1. Determination of Hall Coefficient and carrier type for a Semi-conducting Material

Theory:

Aim:

1. To determine the Hall voltage developed across the sample material.
2. To calculate the Hall coefficient and the carrier concentration of the sample material.

If a current carrying conductor placed in a perpendicular magnetic field, a potential difference will generate in the conductor which is perpendicular to both magnetic field and current. This phenomenon is called Hall Effect. In solid state physics, Hall effect is an important tool to characterize the materials especially semiconductors. It directly determines both the sign and density of charge carriers in a given sample.

Consider a rectangular conductor of thickness ***t*** kept in XY plane. An electric field is applied in X-direction using Constant Current Generator (CCG), so that current ***I*** flow through the sample. If ***w*** is the width of the sample and ***t*** is the thickness. There for current density is given by

$$J_x = I/wt \qquad (1)$$

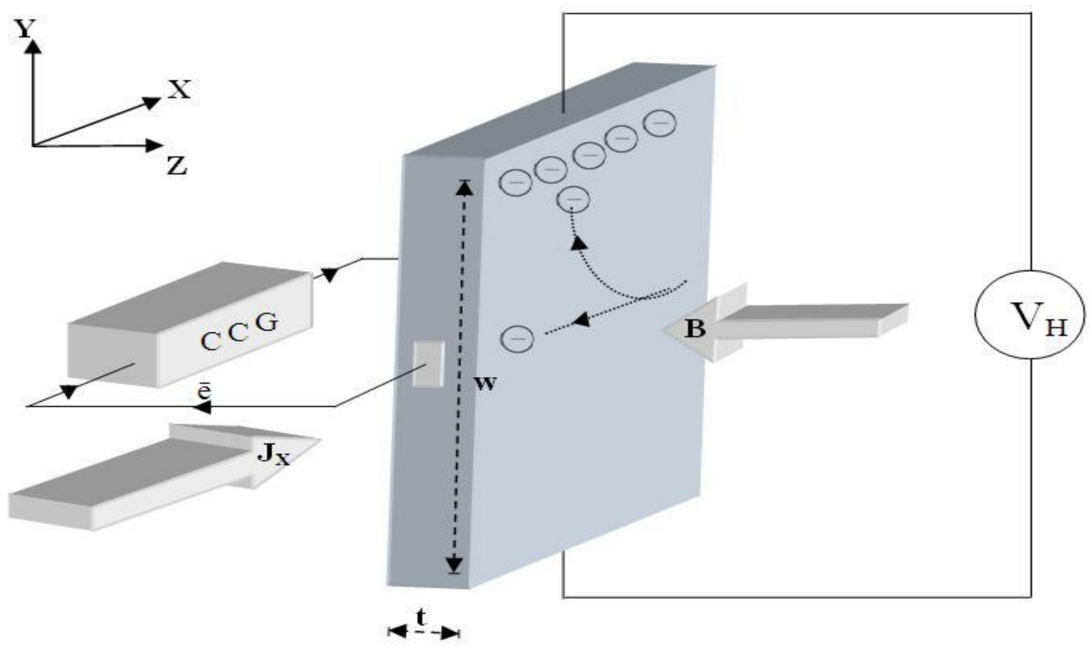


Fig.1 Schematic representation of Hall Effect in a conductor.
CCG – Constant Current Generator, J_X – current density
$\bar{e}$ – electron, ***B*** – applied magnetic field
t – thickness, ***w*** – width
V_H – Hall voltage

If the magnetic field is applied along negative z-axis, the Lorentz force moves the charge carriers (say electrons) toward the y-direction. This results in accumulation of charge carriers at the top edge of the sample. This set up a transverse electric field $\mathbf{E_y}$ in the sample. This develop a potential difference along y-axis is known as Hall voltage V_H and this effect is called Hall Effect.

A current is made to flow through the sample material and the voltage difference between its top and bottom is measured using a volt-meter. When the applied magnetic field B=0,the voltage difference will be zero.

We know that a current flows in response to an applied electric field with its direction as conventional and it is either due to the flow of holes in the direction of current or the movement of electrons backward. In both cases, under the application of magnetic field the magnetic Lorentz force, $F_m = q(vxB)$ causes the carriers to curve upwards. Since the charges cannot escape from the material, a vertical charge imbalance builds up. This charge imbalance produces an electric field which counteracts with the magnetic force and a steady state is established. The vertical electric field can be measured as a transverse voltage difference using a voltmeter.

In steady state condition, the magnetic force is balanced by the electric force. Mathematically we can express it as

$$eE = evB \qquad (2)$$

Where 'e' the electric charge, 'E' the hall electric field developed, 'B' the applied magnetic field and 'v' is the drift velocity of charge carriers.

And the current 'I' can be expressed as,

$$I = neAv \qquad (3)$$

Where 'n' is the number density of electrons in the conductor of length l ,breadth 'w' and thickness 't'.

Using (1) and (2) the Hall voltage V_H can be written as,

$$V_H = Ew = vBw = \frac{IB}{net}$$

$$V_H = R_H \frac{IB}{t} \qquad (4)$$

by rearranging eq(4) we get

$$R_H = \frac{V_H * t}{I * B} \qquad (5)$$

Where R_H is called the Hall coefficient.

$$R_H = 1/ne \qquad (6)$$

Procedure

1. Connect the widthwise contacts of the hall probe to the terminals marked as 'voltage' (i.e. potential difference should be measured along the width) and lengthwise contacts to the terminals marked (i.e. current should be measured along the length) as shown in fig.
2. Switch on the Hall Effect setup and adjust the current say 0.2 mA.
3. Switch over the display in the Hall Effect setup to the voltage side.
4. Now place the probe in the magnetic field as shown in fig and switch on the electromagnetic power supply and adjust the current to any desired value. Rotate the Hall probe until it become perpendicular to magnetic field. Hall voltage will be maximum in this adjustment.
5. Measure the hall voltage and tabulate the readings.
6. Measure the Hall voltage for different magnetic fields and tabulate the readings.
7. Measure the magnetic field using Gauss meter
8. From the data, calculate the Hall coefficient, carrier mobility and current density.

By using the Formulae

i) Hall coefficient (R_H) $= \dfrac{V_H \cdot t}{IH} \times 10^{8}\ cm^3\ C^{-1}$

where V_H = Hall voltage (volt)

t = Thickness of the sample (cm)

I = Current (ampere)

H = Magnetic filed (Gauss)

ii) Carrier density (n) $= \dfrac{1}{R_H\, q}\ cm^{-3}$

where R_H = Hall coefficient ($cm^3\ C^{-1}$)

q = Charge of the electron or hole (C)

iii) Carrier mobility (μ) $= R_H \sigma\ cm^2 V^{-1}\ s^{-1}$

where R_H = Hall coefficient ($cm^3 C^{-1}$)

σ = Conductivity ($C\ V^{-1}\ s^{-1}\ cm^{-1}$)

Measurement of Hall coefficient

Current in the Hall effect setup = ----------mA

Current in the constant current power supply (A)	Magnetic field (H) (Gauss)	Hall Voltage (V_H) (volts)	Hall coefficient (R_H) $cm^3\ C^{-1}$

Observations and Calculations

(1) Thickness of the sample = t = cm

(2) Resistivity of the sample = ρ = $V\ C^{-1}\ s\ cm$

(3) Conductivity of the sample = σ = $CV^{-1} s^{-1}\ cm^{-1}$

(4) The hall coefficient of the sample = $R_H = \frac{V_H . t}{IH} \times 10^8$

= -------------

(5) The carrier density of the sample = $n = \frac{1}{R_H q}$

= -------------

(6) The carrier mobility of the sample = $R_H \sigma$

= ---------------

Result:

1. The Hall coefficient of the given semi conducting material =
2. The carrier density =
3. The carrier mobility =

Assignment Questions (Self-Evaluation):

1. What is Hall Effect?
2. How to determine the type of semiconductor using Hall Coefficient?
3. Write down any two application of Hall Effect?
4. Calculate the carrier concentration for a P-type Ge semiconductor of thickness 0.3mm.
5. Determine the hall coefficient for a typical N-type Germanium semiconductor having thickness 0.8mm.

6. Determine the hall coefficients for an N-type and P-type Ge semiconductor having same thickness.
7. Show that the hall coefficient of a material is dependent of its thickness.

References:

1. 18PYB103J Instructional manual
2. Ramsden and Edward Ramsden.Hall-effect Sensors.Amsterdam:Elsevier/Newnes.2006
3. Fundamentals of solid state engineering by ManijehRazeghi.
4. Materials handbook.Berlin:Springer,2008.

2. Band Gap Determination using Post Office Box

Theory:

Aim:

To find the band gap of the material of the given thermistor using post office box.

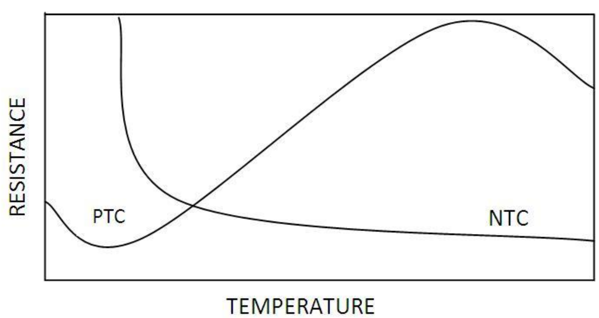
A thermistor is a type of resistor whose resistance strongly depends on temperature. The word thermistor is a combination of words "thermal" and "resistor". A thermistor is a temperature-sensing element composed of sintered semiconductor material and sometimes mixture of metallic oxides such as Mn, Ni, Co, Cu and Fe, which exhibits a large change in resistance proportional to a small change in temperature. Pure metals have positive temperature coefficient of resistance, alloys have nearly equal zero temperature coefficient of resistance and semi conductors have negative temperature coefficient of resistance.

Thermistors can be classified into two types:

Positive temperature coefficient (PTC) thermistor:-resistance increase with increase in temperature.

Negative temperature coefficient (NTC) thermistor:-resistance decrease with increase in temperature.

The thermistor exhibits a highly non-linear characteristic of resistance vs. temperature.



PTC thermistors can be used as heating elements in small temperature controlled ovens. NTC thermistors can be used as inrush current limiting devices in power supply circuits. Inrush current refers to maximum, instantaneous input current drawn by an electrical device when first turned on. Thermistors are available in variety of sizes and shapes; smallest in size are the beads with a diameter of 0.15mm to 1.25mm.

There are two fundamental ways to change the temperature of thermistor internally or externally. The temperature of thermistor can be changed externally by changing the temperature of surrounding media and internally by self-heating resulting from a current flowing through the device.

Apparatus Required

Thermistor, thermometer, post office box, power supply, galvanometer, insulating coil and glass beakers.

Principle and formulae

(1) Wheatstone's Principle for balancing a network $\frac{P}{Q} = \frac{R}{S}$

Of the four resistances, if three resistances are known and one is unknown, the unknown resistance can be calculated.

(2) The band gap for semiconductors is given by,

$$Eg = 2k\left(\frac{2.303 \log_e R_T}{1/T}\right)$$

wherek = Boltzmann constant = $1.38 \times 10 - 23$ J /K

RT = Resistance at T K

Procedure

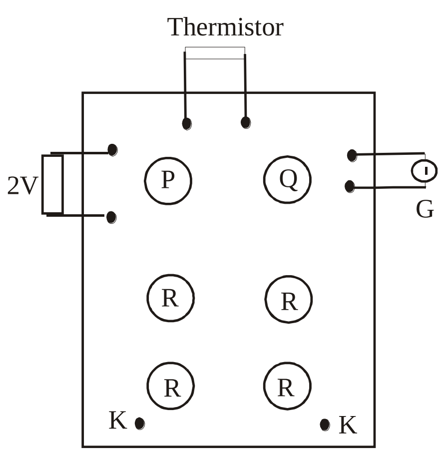
The connections are given as in the Fig. 6.1(a).1. Ten ohm resistances are taken in P and Q.

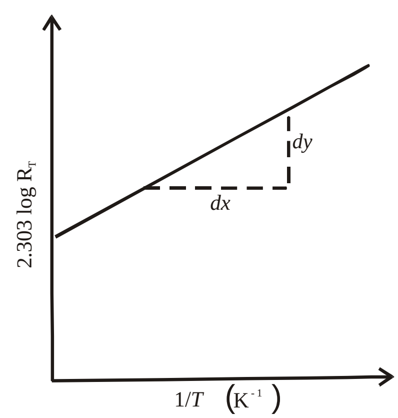
Then the resistance in R is adjusted by pressing the tap key, until the deflection in the galvanometer crosses zero reading of the galvanometer, say from left to right.

1. After finding an approximate resistance for this, two resistances in R, which differ by 1 ohm, are to be found out such that the deflections in the galvanometer for these resistances will be on either side of zero reading of galvanometer.
2. We know $R_T = \frac{Q}{P} \times R = \frac{10}{10} \times R_1$ *or* $(R_1 + 1)$.This means that the resistance of the thermistor lies between R_1 and (R_1+1). Then keeping the resistance in Q the same, the resistance in P is changed to 100 ohm.
3. Again two resistances, which differ by one ohm are found out such that the deflections in the galvanometer are on the either side of zero. Therefore the actual resistance of thermistor will be between $\frac{R_2}{10}$ and $\frac{R_2 + 1}{10}$.

To find the resistance of the thermistor at different temperatures

Temp. of thermistor T = t+273	$\frac{1}{T}$	Resistance in P	Resistance in Q	Resistance in R	Resistance of the thermistor $R_T = \frac{P}{Q} \times R$	2.303 $\log_{10} R_T$
K	K^{-1}	ohm	ohm	Ohm	ohm	ohm





Observation

From graph, slope = (dy / dx) = ……

Calculation

Band gap, $E_g = 2k(dy / dx)$ =…..

4. Then the resistance in P is made 1000 ohms keeping same 10 ohms in Q. Again, two resistances R and (R+1) are found out such that the deflection in galvanometer changes its direction. Then the correct resistance.

$$= \ R_T = \frac{10}{1000}(R) \text{ (or)}$$

$$= \ R+1 \ = 0.01R \text{ (or) } 0.01(R+1)$$

5. Thus, the resistance of the thermistor is found out accurately to two decimals, at room temperature. The lower value may be assumed to be R_T (0.01R).

6. Then the thermistor is heated, by keeping it immersed in insulating oil. For every 10 K rise in temperature, the resistance of the thermistor is found out, (i.e) R_T's are found out. The reading is entered in the tabular column.

Graph: A graph is drawn between $\frac{1}{T}$ in X axis and 2.303 log R_T in Y axis where T is the temperature in K and R_T is the resistance of the thermistor at TK. The graph will be as shown in the Fig.6.1(a).2.

Band gap (Eg)=2k $\times$ slope of the graph = $2k\times\ (\frac{dy}{dx})$

where K = Boltzman's constant.

Result

The band gap of the material of the thermistor = ...eV.

Assignment Questions (Self-Evaluation):

1. What is Energy Gap?
2. What is Thermistor?
3. How Thermistor are classified in to?
4. Write down the balancing condition of the post office box
5. Why for Negative Temperature Coefficient (NTC) thermistor, resistance decreases with increase in temperature?
6. Determine the Resistance of the Thermistor at 100˚C
7. Determine the Energy Gap of the Thermistor at Room Temperature

References:

1. 18PYB103J Instructional manual
2. B.L.Theraja, Basic Electronics Solid State, Fifth edition: S.Chand and company Ltd.
3. R.S.Sedha, A Textbook of Applied Electronics, Third edition: S.Chand and company Ltd.

3. V-I Characteristics of a Light Dependent Resistor (LDR)

AIM: To study the photoconductive nature of the given light dependent resistor (LDR) and to plot the V-I characteristics of the LDR.

THEORY:

Light dependent resistor, LDRs or Photoresistoris a device, which is often used to detect the presence or the level of light.A LDR is a device component that is sensitive to light. When light falls upon it then the resistance changes. Values of the resistance of the LDR may change over many orders of magnitude the value of the resistance falling as the level of light increases.

Principle:

An LDR is made using semiconductor material with a high resistance. When light is incident on LDR, a photon is absorbed and thereby it excites an electron from valence band into conduction band. Due to such new electrons coming up in conduction band area, the electrical resistance of the device decreases. Thus the LDR or photo-conductive transducer has the resistance which is the inverse function of radiation intensity.

$$\lambda_0 = \frac{hc}{eE_\omega}$$

whereλ_0 = threshold wavelength in meters, e = charge on one electron in Coulombs,E_ω = work function of the metal in eV.

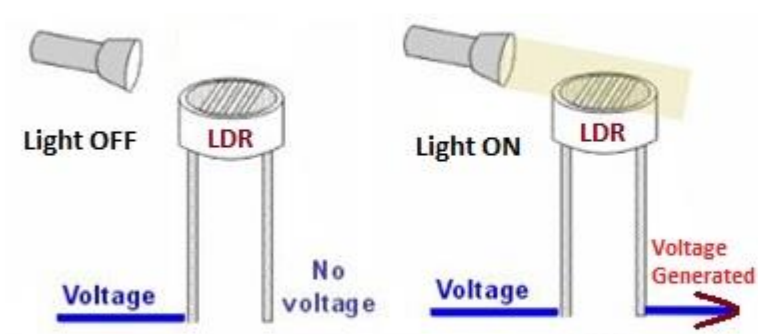


Fig. 3.1. Working of LDR

Any radiation with wavelength λgreater than threshold wavelength(λ_0), will not produceany change in the resistance of this device. Due to large energy gaps, the LDR materials have extremely high resistivity at room temperature. So when the device is kept in darkness, its resistance is called as dark resistance.

The materials used for photoresists are semiconductors and include materials such as CdSe, CdS, CdTe, InSb, InP, PbS, PbSe, Ge, Is, GaAs. Each material gives different properties in terms of the wavelength of sensitivity, etc.

PROCEDURE:

Apparatus Required:

LDR, Resistor (1 kΩ), Ammeter (0 – 10 mA), Voltmeter (0 – 10 V), Light source, Regulated power supply, Measuring Scale.

Formula:

By ohm's law, $V = IR$ (or) $R = \frac{V}{I}$ ohm

where R is the resistance of the LDR (i.e.) the resistance when the LDR is closed. V and I represents the corresponding voltage and current respectively.

Determination of Photoresistance:

1. Circuit connections are given in as shown in Fig. 3.2
2. Light source is turnedON and made to fall on the LDR.
3. Corresponding Voltmeter and Ammeter readings are noted.The value of the resistance can be calculated by Ohm's law.
4. The procedure is repeated by keeping the light source at different distances away from the LDR.
5. A graph is plotted between resistance and distance of LDR from the light source.
6. The value of the dark resistance is determined using Voltmeter and Ammeter readings when the Light source is turnedOFF.

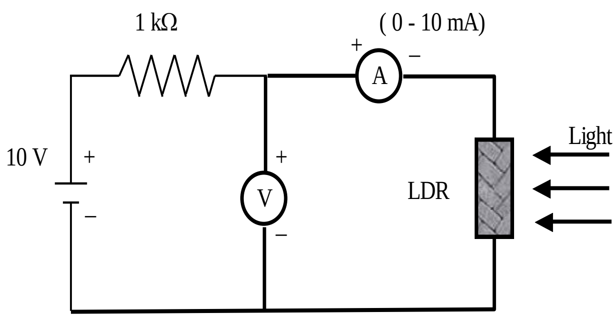


Fig. 3.2. Circuit diagram

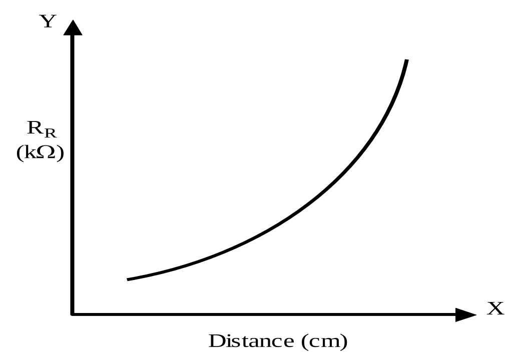


Fig. 3.3. Model graph

OBSERVATION:

Voltmeter reading when the LDR is closed = …… V

Ammeter reading when the LDR is closed = ……. A

Dark resistance = $R = \frac{V}{I}$ = ……. ohm

To determine the resistances of LDR at different distances

S.No	**Distance (cm)**	**Voltmeter reading (V) volt**	**Ammeter reading (I) mA**	**R_R kΩ**
1 2 3 4 5	A (Long Distance)			
1 2 3 4 5	B (Mid Distance)			
1 2 3 4 5	C (Short Distance)			

RESULT:

1. The V-I characteristics of LDR were studied and plotted.
2. The dark resistance of the given LDR is found out to be = …….. ohm

Assignment Questions (Self-Evaluation):

1. What isLDR?
2. What isThreshold Wavelength of LDR
3. What is Dark Resistance?
4. Define Work Function of metal
5. Write down four applications of LDR?
6. Describe how the resistance of an LDR changes in light and dark conditions?
7. Why the resistance of the LDR varies as the distance between the light source and LDR gets varied?

8. Determine the resistance of the LDR component at 10 cm.
9. Evaluate the dark resistance of the LDR component at room temperature.

References:

1. 18PYB103J Instructional manual
2. U.A Bakshi, A.P Godse, “Electronic Devices. Technical Publications”, India, 2008.
3. Robert Diffenderfer,“Electronic Devices: Systems and Applications”, Thomas Delmer Learning, USA, 2005.

4. Resistivity Determination for a Semiconductor Wafer using Four Probe Method

Theory:

Aim

To determine the energy band gap of a semiconductor (Germanium) using four probe method.

In this method, four probes are utilized to measure the resistance of the semiconductor material. For example, two of the outer probes are used to send the current from the source meter and other two inner probes are used to measure the voltage drop across the sample. The typical set up of the four-probe method is shown in Figure. There are four equally spaced tungsten metal tips supported by springs at one end to mount the sample surface without any damage. Where the thickness (t) of the materials is much higher than the space between the probes (s), then the differential resistance due to spherical protrusion of current emanating from the outer probe tips is

$$\Delta R = \rho\left(\frac{dx}{A}\right)$$

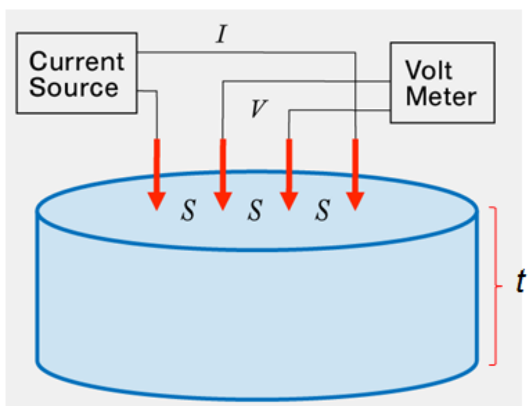


Figure Schematic of four-point collinear probe method on bulk material.

Carrying out the integration between the inner probe tips,

$$R = \int_{v1}^{v2} \rho \frac{dx}{2\pi x^2} = \int_{s}^{2s} \rho \frac{dx}{2\pi x^2}$$

$$R = \frac{\rho}{2\pi}\left(-\frac{1}{x}\right)\Big|_s^{2s} = \frac{\rho}{2\pi}\frac{1}{2s}$$

where probe spacing is uniform.

Due to the superposition of current at outer tips, R = V / (2I).

Therefore,

$$\rho = \left(\frac{V}{I}\right)(2\pi s)$$

Where V and I are the voltage and current across and through the crystal chip.

The energy band gap, Eg., of semi-conductor is given by

$$E_g = 2k_B \frac{2.3026 \times log_{10}\rho}{1/T} \; in \; eV$$

where k_B is Boltzmann constant equal to 8.6×10^{-5} eV / kelvin , and ρ is the resistivity of the semi-conductor crystal.

Procedure

Apparatus

Probes arrangement (it should have four probes, coated with zinc at the tips). The probes should be equally spaced and must be in good electrical contact with the sample), Sample (Germanium or siliconcrystal chip with non-conducting base), Oven (for the variation of temperature of the crystal from roomtemperature to about 200°C), A constant current generator (open circuit voltage about 20V, current range0 to 10mA), Milli-voltmeter (range from 100mV to 3V), Power supply for oven Thermometer.

1. Connect one pair of probes to direct current source through milliammeter and other pair to millivoltmeter.
2. Switch on the constant current source and adjust current I, to a described value, say 2 mA.
3. Connect the oven power supply and start heating.
4. Measure the inner probe voltage V, for various temperatures.

Graph

Plot a graph in $\left(\frac{10^3}{T}\right)$ and $\log_{10}\rho$ as shown in Fig.6.1(b).2. Find the slope of the curve $\frac{AB}{BC} = \frac{\log_{10}\rho}{10^3/T}$. So the energy band gap of semiconductor (Germanium) is given by

$$E_g = 2k \times \frac{2.3026 \times \log_{10}\rho}{1/T}$$

$$= 2k \times 2.3026 \times \frac{AB}{CD} \times 1000 = 2 \times 8.6 \times 10^{-5} \times 2.3026 \times \frac{AB}{CD} \times 1000\,eV = 0.396 \times \frac{AB}{CD}\,eV$$

To determine the resistivity of the semi-conductor for various temperatures:

Current (I) = ………..mA

S.No.	Temperature in°C	Temperature in K	Voltage (V) (Volts)	Resistivity ρ (ohm. cm)	10^{-3}/ T (K)	$\log_{10}\rho$

Observations:

Distance between probes(s) = ……………………..mm

Thickness of the crystal chip (W) = ……………………mm

current (I) = ………………..mA

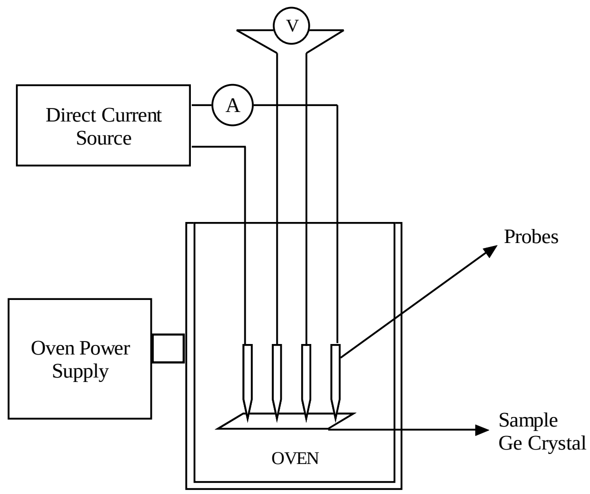


Fig. 4.1. Four Probe Setup

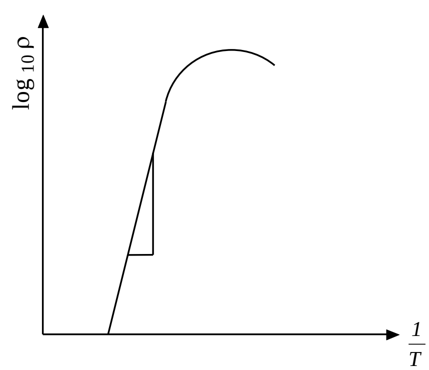


Fig. 4.2. Model Graph

Result

Energy band gap for semiconductor (Germanium) is E_g =….eV

Source of error and precautions

1. The resistivity of the material should be uniform in the area of measurement.
2. The surface on which the probes rest should be flat with no surface leakage.
3. The diameter of the contact between the metallic probes and the semiconductor crystal chip should be small compared to the distance between the probes.

Assignment Questions (Self-Evaluation):

1. What is the principle of four point probe method?
2. Why do we use 4 probes in four probe experiments?
3. Why four probe method is better than two probe methods?
4. What is energy band gap of semiconductor?
5. Why Germanium is used in 4 point probe method?

Reference:

1. Introduction To Semiconductor Materials And Devices, M.S Thyagi, Publisher John Wiley& Sons,2008

2. Physics of Semiconductor Devices, 3rd Ed, S.M.Sze, Kwok K .Ng, Publisher John Wiley& Sons,2008

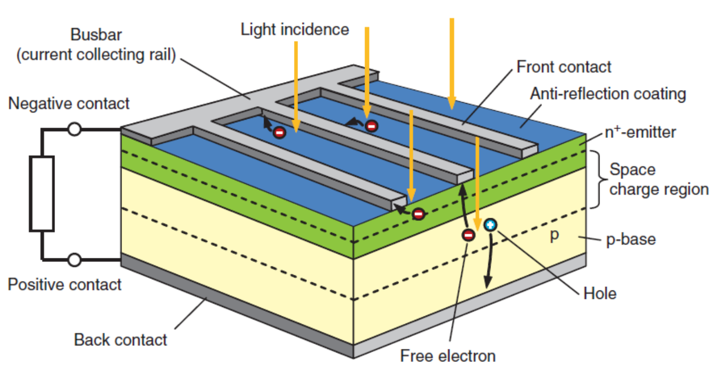
5. Study of V-I and V-R characteristics of a solar cell and Determination of efficiency of solar cell

Aim

To study the V-I and V-R characteristics of a solar cell. In addition to that, calculate the efficiency of the given solar cell using V-I characteristics.

Theory:

Solar cells are typically illuminated with sunlight and are intended to convert the solar energy into electrical energy. The solar energy is in the form of electromagnetic radiation, more specifically described as "black-body". The sun's spectrum is consistent with that of a black body at a temperature of 5800 K. The radiation spectrum has a peak at 0.8 eV. A significant part of the spectrum is in the visible range of the spectrum (400 - 700 nm). The power density is approximately 100 mW/cm^2. Only part of the solar spectrum actually makes it to the earth's surface. Scattering and absorption in the earth's atmosphere, and the incident angle affect the incident power density. Therefore, the available power density depends on the time of the day, the season and the latitude of a specific location. Of the solar light, which does reach a solar cell, only photons with energy larger than the energy bandgap of the semiconductor generate electron-hole pairs. In addition, one finds that the voltage across the solar cell at the point where it delivers its maximum power is less than the bandgap energy in electron volt. Asymmetric of band structure, it creates separation of electrons and holes and it prevented electron-hole recombination. Figure 1 provides information on p-n diode solar cell.



Electrical Efficiency Calculation

The parameter that is of chief concern to researchers and practitioners alike is electrical efficiency, from here on referred to as **efficiency**. Although in principle this can be calculated by the ratio of output power PO to input power PI, in practice it is only calculated under the ideal condition that PO is a maximum. To satisfy this condition, the resistance across the solar cell or module under test is varied across a wide enough range for the relationship of voltage against current to take the form of the curve in Figure 2. At zero resistance the current is at its highest possible value, called the short-circuit current, I_{SC}, while at maximum resistance the voltage is at a maximum, referred to as the open-circuit voltage, V_{OC}. Returning to I_{SC} and increasing the resistance above the impedance of the solar cell, the voltage increases quickly and the current decreases slowly until the 'knee' of the curve. At this point, known as the maximum power point (MPP), the power (product of voltage and current) is at a maximum and the related values of voltage and current are referred to as V_{MPP} and I_{MPP} respectively (see Figure 2).

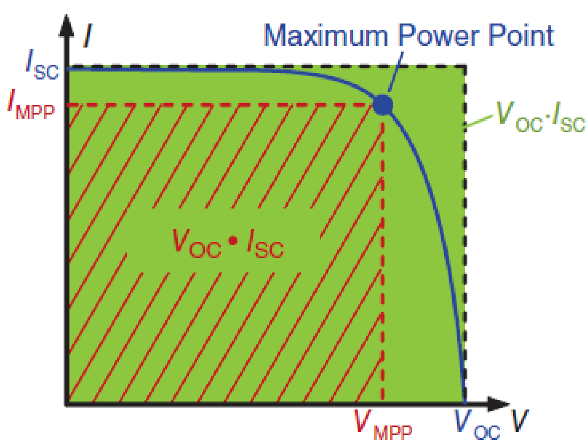


Figure 2 I-V curve showing Maximum Power Point Current and Voltage

The solar cell provides different capacities depending on the actual working point in which it is operated. The operating point at which the maximum power is provided is called the **Maximum Power Point (MPP)**. As the power of a working point always corresponds to the surface V-I, this **area** must be the **maximum** in the case of the MPP. This case is shown in Figure 4.11. The current and voltage values associated with the MPP are called I_{MPP} and V_{MPP}.

The efficiency of a solar cell describes what portion of the optical power P_I incident on the cell is output as electrical energy P_{MPP} again.

Efficiency of solar cell $\eta = [P_{MPP}/AI_o]$ x 100

P_{max} = Maximum power = I_{MPP} x V_{MPP} Watt

A-Area of the solar panel [7.2 cm x 4.5 cm **Single cell only**]

I_o Intensity of light = Power of the bulb/$4\pi d^2$

d - Distance between solar panel and bulb

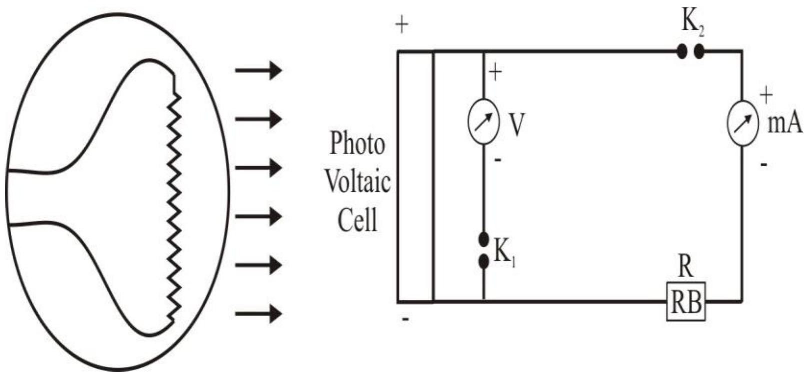
The overall power-conversion efficiency of single-crystalline solar cells ranges from 10 to 30 % yielding 10 to 30 mW/cm^2.

Procedure

Apparatus

Solar cell, voltmeter,milliammeter, a dial type resistance box, Keys, illuminating lamps, connecting wires etc.

When an external circuit is connected through the p-n junction device, a current passes through the circuit. Therefore, the device generates power when the electromagnetic radiation is incident on it. The voltmeter is connected in parallel with the given solar cell through a plug key. A milliammeter and a variable resistor are connected in series to the solar cell through a key as shown in the Fig. The solar cell can be irradiated by sun's radiation. Instead, it can also be irradiated by a filament bulb (75 W). The resistance value is adjusted by a resistance box and the variation of V-I is plotted. From the graph calculate maximum power point.



Distance between solar panel and bulb (d) = cm			Distance between solar panel and bulb (d) = cm		
Intensity of light Io = Wm^{-2}			Intensity of light Io = Wm^{-2}		
Resistance (Ohm)	Voltage (V)	Current (mA)	Resistance (Ohm)	Voltage (V)	Current (mA)

Observation:

Maximum power point P_{MPP} = ……….Watt

Area of the solar panel = ………. m^2

Intensity of the light I_o =…………. W/m^2

Efficiency of solar cell $\eta = [P_{MPP}/AI_o] \times 100$

Result:

Efficiency of solar cell η =…………………….

Assignment Questions (Self-Evaluation):

1. What is the working principle of solar cell?
2. How the charge separation occurring in solar cell?
3. Why solar cells are more expansive?
4. What are the types of solar cell materials?
5. What is I_{SC} and V_{OC} in solar cell?
6. What are the applications of solar cell?

Reference:

1. 18PYB103J – Physics: Semiconductor Physics Instructional Laboratory Manual

2. Introduction To Semiconductor Materials And Devices, M.S Thyagi, Publisher John Wiley& Sons,2008

3. Physics of Semiconductor Devices, 3rd Ed, S.M.Sze, Kwok K .Ng, Publisher John Wiley& Sons,2008

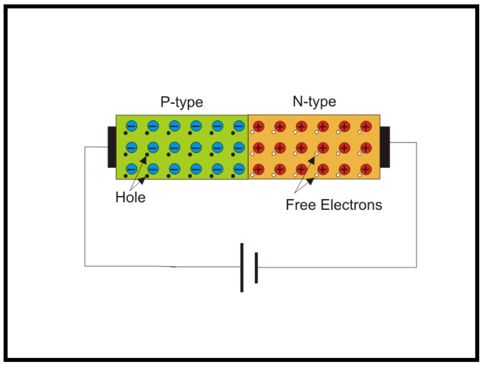
6. Characteristic of PN junction diode under forward bias and reverse bias

Aim: To plot the characteristics curve of PN junction diode under Forward bias and Reverse bias

Theory:

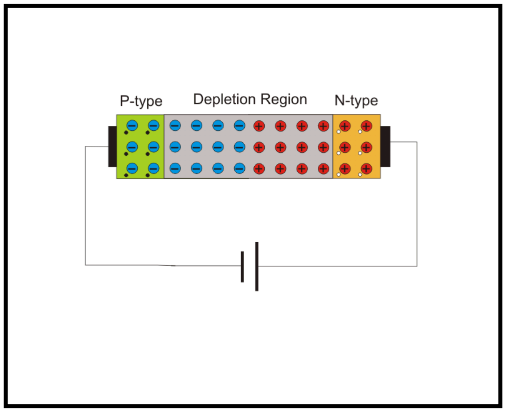
Forward Biased PN Junction

Similarly due to the negative terminal of source the free electrons in the n-type region will repeal towards junction where they will find the layer of positive impurity ions and start recombine with these ions and generate free electrons inside the layer. Consequently, the width of positive impurity ions is reduced, and finally, it vanishes. In these ways, both layers of ions disappear, and there will be no more depletion layer. After the depletion layer disappeared, free electrons from the n-type region can easily drift to p-type region and holes from p-type region to n-type region in the crystal. Hence, ideally there will be no obstruction of flowing current and the pn junction behaves as the short circuit.



Reverse Biased PN Junction

When positive terminal of a voltage source is connected to the n-type region and the negative terminal of the source is connected to the p-type region then the pn junction is said to be in reverse biased condition. When there is no voltage applied across the p n junction, the potential developed across the junction is 0.3 volts at 25°C for germanium pn junction and 0.7 volts at 25°C for silicon p n junction. The polarity of this potential barrier is same as the polarity of voltage source applied during reverse biased condition. Now if reverse biased voltage across the pn junction is increased the barrier potential developed across the pn junction is also increased. Hence, the pn junction is widened. When positive terminal of the source is connected to the n-type region, the free electrons of that region are attracted towards positive terminal of the source because of that more positive impurity ions are created in the depletion layer which makes the layer of positive impurity ions thicker. At the same time since negative terminal of the source is connected to the p-type region of the junction, electrons are injected in this region. Due to the positive potential of the n-type region the electrons are drifted towards the junction and combine with holes adjacent to the layer of positive impurity ions and create more positive impurity ions in the layer. Hence, the thickness of the layer increases.



In this way over all width of the depletion layer increases along with its barrier potential. This increment of the width of depletion layer will continue till the barrier potential reaches to applied reverse biased voltage. Although this increment of barrier potential will continue up to applied reverse biased voltage but if the applied reverse biased voltage is sufficiently high then the depletion layer will disappear due Zener breakdown and avalanche breakdowns. It is also to be noted that after completion of reverse biased depletion layer there is no more drift of charge carriers (electrons and holes) through the junction as the potential barrier opposes the applied voltage which has the same value as the potential barrier. Although tiny current flow from n-type region to p-type region due to minority carriers that is thermally generated electrons in p-type semiconductor and holes in n-type semiconductor.

Forward Current in PN Junction

When battery voltage is applied across the junction in the forward bias, a current will flow continuously through this junction.

$$\textit{Forward biased current}\ \ i_D = I_s\left(e^{\frac{V_D}{nV_T}} - 1\right)$$

I_S is Saturation Current (10^{-9} to 10^{-18} A)
V_T is Volt-equivalent temperature (= 26 mV at room temperature)
n is Emission coefficient ($1 \le n \le 2$ for Si ICs)
Actually this expression is approximated.

Reverse Current in PN Junction

When a p-n junction is connected across a battery in such a manner that its n-type region is connected to the positive potency of the battery and the p-type region is connected to the negative potency of the battery the p n junction is said to be in reverse biased condition and ideally there is no current flowing through the junction. But practically there will be a tiny reverse bias current i_D which is expressed as.
i_D drops to zero value or very small value. i_D can be written as i_0.

$$\textit{Reverse biased current}\ \ i_0 \approx I_s e^{\frac{V_D}{nV_T}}$$

I_S is Saturation Current (10^{-9} to 10^{-18} A)
V_T is Volt-equivalent temperature (= 26 mV at room temperature)
n is Emission coefficient ($1 \le n \le 2$ for Si ICs)
Actually this expression is approximated.

General Specification of PN Junction

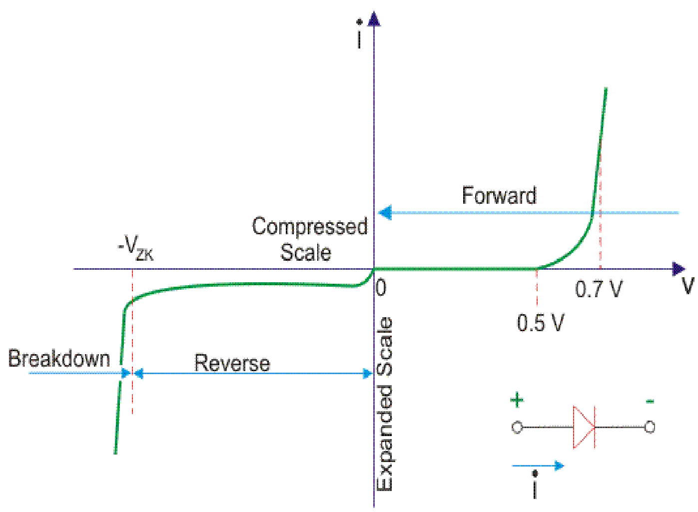
A p-n junction is specified in four manners.

1. Forward Voltage Drop (V_F): Is the forward biasing junction level voltage (0.3V for Germanium and 0.7V for Silicon Diode)
2. Average Forward Current (I_F): It is the forward biased current due to the drift electron flow or the majority carriers. If the average forward current exceeds its value the diode gets over heated and may be damaged.

3. Peak Reverse Voltage (V_R): It is the maximum reverse voltage across the diode at it reverse biased condition. Over this reverse voltage diode will go for breakdown due to its minority carriers.
4. Maximum Power Dissipation (P): It is the product of the forward current and the forward voltage.

V-I Characteristics of A PN Junction

In the forward bias, the operational region is in the first quadrant. The threshold voltage for Germanium is 0.3 V and for Silicon is 0.7 V. Beyond this threshold voltage the graph goes upward in a non linear manner. This graph is for the dynamic Resistance of the junction in the forward bias. In the reverse bias the voltage increases in the reverse direction across the p-n junction, but no current due to the majority carriers, only a very small leakage current flows. But at a certain reverse voltage p-n junction breaks in conduction.



It is only due to the minority carriers. This amount of voltage is sufficient for these minority carriers to break the depletion region. At this situation sharp current will flow through this junction. This breakdown of voltage is of two types.

- Avalanche Breakdown: it is not properly sharp, rather inclined linear graph i.e. after break down small increase in reverse voltage causes more sharp current gradually.
- Zener Breakdown: This breakdown is sharp and no need to increase reverse bias voltage to get more current, because current flows sharply.

Procedure:

For the forward bias of a P-N junction, P-type is connected to the positive terminal while the N-type is connected to the negative terminal of a battery. The potential at P-N junction can be varied with the help of potential divider. At some forward voltage

(0.3 V for Ge and 0.7V for Si) the potential barrier is altogether eliminated and current starts flowing. This voltage is known as threshold voltage (Vth) or cut in voltage or knee voltage .It is practically same as barrier voltage V_B. For $V<V_{th}$, the current is negligible. As the forward applied voltage increase beyond threshold voltage, the forward current rises exponentially.

Observation:

S. No	Forward Voltage (V)	Forward Current (μA)

For the reverse bias of p-n junction, P-type is connected to the negative terminal while N-type is connected to the positive terminal of a battery. Under normal reverse voltage, a very little reverse current flows through a P-N junction. But when the reverse voltage is increased, a point is reached when the junction break down with sudden rise in reverse current. The critical value of the voltage is known as break down (VBR). The break down voltage is defined as the reverse voltage at which P-N junction breakdown with sudden rise in reverse current.

Observation:

S. No	Reverse Voltage (V)	Reverse Current (mA)

Result: PN junction characteristic is studied and curve is drawn.

Assignment Questions (Self-Evaluation):

1. What is PN Junction diode?

2. What is meant by forward bias and reverse bias?

3. Define: Knee voltage

4. Define: Break down voltage

5. What is meant by avalanche break down?

Reference:

1. 18PYB103J Instructional manual
2. B.L.Theraja, Basic Electronics Solid State, Fifth edition: S.Chand and company Ltd.
3. 2. R.S.Sedha, A Textbook of Applied Electronics, Third edition: S.Chand and company Ltd.

7. V-I characteristics of Photocell

AIM: To study the Illumination Characteristics and V-I Characteristicsof given Photocell.

THEORY:

A device used to convert light energy into electrical energy is called Photo Electric Cell or Photocell.

Photo-Voltaic Cell is one among the three types of photo cell other than Photo Emissive Cell and Photo Conductive Cell. Photo-Voltaic Cell works on the principle of Photo-Voltaic Effect. This is called true cell because it generates *emf* without the application of any external potential difference but by only the light incident on it. It consists of a semiconductor layer formed on the surface of them etal plate. Then a film of semi-transparent metal is coated over the semi-conductor. This film maintains the electrical contact with the semiconductor and simultaneously allows the incident light to fall on the semi-conductor.

When light is incident on the semi-conductor, electrons are emitted which flow in a direction opposite to the light rays. If the circuit is completed between the surface transparent film and metal base through a low resistance galvanometer (G), the current can be measured. If the resistance of the circuit is very small, the current is proportional to the intensity of incident light. The main advantage of this cell is that it requires no external voltage for its operation. This type of photocell is widely used in photographic exposure meters, photometers and illumination meters etc.

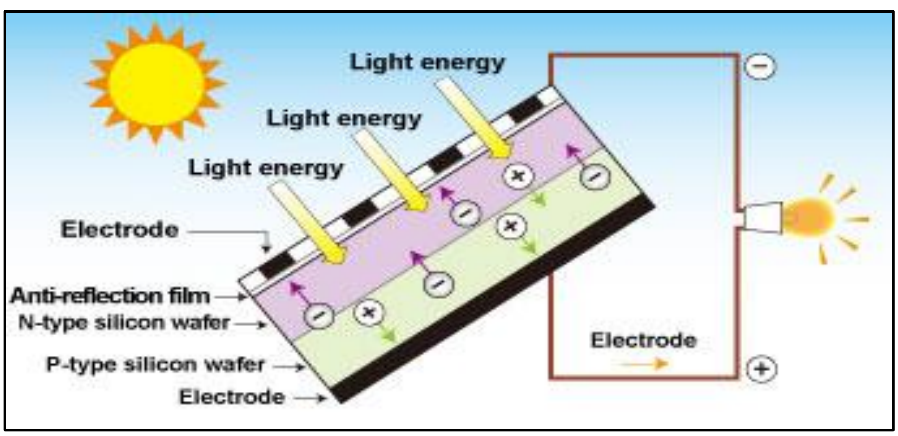


Fig. 7.1. Schematic representation of Photo-Voltaic Cell

Let ‘I_L’ be the Luminous intensity of an electric lamp and ‘E’ be the Illuminance at a point distance‘d’ from it. According to the inverse square law;

$$E = \frac{I_L}{d^2}$$

If light from the lamp be incident on the photovoltaic cell placed at a distance 'd' from it, then the photo-current I_{Ph} given out is proportional to E.

$$I_{Ph} \propto E \propto \frac{1}{d^2}$$

Thus by varying the distance d (or Illumination E) the magnitude of the photo-current I_{Ph} generated in the photo cell can be studied.

PROCEDURE:

Apparatus: Lamp house with lamp, Optical bench, Photocell housed with Red and Black sockets, Photocell Characteristic Kit, Measuring Scale and connecting wires.

A. <u>Illumination Characteristics</u>:

1. Arrange the optical bench in such a way that both the lamp and the photo cell are at the same level as shown in the figure.
2. Connect the voltmeter and ammeter as per circuit diagram shown on the apparatus and set R_L to minimum position.
3. A 100 W lamp is arranged over the Photovoltaic Cell such that light falls on it at normal. Initially, the lamp is placed at maximum distance and is switched ON.
4. The voltage and the current are noted.
5. The intensity of the lamp is varied in steps by changing the distance of lamp. The readings are noted in Table 1.

B. <u>Current-Voltage Characteristics</u> :

1. The Intensity of the lamp is set to Minimum Intensity(I_1) at a longest distance X_1.
2. The Voltmeter and Ammeter are switched on.
3. Initially Load Resistance dial is set at 470 ohms. The Voltage and Current are noted down.
4. ThenLoad Resistance is set to 1 k, 2.2 k, 3.3 k, 4.7 k and 10 k ohms and at each setting the voltage and current are recorded. The readings are recorded.
5. The Medium Intensity(I_2) is achieved by choosing proper distance X_2.At this Intensity, step 3 & 4 is repeated.
6. The Intensity of the lamp is set to its Maximum Intensity (I_3) at a shortest distance X_3. At this Intensity, step 3 & 4 is repeated.
7. Graph is plotted between the current and voltage for three distances X_1, X_2. X_3 respectively.

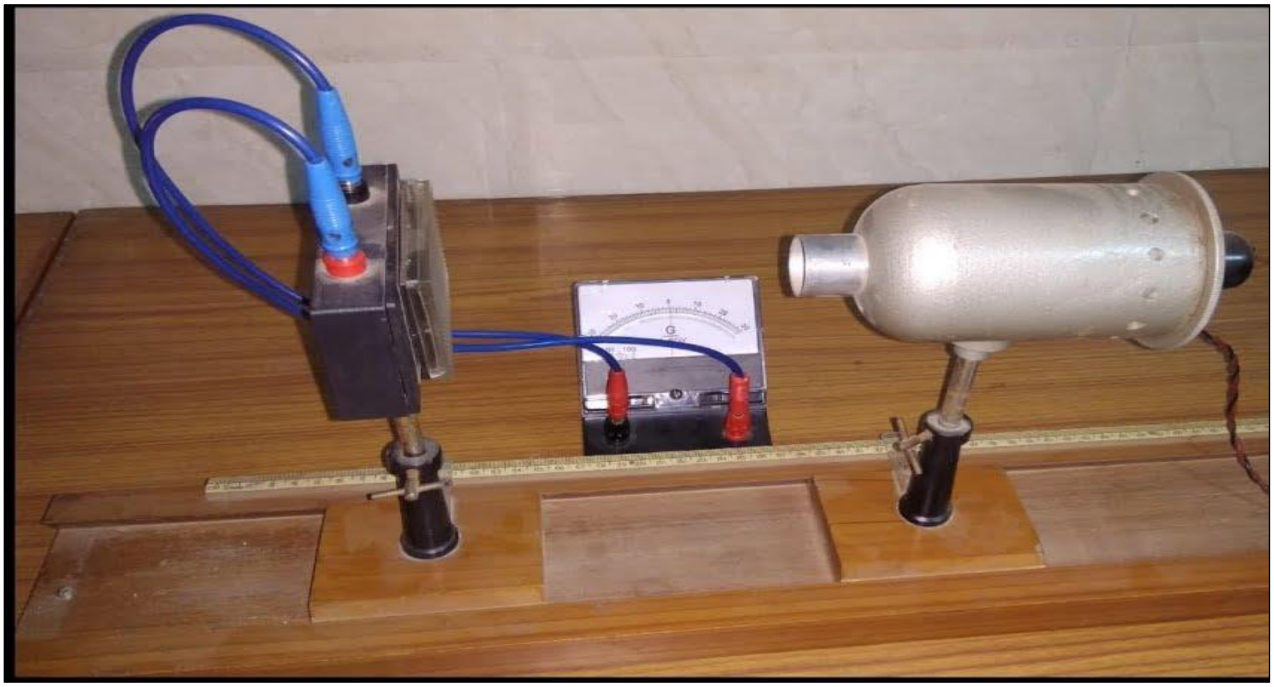


Fig. 7.2. Experimental Setup

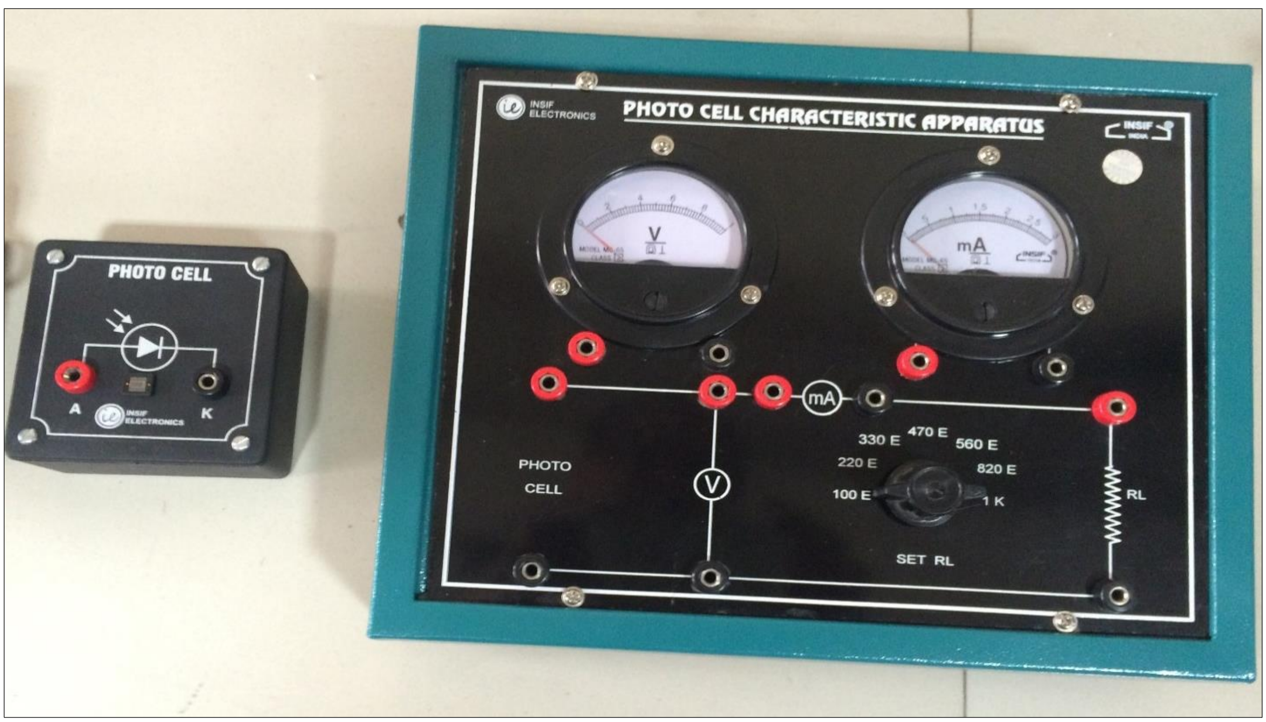


Fig. 7.3. Photo Cell and Photo Cell Characteristics Kit

OBSERVATION:

A. Table 1: Illumination Characteristics

Intensity Variation (distance cm)	At Minimum R_L (kΩ)	
	Voltage (V)	Current (μA)
10 20 30 40 50		

B. Table 2: V-I Characteristics

R_L (kΩ)	Minimum Intensity I_1 (at longest distance X_1)		Medium Intensity I_2 (at mid distance X_2)		Maximum Intensity I_3 (at shortest distance X_3)	
	Voltage (V)	Current (μA)	Voltage (V)	Current (μA)	Voltage (V)	Current (μA)

Graphical Observation: V-I Characteristics of a Photo Cell

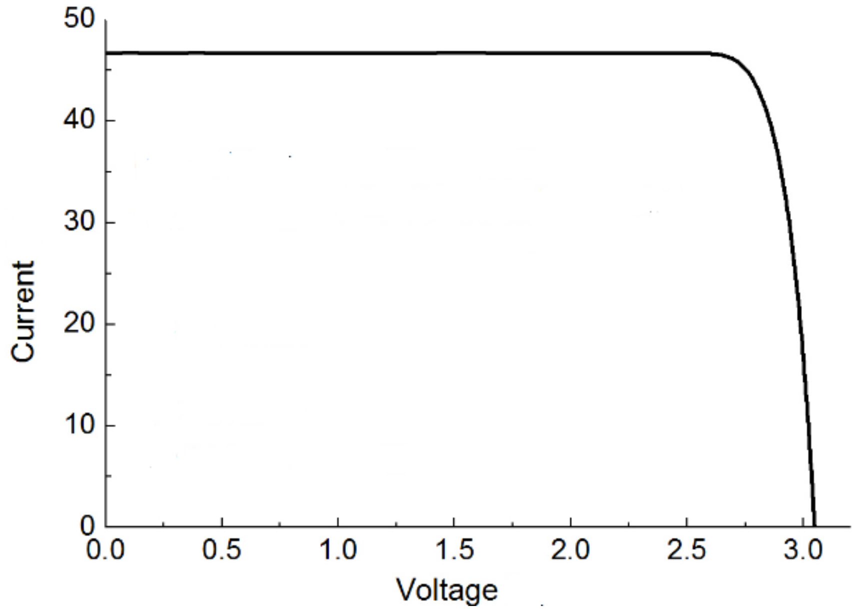


Fig. 7.4. Model graph for V-I Characteristics

RESULT: Illumination andV-I characteristics of Photo cell has been studied.

Assignment Questions (Self-Evaluation):

1. What is the Photo cell?
2. What is Photo-Voltaic effect?
3. How many types of Photocell are available?
4. Define Inverse Square Law of Illumination.
5. Why Photovoltaic cell is known as True cell?
6. Give two applications of Photo cell in daily life
7. Describe the working of the Photo Cell.

References:

4. 18PYB103J Instructional manual
5. BrijeshTripathi, Manoj Kumar,“Solar Energy: From Cells to Grid”, CSFML Publications, India, 2018.
6. R.C. NevilleAngeleReinders, Pierre Verlinden, Wilfried van Sark, Alexandre Freundlich, “Photovoltaic Solar Energy: From Fundamentals to Applications”, John Wiley & Sons Publication, UK, 2017.
7. R.C. Neville, “Solar Energy Conversion: The Solar Cell”, Elsevier Science Publications, Netherlands, 1995.
8. Alan Fahrenbruch, Richard Bube, “Fundamentals of Solar Cells: Photovoltaic Solar Energy Conversion” Academic Press INC, UK, 1983.

8. PARTICLE SIZE DETERMINATION USING LASER

Aim

To determine the size of particles (lycopodium powder) coated on glass plate using monochromatic LASER source.

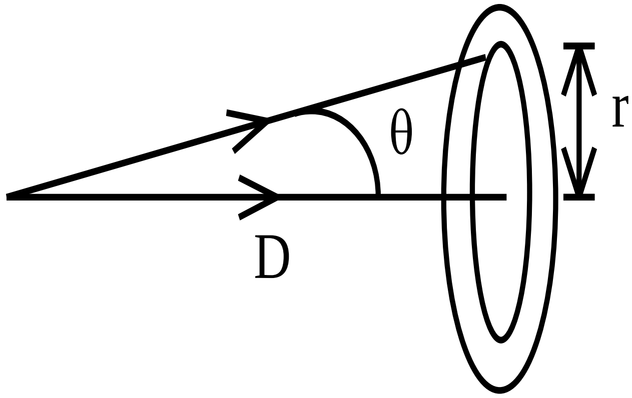
Theory

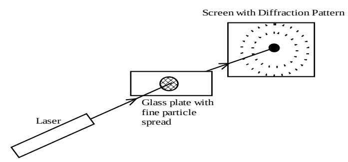
Diffraction is a phenomenon of waves bending when encountering obstacles or slits. Light diffraction has an analytical application to determine the size of the obstacle. This analytical method is based on the fact that the angle of diffraction is inversely proportional to the size of the obstacle. Diffraction of light through a rectangular obstacle is a straight forward extension of one dimensional diffraction. A circular obstacle is qualitatively similar, but an accurate quantitative treatment of the pattern requires more complicated mathematics. The diffraction pattern observed due to circular obstacle is called the "Airy Disk". Using Mie theory, the diffraction angle for first minimum is $\theta = 1.22\ \lambda/D$, where D is the diameter of the obstacle and λ is wavelength of light. On a screen a distance $L >> D$ from the obstacle, the minimum is seen at a radial distance $(r) = 1.22\ \lambda L/D$ from the center of the pattern.

The term LASER is the acronym for Light Amplification by Stimulated Emission of Radiation. It is a mechanism for emitting electromagnetic radiation via the process of stimulated emission. LASER diffraction is widely used for particle size analysis whose principle depends on relationship that exists between light scattering (its angle and intensity) and particle size. The larger the particle, the smaller is the angle and the higher the intensity of the scattering. When monochromatic light from LASER source is passed through a glass plate coated with thin layer of lycopodium powder with spherical particles (obstacle), diffraction of light occurs as a result of particle size (micron or less) which are comparable with wavelength of light. Thus, circular ring pattern are observed on screen as shown in figure and on measuring radii of the observed rings, we can calculate the size of the particles.

If "r" is the radius of the first dark ring and "D" is the distance between the obstacle and screen on which the diffraction pattern is obtained, then

$\tan\theta = \frac{r}{D}$, Since (θ) is very small in this experiment we consider $\tan\theta = \theta = \frac{r}{D}$





According to the theory,

The diameter of the particle is given by $2a = \frac{1.22 n\lambda D}{r_n}$ (meters)

Where, r_n = Radius of the n^{th} order dark ring (m)

D = Distance between the particle and screen (m)

λ = Wavelength of the LASER light (Å)

.

Procedure

Apparatus required: Monochromatic LASER source, a glass plate coated with thin layer of lycopodium powder, Screen and a meter Scale.

Steps to find particle size using LASER

1. The glass plate coated with thin layer of lycopodium powder (obstacle) is taken.
2. A monochromatic LASER source and screen are placed at some distances.
3. Mount the glass plate on a stand and place it between the LASER source and the screen.
4. Switch ON the LASER source and allow the light to pass through the glass plate.
5. Adjust the position of the glass plate to see maximum contrast ring patterns on the screen.
6. Mark the position of dark rings by keeping white paper on screen.
7. Remove the white paper and measure the radii of different order dark rings (r_n) using a scale.

8. Measure the distance (D) between the glass plate and screen.
9. Calculate the diameter of particle as $2a = \frac{1.22 n\lambda D}{r_n}$ (in meters)
10. Repeat the experiment for different distance (D) between the glass plate and the screen.

Table: Determination of particle size using LASER

S. No.	**Distance (D)**	**Diffraction order (n)**	**Radius of dark ring (r_n)**	**Particle size (2a)**
Unit	m	-	m	m
1		1 2		
2		1 2		
3		1 2		
			Mean	

Result

The average size of the particles measured using LASER = ……….....… µm

Assignment (Self Evaluation):

1. The ………… phenomena of light are studied through diffraction effect
2. What is diffraction of light?
3. The source and screen are ………. at distance in Fresnel diffraction and at ……… distance in Fraunhofer diffraction.
4. Mention four differences between LASER and ordinary light source?

5. Define: Stimulated emission of light
6. What are the characteristics of LASER light?
7. If distance of screen is doubled from LASER source and r_n = D then, the size of particle …………
8. Calculate the size of particle, if the distance between glass plate and screen is 22cm and radius of first order dark ring is 4mm for wavelength of light is 450 nm.

References:

1. 18PYB103J – Physics: Semiconductor Physics Instructional Laboratory Manual
2. Lasers: Fundamentals and Applications, Ajay Ghatak and K. Thyagarajan, Springer, 2010
3. Introduction to Optics, Frank L. Pedrotti , Leno M. Pedrotti, Leno S. Pedrotti, Cambridge University Press, 2017

9. STUDY OF ATTENUATION AND PROPAGATION CHARACTERISTICS OF OPTICAL FIBER CABLE

Aim

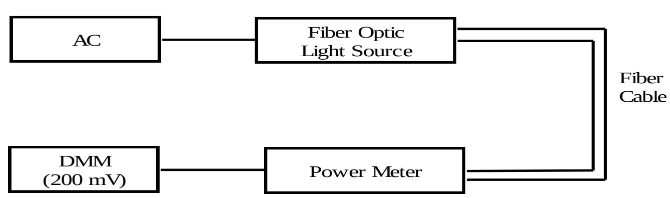
(i) To determine the attenuation for the given optical fiber cable.

(ii) To measure the numerical aperture and hence the acceptance angle of the given fiber cables.

Theory

The optical fiber is a cylindrical, long, thin transparent structure made of glass and plastic, which is designed to guide the light wave from one end to another. The light inside the fiber is guided on the principle of Total Internal Reflection (TIR).

The propagation of light down optical fiber bears some similarity to the propagation of microwaves down metal waveguides. **Attenuation** is the loss of optical power as light travels along the fiber, caused by absorption, scattering and bending loss. It is also called signal loss or fiber loss which is defined as the ratio of optical input power (P_i) to the output power (P_f). The degree of attenuation depends on the wavelength of light transmitted. It is measured as logarithmic ratio of power of incident light at one end (P_i) to the power of remaining light at other end (P_f) in the given fiber cable of length L as shown in figure. It is measured in decibel per kilometer (dB/km).



The following equation defines signal attenuation as a unit of length.

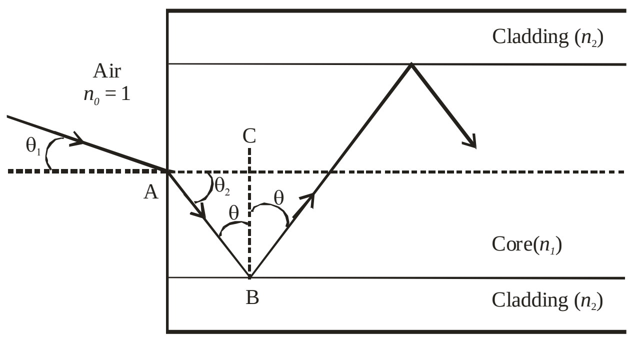
$$\text{Attenuation} = \frac{10\log\left(P_i/P_f\right)}{L} \text{ dB / km}$$

Where, P_i = Power of light incident at one end of fiber (dB)

P_f = Power of remaining light at other end of fiber (dB)

L = Length of optical cable (km)

Numerical Aperture is the measure of the ability of an optical fiber to collect or confine the incident light ray inside it. It is also referred as light collecting efficiency of the fiber cable. **Acceptance angle** is defined as the maximum value of the angle of incidence at the entrance end of the fiber, at which the angle of incidence at the core – cladding surface is equal to the critical angle of the core medium. The light ray should strike the fiber end with in this cone of acceptance else it is refracted out of the fiber.



Let us consider that a ray of light is launched into the fiber at an angle θ_1 which is less than the acceptance angle θ_a for the fiber as shown in figure.

Applying Snell's law of refraction at A $n_0 \sin\theta_1 = n_1 \sin\theta_2$ where ($n_0 = 1$)

If $\theta = \frac{\pi}{2} - \theta_2$ (or) $\theta_2 = \frac{\pi}{2} - \theta$ then $\sin\theta_1 = n_1 \sin\left(\frac{\pi}{2} - \theta\right) = n_1 \cos\theta$ or $\sin\theta_1 = n_1\left(1 - \sin^2\theta\right)^{\frac{1}{2}}$

When TIR takes place, $\theta = \theta_c$ and $\theta_1 = \theta_a$ then $\sin\theta_a = n_1\left(1 - \sin^2\theta_c\right)^{\frac{1}{2}}$

Applying Snell's law of refraction at B $\frac{\sin\theta_c}{\sin 90} = \frac{n_2}{n_1}$ (or) $\sin\theta_c = \frac{n_2}{n_1}$ then

$$\sin\theta_a = n_1\left[1 - \left(\frac{n_2}{n_1}\right)^2\right]^{\frac{1}{2}} = \left(n_1^2 - n_2^2\right)^{\frac{1}{2}} \text{ (i.e.) } N.A = \sin\theta_a \text{ or } \theta_a = \sin^{-1}(N.A)$$

This is called the numerical aperture (N.A). The numerical aperture is also defined as the sine of the half of the acceptance angle.

Procedure

Apparatus required: Monochromatic light source, Optical power meter, 1m and 5m fiber cable, Numerical aperture measurement JIG and Screen.

(i) Steps to find attenuation for optical fiber cable

1. Switch ON the light source and rotate power control to ensure minimum intensity of light.
2. Connect one end of the one meter fiber cable is to light source and other end to the optical power meter.
3. Switch ON the optical power meter to record power of light (P_i) for 1m fiber cable at different light intensities.
4. Repeat the procedure for 5m fiber cable to record (P_f) at different intensities of light.
5. Calculate the attenuation for fiber cable at different light intensities as $\frac{10\log\left(P_i/P_f\right)}{L}$ dB/km.

(ii) Steps to find Numerical aperture and Acceptance angle

1. Connect one end of the one meter fiber cable to light source and the other end to the NA jig.
2. Switch ON the light source and rotate power control to ensure maximum intensity of light.
3. Connect 1m fiber cable such that light appears at other end of fiber connected with NA jig.
4. The white screen having four concentric circles (W = 10, 15, 20 and 25mm) is held vertically in NA jig and distance is adjusted to coincide light spot with 10mm circle.
5. When diameter of light spot (W) is 10mm, the distance between screen and fiber end (L) is noted.
6. The procedure is repeated for (W) is equal to15mm, 20mm and 25mm and (L) is noted.
7. Experiment is repeated for 5m cable and readings are tabulated in tabular column.
8. Calculate the numerical aperture for fiber cable as (NA) = $\frac{W}{\sqrt{4L^2 + W^2}}$
9. Calculate the acceptance angle for fiber cable as $2\theta = 2 \times \sin^{-1}(NA)$

Table 1: Determination of Attenuation for optical fiber cables

L = 4 m = 4×10^{-3} km

Intensity of Light Source	**Power output for 1m cable (P_i)**	**Power output for 5m cable (P_f)**	**Attenuation =** $\dfrac{10\log\left(P_i/P_f\right)}{L}$ **dB / km**
Minimum			
Maximum			

Table 2: Measurement of Numerical Aperture and Acceptance angle

Circle	**Diameter of the spot (W) (mm)**	**Distance between source and screen (L) (mm)**		**NA =** $\dfrac{W}{\sqrt{4L^2+W^2}}$		**Acceptance angle (2θ) = 2 x $\sin^{-1}$(NA) (degree)**	
-	**-**	**1m**	**5m**	**1m**	**5m**	**1m**	**5m**
			Mean				

Result

1. Attenuation at source level A = ………….. (dB/km)
2. Attenuation at source level B = ………….. (dB/km)
3. The numerical aperture for fiber cable (1m) = ... and (5m) = ………….
4. The acceptance angle for fiber cable (1m) =.............. (degree) and (5m) = ………. (degree).

Assignment (Self Evaluation):

1. The light inside the optical fiber is guided by the principle of …………..
2. Explain the physical structure of optical fiber.
3. What are the types of light propagation in optical fiber?
4. Define: Attenuation for optical fiber.
5. What is numerical Aperture?
6. Write the expression to relate numerical aperture and acceptance angle.
7. How does light propagation varies in core-cladding interface if light enters above acceptance angle at air-core interface?
8. Calculate the numerical aperture and acceptance angle of fiber with a core index of 1.52 and a cladding index of 1.50.

References:

1. 18PYB103J – Physics: Semiconductor Physics Instructional Laboratory Manual.
2. Introduction to Fiber Optics, Ajay Ghatak and K. Thyagarajan, Cambridge University Press, 1998.
3. Fiber Optic Communications, Downing, James N., Clifton Park: Thomson Delmar Learning, 2004

10. Calculation of Lattice Cell Parameters – X-ray Diffraction

Aim

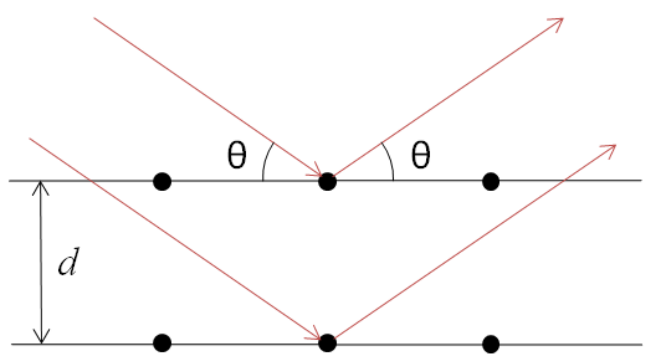
Calculate the lattice cell parameters from the powder X-ray diffraction data.

Theory:

When an X-ray is shined on a crystal, it diffracts in a pattern characteristic of the structure. In powder X-ray diffraction, the diffraction pattern is obtained from a powder of the material, rather than an individual crystal. Powder diffraction is often easier and more convenient than single crystal diffraction since it does not require individual crystals be made. Powder X-ray diffraction (XRD) also obtains a diffraction pattern for the bulk material of a crystalline solid, rather than of a single crystal, which doesn't necessarily represent the overall material. A diffraction pattern plots intensity against the angle of the detector 2Θ.

Bragg's Law

X-rays are partially scattered by atoms when they strike the surface of a crystal. The part of the X-ray that is not scattered passes through to the next layer of atoms, where again part of the X-ray is scattered and part passes through to the next layer. This causes an overall diffraction pattern, similar to how a grating diffracts a beam of light. In order for an X-ray to diffract the sample must be crystalline and the spacing between atom layers must be close to the radiation wavelength.



If beams diffracted by two different layers are in phase, constructive interference occurs and the diffraction pattern shows a peak, however if they are out of phase, destructive interference occurs appear and there is no peak. Diffraction peaks only occur if

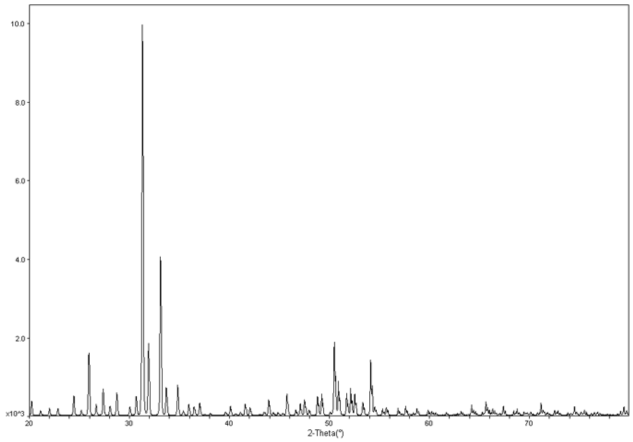
$$2d \sin\Theta = n\lambda$$

where

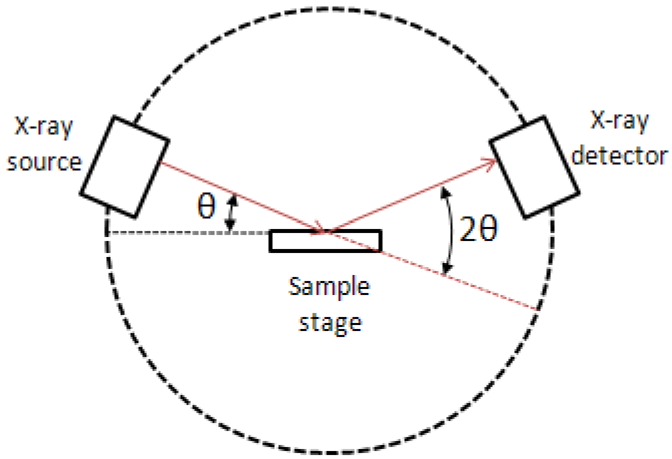
- θ is the angle of incidence of the X-ray,

- n is an integer,
- λ is the wavelength, and
- d is the spacing between atom layers.

Since a highly regular structure is needed for diffraction to occur, only crystalline solids will diffract; amorphous materials will not show up in a diffraction pattern.



A powder X-ray diffractometer consists of an X-ray source (usually an X-ray tube), a sample stage, a detector and a way to vary angle θ. The X-ray is focused on the sample at some angle θ, while the detector opposite the source reads the intensity of the X-ray it receives at 2θ away from the source path. The incident angle is than increased over time while the detector angle always remains 2θ above the source path.



Formula

For a cubic crystal

$$\frac{1}{d^2} = \frac{(h^2 + k^2 + l^2)}{a^2}$$

For a tetragonal crystal

$$\frac{1}{d^2} = \left\{ \frac{(h^2 + k^2)}{a^2} + \frac{l^2}{c^2} \right\}$$

For a orthorhombic crystal

$$\frac{1}{d^2} = \left(\frac{h^2}{a^2}\right) + \left(\frac{k^2}{b^2}\right) + \left(\frac{l^2}{c^2}\right)$$

The lattice parameter and interplanar distance are given for a cubic crystal as,

$$a = \frac{\lambda}{2 sin\,\theta}\sqrt{h^2 + k^2 + l^2} \ \text{Å}$$

$$d = \frac{a}{\sqrt{h^2 + k^2 + l^2}} \ \text{Å}$$

Where, a = Lattice parameter

d = Interplanner distance

λ = Wavelength of the CuKα radiation (1.5405)

h, *k*, *l*= Miller integers

Procedure:

Apparatus required

Powder X-ray diffraction diagram

From the 2θ values on a powder photograph, the θ values are obtained. The $sin^2\theta$ values are tabulated. From that the values of $1 \times \frac{sin^2\,\theta}{sin^2\,\theta_{min}}, 2 \times \frac{sin^2\,\theta}{sin^2\,\theta_{min}}, 3 \times \frac{sin^2\,\theta}{sin^2\,\theta_{min}}$ are determined and are tabulated. The values of $3 \times \frac{sin^2\,\theta}{sin^2\,\theta_{min}}$ are rounded to the nearest integer. This gives the value of $\boldsymbol{h^2+k^2+l}$ .From these the values of *h,k,l* are determined from the Table.6.7.1.

From the *h,k,l* values, the lattice parameters are calculated using the relation

$$a = \frac{\lambda}{2 sin\,\theta}\sqrt{h^2 + k^2 + l^2} \ \text{Å}$$

$$d = \frac{a}{\sqrt{h^2 + k^2 + l^2}} \ \text{Å}$$

Value of $h^2 + k^2 + l^2$ for different planes

h, k, l	***h***^{2} **+** ***k***^{2} **+** ***l***^{2}	***h, k, l***	***h***^{2} **+** ***k***^{2} **+** ***l***^{2}
100	1	300	9
110	2	310	10
111	3	311	11
200	4	322	12
210	5	320	13
211	6	321	14
220	8	40	16
221	9	410	17

S. No	2Θ	$sin^2\ \Theta$	$1 \times \frac{sin^2\theta}{sin^2\theta_{min}}$	$2 \times \frac{sin^2\theta}{sin^2\theta_{min}}$	$3 \times \frac{sin^2\theta}{sin^2\theta_{min}}$	***h***^{2}**+*****k***^{2}**+*****l***^{2}	***hkl***	**a** **Å**	**d** Å

Lattice determination

Lattice type	**Rule for reflection to be observed**
Primitive P	None
Body centered I	$hkl : h + k + l = 2n$
Face centered F	*hkl* : *h, k, l* either all odd or all even

Depending on the nature of the *h*,*k*,*l* values the lattice type can be determined.

Result:

The lattice parameters are calculated theoretically from the powder x-ray diffraction pattern.

Assignment (Self Evaluation):

1. Why X-Rays produce diffraction in crystals?

2. Define: Bragg's Law

3. What is meant by Lattice cell parameters?

4. What is cubic crystal system?

5. What are miller indices?

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3. Skoog, D.A.; Holler, F.J.; Crouch, S.R. *Principles of Instrumental Analysis*. Sixth Edition, Thomson Brooks/Cole, USA (2007).