

Q.2a. Discuss factors affecting the Resistivity of conducting materials.

2a 2.2. Factors Affecting the Resistivity of Electrical Materials

(i) *Temperature.* The electrical resistance of most metals increases with increase of temperature whilst those of semiconductors and electrolytes decreases with increase of temperature. Many metals have vanishing resistivity at absolute zero of temperature. The phenomenon is known as superconductivity.

(ii) *Alloying.* A solid solution has a less regular structure than a pure metal. Consequently, the electrical conductivity of a solid solution alloy drops off rapidly with increased alloy content. In other words, the addition of small amounts of impurities leads to a considerable increase in resistivity. For example, brass (63% Cu and 40% Zn), which is widely used as a contact material in power plugs and sockets has a resistivity of 9μ ohm-cm which however is not in direct proportion to the amounts of the different metals in the alloy.

The high conductivity in metals is associated with the presence of these "free" or conduction electrons. The only electrons having this high degree of freedom are those corresponding to the valence electrons in the atoms. Thus, one may think of a metal as consisting of a lattice of positive ion cores held together by means of a gas of electrons. There are constant collisions between the electrons and the atoms. Lattice spacing in copper is about 3.6Å. Electrons may travel one or two atomic diameters, but mean free path is several hundred atomic spaces. In a copper nickel alloy the copper atoms do not impede the motion of the free electrons, but additional nickel atoms impede their motion.

The temperature coefficient of metals is very small. It is therefore not surprising that the increase in resistivity due to the addition of impurities is temperature independent. This suggests the existence of alloys whose resistance varies little with temperature. See Table 2.2.

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(iii) *Cold Work.* Mechanical distortion of the crystal structure decreases the conductivity of a metal because the localized strains interfere with electron movement. Thus hard drawn copper wire has a lower conductivity than annealed copper. Subsequent annealing restores the electrical conductivity by establishing greater regularity in the crystal lattice.

Hard drawn copper has a resistivity of 1.9×10^{-6} ohm-cm at 20°C whereas annealed copper has a resistivity of 1.72×10^{-6} ohm-cm at 20°C .

(iv) *Age Hardening.* Age hardening increases the resistivity of an alloy.

1.3.1 The resistivity of pure copper is 1.56 micro-ohm-

b. What is contact potential? Draw & explain energy distribution of electrons in two metals before & after contact.

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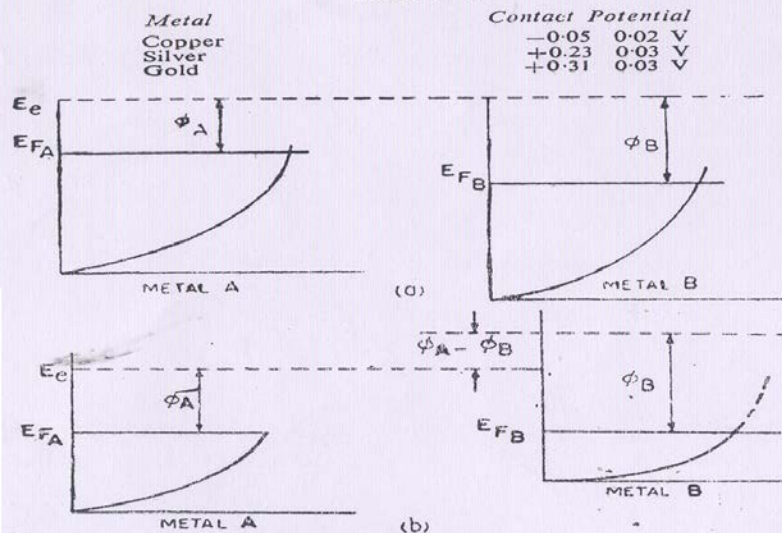
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3.6. Contact Potential

The fact that the work function varies from metal to metal gives rise to the phenomenon of "contact potential". It has been known that when two metals are placed in contact with each other there is a potential difference established between the two.

In Fig. 3.3, if metal A has a lower work function than metal B, electrons from the top energy band in metal A will flow to metal B, since they will then have a lower energy. This flow of electrons establishes a potential difference between the two metals until the tops of the two energy distributions reach the same level and there is no further flow of electrons between the metals. The actual number of electrons transferred from one metal from another is very small, so that the areas of the two energy distribution curves in (a) and (b) of Fig. 3.3 are nearly equal. Hence the contact potential is approximately equal to the difference of the work functions ϕ_A and ϕ_B respectively. The results of measurement of contact potentials of a few metals relative to a clean tungsten surface are given in Table No. 3-2

Table 3-2



The alignment of the Fermi levels entails a transfer of electrons from the metal that has a higher Fermi energy (before contact) to the other metal. Such a transfer of electrons leaves the former metal positively charged while the latter becomes negatively charged. Thus an electrical dipole layer is set up between the metals. As the separation between the metals diminishes, so does the contact potential. In the limit when the contact is perfect, the contact potential disappears because of an infinitesimally thin dipole layer between the metals.

Q.3 a. Discuss the effect of dielectric on the behaviour of a capacitor.

3a Suppose that two large plane parallel plates separated by a distance d (metres) in vacuo are maintained at a potential difference V . The plates will become charged positively and negatively with charges $\pm Q_0$ and a uniform electric field with intensity $E=V/d$ (volts/m) will be created between the plates. The magnitude of the charge accumulated on each plate is proportional to the applied p.d., i.e., $Q_0 \propto V$ or $Q_0=C_0V$, where C_0 is defined as the capacitance.

'By applying Gauss's theorem it will be seen that the magnitude of the flux density D within the parallel plates is given by

$$D = \frac{Q_0}{A}$$

Since the electric field strength E is related to the flux density by the relation $D=\epsilon_0E$, 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 $C_0=\epsilon_0A/d$ where ϵ_0 is termed the absolute permittivity of free space and is expressed in farads/metre. The value of ϵ_0 can be determined from experiment and is

found to be nearly equal to $\frac{10^{-9}}{36\pi}$

If the space between the plates is now filled with a dielectric and V is kept constant, it is found that the value of the charge is increased to a value given by $Q = CV$.

It follows that the new capacitance is given by $C = \epsilon A/d$ where ϵ is defined as the absolute permittivity of the dielectric and the ratio $\epsilon_r = C/C_0 = \epsilon/\epsilon_0$ is called the relative permittivity, specific inductive capacity or the dielectric constant of the material. ϵ_r can be determined experimentally by measuring the capacities with and without the dielectric respectively. The dielectric constant varies between 1 and 10 for normal solid substances. It is greater than 10 for liquids such as ethyl alcohol, glycerine and water and has still higher values for gases at high frequencies. It is 1 for vacuum and about 1.0057 for air at N.T.P. It varies not only from substance to substance, but also with the physical state of any particular substance. The dielectric constant of a medium is constant if the state of the medium does not vary from point to point. At the boundary between two media the dielectric constant changes abruptly, and bodies that are non-homogeneous with respect to density and other properties are usually non-homogeneous with respect to the dielectric constant as well.

b. Derive Clausius-Mossotti relation.

of a molecule.

33 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 is 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 thus 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
$$\begin{aligned} D &= \epsilon_0 E + P && \text{[where } E \text{ is external} \\ &= \epsilon_0 E + N\alpha E_i && \text{applied field]} \end{aligned}$$

The observed dielectric constant is defined by

$$D = \epsilon_0 \epsilon_r E$$

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

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
$$E_i = E + \frac{P}{3\epsilon_0} \quad \dots(9)$$

Equation (9) along with the equation $P = N\alpha E_i$

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

which along with equation (8) gives

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

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

or

This result is known as the Clausius-Mossotti relation.

Q.4a. What is loss tangent? Discuss its significance in dielectrics.

5.6. **Significance of the loss tangent**

ua The loss tangent has a very small value for free space. For solid materials $\tan \delta = 0.003$, which is equivalent to a Q of 3000. A fairly good value of Q for a coil is around 300. This is why we attach importance to losses in a coil and ignore those in a capacitor.

The variation of $\tan \delta$ with frequency will show a normal resonance like behaviour. This is shown in Fig. 5.4. The curve of $\tan \delta$ has the largest value in the region of frequencies where there is a sharp change in the dielectric constant.

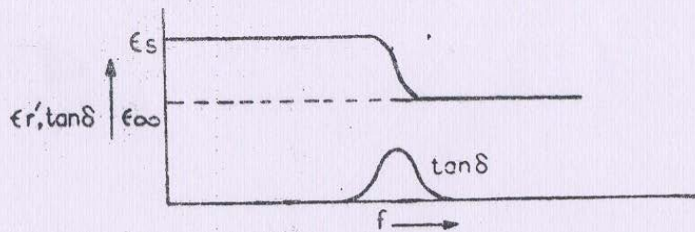
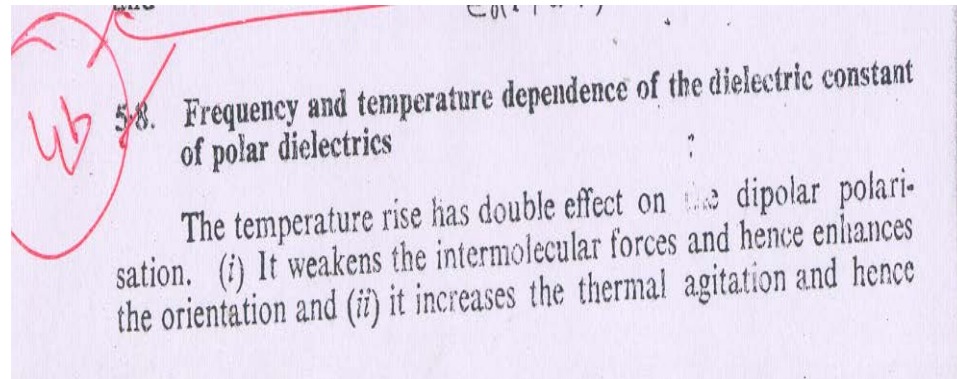


Fig. 5.4.

In case of ionic resonance this change in the dielectric constant occurs from microwave to infrared regions of frequencies. The dielectric losses associated with ionic vibrations are usually referred to as infrared absorption. Similarly the losses in the optical region associated with electronic vibrations are referred to as optical absorption. Hence it is possible to predict whether the dielectric properties are due to ionic or electronic polarisation. The occurrence of absorption in the optical region is the source of colour in materials, e.g. NaCl is transparent in the visible region which means that there is negligible absorption for the corresponding frequencies. Under X-rays, NaCl turns yellow-brown.

Table 5.2 (A. von Hippel) gives the real part of the dielectric constant and the loss tangent at a number of frequencies for various dielectrics.

b. Discuss the dependence of the dielectric constant of polar dielectric on frequency and temperature.



strongly disturbs the orientation. The higher intermolecular forces and lesser thermal agitation, at very low temperature reduce the orientational polarisation. At sufficiently high temperature the dielectric constant is again reduced due to the strong thermal motion which disturbs the orientation of the dipoles. Within these limiting

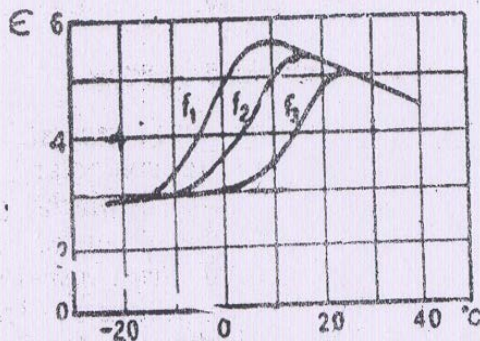


Fig. 5.8. Temperature dependence of the dielectric constant for Sovol at frequencies $f_3 > f_2 > f_1$.

temperatures the dielectric constant reaches a maximum value when the conditions are optimum. Fig. 5.8 shows, the dependence of the dielectric constant of Sovol upon temperature at three different frequencies.

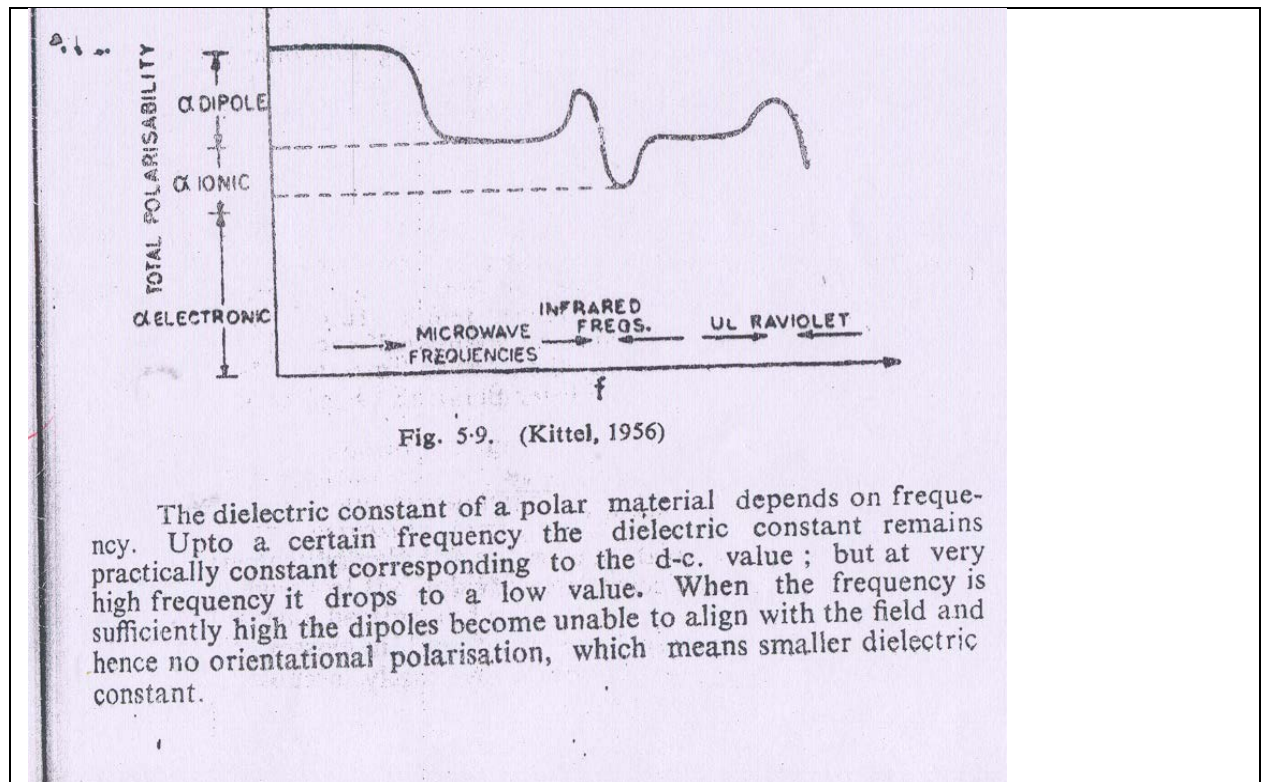


Fig. 5-9. (Kittel, 1956)

The dielectric constant of a polar material depends on frequency. Upto a certain frequency the dielectric constant remains practically constant corresponding to the d-c. value; but at very high frequency it drops to a low value. When the frequency is sufficiently high the dipoles become unable to align with the field and hence no orientational polarisation, which means smaller dielectric constant.

Q.5 a. Write the factors affecting permeability and hysteresis loss.

6.12. Factors affecting permeability and hysteresis loss

In general if the initial permeability is high, the hysteresis loss is low and *vice versa*. The permeability and the hysteresis loss depend upon the physical condition and chemical purity of the sample.

The crystals of a ferromagnetic material when cold worked experience deformation as a result of which the material has very poor magnetic properties. Due to the internal strains on the domains, greater magnetic field is required to give a definite magnetisation. Therefore, the permeability decreases and the hysteresis loss is increased. A material which has suffered magnetic damage due to cold work may be heated to a sufficiently high temperature when the magnetic properties will be restored.

The highest magnetic permeability and the lowest hysteresis loss that can be obtained are limited by the impurity content of the materials. Impurities affect the regular geometric pattern of the crystals and are harmful to the magnetic properties. The main impurities in the magnetic materials used for transformer cores and electrical machinery are carbon, sulphur, oxygen and nitrogen. Carbon is the most detrimental and the amount of carbon is kept to a low value of 0.01% in commercial materials.

Properties of some of the common high permeability materials and permanent magnet materials are given in Tables 6.5 and 6.6 respectively.

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divided by the magnetic space constant, μ_0 gives the magnetic susceptibility and the slope of the latter gives the magnetic permeability, μ which equals $\mu_0\mu_r$. For ferromagnetic materials the susceptibility (or, the permeability) is not constant. It has a low value at weak fields. As the field intensity is increased, the susceptibility increases, reaches a maximum value and then begins to drop, ultimately reaching a constant value on saturation.

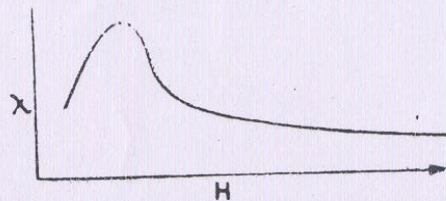


Fig. 6.1. Susceptibility versus field strength (ferromagnetic materials)

b. Give the classification of magnetic materials.

6.2. Classification of magnetic materials

Magnetic materials for which a linear relationship between M and H exists are divided into classes depending upon the sign of χ . Materials which have a negative value of χ of the order of 10^{-4} to 10^{-8} are called diamagnetic and those which have a positive value of χ of about the same order of magnitude are called paramagnetic. When the relationship between M and H is non-linear (i.e., when $\mathbf{B} \neq \mu_0\mu_r\mathbf{H}$) and exhibits the familiar hysteresis effect, we have the third large group of materials in which the resultant magnetisation is one to several orders of magnitude greater than $\mu_0\mathbf{H}$. Such materials are ferromagnetic.

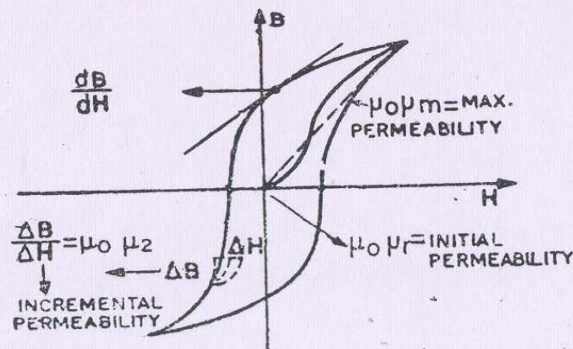


Fig. 6.2. Hysteresis loop.

Fig. 6.2 show the hysteresis loop for such a material from which we may define a number of permeabilities. The initial

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permeability is defined as the slope of the normal magnetisation curve, at $H=0$. The incremental permeability is defined as $\frac{\Delta B}{\Delta H}$ about a given point on the hysteresis loop. Sometimes the term differential permeability is used; it is defined as dB/dH , the slope of the magnetisation curve at the point of interest.

Another classification of magnetic materials consists in the presence or absence of permanent magnetic dipoles in them: the term permanent magnetic dipole being used in the same sense as in the corresponding dielectric case, *i.e.* a permanent dipole exists in the absence of a field. Materials which lack permanent magnetic dipoles are called diamagnetic. Magnetisation of such materials occurs when the applied field induces a magnetic moment in the individual atoms.

This possibility arises since an external magnetic field may cause changes in the electron orbits. In the absence of the external field the net magnetic moment of the orbits is zero but takes a non-zero value when the orbits are charged.

If permanent magnetic dipoles are present in the atoms of a material, it may be paramagnetic, ferromagnetic, antiferromagnetic or ferrimagnetic depending on the interaction between the individual dipoles. Thus if the interaction between the atomic permanent dipole moments is zero or negligible and the individual dipole moments are oriented at random as shown in Fig. 6.3 (a) the material will be paramagnetic. If the dipoles interact in such a manner that they tend to line up in parallel, as shown in Fig. 6.3 (b) the material will be ferromagnetic. Such materials exhibit what is known as ordered magnetism because of the stronger inter-atomic interaction. When neighbouring moments are aligned antiparallel as in Fig. 6.3 (c), the magnetic phenomenon is known as antiferromagnetism. In ferromagnetic materials there is a large resultant magnetisation whereas in antiferromagnetic materials, the magnetisation vanishes. When the order of the magnetic moments is as shown in Fig. 6.3 (d) the phenomenon is known as ferrimagnetism. For ferromagnetic materials [Fig. 6.3 (b)] if the four atoms comprise one molecule, the molecular moment will be four times the atomic moment. For antiferromagnetic materials the molecular moment will be zero and there is no spontaneous magnetisation. The molecular moments in ferrimagnetic materials



Fig. 6.3. Paramagnetic, ferromagnetic, anti-ferromagnetic and ferrimagnetic arrangement of spins.

will have values in between the values for ferromagnetic and anti-ferromagnetic materials.

c. Write applications of the following:

(4)

- (i) Ni-Fe Alloy
- (ii) Si steel

Ans - Ref text book

Q.6a. Give the classification of conductors, semiconductors & insulators based on energy band diagram.

6a
The conduction band energies are high enough so that electrons attaining these levels of energy are loosely attached to individual atoms or practically free such that they could easily move under the influence of an electric field. Electrons in the valence band can leave their band to join the conduction band if given sufficient energy to jump the forbidden energy band (energy gap, E_g). The size of E_g is a prime factor in determining whether a solid is a conductor, an insulator or a semiconductor.

With reference to different band structures shown in Fig. 7.7 we can now broadly divide solids into conductors, semiconductors and insulators. Conductors contain a large number of electrons in the conduction band at room temperature. No energy gaps exist and

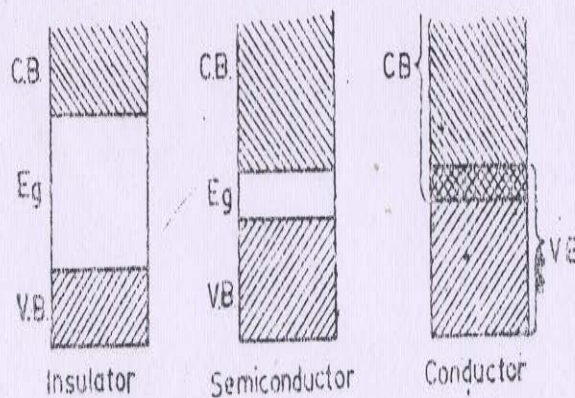


Fig. 7.7. Types of band structure.

the valence and conduction bands overlap. An insulator is a material in which the energy gap is so large that practically no electron can be given enough energy to jump this gap. These materials might conduct little electricity if their temperatures are raised to very high values enabling a number of electrons to join the conduction band.

A semiconductor is a solid with an energy gap small enough for electrons to cross rather easily from the valence band to the conduction band. At room temperature, sufficient energy is available for a few valence electrons to bridge the energy gap to the conduction band, thus the material sustains some electric current.

It is clear that an allowed energy band in a solid contains a large number of individual energy levels. Therefore the energy of an electron in a solid may take one value of a number of closely spaced values within these permitted bands. Naturally it may not take values lying within the forbidden energy bands. Electrons fill up energy positions starting from the lowest possible levels. At 0°K these levels are completely occupied by electrons up to a certain level, and completely unoccupied above it. The highest level completely filled by electrons is the Fermi level.

The energy distribution of electrons in a solid are governed by the laws of Fermi-Dirac statistics. The principal result of these statistics is the Fermi-Dirac distribution function which determines the probability that a given energy state is occupied by an electron.

$$f(E) = 1/[1 + \exp((E - E_F)/kT)] \quad \dots(1)$$

where $f(E)$ is the probability that an electronic state with energy E is occupied by an electron.

E_F is the Fermi level, or the Fermi energy.

and k Boltzmann's constant.

The Fermi level is such that, at any temperature, the number of electrons with greater energy than the Fermi energy is equal to the number of unoccupied energy levels lower than this. In conductors the Fermi level is situated in a permitted band (since the valence band and conduction band overlap with no energy gap). In insulators it lies in the centre of the large energy gap while in semiconductors it lies in the relatively small energy gap.

b.Explain the following:

- (i) Thermal conductivity of semiconductors
- (ii) Electrical conductivity of doped material

7.11. Thermal conductivity of semi-conductors

Heat conduction in semi-conductors takes place in two ways (i) by the electrons, and (ii) by the thermal vibrations of the atoms. The random thermal vibrations of all the atoms of a semi-conductor may be regarded as the sum total of vibrations of individual atoms, vibrations of pairs of atoms, of groups of three and ultimately the vibrations of the body as a whole. The higher the temperature the greater are these vibrations.

The coefficient of thermal conductivity of a semi conductor consists of two parts (i) the thermal conductivity due to the electrons and (ii) the thermal conductivity due to the thermal vibrations of the atoms. When the concentration of free electrons in semi-

conductor varies, the thermal conductivity due to the electrons varies in direct proportion to the electrical conductivity (cf Wiedemann-Franz law for metals) whereas the thermal conductivity due to vibrations of atoms remains practically constant. The Weidemann-Franz Law for metals is $K/\sigma = A_m \cdot T$ where A_m is a constant for all metals. This law as applied to semi-conductors is modified to $K = A_s \cdot T \cdot \sigma + K_{th}$ where A_s is a constant corresponding to the semi-conductors and K_{th} is the contribution to thermal conductivity due to vibrations.

7.12. Electrical conductivity of doped materials

A semi-conductor may be doped with donors or acceptors in which case the density of one type of carrier predominates. Thus in the presence of donor levels, the electrons are the majority carriers and in the presence of acceptor levels, the holes are the majority carriers. The free carrier concentration given by impurity atoms whose valence electrons have an energy less by ΔE_1 than their energy in the free state is

$$n_e = A_1 \exp\left(-\frac{\Delta E_1}{2KT}\right)$$

The valence band, also, always contains a certain number of holes. It may be shown that the electron and hole concentrations are related by

$$n_e n_h = n_i^2,$$

where $n_i = A \exp(-\Delta E/2KT)$ is the concentration of either electrons or holes when no impurities are present and ΔE is the width of the forbidden energy gap.

The product of the two concentrations does not depend upon the number of impurity atoms nor on the electron energies of such atoms. It always equals the square of the free electron or hole concentration for the pure semi-conductor at that temperature.

If the impurity atoms are electronegative the hole concentration will be

$$n_h = A_2 \exp(-\Delta E/2KT)$$

and the electron concentration in such a case would be

$$n_e = n_i^2/n_h$$

If a semi-conductor contains N_1 electropositive impurity levels per m^3 and N_2 electronegative levels per m^3 and if $N_1 > N_2$ then the electrons given by the electronegative atoms will be taken up by the electropositive atoms such that positive and negative ions are formed. Thus, $2N_2$ ions of opposite signs are obtained while the remainder electropositive levels $N_1 - N_2$ make the substance an n -type semi-conductor.

Q.7 a. Draw and explain the working of P-N Junction diode in forward & Reverse bias.

b. The resistance of the p & n layers of a silicon abrupt p-n junction are 10^{-2} & 10 Ohm respectively. The capacitance of the junction at zero applied bias voltage is 200 pF. If the thickness of the p & n layers are 1 mm. Each and the junction has a rectangular cross-section 1 mm².

(i) Determine concentration of impurity atoms on each side of the junction.

(ii) Width of depletion layer at zero applied voltage here $\mu_e = 1.45 \times 10^3$ cm²/v-sec & $\mu_h = 0.5 \times 10^3$ cm²/v-sec.

(iii) Find the contact potential.

(7b) (i) Resistivity in p side

$$\rho = \frac{RA}{l} = \frac{10^{-2} \times 0.001 \times 0.001}{0.001}$$

$$= 10^{-5}$$

for n side $\rho = 10^{-2}$

for n side $\sigma_n = 10^5$

So $\sigma_n = Nd e V_e$

$$Nd = \frac{\sigma_n}{e V_e} = \frac{10^{25}}{2.32} \text{ m}^3$$

& $Na = \frac{\sigma_p}{e V_h} = \frac{10^{22}}{0.8} \text{ m}^3$

(ii) thickness of depletion layer

$$x = \frac{\epsilon_0 \epsilon_r}{C}$$

here ϵ_r is g.

(iii) Contact potential

$$V_0 = \frac{e}{2\epsilon_0 \epsilon_r} \left(\frac{Nd Na}{Nd + Na} \right) x^2$$

Q.8 Discuss working principal & applications of the following:)

(i) Thermistors

(ii) Electrolytic capacitors

(iii) Cored coils

(iv) Relay

Ans(1) TBI /P.No. 266(ix)

(2) TBI /P.No. 273(x)

(3) TBI /P.No. 276(iii)

(4) TBI /P.No. 276 section 12.2 first para

Q.9 Write short notes on the following:)

(i) JFET

(ii) Fabrication of transistors

(i)

14.8. JFET

JFET exists in several practically realizable geometries (Fig. 14.11). The *cylindrical* version is sometimes used for discrete transistor manufacture. Planar form is most suitable for inclusion in I.Cs.

Current i_d flows in the external circuit as shown in Fig. 14.11(d). Since the bulk of the material is *n*-type the current is transported in the semiconductor by majority electrons flowing from source to drain, the left hand contact is thus an electron source and the right-hand contact drains electrons out. Since the bar has an ohmic resistance, the flow of current in it produces an IR drop and the potential at any point in the bar increases from the source to the drain end, becoming more positive towards the drain. Therefore, since the gates have been shorted to the source, the *pn*

junctions between the *p*-type gates and the *n*-type bar are reverse-biased, becoming progressively more so towards the drain end. Now, we know that the thickness of the depletion layer of a reverse biased *pn* junction varies approximately as the square root of the bias voltage. The layer

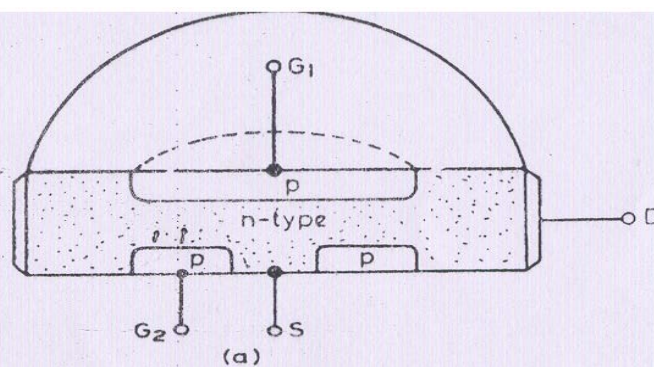


Fig. 14.11(a). Cylindrical version of JFET

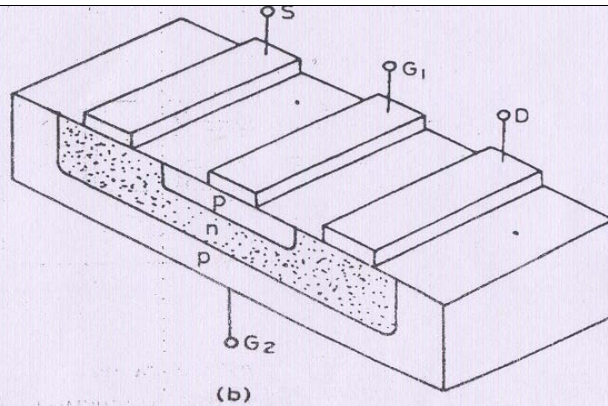


Fig. 14.11(b). Planar geometry of JFET

becoming wider as the reverse voltage increases. Thus the depletion layers between gates and bar become wider towards the drain end. Further the ratio of the thickness of the depletion layer in a *p*-type gate d_p to that in the *n*-type gate, d_n at any point is given by

$$\frac{d_p}{d_n} = \frac{N_d}{N_a}$$

Since *p*-type gates are much more heavily doped than the *n*-type conducting path i.e. $N_a \gg N_d$ and $d_p \ll d_n$, most of the depletion layer thick-

ness occurs in the *n*-type region. As a consequence, current flow in the device is confined to the wedge-shaped region or *channel* since there are no free carriers in the depletion layers.

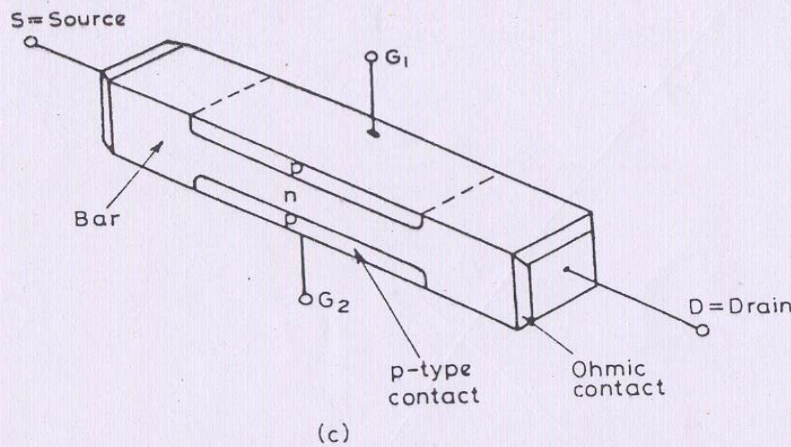


Fig. 14.11(c). Simplified model (rudimentary) for explanation purpose.

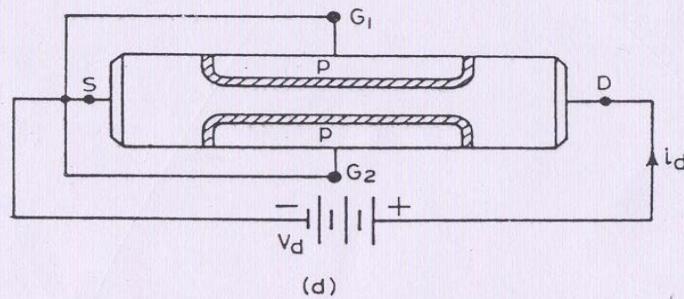
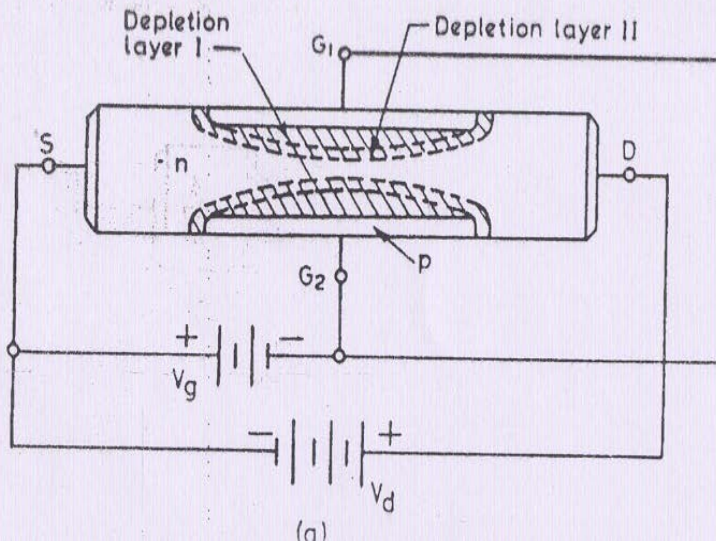


Fig. 14.11(d). Grounded gate operation.

As V_d is increased, the thickness of the conducting channel is reduced because of the widening of gate depletion layers as the reverse bias is automatically increased. The source to drain resistance is increased correspondingly until at some voltage $V_d = V_p$, called the *PINCH-OFF* voltage; the space charge regions from the gates meet; the channel is then said to be pinched off. At drain voltages beyond pinch-off, the drain current becomes essentially saturated and remains at some value, I_{d_0} .

If an additional fixed reverse-bias voltage V_g is applied to the gates G_1, G_2 (Fig. 14.12(a)) in the absence of drain current, the space charge layers would extend uniformly into the channel, region I. When drain current flows due to the application of a drain voltage V_d , the characteristic wedge shaped depletion layers, region II, are superposed on top of the uniform layers due to V_g alone. Under these conditions the IR drop and hence the

the



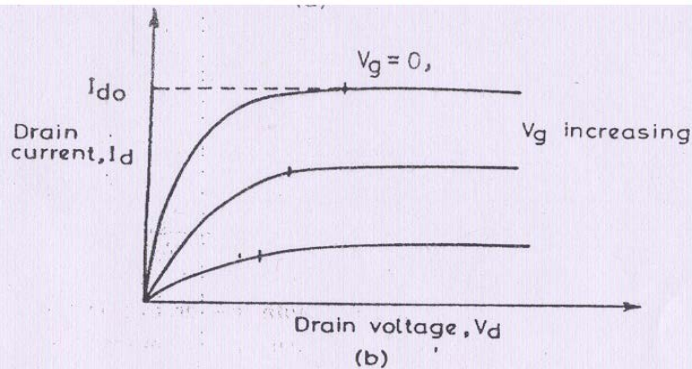


Fig. 14.12. (a) JFET with reverse bias voltage applied to its gate.
(b) drain characteristic of a JFET

value of V_d required to produce pinch-off is smaller and current saturation occurs at lower drain voltages. This results in a family of drain characteristics. Thus as shown in Fig. 14.12 (b) application of a reverse voltage to the gates governs the effective width of the depletion layers, which in turn changes the effective channel dimensions, modulates the channel resistance, and hence controls the drain current. When operating in this fashion the JFET behaves as a depletion mode device since the channel current is reduced as the gate voltage is increased. In the next section, we will consider the operation of a JFET more quantitatively with a view to characterising its d.c. and a.c. performance.

(ii) TBI /P.No. 321 section 14.16.1

TEXTBOOK

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