B,E.2nd Semester Examination December-2007
Paper : PHY-102-E

Time Allowed : 3 hours]   [Maximum Marks : 100

Note:- Attempt **five** questions in all, selecting atleast **two** questions from each part.

PART-A

1. **(a) Define the terms :**
   (i) Space lattice,
   (ii) Unit cell and
   (iii)Packing fraction. Decribe fcc and hcp structure. Calculate c/a for a hcp structure.
   12

Ans. (i) Space Lattice :

A lattice is defined as parallel net like arrangement of points provided the environment about any point is identical with environment about any other point.

The position vector of any lattice in two dimensional lattice by choosing any other lattice point as origin is expressed as

$$\vec{T} = n_1\vec{a} + n_2\vec{b}$$

where n_1 and n_2 *are* integral values which represent the number of lattice point along *PA* and *PB* axes, a and *b* are called the primitives.

The arrangement of points in three dimensions is expressed   by

the translational operator $\vec{T}$ as

$$\vec{T} = n_1\vec{a} + n_2\vec{b} + n_3\vec{c}$$

where the primitives a, b and c are taken along the crystal axes *PA, PB* and *PC* respectively.

Ans. (ii) Unit Cell :

The parallelopiped formed by using the primitives a, b, c as concurrent edges is called the unit cell of the space–lattice. The angles between primitives (b, c), (c, a) and (a, b) are denoted by α, β and γ respectively.
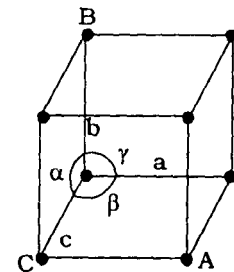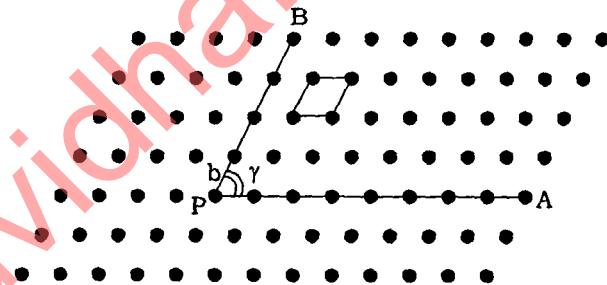
The volume of unit cell is $|a \cdot b \times c|$.

A primitive cell is a type of unit cell which contains lattive points at the corners only and is a minimum volume unit cell. In the fig. unit cell is also primitive cell.
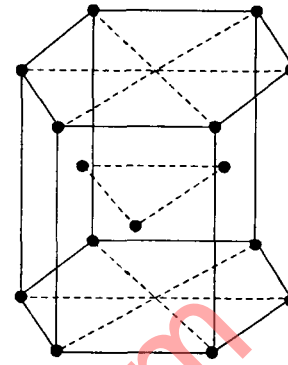
Ans.   (iii) Packing fraction :

The packing fraction is defined as the ratio of volume occupied by atoms in unit cell to the total volume of unit cell, *i.e.,* if *v* is volume occupied by atoms in unit cell and V is the total volume of unti cell, then packing fraction.

$$f = \frac{v}{V}$$

hcp Structure : In the hcp structure, the spheres in alternate lyers are directly above one another as shown in the fig. The atom positions in this structure do not constitute a space lattice. The space lattice is simple hexagonal with a basis of two identical atoms accociated with each lattice point.

The coordination number is a closed-packed crystal (either fcc or hcp) is 12. In both cases each sphere in a particular layer fits into the hollow formed by three spheres in the layer below it; hence each sphere is in contact with three spheres in the layer below it, and with three in the layer above it as well. Adding these six spheres to the six it touches in its own layers, each sphere in a close-packed structure has 12 nearest neighbours; that is the coordination number is 12.

Beryllium, magnesium, cobalt and zinc are among the elements with hcp structures.

Fee Structure : In a face-centered cubic (fee) structure, also called as cubic close-packed, the sequence repeats itself every three layers, instead of every two layers. Copper, lead, gold and argon are examples of close-packed fee structures.

Calculation of c/a for a hep structure : The space lattice is simple hexagonal with two identical atoms associated with each latice point. One atom of the basis is at the origin (0, 0, 0) and the other atom is at $\left(\frac{2}{3}, \frac{1}{3}, \frac{1}{2}\right)$

$$\vec{r} \Rightarrow \frac{2}{3}\vec{a} + \frac{1}{3}\vec{b} + \frac{1}{2}\vec{c}$$

The primitive cell is simple hexagonal, In this, we have

$$a^2 = \frac{a^2}{3} + \frac{c^2}{4}$$

Giving c/a = 1.633

1. (b) What is X-ray diffraction? Describe briefly Laue method for crystal structure analysis.

Ans. X-ray diffraction : X-ray diffraction was first concveived by Von Laue in 1912 and susbquently tested by Freidrich and Knipping who demonstracted that a X-ray beam passing through a single crystal was indeed broken up into a collection of diffracted beams. Our immediate goal with the diffraction of these rays by crystals is only in connection with the direct exploration of the interior of the crystals, that is, in connection with the fixation of the positions of the atoms on the crystal lattice, the measurement of distance between atoms and the associated internal symmetry. Such a study is possible because of the fact that the intensites of the diffracted beams and their directions are related to the atomic arrangements in crystal. Thus, measurement of their intensities and directions would provide the desired information about crystals.

Laue method for crystal structure analysis :
Please answer 1(a) December 2008.

2. (a) What do you understand by group and phase velocity? Explain. 8

Ans. Phase Velocity : When a single wave of a definite wavelength, travels in a medium its velocity of propagation in the medium is called the 'wave velocity' or the 'phase velocity'. Phase velocity is given by

$$u = \frac{c^2}{u}$$

where *v* is partical velocity and c is speed of light in vacuum.

Group Velocity : If however a number of waves of different wavelengths are moving with different velocities in a medium, then the observed velocity is the velocity of the wave packet (or wave group) formed by the waves. This is called the 'group velocity' and is less than the wave velocities.

It is given by $v_g = \dfrac{dw}{dk}$

2. (b) Give the formulation of time-independent Scrodinger wave equation. **12**
Ans. Please see answer 2 (b), Paper May 2008

3. (a) What are the limitations of classical free electron theory? Discuss Drude theory of free electrons for conduction. **12**
Ans. Limitations of classical free electron theory :
Please see answer 3 (a), Paper December 2008.
Drude theory of free electrons for conduction :
Please see answer 4 (iii), Paper May 2008.

3. (b) Discuss Fermi-Dirac distribution function. **8**
Ans. Please see answer 3 (a), Paper May 2008.

4. Write notes on any two :
(i) Point defects in solids,
(ii) Bonds in solids,
(iii)Richardson's thermionic equations. **10+10**
Ans. (i) Point Defects in Solids :
Please see answer 1 (b), Paper May 2008.

Ans. (ii) Bonds in Solids :
The constituent particles of crystals are bound with their neighbours in different ways. The bonding forces in most cases are electrostatic in nature, but the distribution of electrons around the various particles are qualitatively different in different crystals.

(1) Ionic Crystals are those in which electrons are transferred from one type of atoms to the other type of atoms. The net result is that such crystals are composed of positively and negatively charged ions *e.g.,* NaCl.

(2) Covalent Crystal are those in which the velence electrons are shared equally between neighbouring atoms rather than being transferred from one atom to another e.g., Diamond silicon dydrogen molecule.

(3) Metallic Crystals are those in which valence electrons are weakly coupled to the nucleus and assumed to move about throughout the crystals. There are positive ions immersed in gas of free electrons.

(4) Molecular Crystal consist of neutral atoms or the molecules bound together in the solid phase by weak short range attractive forces known as Vander Wal forces e.g., crystals of solidified gas such as O_2, N_2, H_2.

(5) Hydrogen Bonded Crystals : In this atoms of Hydrogen are attracted by extremely electronegatives atoms such as Oxygen, Fluorine and Nitrogen.
Ans. (iii) Richardson's Thermionic Equation :
The emission of the electrons from metal under the influence of thermal energy is known as thermionic emission. The electrons so emitted are known as thermions.

Richardson's Equation : Let us now calculate the emission current density of the emitted electrons :
In the free electron model of a metal, the electrons are free to move throughout the

volume V. According to Fermi-Dirac statistics the number of electrons per unit volume ($V = 1$) having the momentum in the range p and $+dp$ is

$$dn = g_s \frac{4\pi p^2\, dp}{h^3} \cdot \frac{1}{e^{(\varepsilon - \varepsilon_F)/kT} + 1}$$

For electrons $g_s = (2s + 1) = 2$.

Therefore

$$dn = \frac{2}{h^3} \cdot \frac{4\pi p^2\, dp}{e^{(\varepsilon - \varepsilon_F)/kT} + 1} \qquad \ldots(1)$$

If p_x, p_y, p_z be the components of momentum of the electron along X, Y and Z axes, such that

$$P^2 = p_x{}^2 + p_y{}^2 + p_z{}^2$$

then the volume in the momentum space lying between p_x and $p_x + dp_x$, p_y and $p_y + dp_y$, p_z and $p_z + dp_z$ will be

$$dp_x\, dp_y\, dp_z = 4\pi p^2\, dp.$$

So that the number of electrons per unit volume whose momentum components lie between p_x and $p_x + dp_x$, p_y and $p_y + dp_y$ and $p_z + dp_z$ is

$$dn = \frac{dp_x\, dp_y\, dpz}{e^{(\varepsilon - \varepsilon_F)/kT} + 1}$$

If v_x, v_y and v_z denote the velocity components along X, Y and Z-axes, we have

$$dn = \frac{2}{h^3} \frac{(m\, dv_x)(m\, dv_y)(m\, dv_z)}{e^{(\varepsilon - \varepsilon_F)/kT} + 1} = 2\frac{m^3}{h^3} \frac{dv_x\, dv_y\, dv_z}{e^{(\varepsilon - \varepsilon_F)/kT} + 1}$$

This equation gives the number of electrons per unit volume having velocity components in the ranges v_x and $v_x + dv_x$, v_y and $v_y + dy_y$, v_z and $v_z + dv_z$.

As kT is of the order of 0.3 eV and $(\varepsilon - \varepsilon_F)$ is at least 20 times greater than kT, we can neglect one in the denominator of R.H.S. and wirte
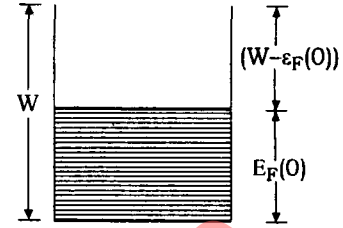
$$dn = 2\frac{m^3}{h^3} \cdot e^{(\varepsilon_F - \varepsilon)/kT} dv_x\, dv_y\, dv_z$$

$$= 2 \cdot \frac{m^3}{h^3} \cdot e^{\varepsilon_F/kT} \cdot e^{-\frac{1}{2}m(v_x{}^2 + v_y{}^2 + v_z{}^2)/kT}\, dv_x\, dv_y\, dv_z$$

Since

$$\varepsilon = \frac{1}{2} m v^2 = \frac{1}{2} m(v_x{}^2 + v_y{}^2 + v_z{}^2)$$

or

$$dn = 2 \cdot \frac{m^3}{h^3} \cdot e^{\varepsilon_F/kT} \cdot e^{-mv_x{}^2/2kT} dv_x\, e^{-mv_y{}^2/2kT} dv_y \times e^{-mv_z{}^2/2kT} dv_z$$

Now, supposing that the surface of the metal lies in X-Z plane and X-axis is normal to this surface, the no. of electrons per unit volume in velocity range v_x and $v_x + dv_x$ is given by

$$dn_x = n(v_x) dv_x = 2 \cdot \frac{m^3}{h^3} \cdot e^{\varepsilon_F/kT} \cdot e^{-mv_x{}^2/2kT} dv_x \int_{-\infty}^{\infty} e^{-mv_y{}^2/kT} dv_y \int_{-\infty}^{\infty} e^{-mv_z{}^2/kT} dv_z$$

$$= 2 \cdot \frac{m^3}{h^3} e^{-mv_x{}^2/2kT} dv_x \sqrt{\left(\frac{2\pi kT}{m}\right)} \sqrt{\left(\frac{2\pi kT}{m}\right)}$$

$$= \frac{4\pi m^3 kT}{h^3} \, \varepsilon^{\varepsilon_F/kT} e^{-mv_x^2/2kT} dv_x$$

when the metal is heated only those electrons can escape from the surface along X-axis which fulfill the condition

$$\varepsilon = \frac{1}{2} m v_x^2 \geq W, \ i.e. \ v_x \geq \sqrt{\left(\frac{2W}{m}\right)}$$

Therefore, the number of electron dealing unit area of the surface in unit time is

$$n_x = \int_{\sqrt{(2W/m)}}^{x} n(v_x) v_x \, dv_x = \frac{4\pi m^2 kT}{h^3} \cdot e^{\varepsilon_F/kT} \int_{\sqrt{(2W/m)}}^{\infty} \cdot e^{-mv_x^2/kT} v_x \, dv_x$$

$$= \frac{4\pi m k^2}{h^3} \cdot T^2 \, e^{-(W-\varepsilon_F)/kT} \qquad \qquad ...(2)$$

$$= \frac{4\pi m k^2}{h^3} \cdot T^2 \, e^{-\phi/kT}$$

where work function $\phi = W - \varepsilon_F = W - \varepsilon_F(0)$ $\qquad \qquad ...(3)$

The emission current per unit area (i.e. emission currrent density) is obtained by multiplying no. of electrons leaving unit area of the surface in the unit time with electronic charge,

i.e. $\qquad \qquad J = n \cdot e = \frac{4\pi m e k^2}{h^3} \cdot T^2 e^{-\phi/kT}$

$$A T^2 e^{-\phi/kT} \qquad \qquad ...(4)$$

where $A = \frac{4\pi m e k^2}{h^3}$ is a constant independent, of the nature of the metal.
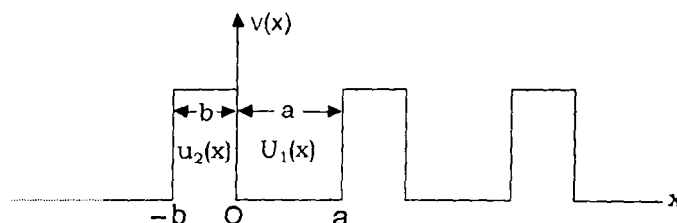
Equation (4) is known Rechardson's equation for thermionic emission.

PART - B

5. (a) Discuss the origin of energy bands in solids on the basis of Kronig-Penny Model.
10
Ans. This model illustrates the behaviour of an electron in a periodic potential. It assumes that the potential energy of an electron in a linear array of positive nuclei has the form of a periodic square potentials of periods $a + b$ such that in regions such as $0 < x < a$, the potential energy is equal to zero and in region such as $-b < x < 0$; the is V_0. The potential function is shown in fig. This model, although idealised, is very useful because it explains many useful periodic features of the behaviour of electron-lattices.

The wave Sanctions associated with this modelm ay be calaculated by solving Schrodinger equations in two regions *viz.*

$$\frac{d^2\psi}{dx^2} + \frac{2m}{\hbar^2}E\psi = 0 \quad \text{for} \quad 0 < x < a \qquad \text{...(1)}$$

$$\frac{d^2\psi}{dx^2} + \frac{2m}{\hbar^2}(E - V_0)\psi = 0 \quad \text{for} \quad -b < x < 0 \qquad \text{...(2)}$$

Let us introduce real quantities α and β such that

$$\frac{2mE}{\hbar^2} = \alpha^2 \quad \text{and} \quad \frac{2m(V_0 - E)}{\hbar^2} = \beta^2 \qquad (E < V_0) \qquad \text{...(3)}$$

Then equations (1) and (2) take the form

$$\frac{d^2\psi}{dx^2} + \alpha^2\psi = 0 \qquad \text{...(4)}$$

and

$$\frac{d^2\psi}{dx^2} + \beta^2\psi = 0 \qquad \text{...(5)}$$

As the potential is periodic, the wave functions must have the Bloch form

$$\psi(x) = e^{ikx}u(x) \qquad \text{...(6)}$$

If $u_1(x)$ and $u_2(x)$ represent the value of $u(x)$ in two regions $(0 < x < a)$ and $(-b < x < 0)$ of potential functions respectively, then equations (4) and (5) give

$$\frac{d^2u_1}{dx^2} + 2ik\frac{du_1}{dx} - (k^2 + \alpha^2)u_1 = 0 \qquad (0 < x < a) \qquad \text{...(7)}$$

$$\frac{d^2u_2}{dx^2} + 2ik\frac{du_2}{dx} - (\beta^2 + k^2)u_2 = 0 \qquad (-b < x < 0) \qquad \text{...(8)}$$

The solution of these equations may be written as

$$u_1 = Ae^{i(\alpha-k)x} + Be^{-i(\alpha+k)x} \qquad (0 < x < a) \qquad \text{...(9)}$$

$$u_2 = Ce^{(\beta-ik)} + De^{-(\beta+ik)x} \qquad (-b < x < 0) \qquad \text{...(10)}$$

here A, B, C, D are constant to be determined by the following boundary conditions.

$$\left. \begin{array}{l} (u_1)_{x=0} = (u_2)_{x=0} \; ; \; \left(\dfrac{du_1}{dx}\right)_{x=0} = \left(\dfrac{du_2}{dx}\right)_{x=0} \\[3mm] (u_1)_{x=a} = (u_2)_{x=-b} \; ; \; \left(\dfrac{du_1}{dx}\right)_{x=a} = \left(\dfrac{du_2}{dx}\right)_{x=-b} \end{array} \right\} \qquad \text{...(11)}$$

The first two conditions are due to requirement of conditinuity of wave function ψ and its derivative $(d\psi/dx)$; while the last two conditions are due to periodicity of $u(x)$. The application of these boundary condition to (9) and (10) yields.

$$\left. \begin{array}{l} A + B = C + D \\[2mm] Ai(\alpha - k) - Bi(\alpha + k) = C(\beta - ik) - D(\beta + ik) \\[2mm] Ae^{i(\alpha-k)a} + Be^{i(\alpha+k)a} = Ce^{-(\beta-ik)b} + De^{(\beta+ik)b} \\[2mm] Ai(\alpha - k)e^{i(\alpha-k)a} - Bi(\alpha + k)e^{-i(\alpha+k)a} \\[2mm] \qquad = C(\beta - ik)e^{-(\beta-ik)b} - D(\beta + ik)e^{(\beta+ik)b} \end{array} \right\} \qquad \text{...(12)}$$

The coefficients *A, B, C* and *D* may be evalauted by solving these equation. However we are interested in evaluation of energy-values. Equations (12) give non-vanishing solutions if the determinant coefficients vanishes, *i.e.,*

$$\begin{vmatrix} 1 & 1 & -1 & -1 \\ i(\alpha - k) & -i(\alpha + k) & -(\beta - ik) & \beta + ik \\ e^{i(\alpha-k)k} & e^{-i(\alpha+k)a} & -e^{(\beta-ik)b} & e^{(\beta+ik)b} \\ i(\alpha - k)e^{i(\alpha-k)a} & -i(\alpha + k)e^{-i(\alpha+k)a} & -(\beta - ik)e^{-(\beta-ik)b} & (\beta + ik)e^{(\beta+ik)b} \end{vmatrix} = 0$$

This leads to the following equation

$$\frac{\beta^2 - \alpha^2}{2\alpha\beta}\sin h\beta b \sin \alpha a + \cos h\beta b \cos \alpha a = \cos k(a + b) \qquad ...(13)$$

This equation is quite complicated, however we may draw important conclusions. Kronig and Penny considered the possibility that $V_0 \to \infty$ $b \to 0$ such that $V_0 b$ remainsfinite. Under these circumstances this model is modified to one of a series of wells separated by infinitely thin potential barriers, the quantity V_0 b (under the limits $V_0 \to \infty$ and $b \to 0$) representing the barrier strength. Under this possibility equation 913) becomes

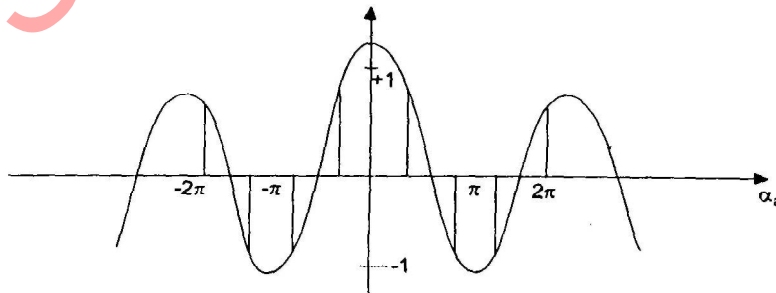$$\left(\frac{mV_0 b}{\hbar\alpha}\right)\sin \alpha a + \cos \alpha a = \cos ka \qquad ...(14)$$

Introducing the quantity such that

$$P = \frac{mV_0 ba}{\hbar^2} \qquad ...(15)$$

Then (14) reduces to $\qquad P = \dfrac{\sin\alpha a}{\alpha a} + \cos\alpha a = \cos ka \qquad ...(16)$

This is the conditions for the solutions of the wave equation to exist. We see that this is satisfied only for those values of *aa* for which its left-hand side lies between +1 and - 1 ; this is because its right-hand side must lie in range. Such values of αa will, therefore, represent the wave-like solutions (6) and are accessible.

The other values of αa will be inaccessible. The consequence of this can be understood

with referrence to following fig. which represents the left-hand side $\left(\dfrac{P\sin\alpha a}{\alpha a} + \cos\alpha a\right)$ of

(16) as a function of for aa for the value $P = \dfrac{3\pi}{2}$. The part of the vertical axis lying between

the horizontal lines represents the range acceptable to the left-hand side $\left(\dfrac{P\sin\alpha a}{\alpha a} + \cos\alpha a\right)$

Remembering that α^2 is proportional to the energy E, the abscissa (αa) will be a measure for the energy.

Clearly there are regions for αa where the value of $\left[\dfrac{P\sin\alpha a}{\alpha a}+\cos\alpha a\right]$ does not lie between -1 and $+1$. For these values of αa and hence of enegy E, no solutions exist. Such regions of energy are prohibited and are called forbidden bands.

Q. 5. (b) What is Fermi energy? Discuss its variation with temperature. 10
Ans. Please see Answer 5 (b), paper May 2008

Q. 6. (a) Define photo conductivity. What are traps? Discuss the effect of traps on the photo-conductivity of a photo-conductor. 12
Ans. Photoconductivity:
When light radiation falls on an insulating crystal, its electrical conductivity increases. this phenomenon is called photoconductivity.

The expression for photoconductivity is given by

$$\sigma = \left(\frac{L}{A}\right)^{1/2} e\mu$$

where L = number of photons absorbed per unit volume per second or L represents light-level, μ = electron mobility, A = constant

Traps : A trap is an energy level in the forbidden energy gap of the crystal capable of capturing either an electron or a hole; the captured carrier may be re-emitted at a subsequent time and may move to another trap.

There are *two types of traps*, distinguished on the basis of their operation : One type helps electrons and holes to recombine and thereby assists in the restoration of thermal equilibrium. This type of traps are known as recombination centres. Another type of traps does not contribute directly in an important way to recombination, but affect principally the freedom of motion of charge carriers of one sign or the other. This features of traps is illustrated in fig.

Effect of Traps on photoconductivity :
We consider a crystal with N electron traps levels per unit volume. Supposing then that the temperature is sufficiently low in relation to the relevant ionization energies so that the concentration of thermal carriers may be neglected, we

Fig. Influence of Traps in electron-hole recombination

modify $\left(\dfrac{dx}{dt} = L - AnP = L - An^2\right)$ as

$$\frac{dn}{dt} = L - An(n + N) \qquad\qquad ...(1)$$

Where n is the electron concentration in the conduction band. For simplicity, we have assumed that the propertionality coefficient A is the same for electron-hole recombination as for electron traps capture, and have omitted the effect of thermal ionization of carriers from traps back into the conduction band; this effect would have added a term B to the right hand side of eqn. (1) . In the steady state, we now therefore have
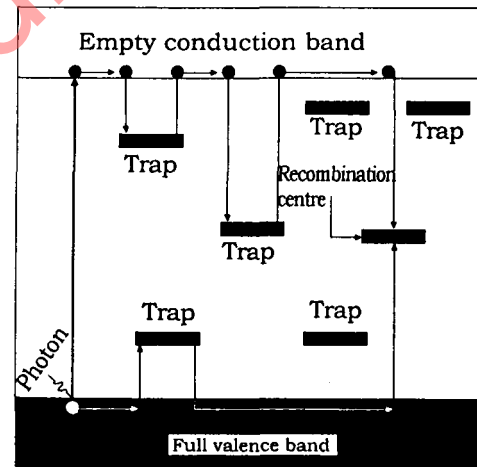
$$n_0 = (n_0 + N) = L/A \qquad \ldots (2)$$

Now it is usually difficult to grow crystals with trap concentrations N much less than 10^{14}cm^{-3}. Accordingly, we may discuss two limiting cases, one in which the carrier concentration n_0 may be very much less than this, perhaps only 10^8 or 10^{10} cm"³, and another in which it is very much greater. The former case holds at low levels of illumination, and the latter at high levels of illumination. Thus, in the limit $n_0 \ll N$, we have

$$n_0 = L/AN \qquad \ldots (3)$$

in eq. $n_0 = \left(\dfrac{L}{A}\right)^{1/2}$. The photocurrent is now directly proportional to the illumination level L, which is in fairly satisfactory agreement. In the limit $n_0 > N$, the response is given by

$$n_0 = (L/A)^{1/2}, \qquad \ldots (4)$$

just as found earlier in the absence of traps. The experimental results act to confirm this change in the response with illumination level.

The decay of the carriers on switching off the light is given by

$$\log \frac{n+N}{n} - \log \frac{n_0+N}{n_0} = NAt \qquad \ldots (5)$$

obtained by solving (1) with L = 0. In the limit $N > n_0$, it reduced to $n = n_0 \exp(-NAt)$, and so the time for the photocurrent to fall to e^{-l} of its initial value is

$$t_0 = 1/NA \qquad \ldots (6)$$

Just compare this result with the earlier result eq. $t_0 = \dfrac{1}{An_0} = (LA)^{-1/2} = \dfrac{n_0}{L}$ in the absence of traps - the presence of traps reduces the response time. Also, note the reduction in photoconductivity from (4).

6. (b) Write a note on photo-voltaic cell and their characteristics.
Ans. Photo-voltaic cell:

Please see answer, 6(b), Paper May 2008.

Characteristics Photo voltaic Cell : The strength of the current is proportional to the intensity of light and flows without any bias, i.e. without any external source of e.m.f.

7. How do you classify materials as dia or para *or* ferromagnic? Describe classical theory of paramagnetism.
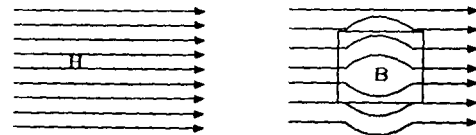**Ans. Diamagnetic Substances** : The substances substances which get weakly magnetised by a strong magnetic field in direction opposite to the applied magnetic field e.g., copper, silver, antimony, quartz, water, alcohol.

Characteristics : (1) When a bar of diamagnetic substance is placed in strong magnetic field the magnetism is induced in a direction opposite to external field, so that total number of magnetic lines induction are less in material than that of free space. This shows that $\mu < 1$ or susceptibility is negative permeability is less than 1.

(2) In a non-uniform magnetic field, diamagnetic substance tends to move from the stronger to weaker part of field.

(3) A diamagnetic susceptibility is independent of temperature.

(4) If a bar of diamagnetic substance is suspended between the poles of a magnet, it stays
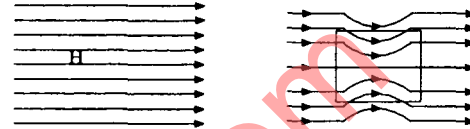
at right angles to the field direction.

(5) A diamagnetic liquid shows a depression in the limb of U-tube placed between pole-pieces of strong magnet.

Paramagnetic Substances : The substance which get weakly magnetised by a strongmagnetic field in same direction as the applied field e.g., aluminium, magnesium, tungesten, air, copper sulphate, chromium etc.

Characterstics : (1) When a bar of paramagnetic substance is placed in a strong magnetic field, the magnetism induced in direction parallel to direction of external field. So the total number of lines within the material are slightly greater than that of free space.

This shows $\chi = + ve$ and $\mu > 1$

(2) In a non-uniform magnetic field, paramagnetic substance tends to move from weaker to the stronger part of the field.

(3) The parmagnetic susceptibility is inversely proportional to temperature.

(4) If a bar of paramagnetic substance is placed in poles of magnet, it stays parallel to the lines of force.
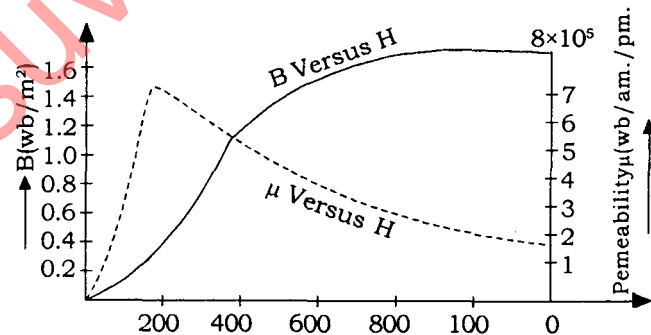
(5) The paramagnetic liquid shows a rise in the limb of U-tube placed between the poles pieces of strong magnet.

Ferromagnetic Substances : Those substances which get strongly magnetised by relatively weak magnetic field in same sense as the field are called ferromagnetic substances e.g., iron, cobalt, steel.

Characterstics (1) When material is placed in external magnetic field, strong magnetism is induced parallel to the direction of the field. This shows μ is very large ; $\chi \Rightarrow + ve$ and very large.

(2) As $B = \mu H$, depending on value of H, μg goes through an entire range of values from infinity to zero.

(3) The susceptibility of ferromagnetic substances decreases with rise of temperature. Above a certain temperature called curie temperature, ferromagnetic substances change to paramagnetic.

Classical Theory of Parmagnetism:
Please see answer 6 (a), Paper December 2008

8. **Write notes on any two :**
    (i) **Hall effect and its applications,**   (ii) **Super conductivity,**
    (iii)   **London**   **equation.**   **10+10**
Ans.   (i) **Hall effect** :
    Please see answer 5 (b), Paper December 2008
    Applications of Hall Effect : (i) Determinates of Type of Semi-conductor : In n-type semi-conductor, the Hall coefficient is negative and for p-type semi-conductor, the Hall coefficient is positive. Thus the sign of Hall coefficient can be used to determine whether a given semiconductor is n-type or p-type.
    (ii) Calculation of Carrier concentration : By measuring Hall coefficient experimentally, the carrier concentration may be found by the relation.

$$n = \frac{1}{eR_H}$$

(iii) Determination of Mobility : If the conduction in the sample is due to one type of charge carrier, the mobility of charge carrier may be estimated by the formula $\mu = \sigma R_H$.

For electrons in conductor or n-type semi-conductor.

$$\mu_e = \sigma R_H$$

knowing the value of σ, the mobility μ can be estimated.

(iv) Determination of Magnetic Flux Density B : As Hall voltage is proportional to magnetic flux density

$$V_H = R_H J_x Bb \Rightarrow B = \frac{V_H}{R_H b J_x} = \frac{V_H t}{R_H I_x}$$

For a given current I_x, B may be estimated by noting Hall voltage and geometry of sample. Thus hall effect may be used as the basis for design of magnetic flux density meter.

Ans. (ii) **Superconductivity** :

The electrical resistivity of many metals and alloys drops suddenly to zero when they are looked to a sufficiently low temperature often a temperature, in liquid helium range. This phenomenon is known as superconductivity. The resistivity of the mercury vanishes completely below 4.2°K, the transition from normal conductivity occur within a very narrow range of temperature of order of 0.05°K
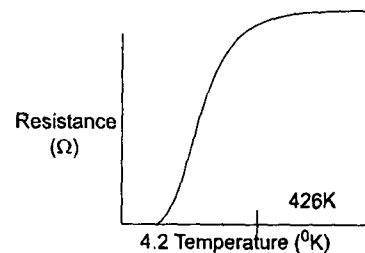
Salient features and uses of superconductors :

1. Electrical properties : The superconducting state of a material is characterised by zero electrical resistance. On superconductivity state $E = 0$, so $\rho = 0$. That is in superconducting state the resistivity of material disappears. Hence a superconductor can conduct electric current even in the absence of an applied voltage, and the current can persist for year without any detectable decay.

2. Magnetic Properties : The superconductinv state of a material mainly depends on temperature and magnetic field. It exists only in a particular range of t emperature and field strength. The superconducting state disappears if the

Resistance (Ω)

426K

4.2 Temperature (^{0}K)

temperatur eof the specimen is raised above its critical temperature T_C or if a sufficiently strong magnetic field is applied. The minimum value of magnetic field at a given tempera-ture at which superconductivity disappears is called the critical magnetic field (H_c).

3. **Thermal Properties** : The thermal properties like entropy, heat capacity thermal conductivity etc. of a metal change sharply at transition temperature (T_c) of superconductiv-ity as the temperature is lowered.

4. Optical properties : The photons of energy $h\nu <$ energy gap Δ are not absorbed by superconductors, nearly all the photons incident on metal are reflected back, but for a thin film of the order 20A more photons are transmitted in the superconducting state than the normal state. This is due to the effect of photon-energies on resistivity of a superconductor.

Ans. (iii) The London Equations :

Please see answer 7 (a), Paper December 2008