

Q.2 a. Explain the effect of temperature on electrical conductivity of metals. (4)**Answer:**

The factors, on which the resistivity of conducting materials depends are:- Temperature: The electrical resistance of most metals increases with increase of temperature while those of semiconductors and electrolytes decreases with increase of temperature. Alloying: Alloying is another factor, which affects the resistivity of a material. By the addition of some impurity to the metal, its resistivity can be changed. Alloys have more resistivity than that of the pure metal. Mechanical stressing: When a material undergoes a mechanical treatment, its resistivity changes due to mechanical distortion of the crystal structure. Age hardening: It increases the resistivity of an alloy. (4Marks)

b. What are the factors which affect the resistivity of Electrical materials?(12)**Answer:**

Temperature dependence of electrical resistivity and conductivity in conductors: As the temperature is increased, there is a greater thermal motion in the atoms, which decreases the regularity in the atoms spacing with a consequent decrease in the mobility of the electrons. The resistivity of most of the conductors therefore increases with an increase in the temperature. Since the number and the energy of the electrons at top of the Fermi distribution curve vary insignificantly with temperature, the change in temperature must be associated with a change in the mean free path. In a perfectly regular lattice, each electron will exist in a particular energy state and will have a fixed velocity. Practically metals do not have a perfect lattice because of impurities and because of deviations of the atoms about their mean positions due to lattice oscillations. Since the lattice oscillations decreases at low temperature the scattering of electron waves falls and the conductivity therefore increases rapidly as the temperature reaches absolute zero. There is a limiting value beyond which the conductivity will not increase. In general, purer the specimen higher is the conductivity. the conductivity of many conductors decreases linearly as the temperature is increased above the room temperature but below this temperature the conductivity increases markedly.(4 Marks)

or $Q_0 = C_0 V$, where C_0 is defined as the capacitance.

By applying gauss theorem the magnitude of the flux density D with the parallel plates is given by

$$D = Q_0 / A$$

since the electric field strength E is related to the flux density by the relation .(4 Marks)

$$D = \epsilon_0 E,$$

the field strength in the region between the plates is given by

$$E = D / \epsilon_0 = Q_0 / A \epsilon_0.$$

Since $V = Ed$,

the capacitance of the system is given by $C_0 = \epsilon_0 A / d$

where ϵ_0 is termed as the absolute permittivity of free space and is expressed in farads meter. The value of ϵ_0 can be determined from experiment and its value is nearly equal to $10^{-9}/36\pi$ if the space between the plates is now filled with a dielectric and V is kept constant, it is found that the value of charge is found that the value of charge is increased to a value given by $Q = CV$ hence the new capacitance is given by $C = Q/V = \epsilon A/d$ where ϵ is defined as the absolute permittivity of the dielectric and the ratio is called the relative permittivity or the dielectric constant of the materials. (4Marks)

Q.3 a. Explain effects of internal fields in solids and liquids.**(12)****Answer:**

4.6 THE INTERNAL FIELD IN SOLIDS AND LIQUIDS

Each dipole moment interacts with its neighbour through its local electric field and therefore the theory of dielectrics in the case of dense substances such as solids or liquids where the dipoles are close together is much more complicated than that for rarefied substances. The main problem which arises in the case of solids and liquids in the calculation of what is known as the internal, local or the *Lorentz field*, E_i , which is defined as *the field acting at the location of a given atom*. In gases, the density of the molecules is reasonably low and we are therefore justified in assuming that the internal field is equal to the applied field. However, in solids and liquids the molecules are so close together that the field seen by a given particle is determined in part by the dipoles carried by the surrounding particles; in general therefore the internal field E_i is not equal to the applied field E . The dipole moment, m , induced in each of the atoms of a string of atoms of polarisability α is that given by

$$m = \alpha |E_i|$$

If there are N dipoles per m^3

$$\begin{aligned} P &= Nm \\ &= N\alpha E_i \end{aligned}$$

This enables us to derive a relationship between the measured dielectric constant, ϵ_r , in terms of the polarisability, α .

Thus $D = \epsilon_0 E + P$ [where, E is external applied field]

$$= \epsilon_0 E + N\alpha E_i$$

The observed dielectric constant is defined by

$$D = \epsilon_0 \epsilon_r E$$

Hence, $\epsilon_r = 1 + \frac{N\alpha |E_i|}{\epsilon_0 |E|}$... (8)

In order to determine ϵ_r from the observed experimental data, it is first necessary to determine the internal field $|E_i|$.

The internal field $|E_i|$ is equal to the applied field $|E|$ plus the field produced at the location of the particular atom by the dipoles on all other atoms. As a first approximation, the field produced due to the dipoles can be expressed in terms of the polarisation, P .

or, $E_i = E + \frac{\nu}{\epsilon_0} P$

where ν is a proportionality constant which takes on different values depending upon the particular symmetry conditions which are met. For the special case of an isotropic substance or for one having cubic symmetry.

$$\nu = \frac{1}{3}$$

and $E_i = E + \frac{P}{3\epsilon_0}$... (9)

Equation (9) along with the equation

$$P = N\alpha E_i$$

$$E_i = \frac{E}{1 - \frac{N\alpha}{3\epsilon_0}}$$

which along with equation (8) gives

$$\epsilon_r = \frac{1 + \frac{2N\alpha}{3\epsilon_0}}{1 - \frac{N\alpha}{3\epsilon_0}} \quad \dots (10)$$

$$\frac{\epsilon_r - 1}{\epsilon_r + 2} = \frac{N\alpha}{3\epsilon_0}$$

This result is known as the *Clausius-Mossotti relation*.

If each side of equation (10) is multiplied by $\frac{M}{\rho}$, where M is the molecular weight of the substance and ρ , its density, the resulting expression will depend only on the polarisability α , since $\frac{NM}{\rho}$ equals Avogadro's Number, N_{AV} . The quantity

$$P_m = \frac{\epsilon_r - 1}{\epsilon_r + 2} \cdot \frac{M}{\rho} = \frac{N_{AV}\alpha}{3\epsilon_0}$$

is called the molar polarisation. On the basis of this quantity, the polarisability may be obtained from measurements of the dielectric constant. The polarisability determined in this manner characterizes the molecular polarisability fully only in the case of isotropic molecules for which the polarisability is the same in all directions. In case of anisotropic molecules, the polarisability is determined by three different axes that correspond to the polarisation of the molecules in the direction of the three axes. In such a case, the quantity α in the expression for molar polarisation, P_m is a mean polarisability of molecule.

Table 4.2: Dielectric constant of gases at atmospheric pressure and 0°C.

Gas	$(\epsilon_r - 1) 10^3$	Dipole moment (debye unit)	Gas	$(\epsilon_r - 1) 10^3$	Dipole moment (debye unit)
He	0.071	0	C ₂ H ₂	1.38	0
H ₂	0.270	0	CO	0.692	0.10
O ₂	0.531	0	N ₂ O	1.08	0.17
N ₂	0.588	0	NH ₃	8.34	1.45
CO ₂	0.988	0	SO ₂	9.93	1.50
CH ₄	0.948	0			

From table 4.2 it is observed that the difference between the dielectric constant for gases and unity is of the order of 10^{-3} and therefore we may write $\epsilon_r + 2$ in the Clausius-Mossotti relation equal to 3 which is tantamount to ignoring the difference between the applied field E and the local field E_r . At high pressures this approximation ceases to hold and the effects of the local field have to be taken into account.

If each molecule were to be regarded as a perfectly conducting sphere of radius a , the polarisability α would be given by $\alpha = 4\pi\epsilon_0 a^3$. Substituting the value of α in the Clausius-Mossotti relation,

we find that the quantity $\frac{\epsilon_r - 1}{\epsilon_r + 2}$ is equal to the actual volume occupied by all the molecules per unit volume. The values of molecular volume calculated in this way and those obtained from kinetic

theory are found to agree within close limits. In the presence of dipolar polarisation, the Clausius-Mossotti relation is modified as follows :

$$\frac{\epsilon_r - 1}{\epsilon_r + 2} = \frac{N}{3\epsilon_0} \left(\alpha_0 + \frac{m^2}{3KT} \right)$$

where, α_0 is the deformation polarisability being the sum of electronic and ionic polarisabilities.

Also,

$$P_m = \frac{\epsilon_r - 1}{\epsilon_r + 2} \frac{M}{\rho} = \frac{N_{AV}}{3\epsilon_0} \left(\alpha_0 + \frac{m^2}{3KT} \right) \quad \dots (11)$$

Equation (11) was first derived by Debye and is called the Debye equation. The Debye equation also forms the basis for one of the methods of determining dipole moments. The results of measurements of dielectric constant of a substance at different temperatures may be represented graphically in co-ordinates of P and $1/T$ by a straight line of the form

$$P = a + b/T$$

where a and b are constants. The magnitude of the dipole moment is determined from the angle of inclination of this line to the $1/T$ axis.

$$\tan \theta = b = \frac{N_{AV}}{9\epsilon_0 K} m^2$$

$$m = 3 \sqrt{\frac{\epsilon_0 K b}{N_{AV}}}$$

In the particular case when the dipole moment is zero, the dielectric constant, like the polarisation, is independent of temperature. In such a case the straight line $P = a$ is parallel to the abscissae.

The accuracy of measurement of the dipole moment by means of the foregoing method is determined by the precision with which θ is determined. To obtain accurate results it is necessary to carry out the measurements in sufficiently wide temperature limits. This may involve considerable experimental difficulties, e.g., the temperature variations may involve a change in the substance under investigation. For this reason, another method which permits the measurement of dipole moments at constant temperature is employed. It consists in the simultaneous measurement of molar polarisation (P_m) and molar refraction (R_m) the latter being determined from the refractive index (n) of the substance.

$$P_m = \frac{n^2 - 1}{n^2 + 2} \cdot \frac{M}{\rho} = \frac{N_{AV}}{3\epsilon_0} \quad \dots (12)$$

[Since $n^2 = \epsilon_r$] [cf. art 5.2, Chapter 5]

Equation (12) is known as the *Lorentz-Lorenz Relation*.

From equations (11) and (12) it follows that

$$P_m - R_m = \frac{N_{AV}}{9KT\epsilon_0} m^2$$

$$m = 3 \sqrt{\frac{(P_m - R_m) KT \epsilon_0}{N_{AV}}} \quad \dots (13)$$

Thus by measuring the index of refraction of the given substance and its dielectric constant for a certain temperature, we may find the appropriate values of molar refraction and molar polarisation, substitution of which into equation (13) gives the dipole moment.

By applying the Lorentz-Lorenz relation to a large number of crystals we may determine empirical values of the electronic polarisabilities which are reasonably consistent with the refractive index. Values obtained in this way are given in table 4.3 below :

Table 4.3: Electronic polarisabilities of ions

*Values from Tessman; Kahn and Shockley.
Phys. Rev; 92, 820 (1953) units $\text{cm}^3 \times 10^{-24}$*

		He	Li+	Be ²⁺	B ³⁺⁺	C ⁴⁺
			0 – 03			
O ²⁻	F ⁻	Ne	Na ⁺	Mg ²⁺	Al ³⁺	Si ⁴⁺
2.4	0.652		0.41			
S ²⁻	Cl ⁻	A	K ⁺	Ca ²⁺	Sc ³⁺	Ti ⁴⁺
5.5	2.97		1.33	1.1		0.19
Se ²⁻	Br ⁻	Kr	Rb ⁺	Sr ²⁺	Y ²⁺	Zr ⁴⁺
	4.17		1.98	1.6		
Te ²⁻	I ⁻	Xe	CS ⁺	Ba ²⁺	La ⁺	Ce ⁴⁺
9	6.44		3.34	2.5		

The molar polarisation, P_m may also be called molar refraction at a field frequency equal to zero or a constant electric field. Since molar refraction R_m is usually determined from measurements of the refractive index for visible light, i.e., at frequencies of the order of 10^{15} sec^{-1} , whereas the dielectric constant is measured in alternating fields, the frequency of which is small relative to the frequency of light it is necessary to extrapolate R_m to a zero frequency when computing molar polarisation from measurements of the refractive index alone.

The molar polarisation and the molar refraction of a gas mixture are additive quantities in so far as the polarisability of each molecule may be considered independent of the surrounding molecules, which is fully permissible in the case of gases. Experiments show that molar refraction is practically independent of temperature and pressure.

b. Explain the effect of dielectric on the behaviour of a capacitor. (4)

Answer:

Effect of dielectric on the behavior of a capacitor: Suppose that two large plane parallel plates separated by a distance d (meter) in vacuum are maintained at a potential difference V . the plates will become charged positively and negatively with charges $\neq Q_0$ and a uniform electric field with intensity $E=v/d$ will be created between the plates. The magnitude of the charge accumulated on each plate is proportional to the applied p.d, i.e. V/Q_0

$$\epsilon_0 \epsilon_r = \epsilon \quad (4\text{Marks})$$

Q.4 a. Explain properties and application of polymers. (10)

Answer:

Properties & application of Polymers;

Polymeric materials or plastics comprise a large group of organic or organo metallic high molecules compound. (2Marks)

The common properties of these materials are their ability to soften and even melt, ability to pass into a liquid state, insolubility in water and solubility in one or more organic solvents. The mechanical properties of these materials vary widely, some can be spun into fibers like nylon and terylene , other

can be moulded and are hard and glass like in mechanical properties. Other group shows rubber like properties. (2Marks)

Plastic are synthetic resins obtained basically in two different ways, by linear polymerization and by polycondensation. The polymers obtained by linear polymerization are known as thermoplastics since they can be repeatedly melted or dissolved in various solvents. The properties of the thermoplastics do not change considerably if they are melted and then cooled and solidified. Example of thermoplastics is polystyrene. (3Marks)

Second types of polymers are thermosetting and are used as binding agents and varnish base. Thermosetting plastic melt on heating but are converted into a rigid solid mass if maintained at an elevated temperature. Examples of these polymer is phenol formaldehyde. Synthetic resins are widely used in electrical industry as insulating and structural components. Some of the important synthetic resins commonly used in electrical engineering are polystyrenes, P.V.C.(polyvinyl chloride.) etc. (3Marks)

b. Explain the term dielectric losses and dielectric constant. (6)

Answer:

Dielectric Loss When an insulating material is subjected to an alternating voltage except in the case of purified gas as an insulator, there is some consumption of power due to flow of small amount of leakage current. This loss is called dielectric loss. Dielectric loss increases with increase in applied voltage and frequency.

Dielectric Constant Every insulation material has the capacity to store charge when placed in between two conducting plates as in capacitors. Relative permittivity or dielectric constant, it is the ratio of the capacitance of a capacitor with a specified dielectric material placed between the plates, to the capacitance of the same capacitor with free space i.e. air between the plates.

Q.5 Discuss the following: (4×4)
(i) Paramagnetism
(ii) Ferromagnetism
(iii) Hysteresis loop
(iv) Magnetic resonance

Answer:

6.5 PARAMAGNETISM

A material has paramagnetic properties if permanent magnetic dipoles exist in its atoms, ions or molecules. On the application of an external magnetic field the permanent magnetic dipoles line up and thus produce a positive induced magnetic moment and give rise to a positive contribution to the magnetic susceptibility. The lining up of magnetic moments takes place because of the shift in positions of the electrons such that the total energy is minimum. Possibilities of permanent dipole moments in paramagnetic materials appear to arise from a definite angular momentum due to orbital motion and spin of the electrons. In the case of diamagnetic materials the spins in opposite directions cancel and therefore, there are no permanent dipoles.

Paramagnetic atoms and ions include particles having one electron over and above a completed shell (*e.g.*, atoms of the alkaline materials), atoms of the transition elements, ions of the rare earth elements with incomplete shell, *etc.*

In paramagnetic bodies located outside the influence of external magnetic fields, the magnetic moments are distributed randomly with respect to direction, and the total magnetic moment of a substance is zero. On the application of a magnetic field the atoms (or molecules) tend to rotate in such a way that their magnetic moment coincides with the direction of the field. As a result, equilibrium is established between two tendencies, *viz.* the ordering action of the field and the tendency to thermal randomness, such that the lining up is not complete. Since thermal agitation giving a random orientation is less at low temperatures, a larger number of dipoles are able to orient themselves in the direction of the field and the magnetisation for a given field is greater.

This is analogous to the dipolar type of polarisation in dielectrics. As in dielectrics, the relationship between the paramagnetic susceptibility and the magnetic moment of an atom may be given by

$$\chi = m^2/3KT$$

where m is the magnetic moment, K is the Boltzmann's constant and T is the absolute temperature. By measuring susceptibility as a function of absolute temperature, the magnitude of the atomic dipole moments may be obtained. In general these are of the order of 10^{-23} Wbm or 1 Bohr Magnetron (10^{-23} A.m²).

Since paramagnetism requires the existence of permanent dipole moments paramagnetic susceptibility may be considered to be analogous to orientational susceptibility associated with dielectrics. In both cases the susceptibility is positive and temperature dependent. Thus the paramagnetic susceptibility varies inversely with the absolute temperature for ordinary fields and temperatures

$$\text{or} \quad \chi = C/T$$

This law is known as the **Curie Law of paramagnetism** and the constant C is called the **Curie constant**. For large fields at low temperatures the magnetisation is no longer proportional to the field and tends to a constant value. Paramagnetic materials have a small positive susceptibility of the order of 10^{-3} at room temperature, which is much larger than the negative contribution due to the diamagnetic effect. The susceptibilities for a few

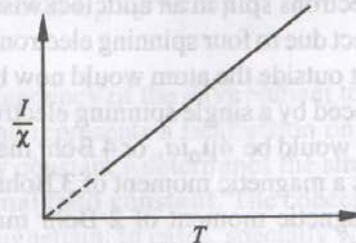


Fig. 6.5 Curie law for paramagnetic material

paramagnetic substances are given in Table 6.3 below.

Table 6.3 The susceptibility of some paramagnetic materials at room temperature

Material	$X = \mu_r - 1$	μ_r
Air	0.038×10^{-5}	1.00000338
Aluminium	2.3×10^{-5}	1.003023
Ebonite	1.4×10^{-5}	1.000014
Liquid oxygen	340×10^{-5}	1.0034
Nitrogen	0.0013×10^{-5}	1.000000013
Oxygen	0.19×10^{-5}	1.00000019
Platinum	36.0×10^{-5}	1.0036
Tungsten	7.6×10^{-5}	1.000076
CoO	580×10^{-5}	1.0058
MnSO ₄	360×10^{-5}	1.0036
Fe ₂ O ₂	140×10^{-5}	1.0014
FeCl ₂	370×10^{-5}	1.0037
NiSO ₄	120×10^{-5}	1.0012

For many applications in electrical engineering, it is a good approximation to take the relative permeability of paramagnetic substances equal to unity.

Paramagnetism in general is a relatively small effect that has found a few technical applications, e.g., paramagnetic salts have been used in obtaining very low temperatures of the order of 10^{-3} °K by adiabatic demagnetisation. They are also the essential materials used in the solid state MASER.

6.6 FERROMAGNETISM

The magnetisation curve for paramagnetic materials is a straight line showing that the relative permeability for such materials is constant whereas the magnetisation of a ferromagnetic material depends in addition to the field intensity on the magnetic history of the sample. Paramagnetics are solids which do not exhibit any spontaneous magnetisation but become magnetic only when subjected to an external magnetic field. On the other hand, ferromagnetics are solids, generally crystalline in nature, which are magnetised independent of any external field. In other words, the magnetisation, M may have a finite value even if the external magnetic field, H is zero. This can be explained in terms of the uncompensated electron spins. Consider the free iron atom shown in Fig. 6.6. In this atom equal number of electrons spin in the clockwise and anticlockwise directions in shells K , L and N . These shells are, therefore, magnetically neutral. In shell M , however, 9 electrons spin in a clockwise direction and 5 electrons spin in an anticlockwise direction. There is therefore, a net effect due to four spinning electrons. The magnetic field produced at a point outside the atom would now be four times that which would be produced by a single spinning electron, or the magnetic moment of the atom would be $4\mu_0 ia$, or 4 Bohr magnetons. On this basis a cobalt atom has a magnetic moment of 3 Bohr magnetons and a nickel atom has a magnetic moment of 2 Bohr magnetons. This applies to free atoms. However, in solids, the electron spin in the M -shell which is near the periphery of the atom is affected due to the proximity of other

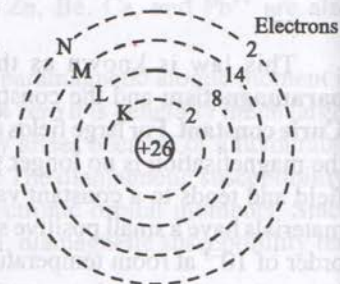


Fig. 6.6

atoms and therefore the actual magnetic moments are smaller than those given above. The average values for iron, cobalt and nickel are 2.22, 1.71, 0.606 respectively.

Each ferromagnetic material has a characteristic temperature above which its properties are quite different from those below that temperature. This temperature is called the *ferromagnetic Curie temperature* or the *transition temperature* T_F . When the temperature exceeds T_F , the susceptibility becomes independent of field strength and the behaviour of a ferromagnetic material becomes similar to that of a paramagnetic material, a fact showing that paramagnetism and ferromagnetism are intimately connected.

6.10 THE HYSTERESIS LOOP

Below the Curie temperature all ferromagnetic materials exhibit the well known hysteresis in the B versus H curves. Starting with an unmagnetised specimen, B varies reversibly with H for small fields. Since there is no hysteresis in this region, one defines the initial permeability, μ_i , in the same way as the permeability of a paramagnetic material. As the field H is increased, B begins to increase rapidly and ultimately approaches a saturation value B_{sat} . Upon reducing the value of H from the saturation region to zero, it is observed that there remains a flux density, B_r , called the remanent flux density. Since $H = 0$, the material must be permanently magnetised; in fact, the magnetisation corresponding to B_r is equal to B_r/μ_0 . The field $-H_C$ required to reduce the flux density to zero is called the *coercive force*.

The magnitudes of the coercive force and the remanent flux density depend on the imperfections in the material, such as voids, impurities and internal strains. The origin of coercive force is in fact due to the existence of these imperfections; energy being required to move a domain over an imperfection. Large values of coercive force occur if the material has large internal stresses and non-magnetic inclusions. High coercivity may be achieved by suppressing the possibility of boundary wall movement by using very fine powders. The more the material is free from strains and inclusions, the greater the size of reversible wall movement and the lower the field required to produce a movement thus giving a large initial permeability and a 'soft' magnetic material. Low values of coercivity occur if the material has non-magnetic inclusions and low anisotropy.

The saturation value of the flux density, however, depends on the chemical constitution and temperature and does not depend on the imperfections.

The value of initial permeability is affected by heat treatment. High values of initial permeability may be obtained when the material has high saturation magnetisation and low coercive force.

The area contained in the hysteresis loop equals the work that is necessary to reverse the direction of magnetisation. The actual shape and area of the loop depend on the details of the

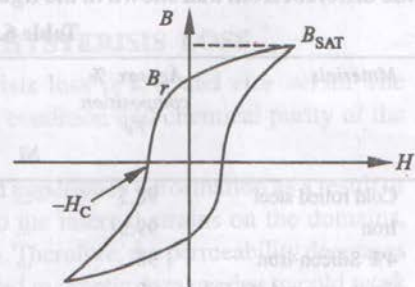


Fig. 6.14 Hysteresis loop

internal structure and composition of the ferromagnetic substance. As the material becomes more pure magnetically, the lattice plays less role with regard to the response of magnetisation with respect to the applied field. The area of the hysteresis loop becomes smaller, the domain wall movement is facilitated and one obtains high initial permeability.

Table 6.4 Saturation magnetisation and paramagnetic (T_p) and ferromagnetic (T_F) Curie temperatures for ferromagnetic materials

Substance	M_{sat} at Room temp. (Amp/m)	M_{sat} at 0°K (Amp/m)	T_F $^\circ\text{K}$	T_p $^\circ\text{K}$	Bohr Magnetons per atom
Iron	1.707×10^6	1.752×10^6	1043	1047	2.22
Cobalt	1.4×10^6	1.446×10^6	1400	1504	1.71
Nickel	0.485×10^6	0.510×10^6	631	645	0.606
Gadolinium	1.09×10^6	1.980×10^6	288	—	7.10

The average energy of thermal agitation at room temperature amounts to about 0.03 eV . In the case of non-ferromagnetic materials this thermal energy easily overcomes the magnetising force of an external field. In ferromagnetic materials the energy of thermal agitation is much less than that created by the magnetic field in the movement or rotation of the domains. Therefore the orienting effect of the magnetic field is predominant and the magnetisation of the ferromagnetic substance increases by many times the magnetic effects of the external field.

The domains in a ferromagnetic material would be aligned parallel only at the absolute zero of temperature. Above this temperature there would be some disorder due to thermal agitation, and with increasing temperature the saturation magnetisation, therefore, would decrease in magnitude. At the Curie point, the magnetisation in a domain under zero external field would vanish and above this temperature, the substance would become paramagnetic.

The magnetisation curves vary with temperature, the value of M increasing with decreasing temperature and eventually approaching zero at the Curie point. Fig. 6.15 shows the ratio of the saturation magnetisation at temperature T to that at 0°K as function of the ratio of the temperature T to the Curie temperature for iron. The curves for cobalt and nickel are little different from that shown in the figure.

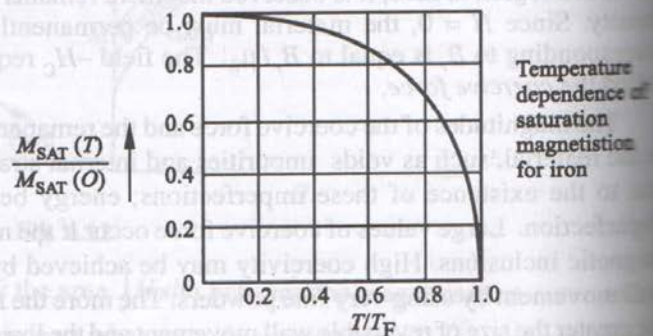


Fig. 6.15

Table 6.5—High permeability materials

Materials	Approx. % composition				Maximum permeability	Saturation flux density, Wb/m^2	Coercive force Amp/m
	Fe	Ni	Co	Other			
Cold rolled steel	98.5	...	...	...	2000	2.10	144
Iron	99.51	...	...	...	5000	2.15	80
4% Silicon-iron	96	...	...	4Si	7000	2.0	40
Grain oriented (Si-Fe)	97	...	...	3Si	30000	1.97	12
Hiperrik	50	50	...	...	70000	2.0	4

78 permalloy	21.7	78.5	...	0.3Mn	100,000	1.6	4
Mumetal	18	75	...	2Cr	100,000	0.54	4
				5Cu			

Table 6.6—Permanent magnet alloys

Material	Composition	Remanent Flux density Wb/m ²	Coercive force Amp/m
Carbon steel	1%Mn, 0.9% Fe	1	4000
Tungsten steel	5%W, 0.3% Mn, 0.7%C, 94% Fe	1.03	7000
Alnico	8%Al, 14% Ni, 24%Co, 3% Cu, 51% Fe	1.25	44000
Platinum cobalt	77% Pt, 23% Co	0.45	2 × 10 ⁵

6.16 MAGNETIC RESONANCE

A rotating body will produce a kinetic moment along the axis of rotation. This kinetic moment is proportional to the speed of rotation. The rate of change of the kinetic moment with time is equal to the couple of the applied force.

An electron having a mass and spin will give rise to both magnetic moment and kinetic moment. If M is the magnetic moment and P is the kinetic moment then the gyromagnetic ratio is given by

$$\gamma = M/P$$

The electron will rotate in a fixed direction along the axis OC (Fig. 6.22), when an external field is applied. If an external field H is applied along the z -axis: this magnetic field exerts a couple on

moment M , that is

$$C = dP/dt = \bar{M} \times \bar{H}$$

Also,
$$dP/dt = -\frac{1}{\gamma} \frac{dM}{dt}$$

Therefore
$$-\frac{1}{\gamma} \frac{dM}{dt} = \bar{M} \times H$$

This is the differential equation of motion of the moment M . The tip of the M vector will rotate in a circle lying in a plane perpendicular to z -axis. The angular velocity is given by

$$\omega = 2\pi f$$

where $f = \gamma / 2\pi H = 2.8 \times 10^6 H$ for electrons.

Now if a circularly polarised high frequency field \bar{h} is applied this field will rotate in the plane of magnetic polarisation which is the plane XOY in the figure. In this condition the vector $(\bar{H} + \bar{h})$ describes a cone carrying the moment M with it which acquires a precessional motion around it. If the sense of rotation of h is such that the resultant vector $(H + h)$ rotates in the same sense as that of precession and if the frequency of h is the same as that of the precession then there will be a synchronisation of the two phenomena and we have the magnetic resonance. This will cause absorption of energy from the high frequency field. This phenomena is known as *gyromagnetic resonance*. On the other hand, if the sense of rotation of the field \bar{h} is such that the resultant vector rotates in the opposite sense to that of the precession then there is no synchronisation and hence no magnetic resonance.

For a circularly polarized high frequency wave the sense of rotation depends on the direction of propagation. Resonance occurs only in one direction of propagation. In the other direction there is no resonance and hence no significant absorption.

The effective permeability of the ferrite for the above two cases, *i.e.*, with a circularly polarized field in the positive sense and that in the negative sense can be represented by μ^+ and μ^- respectively. Further, these permeabilities are to be assumed as complex quantities to represent the losses. Hence, we have

$$\mu^+ = \mu'^+ - j\mu''^+$$

and

$$\mu^- = \mu'^- - j\mu''^-$$

The variations of the real and imaginary parts of the permeabilities with the applied magnetic field for the positive and negative cases are shown in Fig. 6.23. The main application of ferrites at microwave frequencies is to make use of their non-reciprocal behaviour whereby transmission properties depend on the polarization and the direction of incident electromagnetic wave. The most widely used devices are isolators and circulators constructed in waveguide, coaxial or stripline geometries. In the forward direction these devices have low loss, usually 3.5 dB or less and in the reverse direction the loss is 20 dB

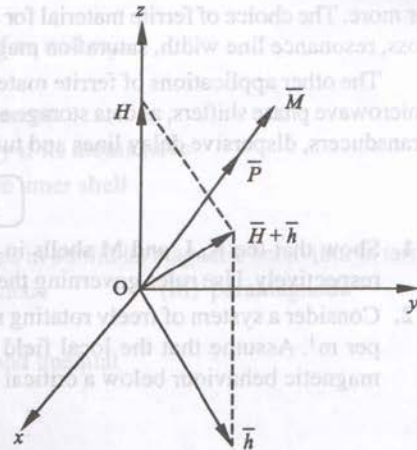


Fig. 6.22

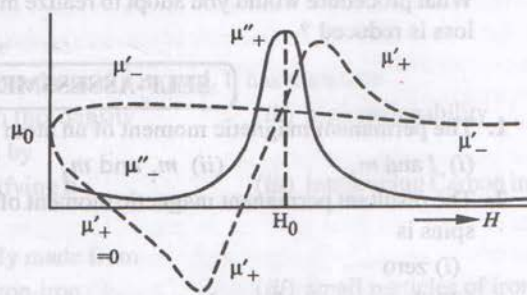


Fig. 6.23 Variation of the coefficients as a function of applied field H

or more. The choice of ferrite material for a resonance isolator depends upon the factors like dielectric loss, resonance line width, saturation magnetisation and Curie temperature.

The other applications of ferrite materials are as cores for inductors, transformers and aerials, microwave phase shifters, as data storage and switching devices in computer, and as electro-mechanical transducers, dispersive delay lines and tunable filters.

Q.6 a. Discuss the following:

(5+5)

- (i) Diffusion in semi conductors
- (ii) Einstein Relation in semi conductors

Answer:

7.8 DIFFUSION

Although the mobility of the carriers in a semi-conductor is greater than that of the electrons in a metal, the conductivity in the former is much less than that in the latter because of the too few current carriers. The conductivity is so less that the random movements of the carriers due to unequal carrier densities plays a greater part in conduction than the drift due to the applied fields. Diffusion arises essentially from density differences and the resulting currents are called *diffusion currents*.

(a) The defining equations for diffusion currents in one direction are

$$J_n = eD_n \frac{\partial n}{\partial x} \text{ for electrons}$$

$$J_p = eD_p \frac{\partial p}{\partial x} \text{ for holes}$$

where, J_n = diffusion current density of electrons

J_p = diffusion current density of holes

D_n = diffusion constant of electrons

D_p = diffusion constant of holes

$\frac{\partial n}{\partial x}$ = gradient of electron density

$\frac{\partial p}{\partial x}$ = gradient of hole density

Therefore the diffusion current due to the random motion of carriers from the dense to the less dense regions is proportional to the gradient or rate of increase of carrier density with distance. The coefficient of proportionality is called the diffusion constant and is denoted by D . In the case of electrons if the density of electrons is greater at the left, the electron flow is to the right and the conventional direction of current is to the left. In the case of holes, if the density of holes is greater at the left, the hole flow is to the right and the current is, therefore, negative. This accounts for the negative sign in the equation of diffusion current for holes. Typical values of D at room temperature are given in Table 7.6.

Table 7.6

Material	$D_n, \text{cm}^2/\text{sec.}$	$D_p, \text{cm}^2/\text{sec.}$
Ge	101	49
Si	35	12
Cu	1	No holes in metal

The total current in a semi-conductor is the sum of conduction and the diffusion currents respectively. Thus, the total current density for electrons is

$$J_n = eU_n \cdot nE_x + eD_n \frac{\partial n}{\partial x} \quad \dots(7)$$

and for holes is

$$J_p = eU_p \cdot pE_x + eD_p \frac{\partial p}{\partial x} \quad \dots(8)$$

where E_x is the applied field.

7.9 THE EINSTEIN RELATION

There exists an important relationship between the diffusion constant and the mobility. This is known as the Einstein relation and may be deduced as follows :

Consider a semi-conductor in which there exists an electric field E_x and a concentration gradient such that the resultant current is zero. Under these conditions the system is in thermal equilibrium and Boltzmann statistics applies. Consider a potential $V(x)$ producing at x an electric field given by $E(x) = -dv/dx$.

The Boltzmann expression for the density of holes as a function of x in thermal equilibrium is

$$p(x) = Ce^{-v/KT}$$

where C is a constant.

The gradient of the hole density is therefore given by

$$\begin{aligned} \frac{dp}{dx} &= (-e/KT) p \cdot \frac{dv}{dx} \\ &= (e/KT) \cdot p \cdot E(x) \end{aligned}$$

The hole current vanishes in thermal equilibrium. Therefore, from equation (8)

$$\begin{aligned} 0 &= peu_p E_x - eD_p dp/dx \\ &= peu_p E_x - (e^2 /KT) D_p \cdot p \cdot E_x \end{aligned}$$

or

$$D_p = (KT/e) U_p \quad (\text{The Einstein relation})$$

A similar relationship holds for electrons.

$$\begin{aligned} \text{Thus,} \quad D_n &= (KT/e) U_n \\ \frac{D}{u} &= 0.02586 \text{ Volt (at } 300^\circ\text{K)} \end{aligned}$$

b. Explain the term mobility, doping and ferroelectricity. (6)

Answer:

Mobility: Average drift velocity of the electrons in an applied field is proportional to the field, the absolute magnitude of the proportionality factor eq/m, called the mobility of the electrons, which is denoted by μ . The mobility may thus be defined as the magnitude of the average drift velocity per unit field. (2Marks)

The mobility of the electrons can be determined by knowing the conductivity of the material and estimating the number of free electrons. Unit of mobility is $m^2/volt.sec$.

Doping: Semiconductors in its extremely pure form are called intrinsic semiconductor. These intrinsic semiconductor to which some suitable impurity is added in extremely small amount are called extrinsic semiconductor. This process is called doping and impurities are called doping agent. Usually the doping agents are pentavalent atom such as arsenic, antimony or trivalent atom such as gallium, indium, aluminium etc. (2Marks)

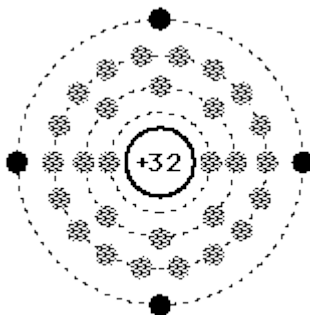
Ferroelectricity: Ferroelectric materials have a high dielectric constant, which is non linear I.e. it depends to a considerable extent on the intensity of the electric field such materials exhibit hysteresis loops, I.e. the polarization is not a linear function of the applied electric field. If the center of gravity of the positive and the negative charges in a body does not coincide in the absence of an applied electric field, the substance has an electric dipole moment and is said to be spontaneously polarized. Such a substance is called ferroelectrics and the phenomenon is called Ferro electricity. It contains small regions, which are polarized in different directions, even in the absence of an electric field. When the temperature exceeds a certain value called the curie point, the substance loses its ferroelectric properties.

Ex: Rochelle salt, potassium dihydrogen phosphate, barium titan ate. μ (2Marks)

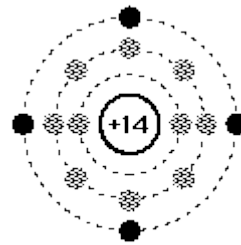
Q.7 a. Describe the atomic structure of silicon and germanium. (8)

Answer:

Germanium:- It is one of the most common semiconductor material used for the application in electronics. The atomic number is 32. The number of electrons in the first, second, third and fourth orbit are 2, 8, 18 and 4. It is clear that germanium atom has four valence electrons in the outermost orbit. It is known as tetravalent element. The germanium atoms are held together through covalent bonds. The forbidden gap in this material is very small 0.7eV. So small energy is sufficient to lift the electrons from valence to conduction band.



Germanium



Silicon

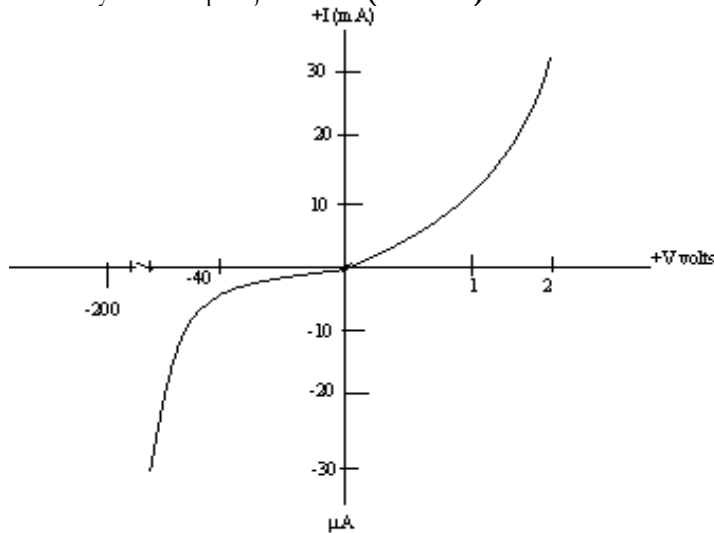
(4Marks)

Silicon:- Silicon is another most commonly used semiconductor. Its atomic number is 14. The number of electrons in first, second and third orbit are 2, 8 and 4. The silicon atoms are also having four valence electrons and are known as tetravalent element. The various silicon atoms are held together through covalent bonds. The atoms of silicon are arranged in orderly pattern and form a crystalline structure. The forbidden energy gap in this material is quite small i.e. 1.1eV. It also needs small amount of energy to lift the electrons from valence to conduction band. (4Marks)

b. What is a PN junction? Draw and Explain V-I characteristic of a PN junction diode. (8)

Answer:

P-N junction: When a p-type semiconductor is suitably joined to an n-type semiconductor the contact surface so formed is called p-n junction. All the semiconductor devices contain one or more p-n junction. P-N junction is fabricated by special techniques namely growing, alloying and diffusion methods. The p-type semiconductor is having negative acceptor ion and holes. The n-type semiconductor is having positive donor ions and negatively charged electrons. When the two pieces are joined together and suitably treated they form a p-n junction. **(3Marks)**



Characteristics of a typical p-n junction diode

(3 Marks)

The leakage current for reasonable voltages in the reverse direction ranges between 0.01 and $1 \mu\text{A}$ depending on the semiconductor material and the doping level of the impurities. Several variations of this simple diode have been developed. **(2Marks)**

Q.8 a. What is Metal Oxide film resistor? Explain in brief.

(6)

Answer:

Metallic –Oxide Film Resisors When a solution of stannic chloride is sprayed on to a glass or porcelain at red heat, hydrolysis takes place and yields a glass –like layer of oxide. This layer may vary in thickness from a few hundred to many thousands of angstrom units, has a milky, translucent appearance and is electrically conducting. Additions of antimony trichloride to the spraying solution impart a blue color to the oxide layer. No film will be produced with pure antimony trichloride solution. Oxide films obtained by this process are hard, adherent to glass and ceramics and unaffected by chemical reagents. Besides the electrical resistance can be varied over a wide range of value by changing the composition of spraying solution. Usually films which have comparatively small temperature coefficients of resistance and small resistivities are used. The following are some of the advantages of oxide-film resistors. 1. No oxidation. 2. Soldering of end connections is comparatively easy 3. Maximum temperature ratings higher than that for carbon. 4. Reasonably low temperature-coefficient. **(6Marks)**

b. Write the properties of ceramic dielectric capacitor and electrolytic capacitors. Write at least two applications of each.

(10)

Answer:

(v) Ceramic Dielectric Capacitors

There are three varieties of ceramic capacitors—low permittivity low loss types, medium permittivity temperature compensatory types and high permittivity types. The constructional details of a ceramic dielectric type are shown in Fig. 12.14. The low permittivity low loss types are generally made of steatite or similar material. Steatite has a permittivity of approximately 8.0 and other materials may give permittivities between 6.0 and 15.0. Their high-frequency performance at frequencies above 50 KHz is very good. The power factor is reasonably low. The temperature coefficient ranges between + 80 and + 120 ppm/°C. They operate at comparatively high voltages (500 V) over a temperature from about 150 °C down to extremely low temperatures.

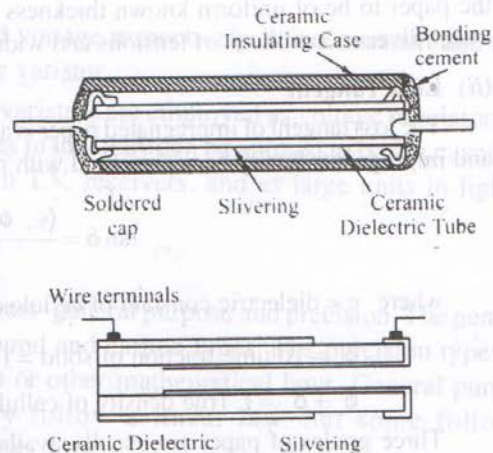


Fig. 12.14 Metallic (tubular) ceramic dielectric types

The second class of medium permittivity ($\epsilon_r = 90$) are used mainly in tuned circuits for compensation. They are based on titanium or its derivatives. The power factor can be lower than 0.0003 at radio frequencies. The high permittivity ceramic capacitors provide a very high capacitance in a compact unit. The capacitance and the power factor, however undergo random changes with temperature. Capacitors using the $\epsilon_r = 1200$ material have a high capacitance peak at about 110 °C, which is two or three times the value at room temperature. The power factor touches a minimum value around 20-40 °C and is in general around 2%. In general, the higher the permittivity the more temperature sensitive is the capacitor. Besides changes with temperature, d.c. voltage stress reduces capacitance, even at room temperature, a reduction in capacitance of 10-20% can normally be expected. The dielectric loss is lower than that for low permittivity type. These capacitors are subjected to hysteresis and accordingly are suitable for working with only very small a.c. voltages. They are mainly used as r.f. bypass capacitors.

(vi) Glass-Dielectric Capacitors

Very thin glass sheets are used to form these capacitors. The sheets are interleaved with aluminum foil and used together to form a solid block. These capacitors are smaller in size compared to encased mica capacitors and can be operated at very high working voltages. Their capacitance stability and Q are very constant. Since the processes in glass manufacture can be controlled accurately, a product of constant and dependable quality can be obtained. The case of a glass capacitor is made of glass and hence Q is constant even at low capacitances. These capacitances can be continuously used at high temperature upto 200 °C.

(vi) Vitreous Enamel Dielectric Capacitors

Vitreous enamel dielectric capacitors are formed by spraying vitreous lacquer on metal plates which are stacked, and fired at a temperature high enough to 'vitrify' the glaze. Capacitors made in this way have excellent r.f. characteristics of exceedingly low loss and can be operated at high temperatures 150-200°C. They are capable of withstanding high humidity conditions and can also operate over a wide temperature range. As in glass capacitor, the encasing material is the same as the dielectric material. They are quite robust and electrical characteristics are preserved except under severe mechanical damage.

(vii) Plastic Dielectric Capacitors

These capacitors are characterised by high insulation resistance at room temperature. They are made of polyesterene-film or polyethylene terephthalate. This type of capacitor is not generally suitable for use above 60°C even though some low value capacitors are used upto 85°C. The power factor, which is independent of frequency, is generally around 0.002. Its low dielectric absorption enables it to be used in long time-constant circuits. The capacitance stability should be of the order of 0.5 percent and permittivity is 2.5. The constructional details of a plastic dielectric capacitor are shown in Fig. 12.15.

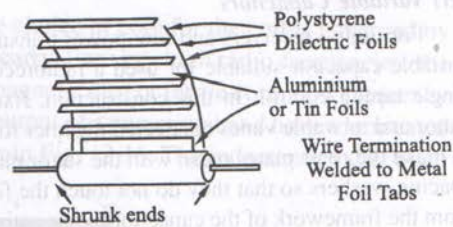


Fig. 12.15 Metal foil plastic dielectric type

(x) Electrolytic Capacitors

A noteworthy characteristics of these types of capacitors is their low volume for large capacitances especially at low working voltages. These are suitable for use for high energy pulse storage applications.

The normal type are made of plane foils of aluminium. Sprayed gauze foils or etched foils can be used to obtain large surface and thus higher capacitance. Periodic reforming of electrolytic capacitors, which are stored for long time, is essential. Reforming is carried out by applying working voltage through a 1 K resistor for about one hour.

Electrolytic capacitors are for direct voltage working. The dielectric in these capacitors is aluminium oxide which is formed by a process of electrolysis on a aluminium electrode. This electrode is called the anode because during manufacture and in use it is connected to the positive side of the voltage source. The electrolyte used for the production of the oxide film is an aluminium borate solution. The aluminium oxide film has a high relative permittivity and a high dielectric strength. For these reasons the film used can be accordingly thin which is the main reason for the high capacitance per unit of space occupied by capacitor. The electrolyte in contact with the aluminium anode oxide coating behaves as the other electrode of the capacitor. The electrolyte is also in electrical contact with an aluminium container which provides the other terminal, or with a non-oxidised aluminium foil to which a second terminal is connected. In the rolled electrolytic capacitor the anode consists of a long strip aluminium foil to which a second terminal is connected. In the rolled electrolytic capacitor the anode consists of a long strip aluminium foil carrying the oxide film on both sides. The ammonium borate electrolyte solution is held in an absorbent paper tissue strip of similar length. A second strip of aluminium foil with no oxide film lies next to the paper tissue and acts as the cathode. These three strips are rolled tightly together as in a rolled paper capacitor and provided with an outer cover of aluminium.

Wide tolerance values are allowed for electrolytic capacitors. Capacitance values may be as much as -20 to + 100% different from their stated values. Rated voltage must never be exceeded and polarity marking must be strictly observed. Otherwise, the insulating oxide film is not formed and there is no capacitance. If the electrolytic capacitor is connected in opposite polarity; the reversed electrolysis forms gas and the capacitor becomes hot and may explode.

Non-polarized electrolytic capacitors are also available, for applications in a.c. circuits without any d.c. polarizing voltage. A non-polar capacitor actually contains two capacitors, connected in series-opposing polarity.

Q.9 a. Give general properties of Field Effect Transistor (FET). (8)

Answer:

This class of transistors may be distinguished from solid state devices by several features which are common to all members of the class:

Flow of carriers in a particular device is controlled by the application of an electric field which permeates into the main conduction path in a semiconductor; this gives rise to the term **field effect**. (4Marks)

Current flow along the main conduction path is almost entirely due to the motion of majority carriers, injection of minority carriers, a mechanism which is essential for the operation of the bipolar transistor is not a necessary requirement in field effect devices.

The generic term unipolar is therefore used as an alternative to field effect to describe the devices since they rely only on one type of carrier for current transport. **(4Marks)**

b. Discusses epitaxial diffused junction diode and its application. (8)

Answer:

Such diodes are now being manufactured commercially on a large scale. The process involve the growing of a thin layer of single crystal semiconductor onto a supporting slice of parent material. The basic chemical reaction of silicon chloride in an atmosphere of H_2 at around $1200^{\circ}C$, Doped impurity layers and even compound semiconductors can be deposited by similar techniques. For discrete diodes, the parent slice called the substrate is highly doped to give it a low receptivity and the epitaxial layer lightly doped with the same impurity type. A pn junction is then formed in the layer and electrodes are deposited by the same processes that are used for diffused diodes. Diodes with high break down voltage and low capacitance can be fabricated in this way in the high resistivity. Epitaxial layer, while the low resistance supporting substrate reduces the series resistance of the diode. **(4+4 Marks)**

Text Book

Introduction to Electrical Engineering Materials by C S Indulkar and S Thiruvengadam, 4th Edition , Reprint 2006 edition, S Chand and Company, New Delhi.