

SOLID STATE PHYSICS
(DPHYL22)
(MSC - PHYSICS)



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Experiment No.1

DIELECTRIC CONSTANT OF A SOLID

Aim:- To study the temperature dependence of dielectric constant of a Ferro - electric material and to determine its Curie temperature.

Apparatus:- Setup consisting of a heater arrangement to heat the sample kept in a dielectric cell with micrometer arrangement, Temperature indicator, capacitance meter ,and a sample (Lead Zerconate tritrate or Barium Titanate) in the form of 20mm diameter circular wafer with conductive coating on opposite faces .

Principle:-

A ferro electric crystal is defined as a crystal that exhibits a spontaneous electric dipole moment; in other words, a crystal for which in the absence of an applied electric field the center of positive charge does not coincide with center of negative charge. The occurrence of Ferro electricity in pervoskite structured compounds like barium titanate is believed to be the result of a polarization catastrophe in which the local electric fields arising from polarization itself increases faster than the elastic restoring forces on the ions in the crystal, thereby leading ultimately to an asymmetrical shift in ionic positions; the shift limited to a finite displacement by the onset of anharmonic restoring forces.

The dielectric constant can be expressed in terms of polarization as

$$\epsilon = \frac{1 + \frac{8\pi}{3} \sum N_i \alpha_i}{1 - \frac{4\pi}{3} \sum N_i \alpha_i}$$

Where α_i is the polarization of an ion of type I and N_i is the number of ions I per unit volume. It is seen that the dielectric constant becomes infinite, corresponding to a finite polarization for zero field, when $\sum N_i \alpha_i = (4\pi/3)^{-1}$, and this is called the polarization catastrophe.

We note that the value of ϵ is sensitive to small departures of $\sum N_i \alpha_i$ from the critical value of $3/4\pi$; if we write

$$(4\pi/3) \sum N_i \alpha_i = 1 - s,$$

Where $s \ll 1$, we have $\epsilon \cong 3/s$.

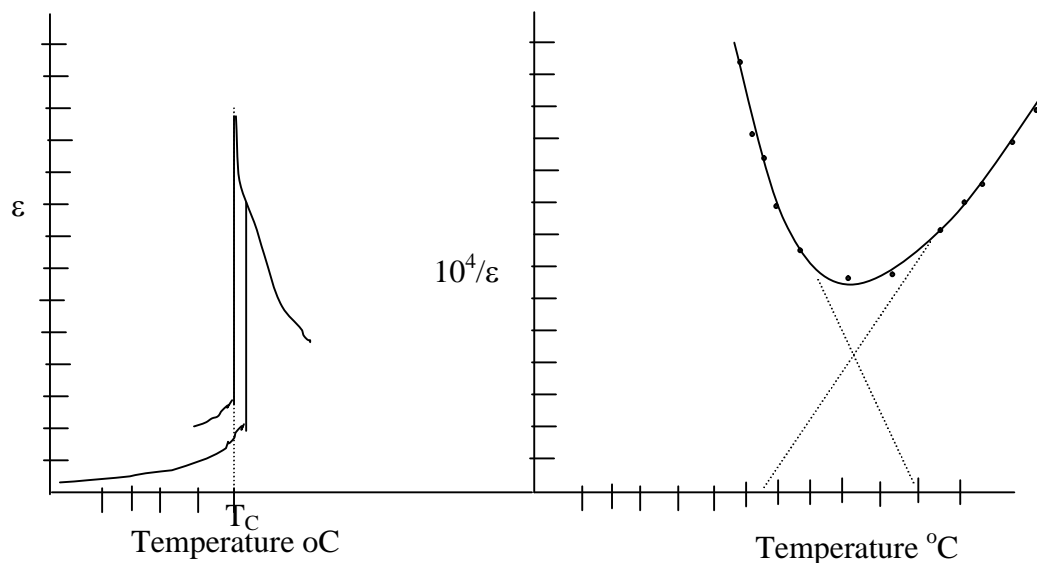
If we suppose that near the critical temperature the value of s varies with temperature in a linear fashion,

$$s \cong \beta (T - T_c),$$

where β is a constant. We have, above the transition temperature, a Curie-Weiss law for the dielectric constant:

$$\epsilon \cong \frac{3/\beta}{T - T_c},$$

Which is of the form of the observed temperature variation, as shown in fig



The dielectric constant versus temperature graph shows a peak at Curie temperature.

Formula:-

Two plane parallel plates of area A and separation d are charged with a surface charge density q , one plate being positive, the other negative. If the space between the plates is evacuated and if d is small compared with the dimensions of the plates, there will result a homogeneous electric field between the plates, the field strength being given by

$$E_{\text{vac}} = 4\pi q \text{ in e.s.u}$$

The potential difference between the plates is equal to

$$\phi_{\text{vac}} = E_{\text{vac}}d$$

The dielectric constant of a system is defined by

$$C_{\text{vac}} = Aq/\phi_{\text{vac}}$$

Suppose now that the space between the plates is filled with a dielectric, the charge on the plates being kept constant. It is then observed that the potential difference is lower than and similarly, the capacitance C of the system is increased. The static dielectric constant ϵ_s is then given by

$$\epsilon_s = \phi_{\text{vac}}/\phi = C/C_{\text{vac}}$$

Description of the apparatus: The apparatus consists of the following items

- 1) A dielectric cell with two parallel plates to keep the sample and a setup to measure the capacitance of the cell.
- 2) A heating arrangement to raise the temperature of the dielectric cell
- 3) A digital thermometer with thermocouple and a temperature controller arrangement to measure the temperature of the sample

Procedure:-

The sample is placed in position between the parallel plates and the capacitance at the room temperature is measured. The sample is heated by feeding power to the plate heater. As the temperature difference across the sample is negligible, the temperature given by the thermo couple D is taken as the sample temperature. The sample is heated to a temperature more than the Curie temperature and the allowed to cool.. The capacitance is measured at different temperature as the sample cools. After cooling the sample to the room temperature, the sample should be removed and the capacitance between the plates is measured which directly gives the capacitance of condenser in air

Observations:

| Sl.No. | Temperature in $^{\circ}\text{C}$ | Capacitance in pf | Dielectric constant |
|--------|-----------------------------------|-------------------|---------------------|
| | | | |

Graph:-

A graph is drawn taking temperature in $^{\circ}\text{C}$ versus dielectric constant. We observe from the figure that the graph increases exponentially and it reaches a peak point and falls again even though the temperature increases.

Precautions:-

1. The sample should be placed exactly between the two parallel plates
2. The sample should be removed carefully without disturbing parallel plates for measuring the capacitance of the cell in air.
3. The micrometer screw has to be tightened for contact of the sample with upper electrode of dielectric cell when the sample reached maximum temperature. The sample should not be heated after establishing contact as the crystal may break itself due to expansion.
4. The micrometer should be changed very slowly in one direction only, without causing pressure on the thin sample. Any undue pressure will break the costly sample. The quick forward and backward motion of micrometer will cause backlash error.

Result:-

The curie temperature of the sample from the graph =
Literature Curie temperature for the sample under test =
The corresponding dielectric constant =

Note to teachers:

The students may be asked to calibrate the LCR meter, temperature indicator with standard values. The capacitance of the empty cell in air may be calibrated with movement of micrometer screw and the students may be used to determine the capacitance of the cell for the corresponding micrometer readings noted at different temperature with the sample present in the cell. They may be asked to repeat the calculations with the C_0 values obtained at different temperatures.

Experiment No. 2

SPECIFIC HEAT OF GRAPHITE

Aim: To determine the specific heat of Graphite (solids).

Apparatus: Sample, Heater with temperature control and temperature indicator, Ammeter 0-5 Amp (wide scale), Voltmeter, Dimmer stat, Stopwatch.

Principle: Specific heat is defined as

$$s = dQ / dT$$

Where dQ is the quantity of heat supplied to one gram of body and dT is the corresponding temperature.

When a solid of mass m is heated by supplying heat energy Q the resulting temperature T is given by the equation

$$Q = m.s.T$$

When a body is heated the temperature increases and attains a steady value. It is usually observed that the rate of heating dQ/dt is exactly equal to the loss due to cooling .

In other words,

$$dQ / dt = m.s.(dT / dt)$$

Thus by measuring dQ / dt and dT / dt the specific heat s can be calculated.

Description of the apparatus: The sample provided, is a graphite rod and the heat energy is provided to the sample using a heating element kept in contact with it and passing electrical current through it. The current which is equal to V / r produces heating in the element. The sample is surrounded with insulating material to avoid heat losses. As the element is in contact with the sample, as equilibrium is reached, the sample heat energy can be considered as equal to the electrical energy supplied to the heating element. The potential difference across the terminals of the heating element can be measured with a voltmeter. The current passing through the element can be measured with Ammeter. The temperature of the sample is measured with a digital thermometer having thermocouple sensor. The time is noted with a stopwatch.

Procedure: The heater is fed electrical power from a Variac. The sample is hold in a wooden box. The space between the sample and the walls of the box is filled with insulting material. The thermocouple or thermometer is inserted in a hole drilled into sample. The leads of the heater are connected to a Variac. The mass of the sample is determined using a suitable balance. The heater and thermometer are inserted into the sample block and assembly is put into the wooden box.

Dimmer stat output is set at half the numeric value of the resistance i.e. if the heating element resistance is 20 ohms apply a voltage of 10 V from dimmer stat to the heating element so that only half-an ampere current flows. Allow for half minute and check if any burning smell is observed or not. Measure the current and the equilibrium temperature of the sample for different voltages (40,80, 120,160 V) with an interval of approximately 40 volts, Continue this process slowly allowing sufficient time for the sample to heat until the temperature of the sample reaches

300⁰ C. The observations are given in the table 1. Potential difference V versus equilibrium temperature graph is shown in fig 1.

dQ/dt is given by V^2/r where $r = V/I$ is the resistance of the sample.

The power is switched off and as the sample block cools, the temperature is noted at regular intervals of time. By plotting the sample temperature as a function of time. We get the cooling curve from which the rate of cooling dT/dt can be obtained at any temperature. Using the value of dT/dt from the cooling curve at the appropriate temp the specific heat can be calculated from the eqn.

$$dQ / dt = d(V^2/r) / dt = m.s.(dT / dt)$$

$$s = (dQ / dt) / m (dT / dt)$$

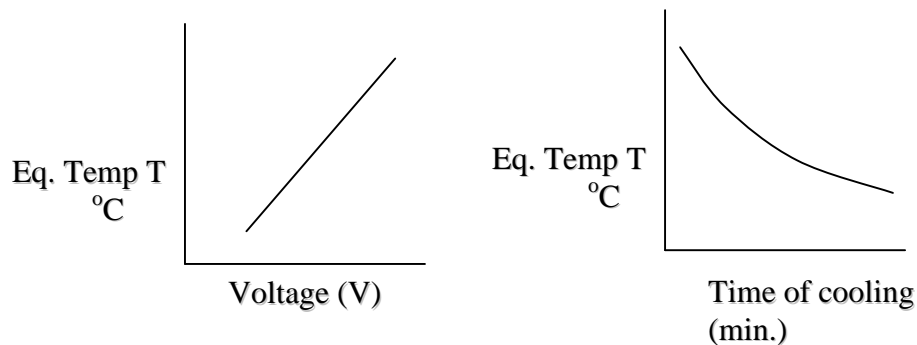
Observations:- Equilibrium temperature and current values of the specimen at different voltages

| Sl.No. | Voltage (volts) | equilibrium temperature ⁰ C | current mA |
|--------|-----------------|--|------------|
| | | | |

Observations for determining the rate of cooling (dT / dt)

| S.No. | Time (t minutes) | Temperatue (oC) |
|-------|------------------|-----------------|
| | | |

Graphs:



Precautions :

- 1) Handle the Graphite block carefully as it may break.
- 2) Keep the Variac at Zero voltage position and then give connections after ensuring that The Variac output is less than at most 5V if not zero. If the Variac is showing higher voltage at minimum position it has to be changed. The thermocouple sensor is delicate and it has to be handled carefully.
- 3) Increase current in small increments say 0.1 amp
- 4) If possible use a dc voltage source like car batteries to supply steady voltages.
- 5) If you use a Dimmer stat (Variac) do not touch the electrical part as it may give electrical shock.
- 6) If a variac is used to supply electrical power do not take face reading as correct. measure it with a voltmeter or a digital multimeter.
- 7) If a variac is used, to avoid fluctuations in power always use a voltage stabilizer.

Result: specific heat of graphite =

Standard value of specific heat for graphite = $0.38 \text{ cal/gm/degree at } 206^\circ \text{C}$

Experiment No. 3

COEFFICIENT OF THERMAL EXPANSION

Aim:- To determine the thermal expansion coefficient of a given solid sample.

Apparatus:- Sample in the form of small (2mm × 2mm × 1mm) rectangular slab or thin metal wire, glass slides to form wedge and a heating arrangement, dimmer stat, sodium vapour lamp, traveling microscope, dimmer stat, arrangement to observe optical interference fringe pattern with optical wedge.

Principle:- When a solid is heated its dimension changes. The change in dimension is described in terms of the coefficient of thermal expansion as the change in the length of the specimen per unit rise in temperature per unit length. A sample is a three dimensional object and due to change in temperature, volume changes. However for isotropic substances the expansion is same in any direction. So if we take the sample in the form of a small rectangular slab the volume expansion can be related to linear expansion using the relation

$$\text{Volume expansion} = 3 \times \text{linear expansion} = 3 \alpha$$

$$L_2 = L_1(1 + \alpha(T_2 - T_1))$$

Where L_2 and L_1 represents the thickness of the specimen at temperatures T_2 and T_1 . If the sample is in the form of a thin wire, the thermal expansion of the diameter of the sample can be considered as linear. So, by measuring the linear expansion we can determine volume expansion of the given material. We can measure the thickness of the sample L_1 with a screw gauge at temperature T_1 . Suppose we heat the sample to temperature T_2 . The change in thickness is so small that we cannot measure it with a screw gauge and we have to use more accurate device or method to determine L_2 or the change in length ($L_2 - L_1$). Usually T_1 is room temperature. However L_2 , the thickness of the sample at an elevated sample cannot be measured very accurately as the change in L is very small because the expansion coefficient is very small. It will be of the order of 50×10^{-6} .

A change of temperature by 200 degree centigrade will result in a change of length of order of 0.01mm. To determine the changes of small magnitude a common method based on the principle of optical interference is used.

A parallel beam of light from a monochromatic source is made to fall vertically on a wedge system formed with two plane parallel glass plates with the sample kept at one end of the system in between the plates. The sample is included in the optical arrangement such that it controls the wedge angle. An air film of uniformly varying thickness is formed between the plates. When a monochromatic light falls on such a system, it results in an optical interference pattern. The light reflected from the surface of the upper plate and lower plate gives rise to a fringe pattern consisting of a set of parallel equally spaced lines. Simple derivation relates the fringe separation to the angle between the two plates. Then the change in fringe separation due to heating of the sample yield the change in thickness of the sample due to change in temperature dT which can be measured with a thermocouple.

$$\alpha = \frac{\lambda D}{2L} \frac{1}{T_2 - T_1} \left(\frac{1}{\beta_2} - \frac{1}{\beta_1} \right)$$

D is the distance between the eyepiece to the glass plate

L is the length of solid (thickness in the case of slab or diameter in the case of a wire)

λ is the wave length of monochromatic light source

β_1 is the fringe width at temperature T_1

β_2 is the fringe width at temperature T_2

Procedure:- The thickness of the sample is measured at room temperature with a screw gauge . The thickness of the sample at room temperature is determined with wedge method and compared with the value determined using screw gauge. The sample is placed on the top of plate Q_1 and the second glass plate is placed over the sample. Screw is manipulated such that Q_2 touches Q_1 for the stability of the assembly. Between Q_1 and Q_2 a thin air film is formed. . If the sample is a metal rod it may be shaped such that it provide a hold for Q_1 and Q_2 .

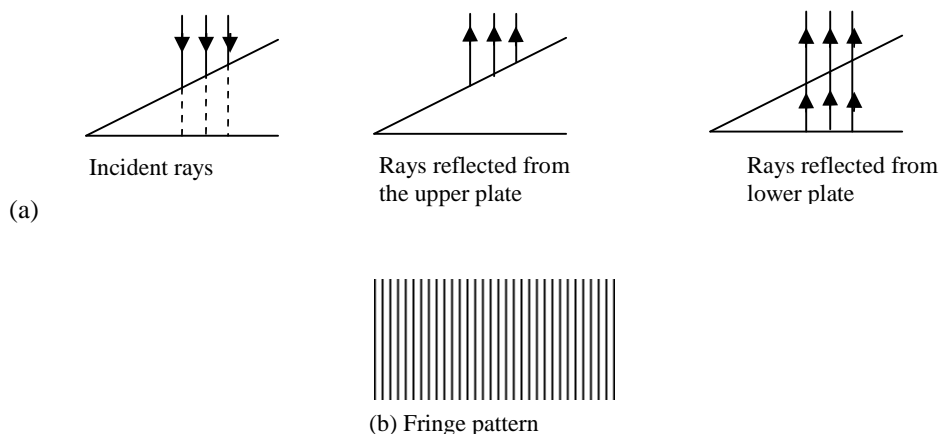


Fig 1. Interface at a wedge (a) incident and reflected rays (b) fringe pattern

Looking through the microscope the screw is gently manipulated such that the light falling the wedge produces the fringe pattern. The fringes are straight and parallel and equidistant. With the help of microscope the distance between 5 or 10 fringes is measured and the fringe width β_1 is determined. The heater is switched on to give the desired temperature (T_2). T_2 is chosen to be about 20-40 degree centigrade above room temperature. The fringe width β_2 is again determined. From the formula calculate the value of α .

Observations:

To determine fringe width.

D is the distance between the eyepiece to the glass plate =

L is the length of solid (thickness in the case of slab or diameter in the case of a wire)

Initial temperature $T_1 =$ $^{\circ}\text{C}$

Final temperature $T_2 =$ $^{\circ}\text{C}$

λ is the wave length of monochromatic light source =

| TEMP($^{\circ}$ C) | No. Of Fringes | Micrometer reading | | | Width of five fringes | Average fringe width (β) |
|---------------------|----------------|--------------------|-----------------------|----------|-----------------------|----------------------------------|
| | | MSR cm | Vernier Scale Reading | Total cm | | |
| | | | | | | |

Precautions :

- 1) Thickness of the sample must be very small
- 2) Arrange the optical system to get bright fringe pattern

Result:- The coefficient of thermal expansion of given specimen (aluminum) is determined.

The calculated value is:-

The standard value is:- $25 \times 10^{-6}/^{\circ}\text{C}$

Experiment No.4

LATTICE DYNAMICS

Aim:- To study the dispersion relation for the monoatomic and diatomic lattice and determine cut off frequency of the mono atomic lattice through electrically simulated network.

Apparatus:- lattice dynamic kit , C.R.O , connecting wires ,

Lattice dynamic kit consists of the following parts.

(1) Audio oscillator with amplitude control and facility to vary the frequency in the following ranges.

| Switch position | frequency range | out put voltage |
|-----------------|-----------------|-----------------|
| Low | 1.3-11.6 kHz | 4-6 v |
| High | 9.64-94 kHz | 4-6 v |

The oscillator uses IC XR 2006 .It has built in power supply and an in put stage to match the impedance of the stimulated lattice.

(2). The lattice dynamic kit consists of an electrical transmission line stimulates one dimensional mono and diatomic lattice.

Theory:- An electric transmission line which stimulates one directional mono atomic and diatomic lattice .the out put of the stimulated lattice is taken via a four pin connector provided with red , green and yellow wires . The red wire is to be connected to the horizontal input, the yellow wire is connected to vertical in put and, the green wire is connected to ground of the C.R.O. When operated on external horizontal mode we see display of Lissajous figures, which indicate the phase difference between in put and out put signals of lattice network.

Fig(1) shows one dimensional monoatomic lattice in mass and spring model. All particles have mass m , force constant f and the distance between particles is a , assuming only the nearest neighbouring interaction. The equation of motion of n^{th} atom is given by

$$Mx^n = f (x_{n-1} + x_{n+1} - x_n) \text{---(1)}$$

Which when solved gives the angular frequency

$$\begin{aligned} W^2 &= 4f/m \sin^2 (ka/2) \\ &= 2f/m (1 - \cos\theta) \text{---(2)} \end{aligned}$$

The electrical analog of the mono atomic lattice is shown in fig(2). The dispersion relation for the circuit is

$$W^2 = 2/lc (1 - \cos\theta) \text{---(3)}$$

The diatomic lattice with alternative masses m and M shown in fig (3) and can be stimulated by the transmission line with alternative capacitors c and c_1 shown in fig (4).

The dispersion for the mechanical and electrical are given as

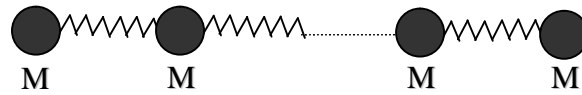


Fig 1: Monoatomic lattice

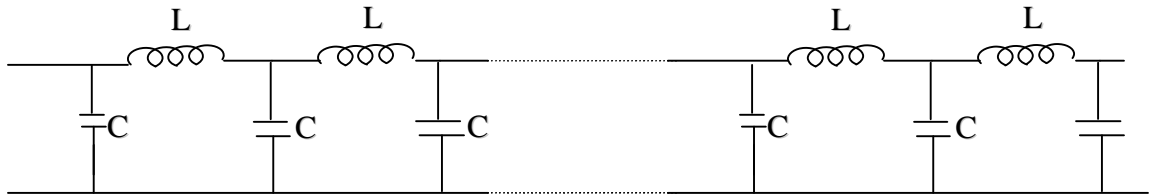


Fig2: Network simulating mono atomic lattice

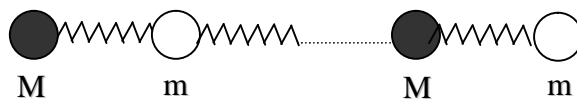


Fig3: Diatomic lattice

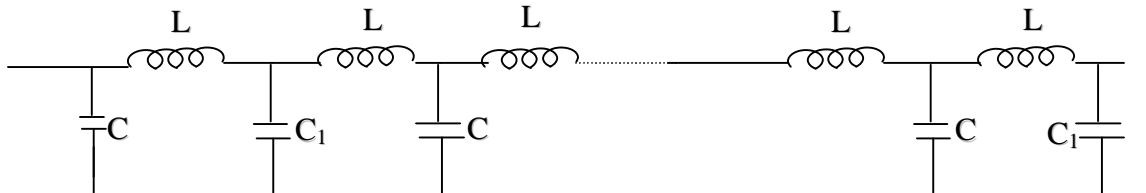


Fig4: Network simulating diatomic lattice

$$W^2 = f [1/m + 1/M] + f [(1/m + 1/M)^2 - 4\sin^2\theta/M*m]^{1/2} \quad \text{mechanical}$$

$$W^2 = 1/L [1/c + 1/c_1] + 1/L [(1/c + 1/c_1)^2 - 4\sin^2\theta/cc_1]^{1/2} \quad \text{electrical}$$

In contrast to the mono atomic lattice there are now two frequencies w_+ and w_- corresponding to a value of the wave vector k . A plot is drawn for frequency versus θ as shown below. This lead to the one corresponding to w_- is called acoustical branch and the other one corresponding to the w_+ is called the optical branch.

Procedure:-**(1) Monoatomic Lattice:**

Connect the lattice dynamic kit to the audio oscillator and plug in the power cord of the oscillator. Feed the out put of kit to a general purpose C.R.O. Select the switch monoatomic on the kit. The transmission line now consists of 10 unit cells. The line is terminated by the resistance R_2 is equal in value to the characteristic impedance

$$R_o = \text{Sqrt}(L/C)$$

Starting with the lowest frequency vary the frequency of the audio oscillator and determine the frequencies at which the phase difference between like input and output voltages of the stimulated lattice is $n\pi/2$. At low frequencies the C.R.O. pattern shows a straight line an ellipse and at a particular frequency the pattern shows a circle. The phase difference is now $\pi/2$. At this point the phase difference per unit cell is $90^\circ/10 = 9^\circ$. Vary the frequency and find out the maximum frequency of transmission. Compare it with the theoretical value of $1/\pi \times \text{sqrt}(L/C)$.

2.Diatomic Lattice: Flip the slide switch on the front panel of the lattice dynamic kit towards the di atomic. The alternate capacitors are now changed to $C_1=0.147\mu\text{F}$

. Repeat the procedure discussed in mono atomic lattice. Adjust R_2 to get distortion free output.

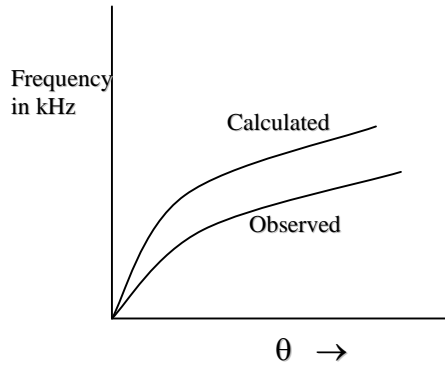
Observations:**Mono atomic**

| S.No | CRO pattern | Dial reading | N θ | θ | frequency(kHz) | |
|------|-------------|--------------|------------|----------|----------------|------------|
| | | | | | Observed | Calculated |
| | | | | | | |

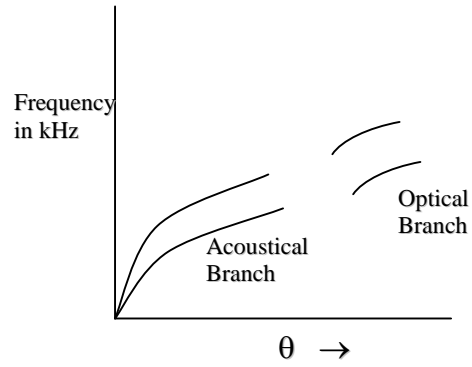
Diatomic

| S.No | CRO pattern | Dial reading | N θ | θ | frequency(kHz) | |
|------|-------------|--------------|------------|----------|----------------|------------|
| | | | | | Observed | Calculated |
| | | | | | | |

Mono atomic



Diatomic

**Precautions:**

1. The connections must be made perfectly.
2. The Lissajous figures must be distortion free. To get distortion free figures we can use R_2 .
3. The frequencies corresponding to the dial reading must be taken from given chart.
4. The output figure must be with mean size without distortion.

Result:

The dispersion relation for mono and diatomic lattice is studied.

Experiment No. 5

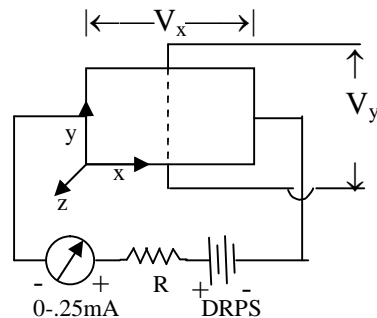
HALL EFFECT

Aim:- To study the Hall effect the semi conductor and determine hall constant and related parameter.

Apparatus : Hall effect apparatus, Semiconductor sample with electrodes, Stabilized voltage sources, Gauss meter, Digital Multimeter, 0-1A current meter , Screw gauge, Vernier calipers etc.

Theory:-

Hall effect is magneto electric effect. A semi conductor in the shape of a thin rectangular slab with its edges taken as parallel to the Cartesian coordinate axes as shown in fig 1. A current flow along X-axis and a magnetic field is applied along Z- axis. Then a potential difference appears between the faces parallel to Y- axis. It is called Hall voltage and the phenomenon is called Hall effect.



Hall coefficient R_H is given by the equation

$$R_H = E_Y / (J_x B_z)$$

E_Y - electric field produced along Y- axis of probe

$E_Y = V_Y/b$

V_Y - hall voltage along Y- axis

b - breadth of hall probe

Current density is given by

$$J_x = I_x/(bt)$$

I_x - hall probe current

t - thickness

B_z - magnetic field produced along X-axis.

Number of charge carriers per unit volume η is given by

$$\eta = 1/(R_H q)$$

where,

q - charge of electron = 1.602×10^{-19}

$$\rho = (V_x b t) / (I_x L)$$

where,

V_x - hall voltage along x axis

Mobility of the charge carriers is given by $\mu = R_H / \rho$

Hall angle $\theta = \tan^{-1}(\mu B_z)$

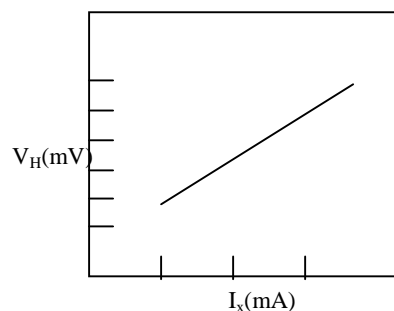
Description:-

A semi conductor in the shape of rectangular parallelopiped is placed between poles of an electro magnet and a current from constant current source is passed through along the length of the bar. A magnetic field is applied in a direction perpendicular to the current direction by passing a current the magnetic coils wound around pole pieces of electro magnet and the current is measured with ammeter of range 500 mA. The potential difference across the length of crystal is measured with a voltmeter. Hall voltage V_H is measured with millivoltmeter. FET electronic voltmeter may be used to measure both voltages. The current through the bar should not exceed the safety limit. The current to the electro magnet is supplied using a stabilized supply. Magnetic field is measured with a Gauss meter.

Procedure:-

The dimensions of specimen are measured carefully. The probe is placed between the poles of electromagnet. By applying voltage across the length a d.c current (I_x) is passed along the length of the probe. The Hall voltage is measured at zero field. Then magnetic field is applied by switching on the current of electro magnet. For each value of I_x , we should take two transverse voltages, one is without field and second is with field and difference of these two gives the Hall voltage. A graph is drawn for V_H versus I_x . It is a straight line.

Graph:



Observations:

Material used :

Sample (Hall probe) thickness :

Length :

Breadth :

Current through the coils :

Magnetic field applied :

Resistance across the length of probe:

| S. No. | V_x | I_x | Transverse Voltage(mv) | | V_y (b-a) | R_H |
|--------|-------|-------|------------------------|-------------------|----------------|-------|
| | | | With out Field (a) | With Field (b) | | |
| | | | | | | |

Precautions :

- 1.The probe should be handled very carefully.
- 2.The maximum current through the probe specified should not be exceeded
- 3 Since the magnetic field is subjected to hysteresis in the material. Value of B is taken corresponding to the increasing or decreasing current as the case may be.

Result:

The various parameters of Hall effect and hall constants are determined.

Standard Values:

Hall coefficient (R_H) = 1.02×10^{-4} Ohm-mt³/web. (InAs)

Observed values :

Experiment No. 6.

NUMERICAL APERTURE

Aim:-To measure the numerical aperture of an optical fiber cable.

Apparatus:-Step index optical fiber cables, laser source, traveling microscope, screen, scale.

Description:-

An important parameter of an optical fiber is Numerical Aperture. Numerical aperture refers to the maximum angle at which the light incident on the fiber end is totally internal reflected and is transmitted properly along the fiber. (Or) Numerical aperture is the light gathering efficiency of the fiber.

The cone formed by the rotation of this angle along the axis of the fiber is the cone of the acceptance of the fiber and the angle is known as the acceptance angle (θ_{\max}). The light ray must strike the fiber end within this acceptance angle else it is reflected out of the fiber core. This indicates the number of modes propagating within the fiber, which has consequent effects on both fiber description and the fiber attenuation.

It is defined as the product of the refracting index of the incident medium and the sine of the maximum ray angle. i.e.

$$NA = n_i \sin(\theta_{\max})$$

$$= \sin(\theta_{\max}) n_i = 1 \text{ for air.}$$

Procedure :- In this experiment one end of the optical fiber cable is connected to the laser source. The laser light is transmitted to the fiber to the other end of the cable through the phenomenon of total internal reflection. The light coming from the second end is focused on the second end as a circle.

Microscope readings are taken by adjusting the cross wires at the two ends of the circle.

The difference between the two readings gives the diameter of the circle from which the radius (r) of the circle can be measured.

The distance between the screen and the fiber end (d) can be measured.

Now the numerical aperture of the optical fiber can be calculated using the following formula.

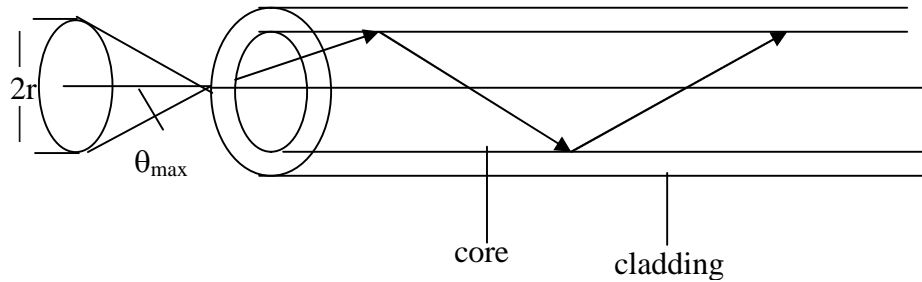
$$NA = \sin \theta_{\max} = r / (r^2 + d^2)^{1/2}$$

Where r is the radius of the circle.

θ_{\max} is the maximum angle at the incident. θ

And d is the distance between the screen and the fiber end.

Fig:-



Observations:

| Distance(d mm) | Diameter (2r) | NA | θ |
|----------------|---------------|----|----------|
| | | | |

Repeat the experiment with available different step index optical fibers (say plastic core - plastic clad, glass core- glass clad, glass core- plastic clad, plastic core- glass clad)

Precautions:-

1. The fiber cable should not bent in order to cut off the loss of light.
2. The laser source must be continuous.
3. The light must be well focused on the screen as a circle with out any diffusion.
4. Don't see the laser light directly. It is hazardous and retina may damage. Care should Be taken.

Result: -

The numerical aperture of the fiber cable is:

Experiment no.7

B-H curve

Aim: a) To trace the B-H loop of a transformer core using CRO
b) To evaluate the hysteresis loss in the specimen

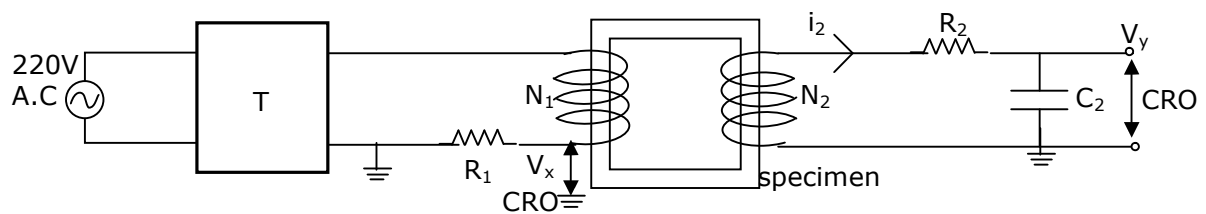
Apparatus: CRO, capacitors, resistor, multimeter, core transformers

Introduction:

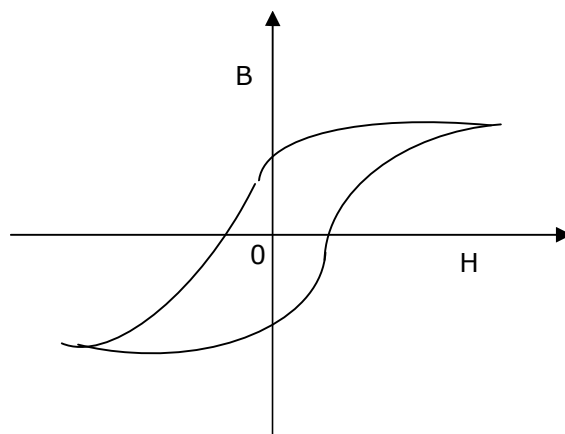
Ferromagnetic materials contain large numbers of small regions called domain .in each domain all the atomic magnets are locked in rigid parallelism. Thus each domain has a net magnetization in a particular direction. When the specimen exposed to external magnetic field H. the domains with magnetization component along the direction of the field grow at a phase of those, which are not favourably oriented. Thus the magnetization increases with field as shown in figure. When all the domains are aligned in the field direction, the specimen gets saturation.

When the external field is removed the domain boundaries do not move completely back to their original positions and as such lead to remnant magnetization. When the specimen is exposed to an alternating magnetic field, the phase difference between B and H causes the hysteresis loop. The tendency of a domain to move around gives rise to mechanical stress in the specimen. These in turn produce heating. This loss due to heat energy is called the hysteresis loss. The area enclosed by the hysteresis loop gives the energy lost due to cyclic magnetization.

Circuit Diagram:



Graph:



Experimental procedure:

1. Arrange the circuit as shown in the figure. The input to the primary of the core is supplied by the step down transformer (T). The voltage across R_1 is given to the horizontal input of CRO while the voltage across C_2 feeds the vertical input of the CRO
2. The horizontal and the vertical gain controls of the CRO are adjusted to get a loop of convenient size.
3. Trace the B-H loop on a graph paper.
4. Determine the vertical sensitivity V_y and horizontal sensitivity V_x without disturbing the gain controls. The sensitivity is expressed in volts per cm.

Energy Loss:

The energy loss of the core is given by $\left(\frac{R_2 C_2}{N_2 A}\right) V_y \left(\frac{N_1}{R_1 L}\right) V_x$

$$= \left(\frac{R_2 C_2}{N_2 A}\right) \left(\frac{N_1}{R_1 L}\right) V_y V_x \times \text{Area of the loop in cm}^2 \quad \text{Joule/second /unit volume}$$

Where L = length of coil in centimeters and A is the area of the coil.

Precautions:

1. The specimen should be at the centre of the magnetizing coil very close to the probe.
2. If the area of the loop is expressed in cm^2 , the sensitivities should be expressed in Volts/centimeter in either case the length of the coil should be in meters.

Result:

Energy loss for Iron core =

Energy loss for Ferrite core =

Experiment No. 8**QUINCKES METHOD**

Aim: To determine the magnetic susceptibility of a paramagnetic salt in a solution and study the variation with concentration.

Apparatus: Quinckes tube, electro magnet, power supply, gauss meter, balance, measuring jar, beakers, cathetometer.

Principle: when a paramagnetic salt like Ferric chloride is dissolved in water, the solution becomes paramagnetic (water is diamagnetic). When the solution is placed in a narrow glass tube and exposed to magnetic field in such a way that part of the same is out side the magnetic field, the level of the solution rises in the narrow limb, due to the force due to susceptibility. In the case of a diamagnetic liquid like water, the level is dispersed.

By measuring the rise of the liquid level the magnetic susceptibility is found out.

Description:

(A). The Quinckes tube is a glass tube with two limbs. The diameter of one limb is about 1.5 cm while that of second is 3mm. The wider tube can be fixed to a wooden stand in such a way that the tubes are vertical.

(B). The cathetometer is an instrument, which can be used to measure accurately vertical (or) horizontal distance, While the object is at an adjustable distance of 1 meter or more. It consists of a sturdy base to which a vertical shaft graduated in cm and mm is fixed. A telescope is fixed to this shaft. Provision is made to fix the telescope at a position and move it finely. The position of the telescope can be observed on the scale with vernier accurate to 0.001 cm. The entire arrangement can be placed horizontally so that horizontal distances can be measured.

Procedure:

The paramagnetic salt is weighed so that it is about 10 gm. It is dissolved in 20 ml of distilled water. The same is transferred to the Quinckes tube so that the level in both limbs is about three fourths. It is fixed to the wooden stand and placed in the magnetic field in such a way that the narrow limb is at the center of the pole pieces while the wider tube is out side the magnetic field.

The level is observed in the cathetometer and adjusted to coincide with the cross wire with the help of fine motion. The level is noted. Now the magnetic field is switched on. This results in a rise in the level (for diamagnetic substance it is a depression). The liquid level is noted and the rise is found out.

Using a gauss meter the magnetic field is measured. The density of the solution is found out using a specific bottle. The experiment is repeated with different concentrations by diluting the solution progressively. The magnetic susceptibility (χ) is found out using the formula.

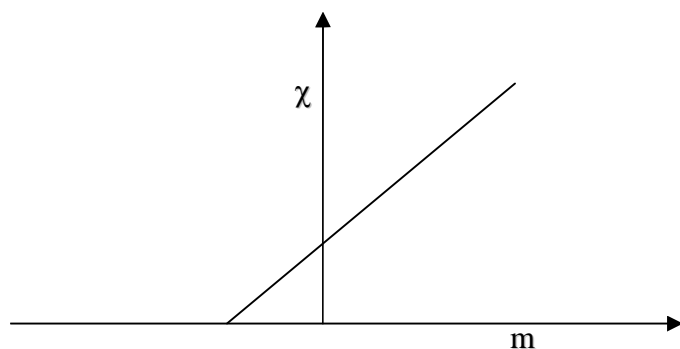
$$\chi = 2\rho gh/H^2$$

Where H = magnetic field

h = rise in the level.

ρ = density of the solution.

Variation of χ with concentration of paramagnetic salt is studied as given below. If **m** denote the mass of salt in solution per c.c, a graph is drawn taking **m** on the X-axis and χ on Y-axis. A graph is obtained which makes an intercept on the - ve X-axis . The intercept gives the value of magnetic susceptibility of the solvent.



Observations:

Magnetic field applied (H) =

| Mass of salt per c.c(m) | Rise in level of liquid (h) | Density of the solution (ρ) | Susceptibility (χ) |
|-------------------------|-----------------------------|------------------------------------|---------------------------|
| | | | |

Precautions:

1. The Quinckes tube is fixed in the magnetic field so that it is vertical.
2. The tube should be handled care fully to avoid breakage.
3. The hall probe should be placed so that the crystal is perpendicular to the magnetic field.

Result:

The paramagnetic susceptibility of given paramagnetic salt is

The variation of susceptibility with different concentration is studied.

Experiment no.9

Energy Band Gap

Aim: To determine the energy band gap of certain materials like silicon, germanium, LED (light emitting diode) by studying the temperature variation of the reverse bias.

Apparatus: Digital panel meter, 9V battery, Jack pins, test tube, thermometer, Dimmerstat, connecting wires, LED, silicon, Ge diode, soldering rod.

Theory: The current voltage characteristic of a P-N junction is given by

$$I = I_s \left[\frac{eq^2}{nkT} - 1 \right] \text{-----(1.1)}$$

Where I- forward junction current

I_s -reverse saturation current

V-junction voltage

q- electric voltage

k- Boltzman constant

T-temperature in Kelvin

n- constant

The reverse saturation current is given by

$$I_s = BT^3 \exp\left(\frac{-E_g}{nkT}\right) \text{-----(1.2)}$$

Where B is constant and E_g is the energy band gap

Combining equations 1.1 & 1.2

$$V = \frac{E_g}{q} - \frac{nkT}{q} \ln \frac{BT^3}{I} \text{-----(1.3)}$$

In the operating range of the diode, the temperature dependence is mainly determined by the term $\frac{nkT}{q}$. Hence a plot of V versus T gives a straight line. The straight line

extrapolate to 0K gives the energy band gap in electron volts.

Procedure:

These are two jacks J_B and J_D on the front panel. J_B is connected to 9V battery using a plug. The diode under investigation is to be connected to the J_D .

1. Switch the main supply. We will observe some numbers on the digital panel meter.
2. Connect a 9V battery to jack J_B .
3. Connect the diode under investigation to jack J_D in reverse bias phase
4. Adjust the current through the diode for a convenient values 80 μ A by varying the potentiometer P.
5. Place the diode in an oil bath. It is convenient to take oil heated to 110⁰C in a closed vessel and to place the diode in the oil.

6. Take the voltage across the diode as a junction of temperature. At each temperature adjust the diode the diode current to the chosen values by adjusting the potentiometer.

7. Tabulate the readings as shown in table below.

8. Repeat the experiment with silicon diode and the light emitting diode or LED

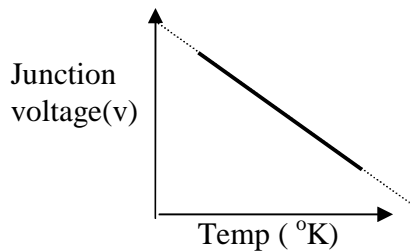
9. The results are recorded.

| Temperature(^o C) | Temperature(^o K) | Junction Voltage | | |
|------------------------------|------------------------------|------------------|---------|-----------|
| | | LED | Silicon | Germanium |
| | | | | |

Graph:

Draw a graph between the junction voltage and absolute temperature.

Extrapolate the graph to 0K. The Y-intercept gives the energy band gap of diode in eV.



Precautions:

1. Don't interchange battery and diode chord.
2. Check the voltage of battery. It should be 9V on load
3. Avoid the use of water for temperature variation as any amount of conditions may load to short circuiting of the diode.
4. If any problem occur, check the polarity of the diode the positive end of the diode must go to the negative end of the battery.

Result:

Standard values of energy band gap are

Germanium = 0.55 e.v

Silicon = 1.12 e.v

LED = 2.14 e.v

Observed values of energy band gap are

Germanium =

Silicon =

LED =

Experiment No.10

X-RAY DIFFRACTION

Aim: To analyse the powder x ray diffraction of a metal and determine the lattice constant.

Apparatus: x ray diffraction photograph, comparative, plate holder.

Principle: When a beam of monochromatic X-ray is incident on a sample contain randomly oriented crystallites, the rays are diffracted satisfying Braggs condition, the scattered beam forming a cone with the incident beam as axis and semi vertical angle $2\theta_{hkl}$ corresponding to a plane hkl. A powdered sample satisfies the Bragg condition. The diffracted lines are curved unless the angle 2θ is very near to 90° in which case the lines are straight. If S is the distance between the lines formed by the same cone of radiation and R is the radius of the camera, the Bragg angle is related by $\theta = S/4R$ radius and $\phi = S_1/4R$ radius where $\phi = 90 - \theta$. The distance between the centres of the two holes on the film (corresponding to incident and emergent beam) corresponds to angle θ . This is used to find R and hence angles θ .

Procedure: the developed x ray film is placed on the plate holder. The plate holder is a box on which a glass plate is fixed and over which the film is placed. The film is illuminated from the back using alight. The x ray comparator used in the present case is a catheto meter placed horizontally. This is properly leveled so that the centres of cross wires of the holes coincide with the centre of cross wires during the traverse across the film.

The positions of the lines L_1, L_2, \dots, L_N and $L^1_1, L^1_2, \dots, L^1_n$ are noted. Form these the center C_F through which the beam leaves is determined using the relationship.

$$C_F = L_1 + L_2/2 \quad I = 1 \text{ to } n$$

In the same way using the lines in the back reflection region the Centre C_B through which the beam enters the camera is determined.

$$R_{\text{eff}} = (C_B - C_F)/\pi.$$

The 'd' spacing of the reflecting planes (hkl) is determined from Braggs law. Using wavelength of CU $K\alpha$ (1.544\AA) the planes (hkl) are determined using $(h^2 + k^2 + l^2) d^2_{hkl} = a^2$.

The sum $(h^2 + k^2 + l^2)$ must be equal to an integer since hkl are integers. To assign suitable indices to lives measured d^2 is multiplied successively by permissible integers 1,2,3.... The products which agree within limits of error give the indices hkl of the respective plane. Using the above relation a, the lattice constant is calculated. An average of all values is taken.

It may be noted that certain class of planes (hkl) may be extinguished due to translational symmetry.

The no. of atoms per unit cell is calculated using

$$N = N_p a^3 / A$$

Where N is Avagadro no.

a is lattice parameter.

ρ is density.

A is atomic weight

$$F_{cu} = 8.96 \text{ g/cc}$$

$$a_{cu} = 63.54$$

$$F_{AL} = 2.70 \text{ g/cc}$$

$$a_{AL} = 27$$

Observations:

| S.No. | Position of line | | Arc length S= x ₂ -x ₁ | correction (p/100)S= a | Corrected Arc length S'=S + a | $\theta = S'/4$ | Sin θ | $d = \frac{\lambda}{2\text{Sin}\theta}$ | $d^2(h^2+k^2+l^2)=a^2$ |
|-------|------------------------|-------------------------|--|------------------------------|--|-----------------|--------------|---|------------------------|
| | Left x ₁ | Right x ₂ | | | | | | | |
| | | | | | | | | | |

Precautions: The comparator reading should be taken only in one direction.

Result: sample analysed

Lattice constant a =

No.of atoms/unit cell n=

Experiment no.11

ELECTRON SPIN RESONANCE SPECTROMETER

Aim: To determine the g-factor of DPPH using ESR spectrometer.

Apparatus: ESR spectrometer, CRO, RF oscillators.

Theory: The g-factor is given by

$$g = \frac{h\nu_0}{\mu_0 H_0}$$

here h = Planck's constant = 6.625×10^{-27} erg-sec

μ_0 = Bohr's magnetron = 0.927×10^{-20} erg/gauss

ν_0 = resonance frequency in Hz

H_0 = Magnetic field in gauss at resonance on the sample.

$$\text{Where } H_0 = 165.25 \times \frac{QI}{\rho}$$

QI is calculated from the graph

Description:

(1) Basic circuit:

The first stage of ESR circuit consists of critically adjusted radio frequency oscillator having a frequency range of approximately 10-17 M Hz. A marginal oscillator is required here so that the slightest increase in its load decrease the amplitude of the oscillation to an applicable extent. The sample is kept inside the tank coil of this oscillator which in term is placed in the 50 Hg magnetic field generated by the Helmholtz coils .At resonance is when the frequency of the oscillation equal to the Larmor's frequency of the sample. The oscillator amplitude registers a dip due to the absorption of the power by the sample this obviously occurs periodically four times in each sample complete cycle of the Helmholtz coil, supply voltage. The result is an amplitude-modulated carrier, which is then detected using a diode detector and amplified by a chain of three low noise, high gain audio amplifier by excellent stability. A sensitivity control is provided in the amplifier to meet the input requirement of any oscilloscope.

(2) Phase shifter:

In order to make it possible to use an ordinary displaying type oscilloscope instead of a measuring oscilloscope which preserve the phase between x and y plates signals a phase shifter is provided this can compensate the underived phase difference which is introduced in the amplification stage of the ordinary oscilloscope.

The circuit diagram of the phase shifter is shown in the fig. The 1⁰ of transformer is feed from the 230V, 50 Hz and the 2⁰ is center tapped developing. The operation of the circuit may be explained with the help of vector diagram shown in fig. The vector OA and BO represent the voltage developed in the 2⁰ phase a magnitude the current flowing in the circuit ADB leads the voltage vector BA due to

the presence of capacitor C and C1 shown in the diagram as I voltage developed across resistor R i.e, V_r is in phase with the current. I_r and the voltage across capacitor V_c is 90° out of phase with the current. The vector sum of V_c and V_r is equal to $2V_i$. These are also plotted in diagram it is clear from the diagram that R is varied V_r will change the point P will trace Q semi circle shown dotted. The vector OD or the voltage points O and D will therefore have a constant magnitude equal to V_i and phase variable from 0 to 180° . This voltage is feed to the X- amplifier of the oscilloscope to correct for any phase change that might have taken place in the rest of the circuit.

(3) 50 Hz Sweep unit:-

For modulation, with low frequency magnetic field, a 50 Hz current flows through the Helmholtz coils. As the resonance in this frequency range occurs at low magnetic fields, no static DC magnetic field is required.

(4) Power Supplier:

(a) DC power supply:-

The ESR circuit requires a highly stabilized almost ripple free frequency voltage. It is obtained as an integrated circuit regulator, the specifications of the D.C power supply are:

- 1) DC voltage 20V
- 2) Load regulation 0.03%
- 3) Line regulation 0.01%
- 4) Ripple < 3 mV
- 5) Long term stability 0.1% per 1000 units
- 6) Helmholtz coil power supply:- The Helmholtz coil power supply consists of a step down transformer (220 to 35V AC) separate winding on the main transformer, a potentiometer (12-15) and a moving coil rectifier type meter. The output is taken from the two terminals provided on a panel.

(5) Helmholtz coils:- There are two coils exactly like a parallel to each other, so connected that current passes through them in same direction. The coils increase the filling factor to the maximum DPPH i.e, a free radical & widely used as a standard for ESR measurements.

(6) RF Oscillator:- It is a transistorized radio frequency oscillator suitable for the determination of resonance frequency. The power to it is provided from the ESR spectrometer through a cable.

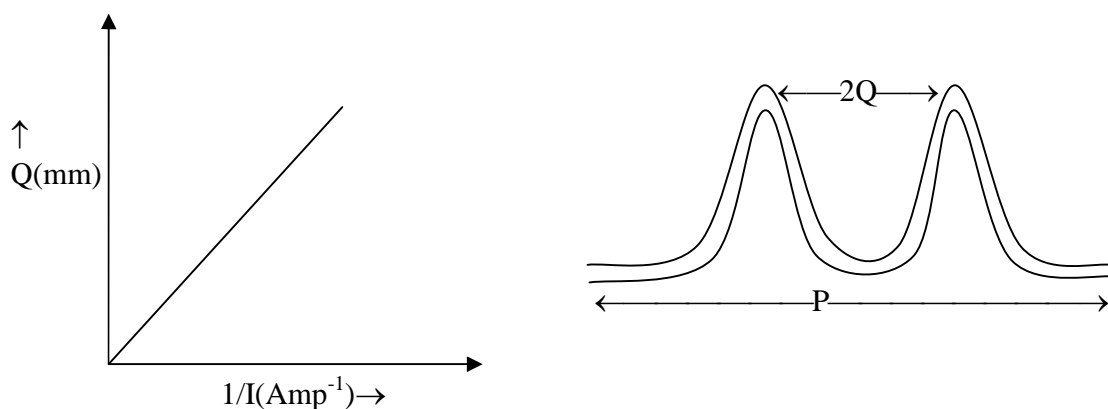
(7) Oscilloscope:- The oscilloscope is not supplied with the spectrometer it is pre assumed that the worker is already familiar with the central knobs and functioning of the oscilloscope in question.

Procedure:

1. Increase the horizontal sensitivity of the oscilloscope to the maximum within the linear range.
2. Obtain the possible resonance peaks by varying the frequency detection level and vertical sensitivity of the Oscilloscope.
3. Keep the frequency fixed but vary the current flowing through the coil and measure the corresponding horizontal separations between the peaks after adjusting the phase take 5-6 sets of observations.
4. Draw a graph $1/I$ Vs Q should be straight. Calculate the g -factor using the QI values from graph.
5. Repeat the experiment with different frequencies.

Observations:

| S.No | Current | Distance between the peaks (2q) | $1/I$ Amp ⁻¹ | Q mm |
|------|---------|---------------------------------|-------------------------|------|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

Graph:

Precautions:

1. Experiment should be set up at quite place free from electrical and mechanical disturbances.
2. Since the Helmholtz current is unstabilized should be taken that it should remain constant during the observations.
3. Y out put from the ESR spectrometer should be taken through shielded cable to minimize external peaks.

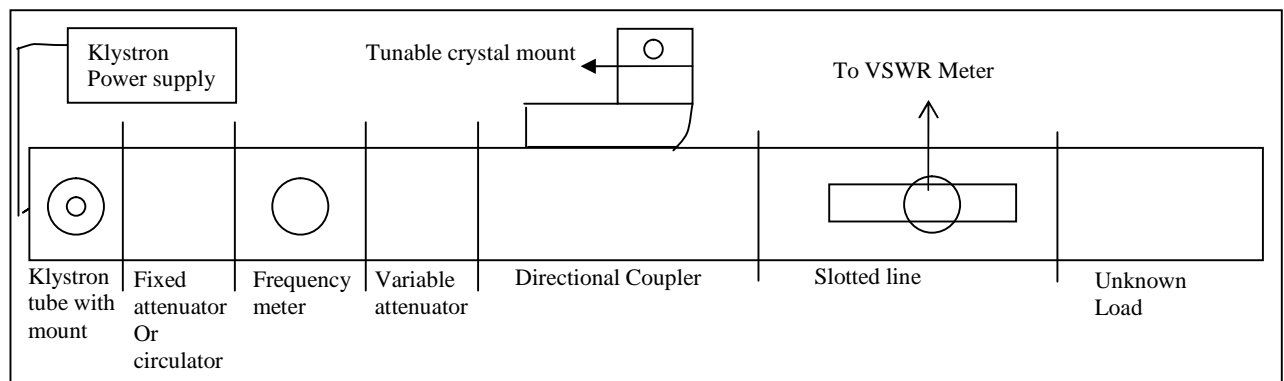
Result: Standard value of $g = 2.0023$
Calculated value of $g = 2.53$

Experiment No.12

Dielectric constant of Liquids / solids at microwave frequency**Introduction:****Basic set-up:**

Basic set up of the microwave test bench is shown in figure1. The klystron power supply is connected to a klystron mounted on klystron mount.

This constitutes the microwave source and generates oscillations at about 9,000 Mc/s. It is followed by padding attenuator, frequency meter, variable attenuator, directional coupler, slotted section and unloaded load which could be a horn or any other impedance to be measured.

**Obtaining oscillation:**

1. Check the klystron power supply. Before connecting the klystron leads to the power supply, switch on the power supply keeping the switch on the front panel in 'beam off' position. Wait for few minutes and then change the switch to 'beam on' position. The meter on the power supply should read 300 volts, which can be adjusted by beam voltage control. Bring back the switch to beam off position. Switch Off the power supply. Now connect the klystron leads to the socket 'output' of klystron power supply. Switch on the fan to cool the klystron.
2. Switch on the power supply and wait for few minutes. Turn the modulation switch to 'CW' position.
3. Set the variable attenuator to maximum attenuation.
4. Connect VSWR Meter to the output of crystal mount. Keep the control knobs of VSWR as follows:

| | |
|---------------------------|------------------------|
| Range db | -50db |
| Input Switch | -Crystal Low impedance |
| Meter Switch | -Normal Position |
| Gain Coarse & Fine Coarse | -Mid Position |

5. Switch on the beam voltage and check the beam current.
The rated values are:
Beam Voltage : 300 V
Beam current : 20-25 mA
6. See if there is any deflection in the VSWR. If there is no deflection decrease the attenuation of variable attenuator to get some deflection . Adjust reflector voltage to get maximum deflection.
7. Adjust the movable short of the crystal mount and also the probe penetration of the klystron mount to get maximum deflection.
8. Adjust the movable short of the crystal mount to get the maximum deflection. Every time variable attenuator must be adjusted so that the deflection of the spot does not exceed full scale.
9. Adjust the micrometer of the frequency meter to get the dip in deflection. Read the micrometer and corresponding frequency of oscillation from the chart provided with frequency meter.
10. Disconnect the meter from crystal mount and connect it to the output of the tunable probe mounted on the slotted section. The probe depth should be about $1/16^{\text{th}}$ inside the slotted section. This should be checked before mounting the slotted section in the bench.
11. Decrease the attenuation of the variable attenuator and tune the probe to get deflection. The connecting lead may have to be reversed to get deflection in the right direction Variable attenuator can be adjusted to get full scale deflection.
12. Shift the position of the probe in the slotted section and see if maxima and minima are being obtained and adjacent maxima or minima are of equal amplitude. The slotted line can be left open circuited at the time of observing the maxima and minima.

The test bench is now ready for experiments.

Aim: To demonstrate the method of measuring the dielectric constant of a sample of low loss dielectric (liquids/solids) at microwave frequencies

Apparatus :

Apparatus used

1. Basic set up with short circuit attached to the standing wave detector.
2. Liquid dielectric.
3. A piece of solid dielectric 0.9”×0.4” thick and one quarter wavelength thick.

Procedure:

For Solids:

One of the simplest methods for the measurement of dielectric constant of a solid material involves the measurement of The shift of the minimum of the standing wave produced by a short circuit (closing) the wave guide aperture. In other words, the position of the standing wave minimum is measured with or without the dielectric. If an approximate value of the dielectric constant is known then only one measurement is necessary. If not then measurements with several different thickness of dielectric

1. Set up the apparatus as shown in fig 1. The short circuits without the solid dielectric should be attached to the slotted section.
2. Obtain oscillations at some frequency.
3. Measure the exact guide/wavelength using the cavity frequency meter.
4. Obtain a piece of dielectric medium. Measure the thickness of this dielectric in cms. As accurately as possible using a micrometer.
5. Measure the exact possible of the first and second minimum from the right hand end of the slotted section by connection the short circuit plate without the dielectric sample or if the sample is firmly fixed to one face of the short circuit, its other face should be attached to slotted section.
6. Now remove the short circuit plate and attach the other face which contains the dielectric sample so as to fit closely in to the wave guide aperture.
7. The minimum will now have moved towards the short circuit. Measure the position of the first minimum from the standing wave detector.
8. Calculate 'L' (actual movement of a particular minimum towards right) or λ (the shift of the first minimum with dielectric from the first minimum without dielectric) which is to the right of the later.
9. Having found 'L' calculate the value of factor 'X' given by

$$X = \frac{\lambda_g}{d} \tan \left(\frac{2(L+d)}{\lambda_g} \pi \right)$$

where λ_g = Guide wave length
 d = thickness of dielectric sample in cms.
 L = Shift as measured.

10. Now a quantity V (which happens to be the number of wavelength of microwave radiation in a distance 'd' of dielectric) is defined by an equation:-

$$X = \frac{\tan(2\pi V)}{V}$$

The value of V to be found from the above expression since 'X' is known. This can be read of directly from the plotted graphs of

$$\frac{\tan(2\pi V)}{V} = X$$

or calculated otherwise.

11. Calculate the value of dielectric constant from:

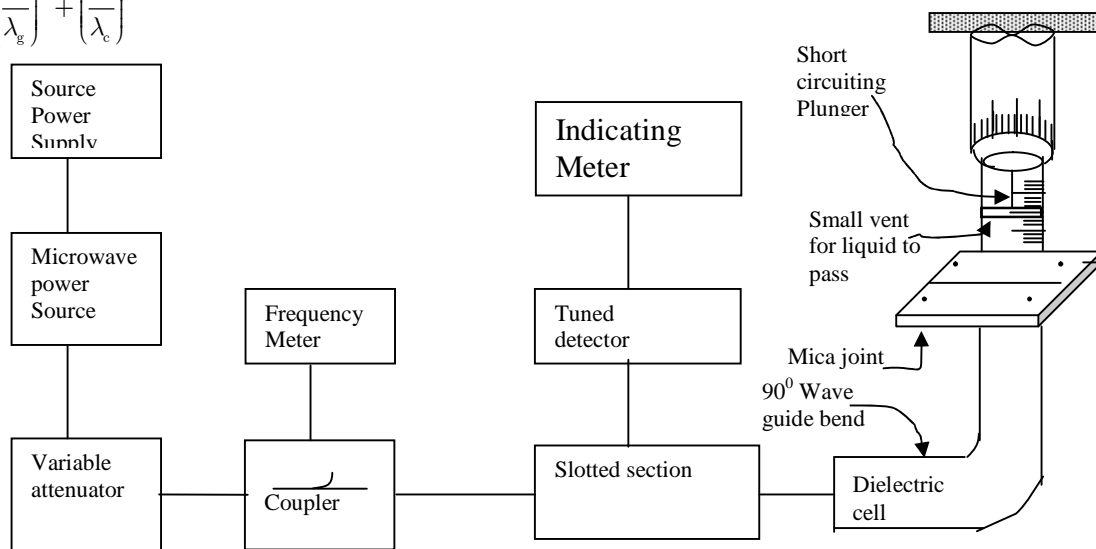
$$E = 1 - \left(\frac{\lambda_a}{\lambda_g} \right)^2 + \left(\frac{\lambda_a V}{d} \right)^2$$

Note:- The above procedure for calculation is only applicable for non-lossing materials.

For Liquids:

1. Assemble in the equipment as in fig2.
2. Energize the microwave power source and obtain suitable power level in the indicating meter.
3. Carefully move the shorting plunger till it touches the 90° bend.
4. Read and record the positions of standing wave voltage minima and determine λ_g and VSWR
5. Measure frequency of the exciting wave using frequency meter . If frequency meter is not available, compute it from

$$\left(\frac{1}{\lambda_0}\right)^2 = \left(\frac{1}{\lambda_g}\right)^2 + \left(\frac{1}{\lambda_c}\right)^2$$



6. With probe positioned at the maximum of the standing wave pattern, fill the cell with the dielectric under test, taking out the shorting plunger. Install the plunger in the cell and move it through the dielectric till it touches the 90° bend.
7. Slowly move the plunger up through the dielectric and record the position of the minimum.
8. Move the plunger down till meter reads double of that in step7, record the plunger position, say X_1 .
9. Move the plunger up till the meter again reads double the value at the minimum in step 7 and record the plunger position, say X_2 .
10. Find double the minimum width $(X_2 - X_1) = \Delta X_1$.
11. Move the plunger up when it is positioned on the second minimum. Measure and record the position of the minimum and double the minimum width.
12. Determine wavelength of the radiation in the dielectric, the distance between successive minima in the dielectric being $\lambda_d/2$.
13. Determine VSWR ($S_n = \frac{\lambda_d}{\pi \Delta X_n}$) for each minimum setting and compute $\rho_n = \frac{1}{S}$

For liquids:

- (e) Waveguide dimensions $a = \dots\dots\dots\text{cm}$, $b = \dots\dots\dots\text{cm}$
 (f) Cut off wavelength $\lambda_C = 2a = \dots\dots\dots\text{cm}$
 (g) Frequency of operation $f = \dots\dots\dots\text{GHz}$
 (h) Free space wavelength $\lambda_0 = \dots\dots\dots\text{cm}$

| S.No | Cell without dielectric | | Cell with dielectric | | Position of minimum | | Double the minimum width | VSWR |
|------|-------------------------|-------------|-------------------------|---|------------------------|-------------------|--------------------------|------|
| | Position of VSWR minima | λ_g | Position of VSWR minima | Wavelength of the radiation (λ_g) in the dielectric | Where power is doubled | | | |
| | | | | | Below the minimum | Above the minimum | | |
| | | | | | | | | |

Precautions:

1. Check the power of the microwave bench before the experiment is being done.
2. The klystron should be cooled with a fan.
3. Both the plunger and slotting section should be moved only in one direction.

Result:

The dielectric constant of solid is

Standard value:

Observed value:

The dielectric constant of Liquid is

Standard value:

Observed value:

SOLID STATE PHYSICS
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