltage.

The iris diaphragm is eliminated for initial adjustment and for the observation of the longitudinal Zeeman effect. During observation of the transverse Zeeman effect the iris diaphragm is illuminated by the Cd-lamp and such it

acts as the light source. The lens L1 and a lens of f = 100 mm, incorporated in the etalon, create a nearly parallel light beam which
the Fabry-Perot etalon needs for a proper interference pattern. The etalon contains a removable colour filter that lets the red cadmium line at 643.8 nm pass. The lens L2 produces an interference pattern of rings which can be observed through L3. The ring diameters can be measured using the CCD-camera and the software supplied with it. In the classical version
the interference pattern is produced within the plane of the screen with a scale mounted on a slide mount which can laterally be displaced with a precision of 1/100th of a millimeter. The measurement here can be done for instance, by systematic displacement of the slash representing the „0" of the scale.

Fig.1b: Set-up for the classical version of the experiment.

The initial adjustment is done in the following way: The rotating table with electromagnet, pole-shoes and Cd lamp already mounted is adjusted so that the center of the holes in the pole-shoes lies about 28 cm above the table. The optical bench with all elements (except iris diaphragm and CCD-camera) mounted, is then moved closer to the electromagnet in such a way that one of the outlet holes of the poleshoes coincides with the previous position of the iris diaphragm. L1 is then adjusted so that the outlet hole is within the focal plane of it. All other optical elements of Fig. 2. Are subsequently readjusted with respect to their height correspondingly. The current of the coils is set for some time to 8 A (increase in light intensity of the Cd-lamp !) and the ring interference pattern in axial direction is observed through L3 by the eye. The pattern must be centered and sharp which is eventually achieved by a last,

slight movement of the etalon (to the right or to the left) and by displacement of L2 (vertically and horizontally).

Finally the CCD-camera with the 8 mm lens attached is mounted to the optical bench and adjusted in horizontal and vertical position as well as in tilt and focus until a clear picture of the ring pattern is visible on the computer screen. For installation and use of the camera and software please refer to the manual supplied with the camera.
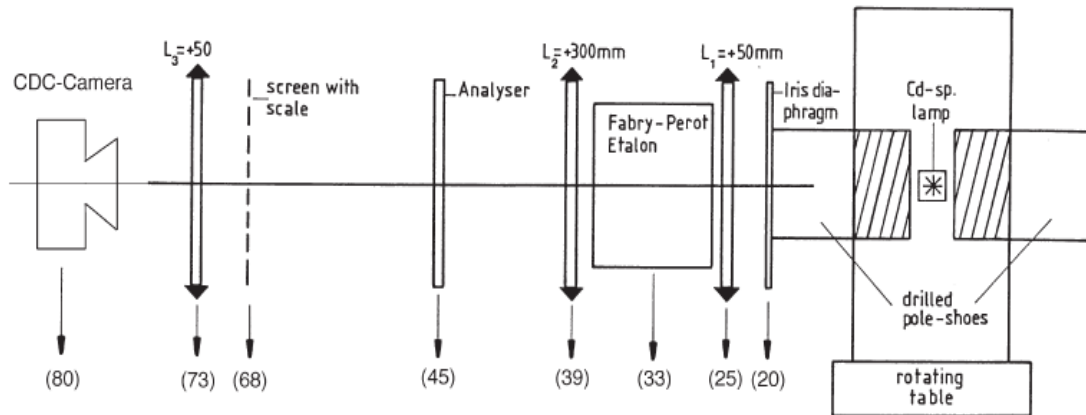

Fig. 2: Arrangement of the optical components.

Measurement and Evaluation

Provided the ring pattern has been properly established as explained in the section "set-up" above, the radii of the rings have to be measured at different magnetic flux densities. Then it is possible by using equation to determine the

$$\Delta \vec{\nu} = \frac{1}{2t} \frac{\delta}{\Delta|}$$

corresponding difference in wave numbers Δn. We proceed in two steps: first we take pictures of the ring patterns at different coil currents/magnetic field intensities. Then in a second step the ring diameters in these pictures are measured. To get a life picture from the camera go to the **<File>** menu and chose the entry **<Capture Window>**. In the capture window the settings regarding e.g. contrast, brightness and saturation of the image can be optimized via the menu you get to when choosing **<Video Capture Filter>** from the **<Option>** menu. When satisfied with the image quality and a certain

coil current (magnetic field) is established, the picture is captured by choosing **<Still Image>** from the **<Capture>** menu. This action also closes the capture window and the picture appears in the main window of the application. At this stage it is advisable to write the value of the coil current at which the picture was taken into it by using the **<Text>** tool. This prevents a mix-up later on. The above procedure is repeated using different magnetic fields for instance, with coil currents of 5 A, 6 A, 8 A and 10 A. Once these pictures have been collected, we proceed to measure the radii of the rings choosing **<Circle>** from the**<Measure>** menu. By dragging the mouse across the picture, a circle is drawn. Fit this circle in size and position as good as possible to the innermost ring. You will see that radius in a table below the picture (compare Fig. 8). What we are mainly interested in is the radius of the circle, this is r1,a. Note that the units (mm, mm, cm) are of no importance in this experiment, that means no calibration of the camera has to be performed. Proceed to draw and fit circles to as many sets of rings as are visible in the picture, this will give you; r1,b; r2,a; r2,b; r3,a…. Do the same with the other pictures captured. , area and perimeter of the circle will be displayed in a little box and In the **classical version** without the CCD-camera a set of radii of rings is determined in the following way:

The slash of the scale „0" is shifted horizontally along a diameter through the ring pattern until it coincides, for instance,with the fourth ring to the left. A magnetic field corresponding to a coil current of lets say 4 A is established and the splitting of the rings observed. The analyzer is put into the vertical position so that only the two s-lines appear. The „0" slash is now adjusted to coincide perfectly with the outer ring of the two rings, into which the fourth ring has split. The first reading on the socket of the sliding mount is taken. The „0" slash is then moved from left to right through all the rings. The last reading is taken when the „0" slash coincides with the outer ring of the fourth ring to the right. The last reading minus the first reading divided by two then provides the radius $r_{4,b}$. Evaluating the previous readings in a similar way leads to the following radii:

I = 4[A]: $r_{4,b}$; $r_{4,a}$; $r_{3,b}$; $r_{3,a}$; $r_{2,b}$; $r_{2,a}$; $r_{1,b}$; $r_{1,a}$

Further sets of radii are received when repeating the procedure, for instance, for coil currents of 5 A, 6 A, 8 A and 10 A. Using the slide mount, all readings are done in "mm" with a precision of 1/100th of a

mm. Still, the dimension used is not significant since it cancels out when evaluating due to equation (10).

$$\Delta \vec{\nu} = \frac{1}{2t} \frac{\delta}{\Delta}$$

Now the following square array can be formed for each set of radii measured, regardless if they are measured with the CCDcamera and the software or the classical way:
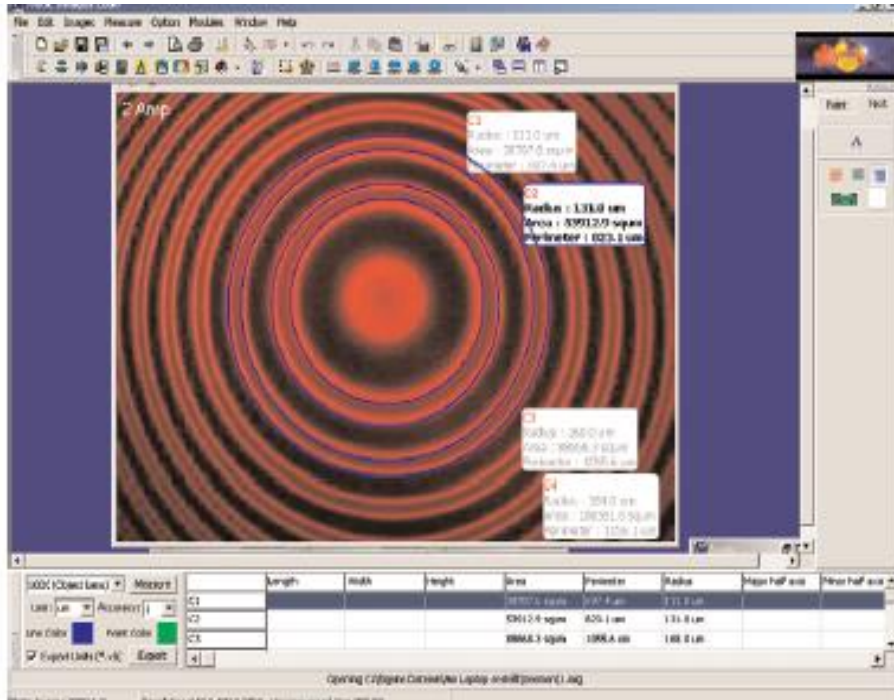
Current I (A)	No. of spectral line	Splitting of spectral line (r) radius	r^2	D	d	B(T)	ΔV	ΔV/2
3								
3.5								
4								
4.5								

Δor D= 1/4 ($(r^2_{2a} - r^2_{1a}) + (r^2_{2b} - r^2_{1b}) + (r^2_{4a} - r^2_{3a}) + (r^2_{4b} - r^2_{3b})$)

d or δ=1/4($(r^1_{1b} - r^2_{1a}) + (r^2_{2b} - r^2_{2a}) + (r^2_{3b} - r^2_{3a}) + (r^2_{4b} - r^2_{4a})$)

$\Delta\upsilon = (1/2nt) \cdot \delta/\Delta$, Where n=refractive index=1 , t=thickness= 3×10^{-3} m

plot the relation between $\Delta\upsilon$ and B, calculate the slope.

find Magneton Bohr= μ_B $\longrightarrow$ $\mu_B = hc \cdot (\Delta\upsilon/B)$

Expt (7)

X-ray -absorption

Aim of the experiment :

1- Determination of the linear and mass absorption coefficient of aluminum.
2- Studying the dependence of the mass absorption coefficient on the atomic number of materials.

Theory:

X-radiation is a form of electromagnetic radiation. Xrays have a wavelength in the range of below 0.01 nm to 10 nm, corresponding to energies in the range 120 eV to over 120 keV. X-rays are attenuated as they pass through matter. That is, the intensity of an x-ray beam decreases the farther it penetrates into matter. Basically, X-ray photons are absorbed by the electrons of the atom of the material, decreasing the propagating X-ray intensity. The decrease in intensity of the X-ray beam depends upon two factors:

• The depth of penetration (t) or thickness

• An intrinsic characteristic of the material namely the attenuation/absorption cross-section**.**
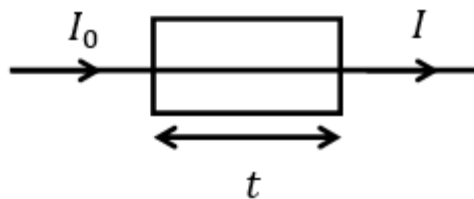
Figure 1: Schematic of incident and transmitted x-ray beam.

The intensity decreases exponentially with the distance travelled (Fig. 1),

or $\quad\quad\quad I_{(t)} = I_0\, e^{-\mu t}$………..1

where I_0 is the initial x-ray beam intensity, **t** thickness of the absorbed material, **μ** linear absorption coefficient and $I_{(t)}$ intensity of transmitted ray . This exponential decay of photon intensity applies in the optical

region of the electromagnetic spectrum as well and was originally defined for optical photon attenuation. It is known as the Beer-Lambert law The half thickness of the absorbent material can be calculated (**t $_{(1/2)}$**)**,** which represents the thickness required to make the intensity of the penetrating rays (**I**) equal to half the intensity of the incident rays (**I$_0$**), and is given by the following relationship:

$$t_{1/2} = \frac{\ln 2}{\mu} = \frac{0.693}{\mu} \quad --- (2)$$

The intensity of the X-rays can be measured by a Keiker counter because its reading is proportional to the intensity of the X-rays. Then equation (1) can be written in the following form -:

$$N = N_0 \, e^{(-\mu t)} \quad --- (3)$$

Where (**N$_0$**) represents the reading of the meter without the presence of the absorbent material, while (**N**) represents the reading of the meter with the presence of the absorbent material, (t) the thickness of the absorbent material. The linear absorption coefficient (**μ**) depends strongly on the density of the absorbent material, and accordingly, the so-called mass absorption coefficient (**μ$_m$**) must be found by dividing the linear absorption coefficient (μ) by the density of the absorbent material (**ρ**) in the following form:-

$$\mu_m = \frac{\mu}{\rho} \quad --- (4)$$

Although the change (**μm**) from one substance to another is much less than the change (**μ**), it is not a constant value. Since substances with a large atomic number absorb X-rays more than materials with a small atomic number,

For example, lead that has a certain mass per unit area is more effective (more absorbent) than aluminum that has the same mass per unit area. In general, the mass absorption coefficient (**μ$_m$**) changes with the change of the cube of the atomic number (**Z**) approximately, and it also depends on the wavelength (**λ**) for X-rays, and it was found experimentally that (**μm**)

depends on both the atomic number **(Z)** and the wavelength **(λ)** and according to the following relationship:

$$\mu_m = K\,\lambda^3 Z^n \quad - - - (5)$$

Whereas **(K)** is almost constant if the wavelength (λ) remains constant at the absorption edge of the material, and the value of (n) is close to three.

The work method:-

Part One: Determine the linear and mass absorption of aluminum:-

1- Aattach the absorbent aluminum strip holder to the slit (in a circular arc) in the sample holder. The aluminum strips are mounted on a cylindrical plate with seven slots. Six of the slits are covered with aluminum sheets with a thickness ranging between (0.5 mm-3 mm), then increase the thickness by (0.5 mm) in each step. As for the first slit, it is not covered (it is a vacuum) that allows direct rays to fall on the detector in order to measure (N_0).

2- Make the voltage applied to the detector equal to (460 volts) from the power supply.

3- Place the zirconium filter in the designated place at the beginning of the collimator slit, to obtain single-wavelength rays (λ=0.71 A^0).

4- Turn on the X-ray machine and set the value of the high voltage difference (21 KV) applied to the x-ray tube to the number (1), and the emission current (I_em=0.8 mA).

5- Turn on the timer and set the counting time to 100 Sec.

6- Place the first slot in front of the detector and record the meter reading for every (100 Sec) at least twice, then find the counting rate (N_0).

7- Place the second slit (covered with a 0.5 mm thick aluminum strip) in front of the detector and record the meter reading for the same period of time at least twice, then find the count rate (N).

8- Repeat step (7) for the other cracks, respectively, and record the count rate (N) for each thickness of aluminum.

9- Arrange your readings in the form of a table as below:

t (mm)	Count / 20 Sec			ln N
	N_1	N_2	N	
0				
0.5				
1				
1.5				
2				
2.5				
3				

10-   Draw a graph between (lnN) as a function of thickness (t) and from the slope, find the linear absorption coefficient of aluminum (μ), which is in units (cm^{-1}) from Equation No. (3), and also find the mass absorption coefficient of aluminum (μ_m).) which is in units (cm^2/gm) from equation (4) and finally find the thickness of the half from equation (2).

11- Find another value for the mass absorption coefficient by setting the value of the high voltage difference (36 KV) directed at the x-ray tube to the number (6), then repeat the previous points (sixth to tenth).

Part Two / Study of the dependence of the mass absorption coefficient on the atomic number of substances:-

12-   Replace the aluminum strip holder with a second similar holder, which has (6) samples of equal thickness with a value of (0.5 mm) and a variable atomic number. The samples placed in the six slits are made of the following materials.

material	symbol	Atomic (Z) number	(gm/cm³)density	lit No.
الفضة	Ag	47	10.50	7
الزركونيوم	Zr	40	6.50	6
النحاس	Cu	29	8.96	5
الحديد	Fe	26	7.86	4
الالمنيوم	Al	13	2.70	3
البوليستايرين	Ps	6	2.23	2

13- Turn on the devices as in the first part, with the filter present, and set the value of the high voltage difference (36 KV) directed at the x-ray tube to the number (6).

14- Place the first slot in front of the detector and record the meter reading for every (100 Sec) at least twice, then find the counting rate (N_0).

15- Place the second slit (covered with a 0.5 mm thick aluminum strip) in front of the detector and record the meter reading for the same period of time at least twice, then find the count rate (N). Then repeat this point for the rest of the cracks and arrange them as in the table below:-

	$(Count/20\ Sec)$		N_{ave}	$\mu\ (cm^{-1})$	$\mu_m\ (gm/cm^3)$
(Z)	N_1	N_2			
6 13 । । । 47					

16- Calculate the linear (μ) and mass absorption coefficients (μ$_m$) for the materials, then find the average mass absorption coefficient (μ$_m$) for

aluminum of the two types (A and B) for the same value of the high voltage difference (36 KV) directed at the x-ray tube.

17-   Draw a graph between (ln Z) as a function of (ln(μ_m)) and from the slope we find the value of the exponent (n).