

Experiment No. : 01(Group-I)

DETERMINATION OF DIELECTRIC CONSTANT OF SOME DIELECTRIC MATERIALS

I. Objective / Aim of the Experiment:- The objective or aim of the experiment is to determine the dielectric constant of two dielectric materials (here glass and plywood).

II. Apparatus:- C.R.O.; Dielectric Constant KIT; Dielectric Cell etc. The Front panel description of the Dielectric Constant KIT is shown in Fig. 1.

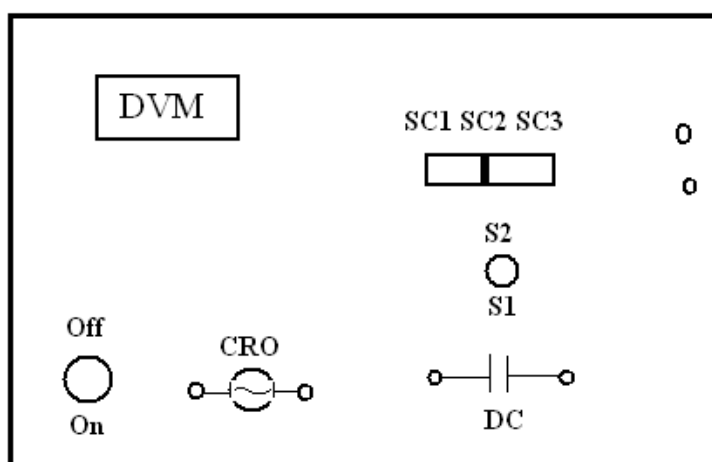


Fig.1

The Front panel comprises of –

- (a). Digital Volt Meter (DVM), that measures the voltage across the dielectric cell (DC) or standard capacitor (SC).
- (b). Switch S_1 to select dielectric cell or standard capacitor.
- (c). Switch S_2 to select one of the standard capacitors SC_1 or SC_2 or SC_3 .

There are two dielectric cells. They are –

- (a). Dielectric cell-1 having two gold plated brass discs (75 mm. each)
- (b). Dielectric cell-2 having two gold plated brass discs (25 mm. each)

Keep the dielectric sample in between the two metallic plates such that dielectric cell and sample should be coaxial.

The description of dielectric cell is given in Fig. 2.

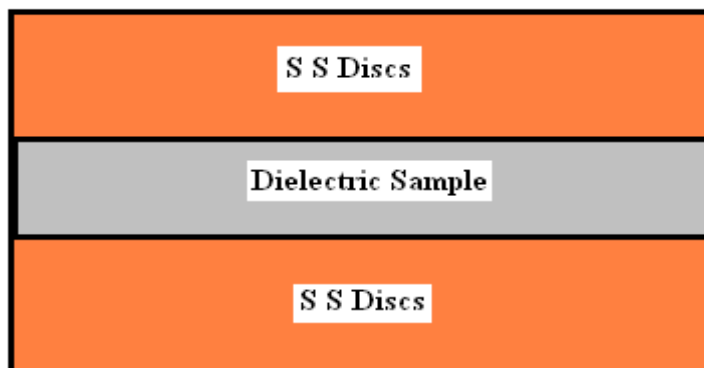


Fig. 2

III. Theory and Working Formula:- A dielectric is a material having electrical conductivity low in comparison to that of a metal. It is characterized by its dielectric constant. It is measured as the ratio of the capacitance (C_{DC}) of an Dielectric Cell filled with the dielectric material to the capacitance C_0 of the evacuated condenser *i.e.*

$$\epsilon = \frac{C_{DC}}{C_0} \dots\dots\dots(1)$$

In this experiment an LC circuit is used to determine the capacitance of the dielectric cell and hence the dielectric constant. The circuit diagram of this experiment is shown in Fig 3.

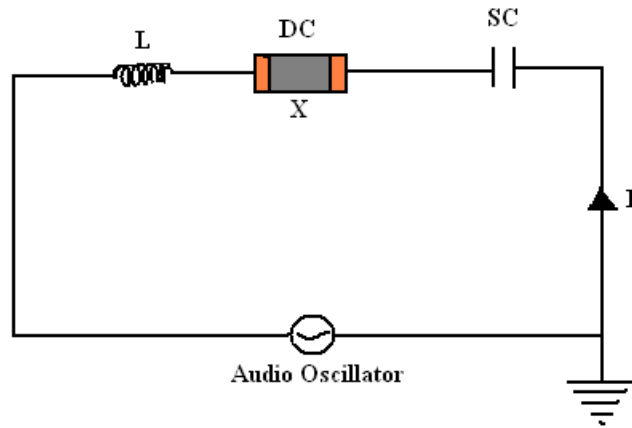


Fig.3

Where, DC : Dielectric Cell

SC : Standard Capacitor

L : Inductor

and X : Dielectric Sample respectively.

The audio oscillator is incorporated inside the instrument. If C_{SC} and C_{DC} represent the capacitances of the standard capacitor and dielectric cell respectively and if V_{SC} and V_{DC} are the voltages across SC and DC then.

$$\frac{V_{SC}}{I} = \frac{1}{\omega C_{SC}} \dots\dots\dots(2)$$

$$\text{or, } I = \omega V_{SC} C_{SC} \dots\dots\dots(3)$$

The same current I passes through the dielectric cell. Hence –

$$\frac{V_{DC}}{I} = \frac{1}{\omega C_{DC}}$$

$$\text{or, } C_{DC} = \frac{I}{\omega V_{DC}} = \frac{\omega C_{SC} V_{SC}}{\omega V_{DC}} = \frac{C_{SC} V_{SC}}{V_{DC}} \dots\dots\dots(4)$$

By measuring V_{SC} and V_{DC} and using the value of C_{SC} , we can determine the capacitance of the dielectric cell.

If C_0 represents the capacitance of the dielectric cell without the sample and the plates separated by air gap whose thickness is the same as the thickness of the sample then C_0 is given by –

$$C_0 = \frac{\epsilon_0 A}{d} = \frac{27.8 r^2}{d} \text{ pF} \dots\dots\dots(5)$$

where r represents the radius of the gold plated discs and d represents thickness of the sample in meters.

Hence, by measuring the values of C_{DC} and C_0 from equation (4) and (5), we can estimate the dielectric constant of the sample using equation (1).

IV. Procedure:-

- (1). Connect C.R.O. (in external mode) to the terminals provided on the front panel of the main unit. If no sinusoidal waveform appears on C.R.O. then adjust 'CAL' such that waveform appear.
- (2). Connect the dielectric cell assembly to the main unit and insert the sample in between the SS plates. Do not put extra pressure, as glass is brittle and may be damaged.
- (3). Switch ON the unit.
- (4). Choose the standard capacitor (with the help of switch S_2) SC_1 for materials having low dielectric constants (like Bakelite, Glass, Plywood etc.) or SC_2 for material having high dielectric constant (PZT sample).
- (5). Throw S_1 towards DC to measure the voltage across dielectric cell, say V_{DC} and towards SC to measure voltage across standard capacitor, say V_{SC} . Again rechecking the sinusoidal waveform on C.R.O. and if necessary, adjusting the waveform, we can take more observations about V_{DC} and V_{SC} and record them in a tabular form.
- (6). Calculate the value of C_{DC} using equation (4).
- (7). Measure thickness of the sample using screw gauge and radius of the sample by slide calipers. Then calculate the value of capacitance C_0 using equation (5).
- (8). Determine the dielectric constant of the sample-1 using the relation (1).
- (9). Repeat step (4) to step (8) for the sample-2.

V. Experimental Observations:-**Table-1**

Measurement of capacitance of the dielectric cell (C_{DC}) using sample-1 and sample-2

Supplied value of capacitance of standard capacitor (C_{SC}) = pF

Dielectric Materials	Sl. No.	V_{DC} (Volt)	V_{SC} (Volt)	C_{DC} (pF)	Mean C_{DC} (pF)
Sample-1	1.				
	2.				
	3.				
Sample-2	1.				
	2.				
	3.				

Table-2

Measurement of thickness (d) of dielectric materials (sample-1 and 2)

The least count (LC) of screw gauge =

Dielectric Materials	Sl. No.	M.S.R. (unit)	C.S.R.	Total reading (unit)	Mean thickness (d) (unit)
Sample-1	1.				
	2.				
	3.				
Sample-2	1.				
	2.				
	3.				

Table-3
Measurement of radius (r) of dielectric materials (sample-1 and sample-2)
The Vernier Constant (VC) of Slide Calipers =

Dielectric Materials	Sl. No.	M.S.R. (unit)	V.S.R.	Diameter of the sample (unit)	Radius of the sample (unit)	Mean radius (r) (unit)
Sample-1						
Sample-2						

VI. Calculations and result:-
Table-4
Calculation of dielectric constant (ϵ) of two dielectric materials

Dielectric Material	C_{DC} (pF)	C_0 (pF)	Dielectric Constant (ϵ)
.....			
.....			

VII. % of Error calculation:

The % of error can be calculated from the following equation-

$$\frac{\partial \varepsilon}{\varepsilon} \times 100\% = \left(\frac{\partial V_{SC}}{V_{SC}} + \frac{\partial V_{DC}}{V_{DC}} + \frac{2\partial r}{r} + \frac{\partial d}{d} \right) \times 100\%$$

VIII. Discussions:-

- (i). When put the dielectric samples in between the SS plates, do not put any extra pressure as some dielectric materials like glass/PZT are brittle and may be damaged.
- (ii). For samples, other than provided with the KIT, measure the capacitance of the sample placed in between the SS discs with the help of any capacitance meter available. If measured capacitance value is not comparable to either of SC₁ or SC₂, put capacitor having value near to that measured value in between the plugs provided at SC₃ and throw switch S₂ to SC₃ and measure the C_{DC} as stated in step 5 and step 6.
- (iii). Remember that the diameter of the sample should not be lesser than the gold plated discs.

Experiment No. :- 03 (Group-I)

DETERMINATION OF THE RESISTANCE OF A BALLISTIC COIL GALVANOMETER BY HALF DEFLECTION METHOD

I. Objective / Aim of the Experiment:- The objective or the aim of the experiment is to determine the resistance of a ballistic coil galvanometer by half deflection method.

II. Apparatus:- (i) Suspended coil galvanometer with lamp and scale arrangement, (ii) Storage Cell or battery, (iii) One 1-5000 Ohms resistance box (R), (iv) One 1-500 Ohms resistance box (r), (v) One 0.1-5 Ohms resistance box (S), (vi) Commutator, and (vii) Connecting wires.

III. Circuit diagram of the Experiment:-

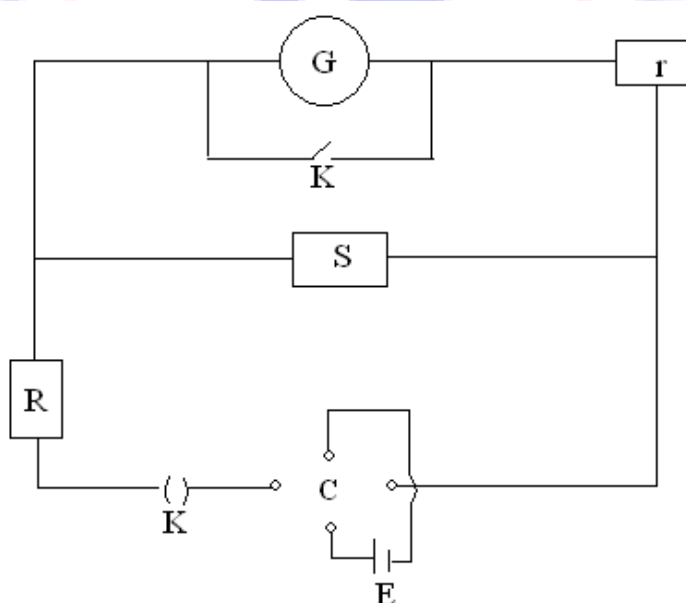


Fig.1: Circuit diagram for half deflection method.

IV. Theory and Working Formula:- In the circuit diagram as shown in the Fig.1, the equivalent resistance of the galvanometer G shunted by a resistance S is equal to

$$\frac{S(G + r)}{S + G + r}$$

Where, r is the resistance in series with the galvanometer. If S is very small then the equivalent resistance of the combination is S , whatever the value of r .

If i be the battery current then the potential drop across the shunted galvanometer is equal to $i.S = V$ (say) and the current flowing through the galvanometer is given by –

$$i_g = \frac{V}{G+r}$$

Therefore, if $r = 0$ then

$$i_g = \frac{V}{G} = C.\theta = K.d \dots\dots\dots(1)$$

Where, θ is the deflection of the galvanometer coil and d is the corresponding throw of the spot of the light, C and K are the constants of the proportionality.

Now, if r' is given such value that the galvanometer deflection is just half then, we have,

$$i_g' = \frac{V}{G+r'} = C.\frac{\theta}{2} = K.\frac{d}{2} \dots\dots\dots(2)$$

Dividing (1) by (2),

$$\frac{G+r'}{G} = 2 \quad \text{or} \quad \boxed{G = r'} \rightarrow \text{This is the working Formula of this experiment.}$$

[The experiment therefore consist of recording the deflections of galvanometer with $r = 0$, for a certain value of R and S and then to half the initial deflection by adjusting the value of r keeping R and S unaltered, this value of r gives the value of G .]

V. Procedure:-

01. Circuit connections are made as shown in Fig.1. S is connected in parallel to the galvanometer through r . Two terminals of the battery (through commutator) are connected to two terminals of S , one directly and the other through R .
02. The lamp and scale arrangement is adjusted to get a well defined spot of light on the scale. A sharp edge of the spot is made to coincide with the zero of the scale.

03. To start with, R is made of the order of 5000 ohm and r is made zero. With $S = 0$, the battery circuit is closed. If the galvanometer shows a deflection then the plugs in S is to be properly inserted till there is no deflection.
04. S is given a minimum value (0.1 ohm) and starting from a large value, R is adjusted still deflection of spot of light lies between 8 to 16 cm., when $r = 0$. [It must be assured that all plugs are tightly inserted in r so that $r = 0$]. The deflection is noted.
05. Keeping R and S unaltered r is now adjusted so that deflection is just half.
06. With the same values of R and S , r is made zero and the current is reversed and the deflection is noted. Then r is again adjusted so that deflection becomes half. [If the deflection with reverse current differs appreciably from that with direct current, the leveling of the galvanometer should be checked.]
07. S is adjusted to next higher value (0.2 ohm) and with proper choice of R , the above observations are repeated, each time keeping the deflection within the above range. In this way, different combinations of R and S , at least six observations are made.

VI. Experimental Observations:-
Table-I
Determination of value of G ($G = r$) using Galvanometer deflections

No. of Obs.	Current	Series resistance R (Ω)	Shunt resistance S (Ω)	Resistance in Galvanometer circuit (Ω)	Galvano-meter deflection (cm)	Galvano-meter resistance $G=r$ (Ω)	Mean G (Ω)
01.	Direct			0(d)		
			(r)(d/2)		
	Reverse						
02.	Direct						
	Reverse						
03.	Direct						
	Reverse						
04.	Direct						
	Reverse						
05.	Direct						
	Reverse						
06.	Direct						
	Reverse						

VII. Result: The measured resistance of the galvanometer, $G = \dots\dots\dots \Omega$.

VIII. Error Calculation:-

The working formula of this experiment is

$$G=r$$

To measure G , we measure the deflection of light spot on the scale. Hence percentage of proportional error can be obtained by the formula-

$$\frac{\partial G}{G} \times 100\% = \left(\frac{4\partial d}{d} + \frac{\partial r}{r} \right) \times 100\%$$

IX. Discussions:-

1. For properly leveled galvanometer, the motion of the galvanometer coil would be free and the deflection for the direct and reversed currents would be same.
2. The value of S must be very low so as to satisfy the assumption made in the theory.
3. In order that the throw of the spot light is linearly proportional to current strength, the deflection should lie in between 8 to 16 cm.
4. From time to time the zero position of the spot should be checked. If there is a small shift in the position of the spot of light, it should be adjusted accordingly.
5. The storage cell used in the circuit must have a steady value of e.m.f. throughout the experiment.

Experiment No. :- 04 (Group-I)

DETERMINATION OF THERMO-ELECTRIC POWER AT A CERTAIN TEMPERATURE OF A GIVEN THERMOCOUPLE

I.Objective(s):

To draw the calibration curve of the thermocouple and hence to determine the thermo electric power of the thermo couple at a certain temperature.

II. Apperatus:

Thermocouple, Potentiometer, Voltage source, Resistance box, Galvanometer, Thermometer, Water heater and other components.

III.Theory and working formula:

If two junction of a thermocouple are maintained at different temperatures then a thermo e.m.f. is developed between them. It can be measured by balancing it against the potential drop across a length 'l'(say) of the potentiometer wire.

If the thermo e.m.f. E_T is balanced by the length 'l' of the potentiometer wire, then

$$E_T = e.l \dots\dots\dots (1)$$

Where e is the potential drop per unit length of the potentiometer wire and it is given by

$$e = E R_p / (R + R_p)L \dots\dots\dots (2)$$

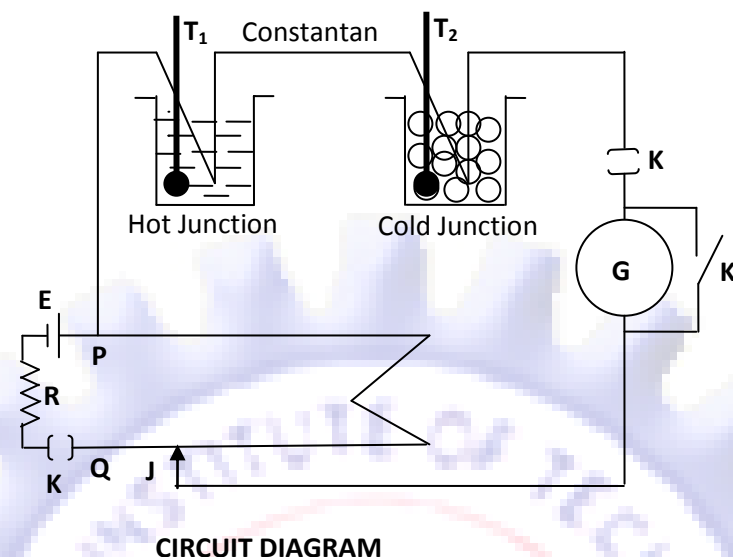
Where E is the e.m.f. of the voltage source, R and R_p are the resistances of the voltage source and the potentiometer respectively, L is the total length (10 m) of the potentiometer wire

Putting the value of 'e' from equation (2) to (1), we get

$$E_T = (E R_p) l / (R + R_p) L \dots\dots\dots (3)$$

Thermo-electric power can be determine by plotting a graph between thermo e.m.f. Vs. temperature. Draw a tangent to the calibration curve at the point corresponding to $T_1^{\circ}\text{C}$ of the hot junction. Then find the slope of the tangent to calculate the thermo-electric power, (i.e. $P = (dE_T / dT)$) at $T_1^{\circ}\text{C}$.

IV. Circuit diagram:



V. Procedure:

1. Connect the circuit as shown in the circuit diagram.
2. To avoid troublesomeness in the calculation students are advised to keep R at a fixed value throughout the experiment. The average value of 'e' is equal to 5×10^6 volt/cm below the hot junction temperature of the thermocouple higher than 100°C .
3. Let place the two junctions of the thermocouple at two different beakers, one in ice beaker and another in water filled beaker respectively. Now switch on the heater to increase the temperature of one of the junction placed in water filled beaker.
4. Notice the temperature of the two junctions by the attached thermometer placed in two beakers respectively. When the hot junction temperature is increased to 5°C above the room temperature then find out the null point by using the potentiometer as follows.....

First using the potentiometer jockey find out the jockey keys in between which the galvanometer's mirror deflection deflects both sides on the scale w.r.t. midpoint of the scale. After getting the pair of jockey keys (in between which the galvanometer's mirror deflection deflect both sides on the scale) let move the jockey to left or right to find the proper position where there is no deflection occurs. This is nothing but the null point (l) of a corresponding temperature. The value of the null point (l) can be

designated by the attached scale on the potentiometer (odd keys-upper scale, even keys-down scale).

5. In the same manner record the data at every 5°C increment of the hot junction. Student should take at least 7 sets of data.
6. When the temperature of the hot junction is stable then record the data for cooling as described earlier (pt. 4).
7. Plot the graph of Thermo e.m.f. in mV Vs Temperature in $^{\circ}\text{C}$ of the hot junction and find out the thermo-electric power at a certain temperature. Since the hot junction temperature is kept much less than the neutral temperature of the thermocouple, the nature of the graph should be a straight line. Indicate the cold junction temperature of the thermocouple from graph.
8. Good result can be expected if the temperature difference between the thermocouple junctions should not below 20°C .

VI. Observations:

Length of the Potentiometer wire (L) = 1000 cm

Resistance of the Potentiometer wire (R_p) = Ohms

E.M.F. of the Battery (E) = Volts

Cold junction temperature = $^{\circ}\text{C}$

Potential drop/length of the Potentiometer Wire (e) =Volts/cm

Value of R =ohms, from equation (2)

Table-1**Data for Thermo e.m.f. Vs Temperature Graph**

No. of Obs.	Hot Jn. Temp. ($^{\circ}\text{C}$)	Reading for Null points during heating			Reading for Null points during cooling			Mean Scale Reading(g) $(l_1+l_2)/2$ in cm	Thermo e.m.f. (mV)
		Wire No.	Scale Reading(cm)	Total Balance in length (l_1) in cm	Wire No.	Scale Reading(cm)	Total Balance in length (l_2) in cm		
1									
2									
3									
4									
5									
6									
7									

Graph plotting:

Plot a graph of Thermo e.m.f. E_T in mV Vs Temperature (T) in $^{\circ}\text{C}$ of hot junction of the thermocouple from the data of Table-1.

Table-2**Determination of Thermo-electric Power (dE_T/dT) from graph**

Given Temp. ($^{\circ}\text{C}$)	dE_T from graph (mV)	dT from graph ($^{\circ}\text{C}$)	$P = dE_T/dT$ at given Temp. (mV/ $^{\circ}\text{C}$)

The thermo-electric power at $^{\circ}\text{C}$ is =mV/ $^{\circ}\text{C}$.

[Note: If the thermo e.m.f. and temperature is measured in μV and in $^{\circ}\text{C}$, the unit of thermo-electric power will be $\mu\text{V}/^{\circ}\text{C}$.]

VII. Error calculation:

The thermo e.m.f. of the thermocouple is given by

$E_T = (E R_p)l / (R + R_p)L$, then the maximum error in measuring E_T will be –
 $(\delta E_T / E_T)_{\max} = \delta l / l$

Since L , R , R_p and E are constants and not measured.

Thus maximum percentage error is given by

$$(\delta E_T / E_T)_{\max} \times 100\% = (\delta l / l) \times 100\%$$

VIII. Discussions:

1. Ensure that the circuit is properly connected. Take care about the connection of polarities of the source and the thermocouple terminals.
2. The water in the beaker should be heated slowly so that for null point reading the temperature can be held constant for a couple of minutes by constantly stirring the water.
3. The temperature of the hot junction should be limited to the boiling point of water so that E_T Vs T curve will be straight line.

Model viva questions about Thermoelectric Effect:

1. What do you mean by Thermocouple?

Ans: The circuit formed by the two different metals whose junctions are at two different temperatures is known as thermocouple.

2. What do you mean by Neutral Temperature?

Ans.: The temperature of the hot junction at which the thermo e. m. f. or the thermoelectric current attains its maximum is called the neutral temperature for the given thermocouple.

3. What do you mean by inversion temperature?

Ans.: The temperature of the hot junction where the thermo e. m. f. or the current is zero and changes direction, is called inversion temperature for the given thermocouple.

4. What is Seebeck series?

Ans.: Seebeck made a series of metals such that if a couple is constructed with any two metals in the series, the thermo-current flows across the hot junction from the metal appearing earlier in the series to the one appearing later. According to this series metals are placed as follows:

Bi, Ni, Co, Pd, Pt, U, Cu, Mn, Ti, Hg, Pb, Sn, Cr, Mo, Rh, Ir, Au, Ag, Zn, W, Cd, Fe, As, Sb, Te

5. How many effects are there to create thermoelectric power?

Ans.: Seebeck effect, Peltier effect, Thomson effect.

Basic Concept About Thermoelectric Effect:

The **thermoelectric effect** is the direct conversion of temperature differences to electric voltage and vice-versa. A thermoelectric device creates voltage when there is a difference in temperature on each side. Conversely, when a voltage is applied to it, it creates a temperature difference. At the atomic scale, an applied temperature gradient causes charge carriers in the material to diffuse from the hot side to the cold side.

This effect can be used to generate electricity, measure temperature or change the temperature of objects. Because the direction of heating and cooling is

determined by the polarity of the applied voltage, thermoelectric devices can be used as temperature controllers.

The term "thermoelectric effect" encompasses three separately identified effects: the Seebeck effect, Peltier effect, and Thomson effect.

An applied temperature difference causes charged carriers in the material, whether they are electrons or holes, to diffuse from the hot side to the cold side, similar to a gas that expands when heated.

Mobile charged carriers migrating to the cold side leave behind their oppositely charged and immobile nuclei at the hot side thus giving rise to a thermoelectric voltage (thermoelectric refers to the fact that the voltage is created by a temperature difference). Since a separation of charges also creates an electric field, the buildup of charged carriers onto the cold side eventually ceases at some maximum value since there exists an equal amount of charged carriers drifting back to the hot side as a result of the electric field at equilibrium. Only an increase in the temperature difference can resume a buildup of more charge carriers on the cold side and thus lead to an increase in the thermoelectric voltage. Incidentally the thermopower also measures the entropy per charge carrier in the material.

The thermopower of a material, represented as S , depends on the material's temperature, and crystal structure. Typically metals have small thermopowers because most have half-filled bands. Electrons (negative charges) and holes (positive charges) both contribute to the induced thermoelectric voltage thus canceling each other's contribution to that voltage and making it small. In contrast, semiconductors can be doped with an excess amount of electrons or holes and thus can have large positive or negative values of the thermopower depending on the charge of the excess carriers. The sign of the thermopower can determine which charged carriers dominate the electric transport in both metals and semiconductors.

Superconductors have zero thermopower since the charged carriers carry no entropy. Equivalently, the thermopower is zero because it is impossible to have a finite voltage across a superconductor. (For example, by Ohm's law, $V=IR=0$, since the resistance, R , is equal to zero in a superconductor.)

If the temperature difference ΔT between the two ends of a material is small, then the thermopower of a material is defined as:

$$S = -\frac{\Delta V}{\Delta T}$$

where ΔV is the thermoelectric voltage seen at the terminals in steady-state when the current is zero. (See below for more on the signs of ΔV and ΔT .)

This can also be written in relation to the electric field E and the temperature gradient ∇T , by the equation:

$$S = \frac{E}{\nabla T}$$

Strictly speaking, these two expressions are not quite the same, and it is the first, not the second, which agrees with the practical, experimental definition. (They differ because voltage, defined here as "the quantity measured with a voltmeter", depends not only on the electric field but also the internal chemical potential gradient of electrons in the material.

Sign of the thermopower

Here, again, are the formulas for the Seebeck coefficient, with the sign made explicit:

$$S = -\frac{V_{left} - V_{right}}{T_{left} - T_{right}}$$

$$E = S \nabla T$$

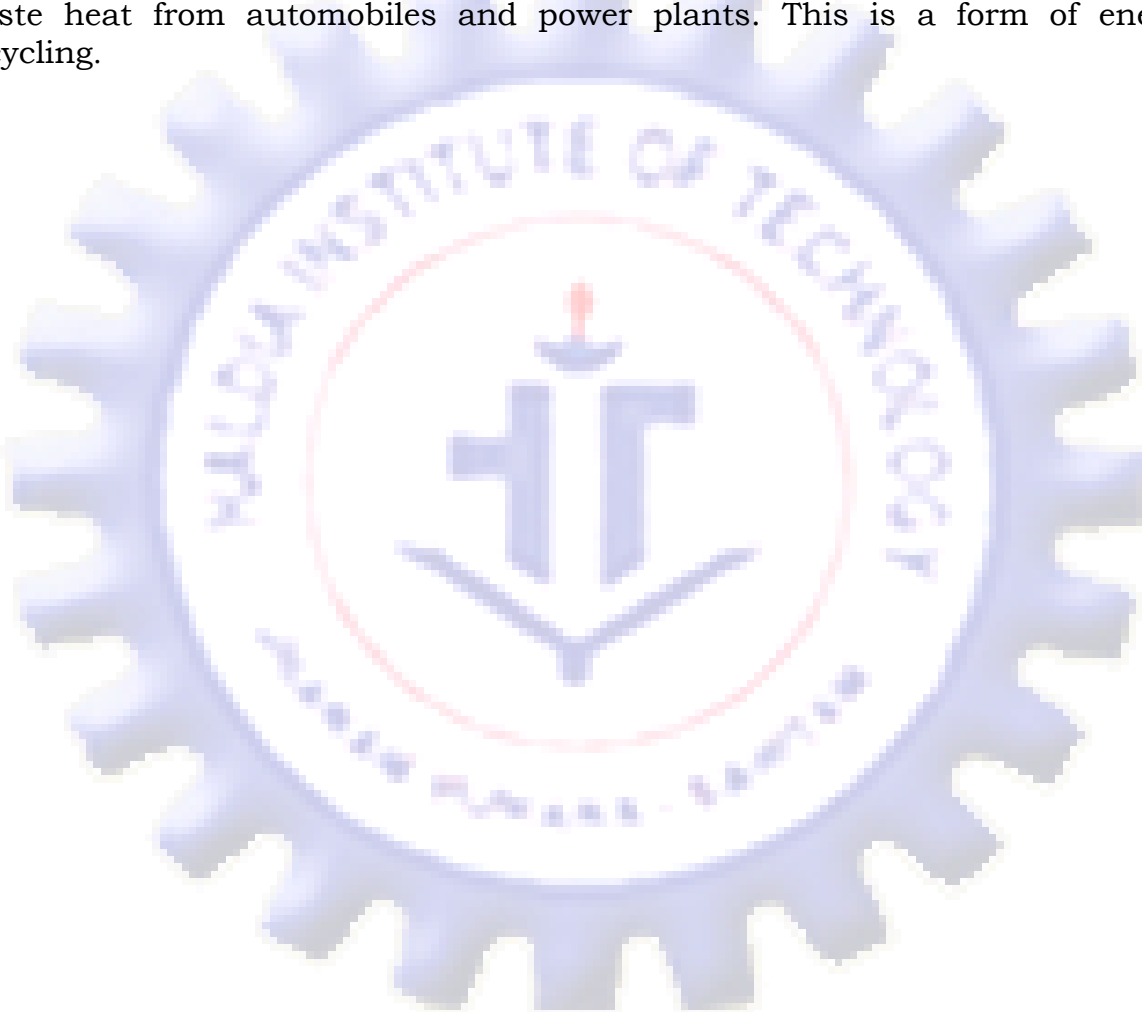
where "left" and "right" denote two ends of the material, and where the second equation is understood as vector multiplication. Thus, if S is positive, the end with the higher temperature has the lower voltage, and vice-versa, and the electric field will point in the same direction as the temperature gradient.

Note that there is a minus sign in the first equation, but not the second. This is because the electric field points from the higher voltage towards the lower voltages, whereas the temperature gradient points from the lower temperature towards the higher temperature.

Charge carriers tend to respond to a temperature gradient by moving in the opposite direction, i.e. from the hot end to the cold end. They tend to respond to an electric field in different ways depending on their charge: positive charges tend to move in the same direction as the field, while negative charges move in the opposite direction of the field. For equilibrium to be reached, these two tendencies have to cancel out. Thus, for purely p-type materials which have only positive mobile charges (holes), the electric field and temperature gradient should point in the same direction in equilibrium, giving $S > 0$. Likewise, for purely n-type materials which have only negative mobile charges (electrons), the electric field and temperature gradient should point in opposite directions

in equilibrium, giving $S < 0$. In practice, real materials often have both positive and negative charge-carriers, and the sign of S usually depends on which of them predominates.

The thermoelectric effect is sometimes used to generate electrical power, starting from a source of a temperature gradient. For example, some spacecraft are powered by a radioisotope thermoelectric generator, exploiting the temperature difference between a radioactively-heated plate and the cold empty space surrounding the craft. Some researchers hope that, in the future, much wider use could be made of thermoelectric power generation, including using waste heat from automobiles and power plants. This is a form of energy recycling.



Experiment No. :- 05 (Group-I)

DETERMINATION OF SPECIFIC CHARGE (e/m) OF ELECTRON BY J.J. THOMSON'S METHOD

I. Objective(s):

To determine the value of e/m for an electron by using a cathode ray tube (CRT) and a pair of bar magnets

II. Apparatus:

Cathode Ray Tube (CRT), Variable Power Supply, Wooden stand, Two bar magnets, Magnetometer.

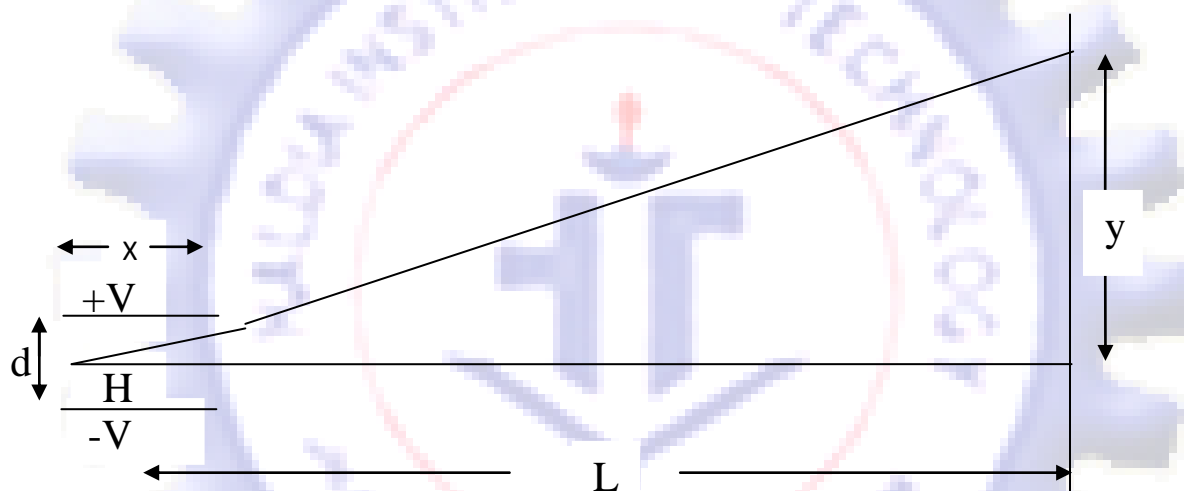


Fig.1: Motion of the Electron within the CRT

III. Theory and working formula:

Let an electron of charge e and mass m moving along the magnetic meridian (X axis) enter a pair of deflecting plates with a velocity u . If V be the voltage applied between plates of spacing d , then the deflection y of the electron on the screen is

$$y = \frac{eVxL}{md u^2} \quad \dots\dots\dots (1)$$

Where x is the length of each deflecting plate and L is the distance of the screen from the centre of the plates.

Now when a magnetic field H is present in the region between the plates such that there is no deflection of the electron on the screen then effectively the Lorentz force (eHu) equals the electric force acting in the opposite direction. Thus we can write

$$eHu = eE \dots \dots \dots (2)$$

where E is the electric field $E = V/d \dots \dots \dots (3)$

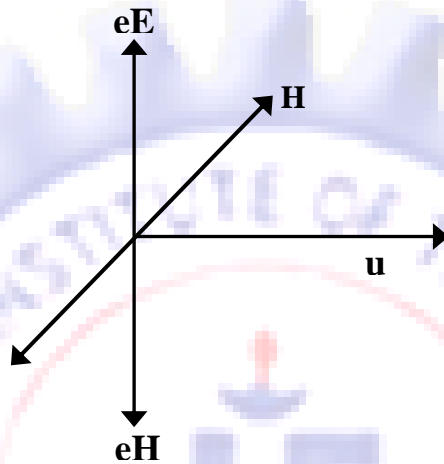


Fig.2: Directions of the forces

Again the magnetic field H produced due to presence of two symmetrically placed bar magnets is

$$H = H_0 \tan \theta = 0.37 \times 10^{-4} \tan \theta \text{ Tesla} \dots \dots \dots (4)$$

Where θ is the angular deflection of the pointer of the compass and H_0 is the earth's magnetic field. If we substitute the value of u in equation (1), we get the specific charge (e/m)

$$\frac{e}{m} = \frac{Vy}{dLxH_0^2 \tan^2 \theta} \dots \dots \dots (5)$$

This is the working formula of this experiment.

IV. Procedure:

(i) Place CRT in wooden stand and keep it in North/South direction and stand in East/West direction.

(ii) Read initial reading of the spot on scale attached with the screen. Now give deflection in upward direction by rotating Y knob such that the final reading is y. Note the applied deflecting voltage for such deflection.

(iii) Place magnets symmetrically and adjust so that the spot is again at initial position. Note the distance of poles of magnets closed to CRT from the stand. Now to measure the value of H remove the CRT from the stand and put magnetometer. Adjust the pointer of the compass so that it makes 0-0. Now place the magnets exactly they were placed so in the previous arrangement corresponding to the distance previously noted. Take the reading of the pointer and calculate the value of H.

V. Experimental Observations:**Table -1****Constants of the CRT**

Length of the deflecting plates x (m)	Separation between the plates d (m)	Distance of the screen from centre of the deflecting plates L (m)

Table-2
Data for electrostatic deflection y

No.of Obs.	Applied Voltage (V) (volt)	Direct Field					Reverse Field				
		Position of Spot			Mag. Pole's distance		Position of Spot			Mag. Pole's Distance	
		Initial (m)	Final (m)	Deflection (m)	East Arm r_1 (m)	West Arm r_2 (m)	Initial (m)	Final (m)	Deflection (m)	East Arm r_1 (m)	West Arm r_2 (m)

Table-3**Data for deflection of the pointer of the magnetometer θ**

No. Of Obs.	Applied Voltage (V) (volt)	Reading of two ends of pointer when magnetic poles are at r_1 and r_2 (degree)		Reading of two ends of pointer when magnetic poles are interchanged (degree)		Mean $\theta =$ $(\theta_1 + \theta_2 + \theta_3 + \theta_4)/4$ (degree)	$H = H_0 \tan \theta$ (Tesla)
		θ_1	θ_2	θ_3	θ_4		

VI. Calculations:

Table- 4**Determination of e/m**

L from Table-1 (m)	x from Table-1 (m)	D from Table-1 (m)	V from Table-2 (v)	Y from Table-2 (m)	Value of H ² From Table-3 (Tesla ²)	Calculation of e/m (C/kg)	Average e/m (C/kg)

VII. Result:**VIII. % of error calculation:**

The % of error can be calculated using the following equation,

$$\frac{\partial \left(\frac{e}{m} \right)}{\left(\frac{e}{m} \right)} \times 100\% = \left[\frac{\partial V}{V} + \frac{\partial y}{y} + \frac{2 \sec^2 \theta}{\tan \theta} \partial \theta \frac{\pi}{180} \right] \times 100\%$$

IX. Discussions:

Additional information:

Properties of Cathode rays:-

- 1) The cathode rays travel in straight lines.
- 2) The cathode rays are found to be deflected by electric and magnetic fields which prove that they are composed of electrically charged particles. From the directions of their deflections it is found that these are negatively charged particles.
- 3) Cathode rays produce fluorescence when they are incident on certain substances like barium platino cyanide, Zinc sulphide etc.
- 4) When the cathode rays fall on some substances they exert a pressure on it.
- 5) They ionize the gas through which they pass and can affect a photographic plate.
- 6) The rays can penetrate small thickness of metal foils and few cm of air.

*(The **discharge tube** is a cylindrical glass tube with two aluminium disc electrodes- the anode and the cathode- at the ends. The cathode is connected to the negative and anode to the positive terminal of a high voltage dc source. The tube could be evacuated to any desired degree through the outlet tube. At a low pressure of 0.01 mm of Hg Crooke's dark space fills the entire discharge tube. There is no visible discharge and luminous streaks come out of the cathode causing fluorescence on the walls of the tube. The colour of fluorescence depends on the nature of the glass of the tube. The rays coming out of the cathode are called the cathode rays.*

Dual-trace operation allows you to view two independent signal sources as a dual display on a single CRT. This operation allows an accurate means of making amplitude, phase, time displacement, or frequency comparisons and measurements between two signals.)

Experiment No. :- 06 (Group-II)

DETERMINATION OF PLANCK'S CONSTANT USING PHOTOCELL

I. Objectives:

- i) To draw the V-I characteristics of photocell for three different intensities. [Using Filters]
- ii) To determine the Plank's constant using Einstein's equation of photoelectric effect.

II. Theory and working formula:

When light hits an object, only a part of its energy is absorbed by the object and turned into heat; the rest becomes the energy of electrons inside the object, enabling the electrons to escape to the surface. This phenomenon is called photoelectric effect. In this process, light shows its nature as particles.

In 1905, Einstein put forward the “light quantum” hypothesis in an effort to explain the photo electric effect phenomenon: a photon with frequency of ν possesses the energy $h\nu$. When an electron absorbs photon of energy $h\nu$, a part of the energy becomes the electron's escaping power (i.e. work function W_0) and the rest of energy is transferred into the electron's kinetic energy ($\frac{1}{2}m\nu^2$).

$$E_{max} = \frac{1}{2}m\nu^2 = h\nu - W_0 \dots\dots\dots(i)$$

This relation is known as Einstein's photoelectric equation.

Suppose the photo electrons emitted from the surface of cathode of a photocell are made to produce photo current which is detected by galvanometer placed in an external circuit. The maximum energy of the photo electrons emitted when light of particular frequency falls on the cell can be found by applying negative voltage to the anode just large enough to stop all the electron reaching it (i.e. photo current zero). This particular external voltage is called stopping potential (V_s). Thus, $E_{max} = eV_s$.

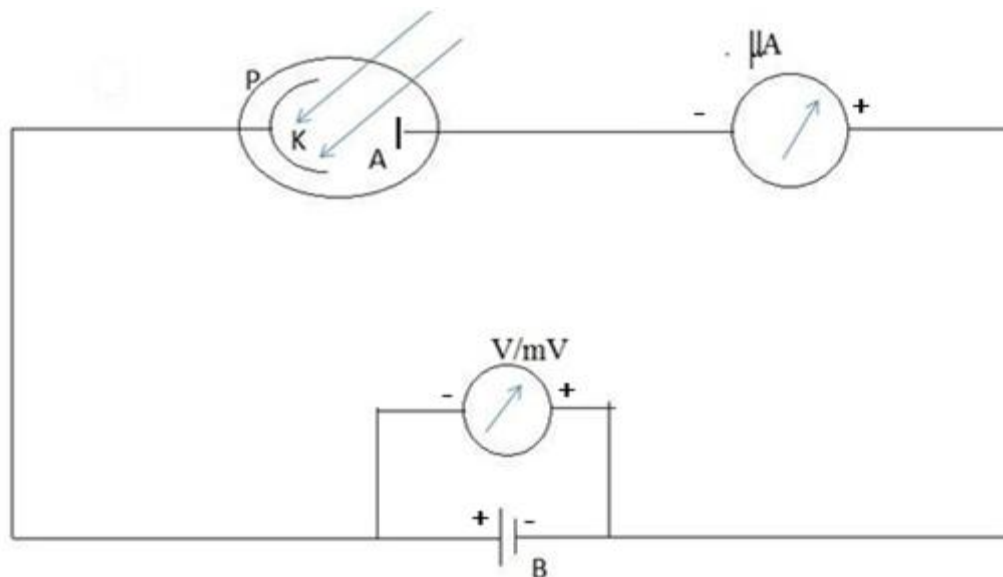
Let monochromatic lights of frequency ν_1 and ν_2 are incident on photocell and corresponding stopping potential eV_{s1} and eV_{s2} respectively then Einstein's photoelectric equations can be written as:

$$h\nu_1 = eV_{s1} + W_0 \dots\dots\dots(ii)$$

$$h\nu_2 = eV_{s2} + W_0 \dots\dots\dots(iii)$$

From equation (ii) & (iii), we can write

$$h = \frac{e(V_{s1} - V_{s2})}{(v_1 - v_2)} \dots\dots\dots(iv)$$



P= Photo cell, K=Cathode, A=Anode

Fig-1: Circuit Diagram

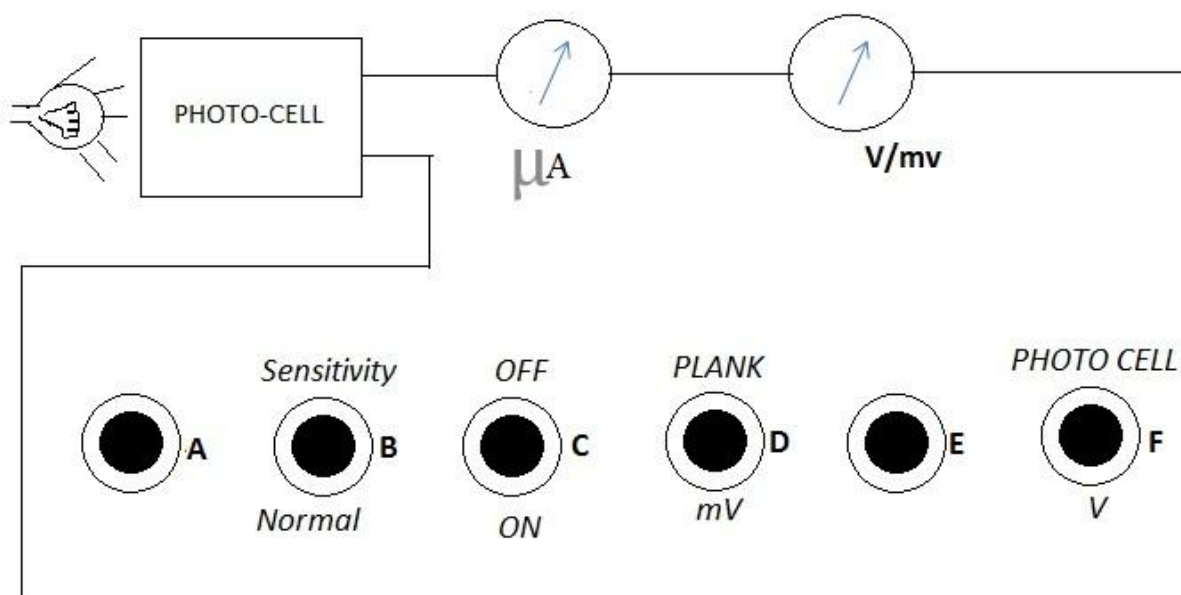
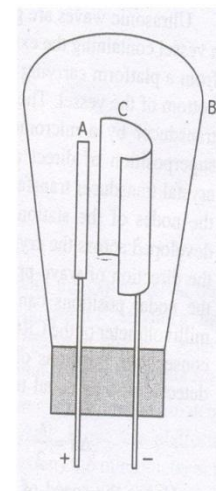


Fig-2: Block Diagram

III. Apparatus:

- i) A photocell: It is a device for converting light energy into electrical energy by using photoelectric effect. At high vacuum photocell consists of an evacuated cylindrical bulb (B) which is made of glass for use with visible light. It consists of semi-cylindrical plate of large surface area which is called the cathode (C) of the cell. A straight wire placed along the axis of the cylinder acts as anode (A). To get a profuse supply of electrons the cathode surface is coated with photo-sensitive material like caesium and silver oxides, antimony-caesium alloy, etc. Ordinarily the photocurrent is a small order of a few micro-amperes only. For higher current, gas-filled photocell are sometimes used.
- ii) Known pass-band filter
- iii) A sensitive galvanometer
- iv) Micro ammeter
- v) White light source



IV. Experimental procedure:

Step 1: Make the circuit as shown in fig: 1

Step 2: Switch on the apparatus with switch C keeping the window of the photocell P closed and knobs D and F at their minimum position.

Step 3: Turn the switch B to NORMAL and switch E to photocell position and at the same time adjust the current in the micro-meter to zero for zero voltmeter reading using the zero adjustment knob A. for final adjustment push the switch B to SENSITIVITY position again bring back to Normal position.

Step 4: Now open PHOTO-CELL window and keeping a filter on the window switch on the table lamp. If you apply a voltage (using knob F) you will see the current is rising. This proves that the PHOTO-CELL is working properly. Switch off the table lamp and go to next step.

Step 5: Now put the switch E to PLANK'S CONSTANT position and switch B to SENSITIVITY position. This time the knob D will operate and F will in active. Keeping the knob D in minimum position switch on the table lamp and see the current increases or decreases with increases or decreases of applied voltage through knob D. At this stage you will see that current is nonzero even when

voltage is zero. Now apply a reverse voltage (inter change the connecting wires of voltmeter terminal 5 and 6). Put the reverse voltage on the PHOTO-CELL by using knob D that time the current will decrease. Increase the reverse voltage and note the current until the current is zero. This voltage reading in this stage is say Stopping Potential. It depends on the frequency of the incident radiation not on the intensity.

V. Experimental Observations:

Table-1

Current-Voltage data for different filters

Given Data: $v_{blue} - v_{yellow} = 2.46 \times 10^{13} \text{ Hz}$, $v_{green} - v_{yellow} = 8.46 \times 10^{12} \text{ Hz}$,

$$v_{blue} - v_{green} = 1.62 \times 10^{13} \text{ Hz}$$

No. of Observation	Blue Filter		Green Filter		Yellow Filter	
	Voltage (mV)	Current (μA)	Voltage (mV)	Current (μA)	Voltage (mV)	Current (μA)
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

VI. Calculation:

$$h_1 = \frac{e(V_{s\text{ blue}} - V_{s\text{ yellow}})}{(v_{\text{blue}} - v_{\text{yellow}})} =$$

$$h_2 = \frac{e(V_{s\text{ blue}} - V_{s\text{ green}})}{(v_{\text{blue}} - v_{\text{green}})} =$$

$$h_3 = \frac{e(V_{s\text{ green}} - V_{s\text{ yellow}})}{(v_{\text{green}} - v_{\text{yellow}})} =$$

$$h = \frac{h_1 + h_2 + h_3}{3} =$$

VII. Result: The average value of planck constant $h =$ J S

VIII. Error calculation:

We have $h = \frac{e(V_{s1} - V_{s2})}{(v_1 - v_2)}$. So maximum proportional error

$$\frac{\delta h}{h} = \frac{\delta e}{e} + \frac{\delta(V_{s1} - V_{s2})}{(V_{s1} - V_{s2})} + \frac{\delta(v_1 - v_2)}{(v_1 - v_2)}$$

As charge of electron e and frequency of incident light is given so there should not any error in our measurement. Therefore δe , $\delta(v_1 - v_2)$ should be equal to zero and

$$\delta(V_{s1} - V_{s2}) = 2\delta V$$

$$\frac{\delta h}{h} = \frac{2\delta V}{(V_{s1} - V_{s2})}$$

Therefore maximum percentage error is

$$\frac{\delta h}{h} \times 100\% = \frac{2\delta V}{(V_{s1} - V_{s2})} \times 100\%$$

IX. Precaution and Discussion:

1. After inserting each filter in the photo-cell, you should wait at least 3-4 minutes to find actual readings.
2. You should determine the stopping potential for each filter very carefully and precisely
3. Photocurrent of photocell must be positive zero (not negative zero) at any stopping potential. If you get negative zero, you should make it positive zero by rotating voltage adjustor knob slightly anticlockwise.
4. While you start to take reading and determine the stopping potential, you should start to rotate the voltage adjuster knob from zero.
5. Filters are very sensitive and can be broken down due to mishandling. So, you must handle this component with care.
6. Instrument should be protected from external electric field, magnetic field and outside vibrations.

EXPERIMENT NO.: - 10 (Group – II)

DETERMINATION OF RYDBERG'S CONSTANT BY STUDYING HYDROGEN/HELIUM SPECTRUM

I. Objective(s):

To determine the value of Rydberg's Constant by studying Hydrogen Spectrum

II. Apparatus:

Grating, Hydrogen light Source, Spectrometer, Spirit Level etc.

III. Theory and Working Formula:

In an atom, the energy of the outer orbit is greater than the energy of the inner ones. When the hydrogen atom is subjected to external energy, the electron jumps from lower energy state to a higher energy state & after some fraction of a second, it returns to its ground state (*i.e.* lower energy state).

The excess of energy is now radiated in the form of radiation of different wavelengths, & form spectral series. The wavenumbers of the series can be found from the following relation:

$$\bar{\nu} = \frac{1}{\lambda} = R_h \left(\frac{1}{n_i^2} - \frac{1}{n_r^2} \right) \dots\dots\dots(1)$$

Where,

R_h = Rydberg's Constant.

n_i = Principal quantum number of lower energy state to which the electro returns back.

λ = Wavelength of radiation.

$\bar{\nu}$ = Wave number of radiation.

n_r = Principal quantum number of the higher energy state from which it returns back.

Again in case of diffraction we know that,

$$\lambda = \frac{\sin \theta}{nN} \dots\dots\dots(2)$$

Where,

λ = Incident Wavelength.

θ = Angle of diffraction

$N = \frac{1}{(a+b)}$ = Number of ruling unit length (cm).

n = Order number of spectrum.

Hence, measure θ for different orders (n) at a given value of N , we can calculate λ

Again, $R_h = \frac{1}{\lambda \left(\frac{1}{n_i^2} - \frac{1}{n_r^2} \right)}$

It is found that the Balmer series of the spectrum (*i.e.*, $n_i = 2$) lies in visible region In that spectrum, red color appears for $n_r = 3$, green-blue appears for $n_r = 4$, violet appears for $n_r = 5$ and $n_r = 6$.

Hence, $R_h = \frac{1}{\lambda \left(\frac{1}{n_i^2} - \frac{1}{n_r^2} \right)} = \frac{nN}{\left[\sin \theta \left(\frac{1}{2^2 - n_r^2} \right) \right]} \dots\dots\dots(3)$

Using equation (3), we can calculate R_h .

IV. Schematic diagram:

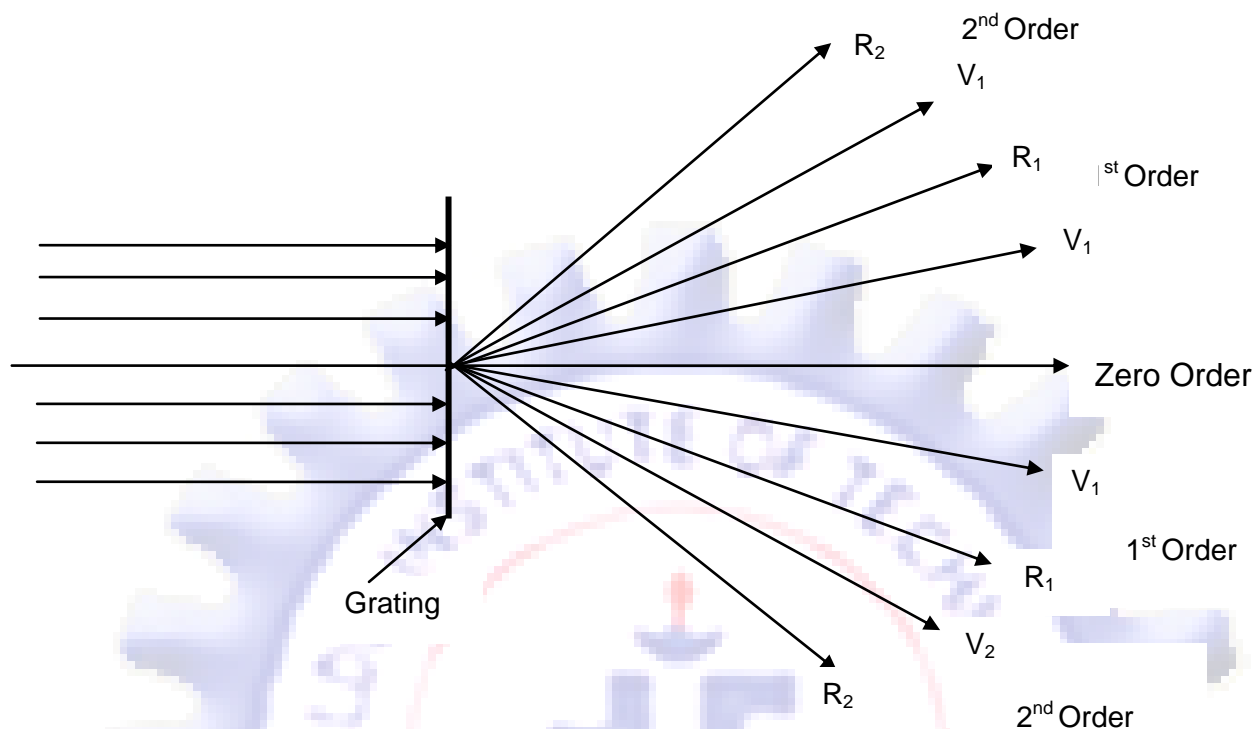


Fig.1: SET-UP RAY DIAGRAM

V. Experimental Observations:

Table-1

Determination of Vernier Constant of the Spectrometer

Value of one smallest div. of Main Scale m (deg)	Number of div. in the vernier scale n	No. of coincident div. in the main scale n'	Vernier Constant $V.C. = m(1 - \frac{n'}{n})$ (deg)

No. of rulings (N)=_____ per mm =_____ per cm

Table-2
Determination of the angles of diffraction for different order fringe

V.C. of spectrometer =

Colour of the bands	Order number (n)	Vernier number	Reading of the diffracted images with telescope						Differences between the left and right readings of vernier $2\theta =$ (deg)	Mean $2\theta=$ (deg)	$\theta=$(deg)
			Left			Right					
			MSR (M)	VSR (V)	TOTAL(M+ V.C. \times V)	MSR (M)	VSR (V)	TOTAL(M+ V.C. \times V)			
Red	n=1	V ₁									
		V ₂									
	n= 2	V ₁									
		V ₂									
Green-blue	n=1	V ₁									
		V ₂									
	n=2	V ₁									
		V ₂									

Table-3
Determination of the wavelength of unknown lines

Colours of spectral band	No. of ruling (lines/cm) of the Grating (N)	Order no. (n)	Angle of diffraction (θ)	Wavelength of spectral lines (λ) (m)	Mean λ (m)
Red		1 st			
		2 nd			
Green-Blue		1 st			
		2 nd			

VI. Calculations:

$$R_h = \frac{1}{\lambda \left(\frac{1}{n_i^2} - \frac{1}{n_r^2} \right)}$$

Here, for **Red** colour $n_i = 2$, $n_r = 3$, So, $R_h = \frac{1}{\lambda \left(\frac{1}{2^2} - \frac{1}{3^2} \right)} = \dots\dots\dots \text{m}^{-1}$

And for **Green-blue** colour, $n_i = 2$, $n_r = 4$, So, $R_h = \frac{1}{\lambda \left(\frac{1}{2^2} - \frac{1}{4^2} \right)} = \dots\dots\dots \text{m}^{-1}$

Mean Value of $R_h = \dots\dots\dots \text{m}^{-1}$

VII. Error Calculation:

The maximum % of error can be evaluated from the following equation-

$$\frac{\partial R_h}{R_h} \times 100\% = \left(\frac{\partial \theta}{\tan \theta} \times \frac{\pi}{180} \right) \times 100\%$$

VIII. Discussion:

- (1) The ray must fall on the grating surface normally; otherwise the working formula of determination of wavelength is not valid.
- (2) For greater accuracy, higher order spectra should be used.
- (3) The source position should be so adjusted as to make the diffracted images on both sides of the central one equally bright.
- (4) The slit should be made very narrow to increase the brightness of the higher order diffracted image.
- (5) If necessary, the slit illumination can be increased by forming an image of the source on the slit by inserting a convex lens of short focal length between the slit & the source.

EXPERIMENT NO.: - 11 (Group – III)

DETERMINATION OF HALL CO-EFFICIENT, NUMBER OF MAJORITY CARRIERS AND TYPE OF A GIVEN SEMICONDUCTOR SPECIMEN

I.Theory and Working Formula:

When a piece of conductor carrying a current is placed in a transverse magnetic field, an electric field is produced inside the conductor in a direction normal to both the current and the magnetic field. This phenomenon is known as the Hall-Effect.

Let a current I_x is passed through a superconducting slab along its length and a magnetic field B_z is applied in the direction perpendicular to I_x then an electric field E_y will be developed (see fig. 1 & fig. 2) along Y direction, Which is perpendicular to both I_x and B_z . As the moving charge in a magnetic field experience a force perpendicular to the drift velocity v_x and the magnetic field B_z the moving electron experiences a force which is given by -

$$F = -e v_x B_z = -(1/n) J_x B_z \text{ where, } J_x = n e v_x \text{ ----(1),}$$

J_x is the current density along X direction, e is the charge of electron and n is the number of electrons per unit volume.

$$\text{Now, } F = e E_y \text{ -----(2)}$$

From equation (1) and (2)

$$E_y = -(1/n e) J_x B_z \text{ -----(3)}$$

Now, $J_x = I_x / (b \times d)$ ----(4), where b =width of the specimen and d =thickness of the specimen.

From equation (3) and (4)

$$E_y = -(1/n e) (I_x / (b \times d)) B_z$$

$$E_y \times b = -(1/n e) (I_x / d) B_z = R_H I_x B_z / d$$

$$\text{or, } V_H = R_H I_x B_z / d \text{ -----(5)}$$

where, $V_H = E_y \times b$ = Hall Voltage, R_H = Hall-Coefficient = $-1 / n e$.

From equation (5),

Hall Co – efficient, $R_H = V_H \times d / I_x B_z$
and
Carrier Concentration, $n = -1 / R_H e$

Practical Applications of the Experiment:

1. To measure the unknown magnetic field.
2. To measure the type of a material (whether it is metal, semiconductor or insulator, if it is semiconductor then whether it is p type or n type).
3. To measure the carrier concentration of a material.

II.Apparatus:

Electromagnet, Digital Gauss meter, Hall-Probe (Specimen), Constant Current Power Supply, Hall Effect Set-up (Digital).

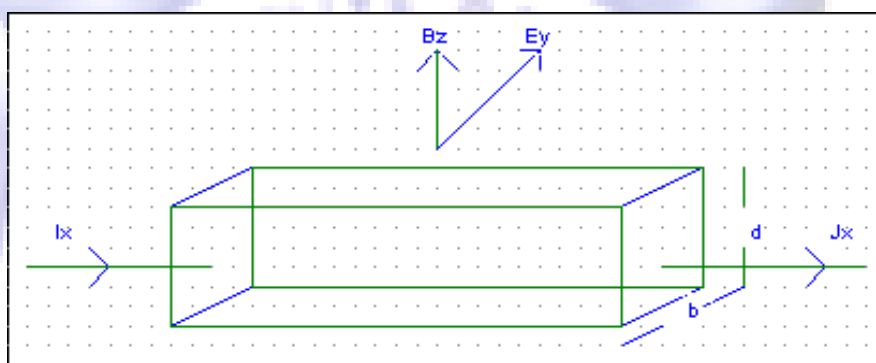


Fig.1 Sample for Studying Hall-Effect

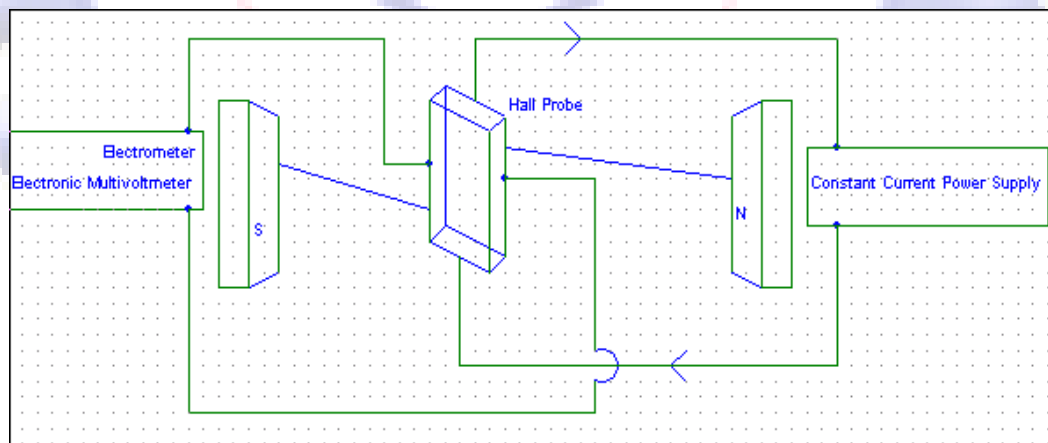


Fig.2 Hall-Effect Experiment Set-up

Function of Each Instrument and Component:

1. Electromagnet: Electromagnet is used for producing magnetic field as we desire.

2. Digital Gauss meter: The Gauss meter operates on the principle of Hall Effect in semiconductors. A semiconductor material carrying current develops an electromotive force, when placed in a magnetic field, in a direction perpendicular to the direction of both electric current and magnetic field. The magnitude of this e.m.f. is proportional to the field intensity if the current is kept constant; this e.m.f. is called Hall Voltage. This small Hall Voltage is amplified through a high stability amplifier so that a millivoltmeter connected at the output of the amplifier can be calibrated directly in magnetic field unit (gauss).
3. Hall Probe: This is the specimen (semiconductor) of which we are finding the Hall-Coefficient and Carrier Concentration. It may be Germanium (Ge) crystal or Indium Arsenide (In As).
4. Constant Current Power Supply: This is for the supply of constant current through the specimen. It is specially designed for Hall Probe provides 100% protection against crystal burn-out due to excessive current. The supply is highly regulated and practically ripple free d.c. source.
5. Hall-Effect Set-up (Digital): It is a high performance instrument of outstanding flexibility. The set-up consists of an electronic digital voltmeter and a constant current power supply. The Hall Voltage and probe current can be read on the same digital panel meter through the selector switch.

III. Experimental Procedure:

Ge crystal (n-type) is selected here for the present experiment. Thickness of the crystal is 0.04×10^{-2} m. Resistivity of the specimen is $10 \text{ volt.coulomb}^{-1}.\text{sec}$. Conductivity of the crystal is $0.1 \text{ coulomb.volt}^{-1}.\text{sec}^{-1}.\text{cm}^{-1}$.

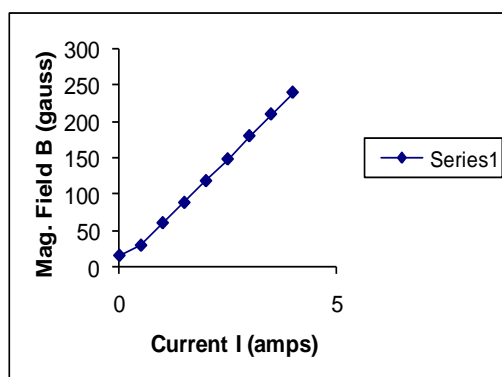
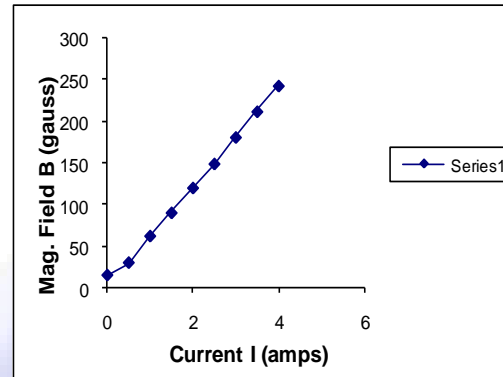
1. Measuring system is developed as given in fig.2.
2. For the calibration of the electromagnet, the probe of the Gauss meter is placed in just middle of the electromagnet. Recorded data of change of magnetic field for the direct current passing through the electromagnet from 0 to 4.0 amps with equal increment (e.g. 0.5 amps). Data of I_x Vs B_z is collected. I_x is the current through electromagnet.
3. Repeated the same process as before for reverse current through the electromagnet.

4. The Hall Probe (specimen) is placed then within the electromagnet during rest of the whole experiment, i.e., after the calibration of the electromagnet. Now we collect the data for I_x Vs V_H graph keeping the magnetic field through electromagnet is fixed (e.g. 200, 300, 400 Gauss etc.). To maintain the magnetic field through the electromagnet for both direct and reverse current, the current may be changed accordingly and proper current selection may be done for the I_x Vs B_z data collection.
5. Now we fixed the Hall Current in a particular value (e.g. 1mA, 2 mA etc.) and then collect the data for magnetic field (B_z) Vs Hall Voltage (V_H) graph.
6. Hall-Coefficient (R_H) and Carrier Concentration are obtained from the I_x Vs V_H graph & B_z Vs V_H graph. The value of the ratio of I_x and V_H is obtained from the slope of the I_x Vs V_H graph. Similarly the value of the ratio of B_z and V_H is obtained from the slope of the B_z Vs V_H graph.

IV. Observations (Data Recording):

Table-1
Data for Calibration of the Electromagnet

Current (I_x) Passing Through Electromagnet (in Amp)	Magnetic Field (B_z) (in Gauss)	
	For Direct Current	For Reverse Current
0.0		
0.5		
1.0		
1.5		
2.0		
2.5		
3.0		
3.5		
4.0		

Sample Graph – 1(a)Fig.3: Calibration of Electromagnet
(for direct current)**Sample Graph – 1(b)**Fig.4: Calibration of electromagnet
(for reverse current)

Note: Practically mag. field should not 0 (zero) for 0 (zero) current through electromagnet because of the residual magnetism in the electromagnet.

Table-2(a)**Data for I_X Vs V_H graph**

Corresponding fixed magnetic field = Gauss

Current Through Specimen (mA)	Magnitude of the Hall Voltage (mV)		
	For Direct Current	For Reverse Current	Mean
0.0			
0.5			
1.0			
1.5			
2.0			
2.5			
3.0			
3.5			
4.0			

Table-2(b)**Data for I_x Vs V_H graph**

Corresponding fixed magnetic field = Gauss

Current Through Specimen (mA)	Magnitude of the Hall Voltage (mV)		
	For Direct Current	For Reverse Current	Mean
0.0			
0.5			
1.0			
1.5			
2.0			
2.5			
3.0			
3.5			
4.0			

Sample Graph - 2

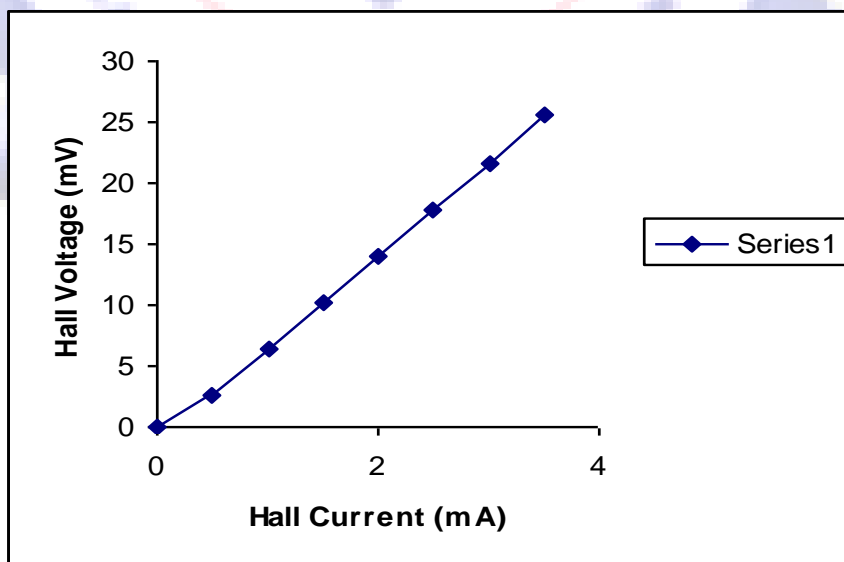


Fig.5: Hall voltage variation with Hall current

Table-3(a)

Data for magnetic field (B_z) Vs Hall voltage (V_H)

Fixed Hall Current = mA

Power Supply Current (Amp)	Magnetic Field (B_z) (Gauss) (From Table – 1)	Hall Voltage (mV)
0.0		
0.5		
1.0		
1.5		
2.0		
2.5		
3.0		
3.5		
4.0		

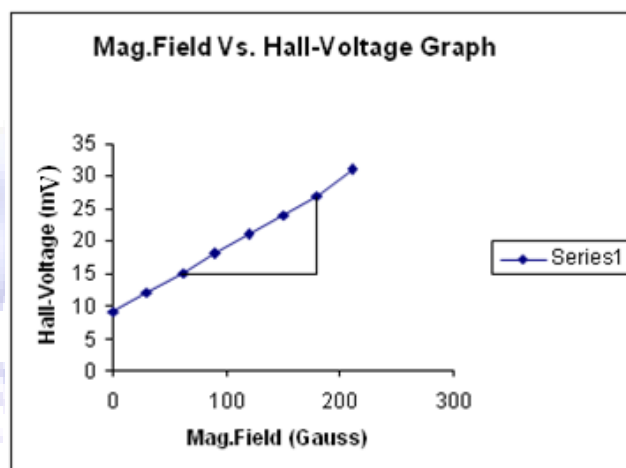
Table-3(b)
Data for magnetic field (B_z) Vs Hall voltage (V_H)

Fixed Hall Current = mA

Power Supply Current (Amp)	Magnetic Field (B_z) (Gauss) (From Table – 1)	Hall Voltage (mV)
0.0		
0.5		
1.0		
1.5		
2.0		
2.5		
3.0		

3.5		
4.0		

Sample Graph - 3
For fixed Hall Current =mA



V. Calculations:

Table-4

Determination of Hall-Coefficient from I_X Vs V_H Graph

$$R_H = V_H \times d / B_z I_x$$

Thickness of the specimen $d = 0.04 \times 10^{-2}$ m

No. of Observation	Mag. Field B_z (Gauss)	Difference of Hall Current from graph (mA)	Difference of Hall voltage from graph (mV)	R_H $\text{m}^3/\text{Coulomb}$	Mean R_H $\text{m}^3/\text{Coulomb}$
From Table-2(a)					
From Table-2(b)					

Table-5
Determination of Hall-Coefficient from B_z Vs V_H Graph
 $R_H = V_H \times d / B_z I_x$
Thickness of the Specimen $d = 0.04 \times 10^{-2} \text{ m}$

No. of Observation	Fixed Hall Current (mA)	Difference of Mag.Field B_z from graph (Gauss)	Difference of Hall voltage from graph (mV)	R_H m ³ /Coulomb	Mean R_H m ³ /Coulomb
From Table-3(a)					
From Table-3(b)					

Table-6
Data for Carrier Concentration per (m³) From Table – 4 & Table - 5

No. of Observation	R_H m ³ /Coulomb	Carrier Concentration m ⁻³	Avg. Carrier Concentration m ⁻³
From Table-4			
From Table-5			

VI) Results:

Sample - Ge crystal,

From Table – 4, $R_H =$

From Table – 5, $R_H =$

From Table – 6, **Carrier Concentration, $n =$**

Type of the Semiconductor: -.....

VII) % Error Calculation:

Discussions:

1. The voltage produced between the voltage terminals of Hall probes is not generally the Hall voltage alone. There are other galvano-magnetic and thermo-magnetic effects (Nernst effect, Righi-Leduc effect and Ettingshausen effect) which can produce voltages between the Hall probes.
2. I-R drop due to the probe misalignment and thermo-electric voltage due to transverse thermal gradient may arise.
3. The Hall probe must be rotated in the field until the position of maximum voltage is reached. This is the position when the direction of current in the probe and magnetic field would be perpendicular to each other.
4. While taking readings with a varying magnetic field at a particular current value, it is necessary that the current value should be adjusted for each reading. Otherwise, this result is effective to decrease of mean free path and hence an increase in resistivity may occur.
5. The initial drop across the Hall contacts can be eliminated by taking of Hall voltages measured in direct and reverse sample current and magnetic field. Large current should not be passed through the sample to avoid Joule's heating.
6. Electrical contacts taken from the sample should be ohmic.
7. From the Fleming's left hand rule, we can determine the sign of the Hall-Coefficient and hence we can get the idea of the specimen whether it is n-type or p-type.
8. Although the dimensions of the crystal do not appear in the formula except the thickness, but the theory assumes that all the carriers are moving only lengthwise. Practically it has been found that a closer to ideal situation may be obtained if the length may be taken three times the width of the crystal/specimen.

Experiment No. :- 12(a) (Group-III)

Determination of Band gap by Electrical Measurement Method (Two Probe Method)

TEMPERATURE DEPENDENCE OF REVERSE SATURATION CURRENT OF PN JUNCTION DIODE – ESTIMATION OF BAND- GAP OF SEMICONDUCTOR MATERIALS

I. Theory and Working Formula

The voltage-current characteristic of p-n junction diode can be described by the Shockley equation, (Equation-1),

$$I_{\text{total}} = I_0[\exp(qV/\eta kT) - 1] \dots\dots\dots(1)$$

Where, I_0 is the reverse bias saturation current, q the charge of the electron, k is Boltzmann's constant, V is voltage (volts), η is the ideality factor which varies per diode, and T is the temperature in Kelvin.

The reverse bias generation current is small compared with the forward bias current. A typical I - V curve for a diode is shown next:

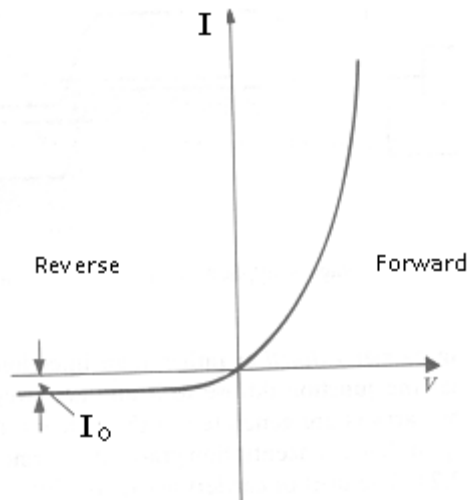


Figure-1: Current-Voltage characteristic of a p - n junction diode

For very large value of reverse bias, the current I is saturated and equal to I_0 . This saturation current is the sum of diffusion current, generation current inside the depletion zone, surface leakage effects and tunneling of carriers between states in the band gap.

In a first approximation at a certain condition, I_0 can be interpreted as being solely due to minority carriers accelerated by the depletion zone field plus the applied potential difference. Therefore it can be shown that, Equation-2 where A is a constant, E_g the energy gap (slightly temperature dependent), and γ an integer depending on the temperature dependence of the carrier mobility μ .

$$I_0 = AT^{(3+\gamma/2)} \exp(-E_g(T) / \eta kT) \dots \dots (2)$$

On substitution, the value of I_0 given by Equation-2 into Equation-1 and taking logarithm of the two sides and multiply them by kT for large forward bias ($qV > 3kT$); thus, rearranging, we have Equation-3.

$$qV = E_g(T) + T[k \ln(I/A) - (3+\gamma/2)k \ln T] \dots \dots \dots (3)$$

As $\ln T$ can be considered as a slowly varying function in the 200 - 400 K interval, therefore for a constant current, I , flowing through the junction a plot of qV versus the temperature should approximate a straight line, and the intercept of this line with the qV axis is the required value of the band gap E_g extrapolated to 0 K.

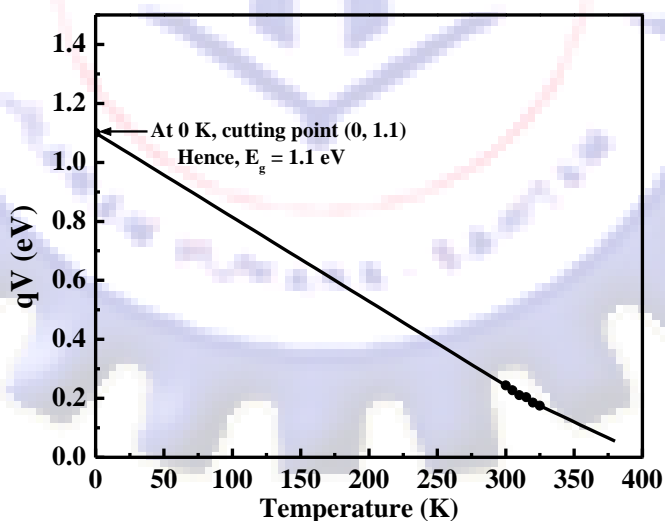


Figure-2: Plot of corrected voltage versus temperature for silicon.

II. Procedure

1. The experimental set-up involves a heater, diode and a power supply.
2. Insert thermometer and switch on the oven. Increase the temperature in small steps starting from room temperature and note the value of saturation current I_0 .
3. The temperature is adjustable in the range from room temperature to about 90°C . Reverse current should be fixed at $70\ \mu\text{A}$ at room temperature.
4. Record the readings of the temperature and corresponding junction voltage.
5. Plot a graph of Temperature (in Kelvin) vs Junction Voltage.
6. The intercept in y-axis will give the energy bandgap of the semiconductor at absolute zero temperature.



III. Observation Table:**Table: Record for Temperature vs Junction Voltage for P-N junction diode under reversed biased condition**

Record Room Temperature (T) = K

Reverse saturation Current at room temperature = 70 μ A

No. of Obs	During Increase of Temperature		During decrease of Temperature		Average value of Junction Voltage
	Temperature (K)	Junction Voltage (V)	Temperature (K)	Junction Voltage (V)	
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					
11.					
12.					
13.					

IV. Estimation of Bandgap by Graphical Method

V. Maximum % Error Calculation

$$\text{Use } E_g = eV_g \Rightarrow \frac{\delta E_g}{E_g} \times 100\% = \frac{\delta V_g}{V_g} \times 100\%$$

VI. Discussions

Experiment No. :- 12(b) (Group-III)

DETERMINATION OF BANDGAP OF SEMICONDUCTORS (FOUR PROBE METHOD)

I. Aim & Objective: To Find the Bandgap of Semiconductor Material by Four-Probe Method

II. Theory and Working Formula:

Electrons are restricted to sets of discrete energy levels in atomic structure. But, in the extended solids, many atoms interact with one another, and there will be the same number of molecular orbitals, delocalized over the entire solid, as the number of atomic orbitals being combined and finally form a so-called "**band**" which represents a kind of electronic highway allowing electrons to move throughout the solid, thereby conducting electricity.

The lowest unoccupied band is called the **conduction band**, and the highest occupied band containing the valence electrons is called the **valence band**. The energy separation between the valence and conduction bands is known as the **bandgap energy** and it is denoted by E_g . Therefore, the bandgap, $E_g = E_c - E_v$

In Semiconducting materials, temperature dependence of intrinsic carrier concentration (or carrier density) is given by

$$np = n_i^2 = N_c N_v \exp(-(E_c - E_v)) = N_c N_v \exp\left(-\frac{E_g}{kT}\right) \dots\dots(1)$$

$$n_i = \sqrt{N_c N_v} \exp\left(-\frac{E_g}{2kT}\right) \dots\dots\dots(2)$$

This is known as *Law of Mass Action* and it is valid also for extrinsic semiconductor. Due to incorporation of impurity, which either donates extra electrons or holes, the number of carriers remains constant for a given temperature.

Therefore, the electrical resistivity of semiconductor is given by,

$$\frac{1}{\rho} = \sigma = nev = ev\sqrt{N_c N_v} \exp\left(-\frac{E_g}{2kT}\right) \dots\dots\dots(3)$$

for a particular temperature number of free carriers in conduction and valence band, average drift velocity of carriers will be constant, therefore we have,

$$\ln \rho = \frac{E_g}{2kT} - \ln A \text{ -----(4)}$$

Now, plotting graph considering $\ln \rho$ vs T^{-1} , we can estimate band gap (E_g) by taking the slope of the curve. This portion is described in the procedure section in details.

The energy gap of the semiconductor is given by

$$E_g = \frac{2k\Delta \ln \rho}{\Delta(1/T)} \text{ eV(4a)}$$

Where, ρ is the resistivity of the semiconductor,

E_g is the bandgap of the semiconducting material, k is Boltzmann's constant

($k = 1.38 \times 10^{-23} \text{ J/K}$; or $k = 8.6 \times 10^{-5} \text{ eV/deg}$),

A is constant, T is absolute temperature (in Kelvin)

The resistivity of the given semiconductor is given by $\rho = \frac{\rho_0}{G_7(W/S)} \text{(5a)}$

where $G_7(W/S)$ is the correction factor, expressed as

$$G_7(W/S) = \frac{2S}{W} \ln 2 \text{(5b)}$$

$$\text{Again, } \rho_0 = \frac{V}{I} \times 2\pi S \text{ in ohm-cm.....(6)}$$

$$\text{Therefore, } \rho = \frac{\rho_0}{G_7(W/S)} = \frac{V}{I} \times 2\pi S \times \frac{W}{2S \ln 2} = \frac{V}{I} \times \left(\pi \frac{W}{\ln 2} \right) \text{(7)}$$

where, V is the applied voltage between inner two probes,

I is the current through the crystal,

W is the thickness of the crystal (supplied, measured in mm)

and S is the distance between two contact probes (supplied, measured in mm).

Equation (4a), (5a, b), (6) and (7) are the desired expression for determination of bandgap of a given semiconducting material.

III. Description of Experimental Set-Up:

This experimental set-up is basically consists of 4-contact probes attached with the semiconducting sample shown in Figure-1. **A constant current is passed through the outer probes** connecting it to the constant current source of the set-up. **The voltage developed across the middle two probes is measured** using a digital milli-voltmeter. **In our laboratory, the current is set to 5mA.** A thermometer is inserted into the position to read the temperature of the semiconductor sample.

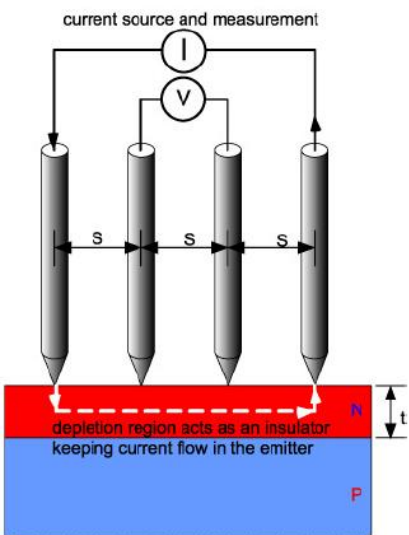


Figure -1: Schematic Diagram of 4-contact probe with semiconductor sample (The dimensions of the four probes and the crystal thickness)

Graphical Plot

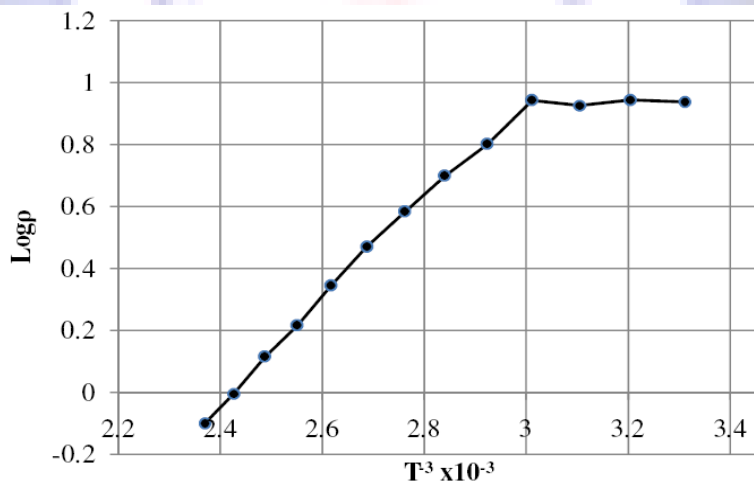


Figure-2: Variation of $\log p$ with temperature

IV. Experimental Procedure:

1. Before starting the experiment, the room temperature is noted, say for example $T = 29^\circ\text{C}$.
2. The trial is repeated by placing the four probe arrangement inside the oven. The oven is connected to the heater supply of the set-up. Probe current is fixed at 5 mA. For different temperatures, up to 150°C , the voltage developed is noted and tabulated in Table-1 during increase and decrease the temperature.
3. The distance between the probes (S) and the thickness of the crystal (W) are measured. The value of resistivity is calculated using the formula $\rho = \frac{V}{I} \times \left(\pi \frac{W}{\ln 2} \right)$
4. The values of $\frac{1}{T} \times 10^{-3}$ and the corresponding values of $\log_{10} \rho$ are plotted ($\log_{10}(\rho)$ [along y-axis] vs $T^{-1} \times 10^{-3}$ [along x-axis]) on the graph as shown in Figure-2.

The slope of the curve $\frac{\Delta \log_{10} \rho}{\Delta \left(\frac{1}{T} \right) \times 10^{-3}}$ is calculated as shown in Figure-2.

Slope will give the value of $\frac{E_g}{2k}$ and hence E_g can be determined.

V. Observation Table:

Table-1
Variation of Voltage with Temperature

No. of Obs.	Temperature (T)		T^{-1} (K^{-1})	Current (I) fixed (mA)	Voltage (mV)		Avg. Voltage (V) (mV)	(V/I)	$\rho = \frac{V}{I} \times \left(\pi \frac{W}{\ln 2} \right)$ (Ω -cm)
	$^{\circ}C$	(K)			During Increase	During decrease			
1.	30			5					
2.	35								
3.	40								
4.	45								
5.	50								
6.	55								
7.	60								
8.	65								
9.	70								
10.	75								
11.	80								
12.	85								
13.	90								
14.	95								
15.	100								
16.	105								
17.	110								
18.	115								
19.	120								
20.	125								
21.	130								
22.	135								
23.	140								
24.	145								

Table-2:
Variation of Resistivity with Temperature

[illegible]

VI. Calculations:

$$E_g = 2 \times 2.303k \times \frac{\Delta \log_{10} \rho}{\Delta(\frac{1}{T}) \times 10^{-3}} eV = 2 \times 2.303 \times 8.6 \times 10^{-5} \times \frac{\Delta \log_{10} \rho}{\Delta(\frac{1}{T}) \times 10^{-3}} eV$$

VII. Maximum % Error Calculation:

$$E_g = 2 \times 2.303k \times \frac{\Delta \log_{10} \rho}{\Delta \left(\frac{1}{T}\right) \times 10^{-3}} eV$$

$$\frac{\delta E_g}{E_g} \times 100\% = \left[\frac{\delta(\log_{10} \rho)}{(\log_{10} \rho)} + \frac{\delta(1/T)}{(1/T)} \right] \times 100\% \cong \left(\frac{\delta \rho}{\rho} + \frac{\delta(1/T)}{(1/T)} \right) \times 100\%$$

Again,

$$\rho = \frac{\rho_0}{G_7(W/S)} = \frac{V}{I} \times 2\pi S \times \frac{W}{2S \ln 2} = \frac{V}{I} \times \left(\pi \frac{W}{\ln 2} \right), \text{ Or, } \frac{\delta \rho}{\rho} = \left(\frac{\delta V}{V} + \frac{\delta I}{I} \right)$$

$$\text{Hence, } \frac{\delta E_g}{E_g} \times 100\% \cong \left(\frac{\delta V}{V} + \frac{\delta I}{I} + \frac{\delta(1/T)}{(1/T)} \right) \times 100\%$$

VIII. Precaution and Discussions:

1. Care is taken to see that all the four probes touch the sample surface and make contact with the sample.

Additional Information:

Semiconductor is the class of material where the conductivity of the material is intermediate between the conductor and insulator. The resistivity of semiconductors (ρ) is typically between 10^{-2} and $10^8 \Omega\text{-cm}$. It acts as insulator at absolute zero temperature but behaves like a conductor at room temperature. At temperatures other than 0 K, the magnitude of the band gap separates an insulator from a semiconductor. With thermal or optical excitation, some of these electrons can be excited from the valence band to the conduction band, and then they can contribute to the current transport process. Number of electrons available for conduction can be increased greatly in semiconductors by reasonable amount of thermal or optical energy due to breaking of covalent bonds and as a result of this conductivity of the semiconductor materials increases.

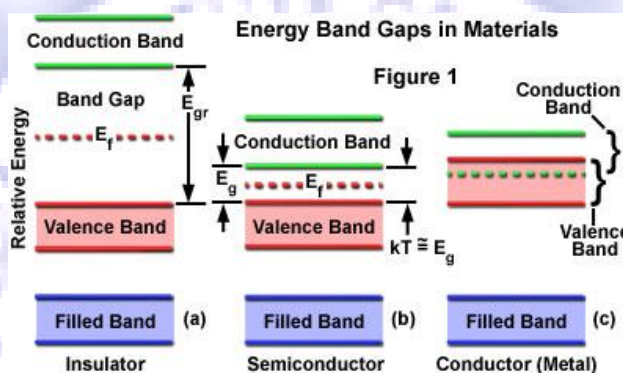


Fig. 1: The Schematic View of the Energy Band structure



Fig. 2: - Four Probes Experimental Set-up

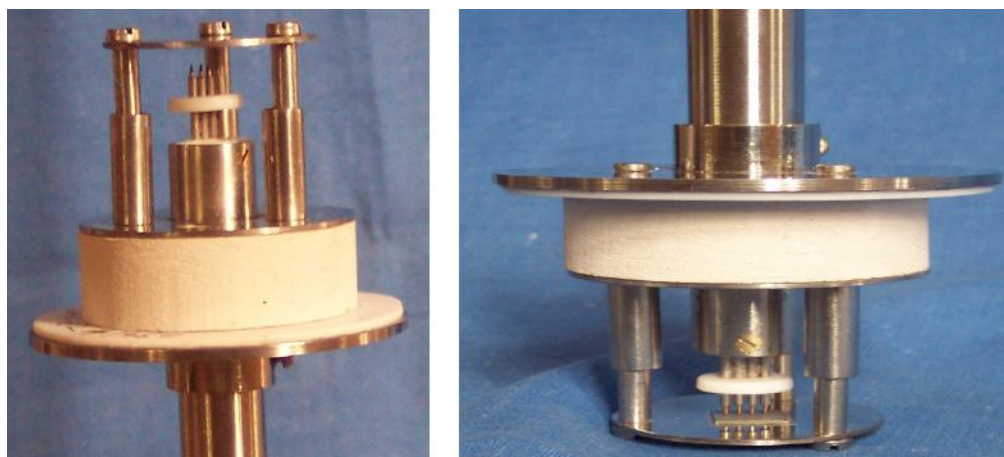


Fig. 3- (a) Four probes arranged linearly in a straight line (b) Crystal placed under four probes

Figure-3(a) shows the arrangement of the four probes that measure voltage and supply current to the surface of the crystal. **The probes are about 2 mm dia metal rods** fitted to the base using a spring. This arrangement provides a smooth touch on the crystal surface as shown in Figure-3(b).

The distance between the probes (S) and the thickness of the crystal (W) are measured. The values of (W/S) are calculated and the value of the function $f(W/S)$ is taken from the standard table (Table -1). Using these values η is calculated for various

temperatures (Table-1).

$$\rho = \frac{\rho_0}{G_7(W/S)} \text{ where, } \rho_0 = \frac{V}{I} \times 2\pi S$$

For a germanium crystal the (W/S) and corresponding $f(W/S)$ values are given in Table-1. [It may be noted that if (W/S) value is not available in the Table, then a graph between (W/S) and $f(W/S)$ values can be plotted. From the graph, the desired values of $f(W/S)$ corresponding to any value of (W/S) can be found out.]

Table-1

W/S	$f(W/S)$
0.100	13.863
0.141	9.704
0.200	6.931
0.333	4.159
0.500	2.780
1.000	1.504
1.414	1.223
2.000	1.094
3.333	1.0228
5.000	1.0070
10.000	1.00045

Experiment No. :- 13 (Group-III)

TO STUDY CURRENT-VOLTAGE CHARACTERISTICS, LOAD RESPONSE, AREAL CHARACTERISTICS AND SPECTRAL RESPONSE OF PHOTOVOLTAIC SOLAR CELL

I.Theory and Working Formula:

Solar Cell is basically p-n junction diode by which light energy is converted into electricity. Due to illumination photogeneration takes place in the active layer. Output voltage is measured across the load.

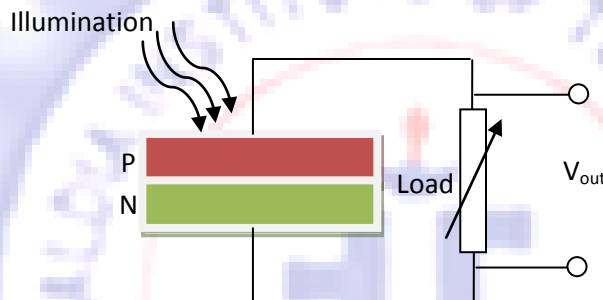


Figure-1: Schematic of P-N junction Solar Cell

The schematic diagram of p-n junction diode and energy band diagram of a p-n junction solar cell is shown in Figure-1 and Figure-2 respectively.

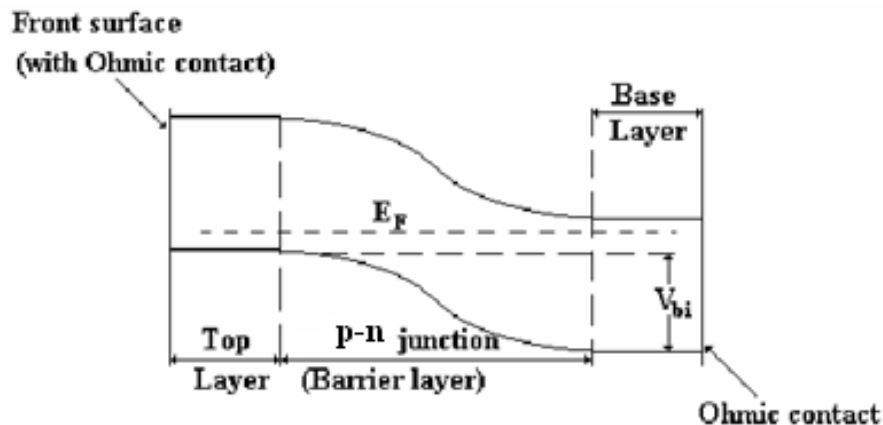


Fig.2- Energy Band Diagram of p-n solar cell

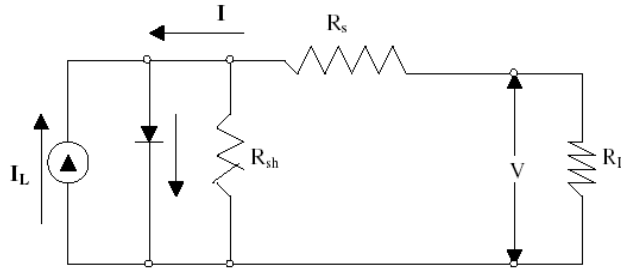


Fig.3: Equivalent circuit of a solar cell including series (R_s) and shunt (R_{sh}) resistances

The Characteristic equation of the Solar Cell under illumination is given by

$$I = I_0 \left\{ \exp \left[\frac{eV}{\eta kT} \right] - 1 \right\} - I_L$$

I_L is the current due to electron-hole pairs produced by absorption of light. Figure 4 shows the current (I) vs. (V) characteristics of a p-n junction diode in dark and with light respectively.

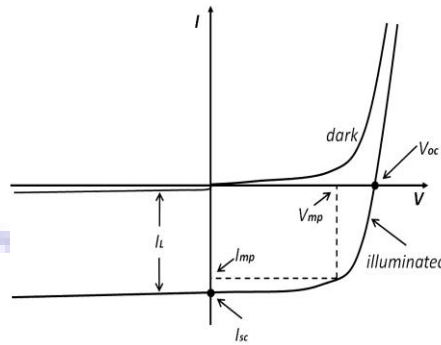


Figure-4: Current (I) vs. (V) characteristics of a p-n junction diode

Taking inversion of this plot about the voltage axis is represented in Figure.5a. The power delivered by the devices is equal to the shaded area, maximum power rectangle (P_m) and it is equal to $I_m V_m$.

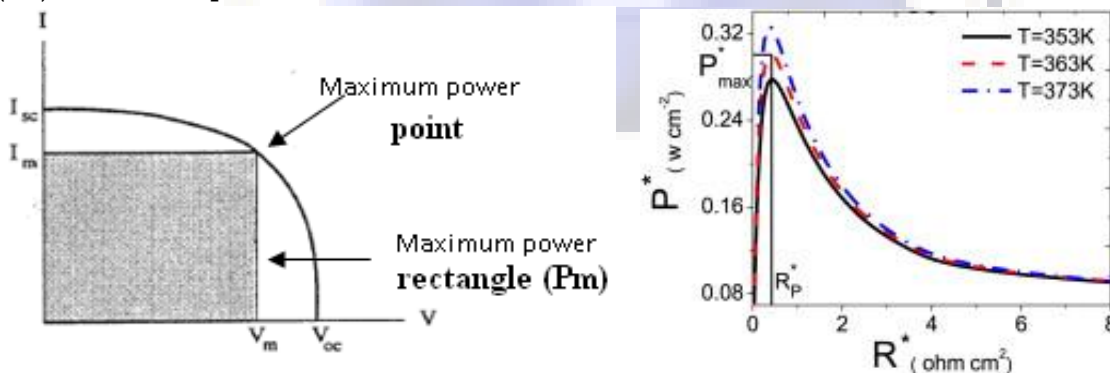


Figure-5a,b: I-V plot and Load Response of Solar Cell

The open circuit voltage, V_{oc} can be derived quantitatively using:

$$V_{oc} = \frac{nkT}{e} \ln\left(\frac{I_L}{I_0} + 1\right)$$

Photovoltaic Parameters

Maximum Output Power $P_{max} = I_m V_m$

In order to quantify the device sensitivity and device quality a parameter called **Fill Factor (FF)** is defined as:

$$FF = \frac{I_m V_m}{I_{sc} V_{oc}}$$

Power Conversion Efficiency

$$\begin{aligned} \eta &= \frac{P_{out}}{P_{in}} \times 100 \% \\ &= \frac{I_m V_m}{P_{in}} \times 100 \% \\ &= \frac{FF \cdot I_{sc} V_{oc}}{P_{in}} \times 100 \% \end{aligned}$$

Quantum Efficiency

Quantum Efficiency of a p-n junction device is defined as the ability to collect photo generated (e-h) pairs at a particular wavelength per incident photon.

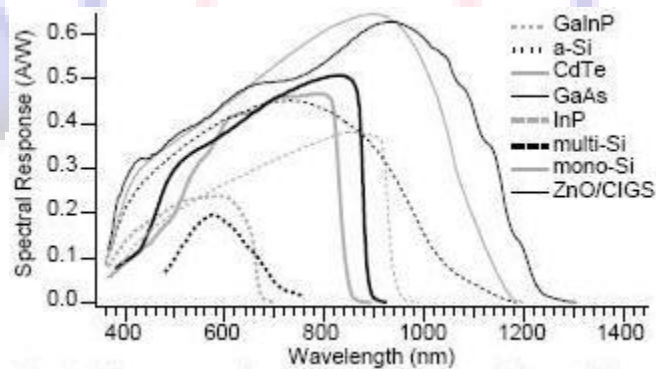


Figure-6: Typical Spectral Response (or frequency Response) of different solar cell

II.Procedure:

For I-V and Load Response

- Switch on the power supply and illuminate the solar cell.
- Record the current and voltage across the load resistor under illumination condition.
- Draw I - V characteristics, estimate maximum power point (I_m, V_m) from I - V characteristics, and hence compare with tabulated max^m output data.
- Draw maximum power rectangle, measure V_{oc} (open circuit voltage) and I_{sc} (short circuit current) from the I - V curve.
- Plot power output vs load resistance (*Nature is shown in Figure-5b*). Find optimum value of load resistance for which the output power is maximum.
- Calculate Max^m Power Output, Fill Factor, Power Conversion Efficiency

For Areal Characteristics

- Record I and V at optimum load condition using mask of different area.
- Calculate the power output for different area and plot it in graph paper.

For Spectral Response

- Illuminate the solar cell using different filter and record I , V at optimum load condition.
- Calculate the output power for the particular wavelength and plot output power vs wavelength (*Nature is shown in Figure-6*).

III.Observation Table:
Table-1
For I-V characteristics and Load Response (Use White light Source)

No. of Obs.	Load Resistance (R) in ohm	Voltage (V)	Current (mA)	Power output (mW)
	Infinity	$V_{oc} = \dots\dots\dots$	0	
	200			
	180			
	160			
	140			
	120			
	100			
	80			
	60			
	40			
	20			
	0		$I_{sc} (max) = \dots\dots\dots$	

Table-2**For Areal Characteristics of Solar Cell (Use White light Source)**

No. of Obs.	Optimum Load Resistance (R) in ohm	Mask with different Area (cm ²)	Voltage (V)	Current (mA)	Power output (mW)
		Mask-1			
		Mask -2			
		.			
		.			
		.			
		.			
		.			
		.			

Table-III**Spectral Response or Frequency Response (Load Resistance fixed)**

Load Resistance (Ohm)	Filter Used	Wavelength (nm)	Voltage (volt)	Current (mA)	Output Power (mW)
Optimum Load Resistance	Blue ($\lambda=$)				
	Green ($\lambda=$)				
	Yellow ($\lambda=$)				
	Orange ($\lambda=$)				
	Red ($\lambda=$)				

IV. Calculations & Results:

Maximum Power Output:

Both by Direct and Graphical Method;

Fill Factor:

Power Conversion Efficiency:

V. Maximum Percentage Error:

Maximum Output power: $P_m = I_m V_m$

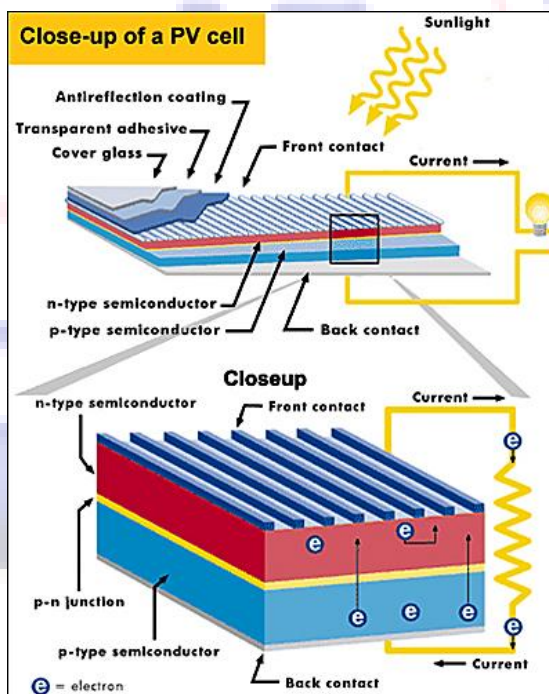
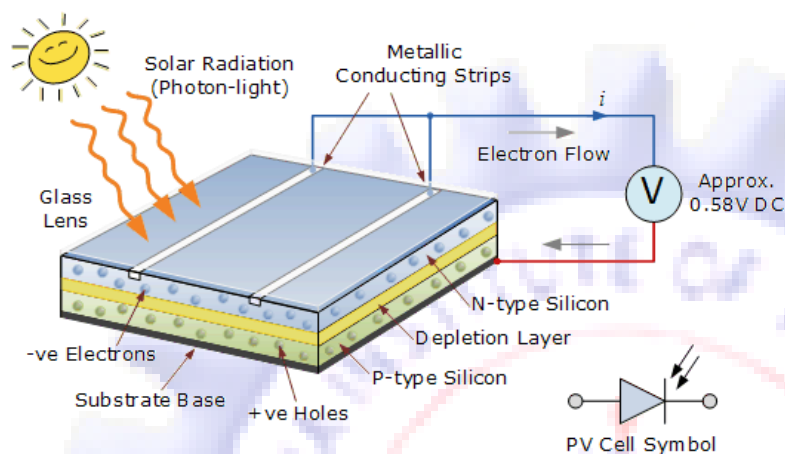
$$\frac{\delta P_m}{P_m} \times 100 = \left(\frac{\delta I_m}{I_m} + \frac{\delta V_m}{V_m} \right) \times 100,$$

use, $\delta I_m, \delta V_m$ will be the considered from instrumental minimum measurement unit.

VI. Discussions:

Fundamentals:**Basic Solar Cell Structure**

In p-n junction solar cells photo-generated electron hole pairs (e-h) are separated by a built-in-field within the device and photogenerated electron will be collected towards n-side and hole will be collected towards p-side.



From the equivalent circuit it is evident that the current produced by the solar cell is equal to that produced by the current source, minus the current which flows through the diode, and is given by

$$I = I_D - I_L$$

where,

- I = output current (amperes)
- I_L = photogenerated current (amperes)
- I_D = diode current (amperes)

Dark current flowing through p-n junction diode is given by *Shockley diode equation*

$$I_D = I_0 \left\{ \exp \left[\frac{qV_j}{nkT} \right] - 1 \right\}$$

where,

- I_0 = reverse saturation current (amperes)
- n = diode ideality factor (1 for an ideal diode)
- q = elementary charge
- k = Boltzmann's constant
- T = absolute temperature
- For silicon at 25°C, $kT/q \approx 0.0259$ volts

Typical V_{oc} of silicon cells under solar conditions are around 550mV.

A solar cell's *energy conversion efficiency* is the percentage of power converted (from absorbed light to electrical energy) and collected. The Power conversion efficiency (η) of a p-n junction device is calculated using the ratio of the maximum power output (P_{out}) to incident power of illumination (P_{in} , in W/m²) when a solar cell is connected to an electrical circuit.

All the measurements will be performed with standard test conditions (STC) and the *surface area* of the solar cell (A in m²). STC specifies a temperature of 25°C and an irradiance of 1000 W/m² with an air mass 1.5 (AM1.5) spectrum.

Classification of Solar Cell

- Single crystal Si based solar cell
- Thin film solar cell
- Amorphous Si solar cell
- Microcrystalline Si solar cell
- Polycrystalline Si solar cell
- Cu-In-Se₂ solar cell
- CdTe, CdSe solar cell
- Dye Sensitized Solar Cell
- Organic –Inorganic Hybrid Solar Cell
- Quantum dot (Excitonic) Solar Cell

Solar Cell Materials

Crystalline Silicon, Amorphous Silicon, CuInSe_2 , GaAs, CdSe, CdTe, GaInP, Different Organic Dyes, Quantum dots etc

Concept of Air mass:

Air Mass is the measure of how far light travels through the Earth's atmosphere. One air mass, or AM1, is the thickness of the Earth's atmosphere. Air mass zero (AM0) describes solar irradiance in space, where it is unaffected by the atmosphere. The power density of AM1.5 light is about $1,000\text{W/m}^2$; the power density of AM0 light is about $1,360\text{W/m}^2$, which is considered to be the solar constant.

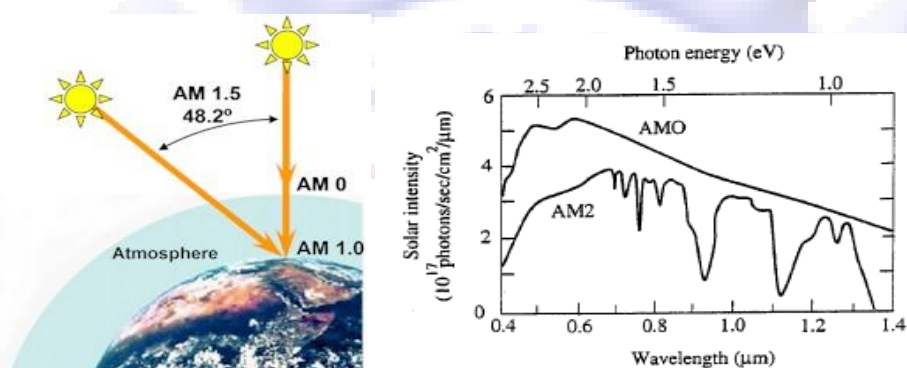


Figure: AM0 and AM2 solar spectra

For PV testing (terrestrial use), the Standard Test Condition (STC) is defined as an insolation of 1000W/m^2 (1 SUN) at 25°C and with a solar spectral distribution equivalent to global AM1.5, per ASTM G173-03 and IEC 60904-3. For solar simulation performance classification, a spectral irradiance distribution standard has been established.