Total No. of Questions: 6 *Total No. of Printed Pages:3*

Enrollment No......................................

Faculty of Engineering

End Sem (Odd) Examination Dec-2017

EC3ES09 / EI3ES09 Engineering Materials

Programme: B.Tech. Branch/Specialisation: EC/EI

Duration: 3 Hrs. **Maximum Marks: 60**

Note: All questions are compulsory. Internal choices, if any, are indicated. Answers of Q.1 (MCQs) should be written in full instead of only a, b, c or d.

Q.1 i. In an atom containing more than one electron, the states of electrons can be determined using **1**

(a) Pauli's exclusion principle
(b) Types of bonding with other atoms
(c) Electronic Configuration
(d) Lattice orientation.

ii. For cubic structure we have **1**

(a) $a = b \neq c$ & $\alpha = \beta = 90^o$ $\gamma=120^o$
(b) $a = b = c$ & $\alpha = \beta = \gamma = 90^o$
(c) $a \neq b \neq c$ & $\alpha = \beta = \gamma = 90^o$
(d) $a \neq b \neq c$ & $\alpha \neq \beta \neq \gamma \neq 90^o$

iii. The impedance offered by the material in the path of m.m.f. is called **1**

(a) Impedance (b) Reluctance (c) Reactance (d) Resistance.

iv. Gold is an example of **1**

(a) Diamagnetic (b) Paramagnetic
(c) Ferromagnetic (d) Ferrimagnetic.

v. Critical temperature for a superconductor is **1**

(a) 273K
(b) 0K
(c) Temperature which transits from normal to superconducting state.
(d) Temperature at which conductivity drops to zero.

	vi.	Heat developed between current carrying conductors is governed by (a) Linde's rule (b) Joule's law (c) Wiedemann law (d) Meissner effect.	**1**
	vii.	Energy gap in conductors is equal to (a) 1 eV (b) 5 eV (c) 0 eV (d) None of these	**1**
	viii.	The process in which energy of dopants is increased to such a high level so that it penetrates the silicon wafer is called (a) Oxidation (b) Photolithography (c) Diffusion (d) Ion Implantation.	**1**
	ix.	The ratio of velocity of light in vacuum to the velocity of light in material is called (a) Miller index (b) Refractive index (c) Reflective index (d) Molar index.	**1**
	x.	Lasers works on the principle of (a) Reflection (b) Total Internal reflection (c) Population inversion (d) Dispersion.	**1**
Q.2	i.	Calculate the interplanar distance of (200) plane and (111) plane of nickel (fcc). The radius of nickel atom is 1.245 Å.	**2**
	ii.	A beam of X-rays of wavelength 0.842 Å is incident on a crystal at a grazing angle of 8° 35' when the first order Bragg's reflection occurs. Calculate the angle of incidence for third order reflection.	**3**
	iii.	Explain the crystal imperfections. Discuss their classification.	**5**
OR	iv.	What are miller indices? How will you determine miller indices for a crystallographic plane in a cubic unit cell?	**5**
Q.3	i.	Define relative permittivity. Prove that $\mu_r = 1 + \chi$, where χ is the magnetic susceptibility.	**2**
	ii.	Derive the relationship between B, H and M, where B is flux density, H is magnetic field intensity and M is magnetisation.	**3**

	iii.	Define ferromagnetism. What causes ferromagnetism in iron, cobalt and nickel?	**5**
OR	iv.	What are diamagnetic, paramagnetic and ferromagnetic materials? Explain.	**5**
Q.4		Attempt any two:	
	i.	Show that the heat developed per m^3 per second in a conductor carrying a current density J as a result of an applied field E is given by : $W = \sigma.E^2$ where σ is conductivity of the conductor.	**5**
	ii.	State and explain Linde's rule. What is the difference between electronic and ionic conduction?	**5**
	iii.	Give a brief account of superconductivity on account of free electron model. State the properties of superconductors.	**5**
Q.5		Attempt any two:	
	i.	With the help of energy bands, explain the difference among semiconductors, conductors and insulators.	**5**
	ii.	What are direct and indirect bandgap semiconductors? Explain each one of them with examples.	**5**
	iii.	Explain Hall effect and its relation to the force exerted by the magnetic material on a conductor. Write significance of Hall coefficient positive for p-type of semiconductor.	**5**
Q.6	i.	Calculate Δ for a step index Fibre having core and cladding refractive indices of 1.48 and 1.46 respectively.	**2**
	ii.	Calculate the number of modes in the graded index fibre at an operating wavelength of 850 nm.	**3**
	iii.	Calculate numerical aperture and acceptance angle of a fibre having the following characteristics- μ (core) = 1.35 and Δ = 2 %.	**5**
OR	iv.	What is the structure of optical fibre? Write advantages of optical fibre over metallic wires and cables?	**5**

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EC3ES09 / EI3ES09 Engineering Materials

Marking Scheme

Q.1	i.	In an atom containing more than one electron, the states of electrons can be determined using (a) Pauli's exclusion principle	**1**
	ii.	For cubic structure we have (b) $a = b = c$ & $\alpha = \beta = \gamma = 90^o$	**1**
	iii.	The impedance offered by the material in the path of m.m.f. is called (b) Reluctance	**1**
	iv.	Gold is an example of (a) Diamagnetic	**1**
	v.	Critical temperature for a superconductor is (c) Temperature which transits from normal to superconducting state.	**1**
	vi.	Heat developed between current carrying conductors is governed by (b) Joule's law	**1**
	vii.	Energy gap in conductors is equal to (c) 0 eV	**1**
	viii.	The process in which energy of dopants is increased to such a high level so that it penetrates the silicon wafer is called (d) Ion Implantation.	**1**
	ix.	The ratio of velocity of light in vacuum to the velocity of light in material is called (b) Refractive index	**1**
	x.	Lasers works on the principle of (c) Population inversion.	**1**

Solutions

Q.2. (i) $r = 1.245\ A^\circ$

$$a = \frac{4r}{\sqrt{2}} = 3.521\ A^\circ$$

For cubic crystal

$$d = \frac{a}{\sqrt{h^2+k^2+l^2}} \quad (1)$$

(1)

$$d_{200} = \frac{3.521}{2} = 1.760\ A^\circ$$

$$d_{111} = \frac{3.521}{\sqrt{3}} = 2.032\ A^\circ$$

Q.2. (ii) $n\lambda = 2d \sin\theta$ (1)

First order reflection, $n = 1$

(1)

$$d = \frac{0.842}{2 \sin 8^\circ 35'}\ A^\circ$$

Third order reflection, $n = 3$

(1)

$$\sin\theta = \frac{3 \times 0.842\ A^\circ}{2 \times \frac{0.842\ A^\circ}{2 \sin 8^\circ 35'}}$$

$$\sin\theta = 3 \sin 8^\circ 35'$$

Vacancy + interstitial = Frenkel

Q.2 (iii) Crystal Imperfections - An idealized crystal does not exist, so imperfections or defects are always present.

Imperfections result due to deviation from an orderly periodic array.

1) Point defect → it is a very localised defect in the regularity of a lattice.

a) Vacancies defect → In this there may be missing atom. (Schottky)

b) Interstitial defect → In this atom occupies a position b/w atoms of ideal crystal

c) Impurity defect → In this foreign atom are introduced into crystal lattice either as interstitial or substitutional.

2) Line defect → one dimensional defect or dislocation. These are produced due to atomic mismatch in solid solution.

a) Edge dislocation
b) Screw dislocation

[distortion along a line in some direction]

3) Surface Imperfection - two dimensional, takes place on surface of material. It is either due to imperfect packing during crystallisation or defective orientation of surface.

a) Grain boundary

Superconductivity - Free e^- model

$$\rho = \frac{m}{ne^2\tau} \quad -(1)$$

Acc to this eq resistivity ↓ as temp ↓.
Because on lowering temp. lattice vibrations freeze reducing the e^- scattering cause τ to increase & thus resistivity decrease.

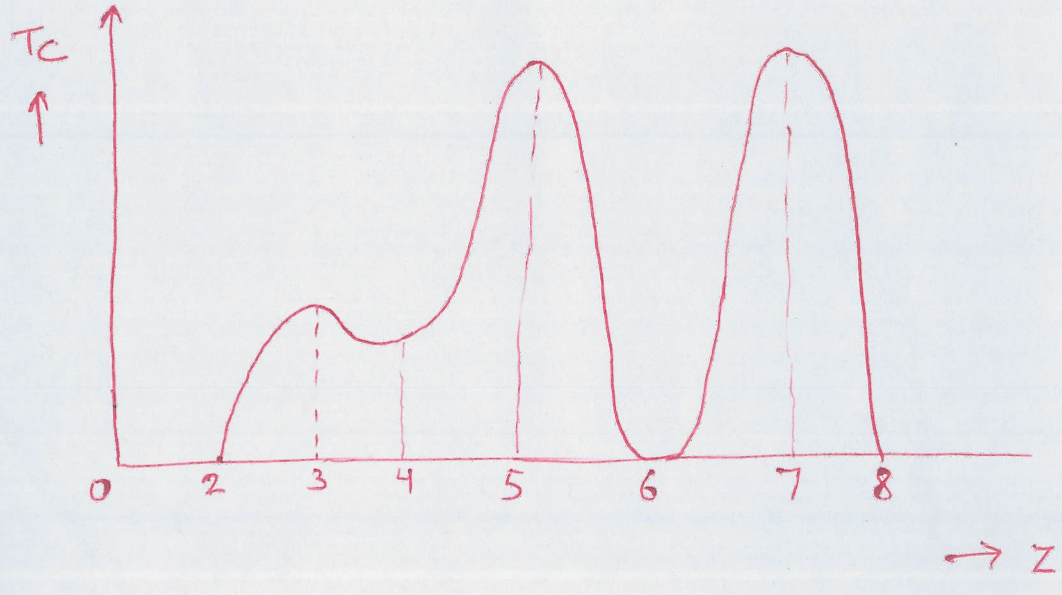
(1) The materials in which no. of valence e^- Z lies b/w 2 & 8 show superconductivity.

(2) The materials in which value of Z = 3, 5 & 7 show max. value of critical temp. Tc.

(3) The graph b/w Z^2 & Tc is straight line.

(4) Tc is inversely proportional to atomic mass of superconducting material.

(5) The material have high resistivities under normal conditions show superconductivity.



Properties

The properties of ferromagnetic materials are as follows:

(1) The magnetic dipoles are arranged parallel to each other. The dipoles arrangement is shown in Fig. 19.5.

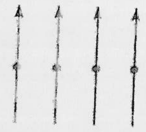


Fig. 19.5 *Ferromagnetic materials—dipoles arrangements*

(2) They possess permanent dipole moment.
(3) They attract the magnetic lines of force strongly.
(4) They have characteristic temperature, namely, *ferromagnetic Curie temperature* (θ_f). Materials below θ_f behave as ferromagnetic materials and obey hysteretic curve. A material behaves as a paramagnetic when it is above θ_f. ($T < \theta_f$) - ferro ($T > \theta_f$) - para
(5) During the absence of a magnetic field, it exhibits magnetisation which is due to the property of spontaneous magnetisation.
(6) The susceptibility of a ferromagnetic material is

$$\chi = \frac{C}{T - \theta} \tag{19.14}$$

where, C is Curie constant and θ, the paramagnetic Curie temperature.

Equation (19.14) is shown as *Curie–Weiss law*. This law holds good when the temperature is greater than ($T > \theta$).

Examples of ferromagnetic materials are iron, cobalt and nickel.

19.4.4 Anti-ferromagnetic Materials

In ferromagnetic materials, we know that the magnetic dipoles are parallel to each other. This is due to the existence of a strong interaction known as *exchange interaction* between the spin magnetic moments. Similarly, in a few materials, the exchange interaction leads to anti-parallel alignment of dipoles. The magnitudes of all dipoles are equal and hence, resultant magnetic moment and magnetisation is zero. The anti-parallel alignment exists in materials below a critical temperature known as *Neel temperature.*

Properties

The important properties of anti-ferromagnetic materials are as follows:

(1) The dipoles are aligned anti-parallel as shown is Fig. 19.6.

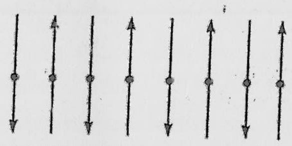
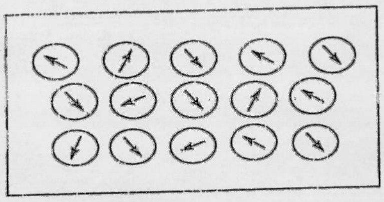
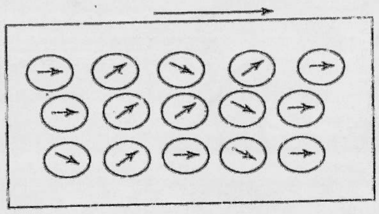


Fig. 19.6 *Anti-ferromagnetic materials—dipole arrangements*



$H = 0$ and $M = 0$

(a) *Absence of field*



$H = H_0$ and $M = +M_0$

(b) *Presence of field*

Fig. 19.3 *Paramagnetic properties*

Properties

Following are the properties of paramagnetic materials:

(1) Paramagnetic materials possess a permanent dipole moment.

(2) The magnetic dipoles are aligned randomly. The magnetic spin alignment is shown in Fig. 19.4.

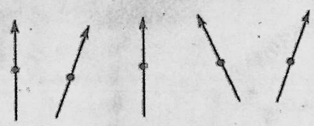


Fig. 19.4 *Paramagnetic material—spin arrangement*

(3) They attract the magnetic lines of force.

(4) The susceptibility is positive and depends on temperature:

$$\chi = \frac{C}{T} \tag{19.13}$$

where C is the Curie constant and T, the temperature. Equation (19.13) is known as the *Curie law of paramagnetism*.

(5) Paramagnetic susceptibility is inversely proportional to temperature.

Examples of paramagnetic materials are aluminum, chromium, sodium, titanium, zirconium, etc.

19.4.3 Ferromagnetic Materials

Ferromagnetic materials possess permanent magnetic moment which is mainly due to the spin magnetic moment. The magnetic dipoles are aligned parallel to each other due to interaction between any two dipoles. The ferromagnetic materials exhibit spontaneous magnetisation, even in the absence of an external field. Due to the strong internal field which exists in materials, the alignment of magnetic moments results. On the other hand, when a small magnetic field is applied, it produces a large value of magnetisation due to the parallel alignment of dipoles.

In a ferromagnetic material, the influences of internal and external fields make them different from other magnetic materials. The molecular field theory, or Weiss theory, is used to explain the ferromagnetic properties of materials.

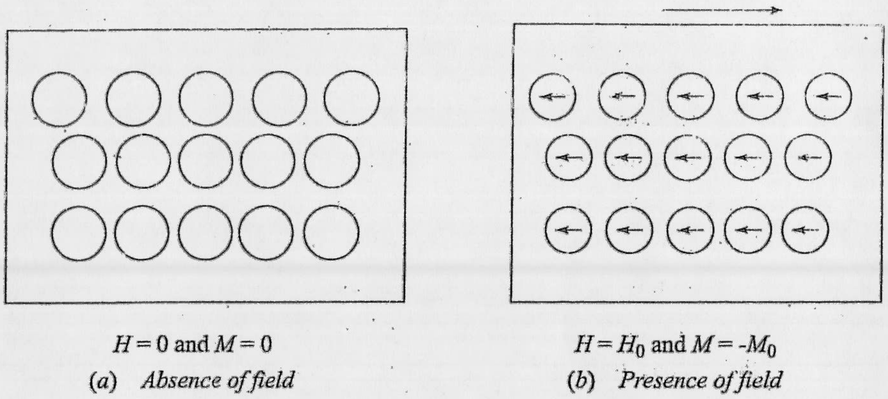


Fig. 19.1 Diamagnetic properties

Properties

Following are the properties of diamagnetic materials:

(1) They do not have a permanent dipole moment.
(2) Magnetic effects are very weak and hence, often masked by other kind of magnetism.
(3) They repel the magnetic lines of force. The existence of this behaviour in a diamagnetic material is shown in Fig. 19.2.

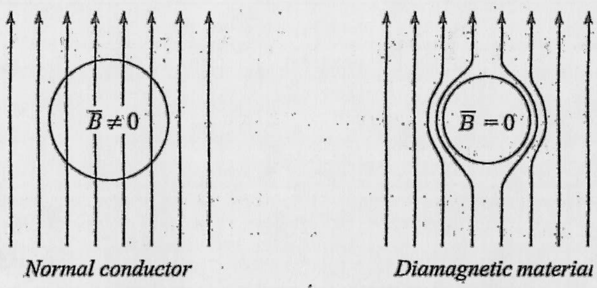


Fig. 19.2 Diamagnetic material—Magnetic field

(4) The magnetisation becomes zero on removal of the external field.
(5) The susceptibility of a diamagnetic material is negative.
(6) The susceptibility is independent of temperature and external field.

Examples of diamagnetic materials are copper, gold, mercury, silver and zinc.

19.4.2 Paramagnetic Materials

Paramagnetic materials possess a permanent magnetic moment. During the absence of an external magnetic field, the dipoles are randomly oriented. This is due to thermal agitation present in materials. Therefore, the net dipole moment and hence, magnetisation of the material is zero. When an external magnetic field is applied, the magnetic moments of individual atoms align themselves in the direction of the field and hence, give nonzero magnetisation. The behaviour of a paramagnetic material under the influence of an external field is shown in Fig. 19.3.

Date

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Solved Problems

Q.1 A fibre has the following characteristics : $\mu_1 = 1.35$ (core index) & $\Delta = 2\%$. Find the N.A. & the acceptance angle.

Soln $\mu_1 = 1.35$, $\Delta = 2\% = 0.02$

(2) $\therefore$ $N.A. = \mu_1 \sqrt{2\Delta}$

$= 1.35\sqrt{2 \times 0.02}$

$= 0.27$ ✓

Half Acceptance Angle

(2) $\theta_0 = \sin^{-1}(NA)$

$= \sin^{-1}(0.27)$

$= 15.66^\circ$ ✓

$\therefore$ Acceptance Angle $= 2\theta_0$ [Cone of acceptance]

(1) $= 2 \times 15.66$

$= 31.33^\circ$ ✓

Q.2 A silica optical fibre has a core R.I. of 1.50 & a cladding R.I. of 1.47. Determine (i) the critical angle at the core-cladding interface, (ii) the N.A. for the fibre & (iii) the acceptance angle for the fibre.

Soln

$$\theta_c = \sin^{-1}\left(\frac{\mu_2}{\mu_1}\right) = \sin^{-1}\left(\frac{1.47}{1.50}\right) = 78.5^\circ$$

$N.A. = \sqrt{\mu_1^2 - \mu_2^2}$

$= \sqrt{1.50^2 - 1.47^2}$

$= 0.30$

Teacher's Signature :

The acceptance angle $= 2\theta_0 = 2\sin^{-1}(NA) = 2\sin^{-1}(0.30) = 34.9^\circ$

Table 19.1 Comparison of Magnetic and Dielectric Parameters

Sr. No.	Dielectric parameters	Magnetic parameters
1.	Electric field	Magnetic field
2.	Electric displacement	Magnetic induction
3.	Electric dipole moment	Magnetic dipole moment
4.	Permitivity	Permeability
5.	Polarisation	Magnetisation
6.	Nonpolar dielectric	Diamagnetic
7.	Polar dielectric	Paramagnetic
8.	Ferroelectric hysteresis	Ferromagnetic hysteresis
9.	Remanent polarization	Remanent magnetisation
10.	Coercive electric field	Coercive magnetic field
11.	Ferroelectric domain	Magnetic domain
12.	Ferroelectric Curie temperature	Ferromagnetic Curie temperature
13.	Converse piezoelectric effect	Magnetostriction effect

19.4 CLASSIFICATION OF MAGNETIC MATERIALS

Magnetic materials are classified into two categories based on existence of dipole moment and the response of the magnetic material to external magnetic fields.

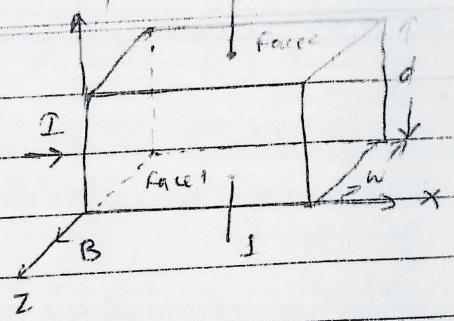
(1) Diamagnetic materials—no permanent magnetic moment.
(2) Paramagnetic, ferromagnetic, anti-ferromagnetic and ferrimagnetic materials—possess permanent magnetic moment.

Generally, diamagnetic and paramagnetic materials are known as *nonmagnetic materials*, due to poor response to an external magnetic field. Ferromagnetic, anti-feromagnetic and ferrimagnetic materials are known as *magnetic materials*. These materials are strongly responsive to an external magnetic field. The different types of nonmagnetic and magnetic materials are discussed briefly in the following sections:

19.4.1 Diamagnetic Materials

All materials exhibit diamagnetic properties. In diamagnetic materials, magnetic dipoles are oriented in such a way that the resultant dipole moment is zero. When an external magnetic field is applied, the individual dipoles are rotated and hence, produce an induced dipole moment. The induced dipole moment opposes the external magnetic field. As a result, the magnetic fields are repelled from the materials. This effect is known as *diamagnetism*. The existence of diamagnetism is represented by means of simple representation as shown in Fig. 19.1. During the absence of an external magnetic field, the magnetic moment of atoms is zero. On the other hand, when an external field is applied, atoms acquire induced dipole moment and hence, move opposite to field directions. This results in repulsion of magnetic lines of force.

When a specimen is placed ... then an electric field is induced ... current is passed through it, ... in the ⊥ direction of current & mag. field ... across its edges in the ⊥ direction of current & mag. field. This phenomena is known as Hall Effect



Let I be the current applied through specimen along x-direction, B be the magnetic field applied along z direction. Now, a force is exerted on charge carriers in negative Y direction.

If speciemen is of N-type semiconductor, e^- will be forced downwards. ∴ the upper face becomes +ve & bottom surface becomes -ve. Thus a potential difference V_H called Hall voltage is developed b/w surfaces 1 & 2.

In the equilibrium state, the electric field intensity E due to Hall effect must exert a force on the charge carriers which just balance the magnetic force.

(v - drift velocity)

$$eE_H = Bev$$

$$\boxed{E_H = \frac{V_H}{d}}$$

(d - distance b/w surfaces 1 & 2)

$$V_H = E_H d = Bvd$$

(w → width)

$$J = nev$$

$$\left(J = \frac{I}{A} = \frac{I}{wd} \right)$$

$$V_H = Bd\frac{J}{ne}$$

$$V_H = \frac{BdI}{ne\,wd}$$

$$\boxed{V_H = \frac{BI}{new}} \quad -① $$

charge density
$$\rho = ne$$

$$\boxed{V_H = \frac{BI}{\rho w}} \quad -② $$

Thus from above eq. ρ can be determined if I, B, V_H & w are measured.

Hall field per unit current density per unit magnetic field is called Hall coefficient.

$$R_H = \frac{\text{Electric field due to Hall effect}}{\text{Current density} \times \text{magnetic field}} = \frac{E_H}{JB} = \frac{V_H/d}{JB}$$

$$\boxed{R_H = \frac{BI}{\rho w}\,\frac{1}{dJB} = \frac{1}{\rho} = \frac{1}{ne}} \quad ③$$

the lattice & at the moment the velocity components of the e^- be v_x, v_y & v_z in x, y & z direction respectively. At $t>0$, let the e^- has not collided with the lattice after the application of field E along -ve x direction.

The component of the velocities after the application of field are respectively

$$\left(v_x + \frac{eEt}{m}\right), \quad v_y \quad \& \quad v_z$$

where, eEt/m is due to acceleration in x direction owing to the application of field on e^-. ∴ increment in energy over the period t is

$$\Delta W = \frac{1}{2} m \left[\left(v_x + \frac{e}{m} E t\right)^2 + v_y^2 + v_z^2 - \left(v_x^2 + v_y^2 + v_z^2\right) \right]$$

$$\Delta W = \frac{1}{2} m \left[\frac{2e}{m} E v_x t + \left(\frac{eEt}{m}\right)^2 \right] \quad -(1)$$

However, there will be large no. of e^- which would have not collied for time t & have random distribution of velocities. For them we have avg. velocity such that $\langle v_x \rangle = 0$.

$$\langle \Delta W \rangle = \frac{1}{2} m \frac{e^2 E^2 t^2}{m^2} = \frac{e^2 E^2 t^2}{2m} \quad -(2)$$

Prob. of e^- without suffering collision for time interval t is

$$R(t) = e^{-t/\tau} \quad -(3)$$

Prob. that an e^- will make collision during time interval dt is

$$R(dt) = dt/\tau_c, \quad -(4)$$

so the prob. of e^- makes collision b/w t & (t+dt) is

$$\left[e^{-t/\tau_c} \cdot \frac{dt}{\tau_c} \right] \quad -(5)$$

Avg. increase in energy b/w collisions

$$W_T = \int_{t=0}^{\infty} \langle \Delta W \rangle e^{-t/\tau_c} \frac{dt}{\tau_c} \quad -(6)$$

$$= \frac{1}{2m} \frac{e^2 E^2}{\tau_c} \int_{t=0}^{\infty} t^2 e^{-t/\tau_c} dt$$

integration by parts

$$W_T = \frac{1}{2m} \frac{e^2 E^2}{\tau_c} 2\tau_c^3 = \frac{\tau_c^2 e^2 E^2}{m}$$

for isotropic conductor $\tau_c = \tau_x = \tau$

Total energy dissipated per m^3 due to n e^- per m^3 per second is

$$W = \frac{n}{\tau} \frac{\tau^2 e^2 E^2}{m} = \frac{n}{\tau} \frac{\tau^2 e^2 E^2}{m} = \left(\frac{ne^2\tau}{m}\right) E^2 = \sigma E^2$$

Date: ________ Page no: ________

Conductors

Conductivity range – Metals are good conductors, having conductivities on the order of $10^7 \ (\Omega m)^{-1}$.

Materials with very low conductivities, ranging b/w 10^{-10} to $10^{-20} \ (\Omega m)^{-1}$ are insulators.

Materials with intermediate conductivities, generally from 10^{-6} to $10^4 \ (\Omega m)^{-1}$, are termed as semiconductors.

Reverse of conductivity range is resistivity range.

Electronic & Ionic conduction ⇒ An electric current results from the motion of electrically charged particles in response to forces that act on them from an externally applied electric field. +vely charged particles are accelerated in the field direction, −vely charged particles in the direction opposite. Within most solid materials a current arises from the flow of e^- which is termed as electronic conduction. In addition, for ionic materials a net motion of charged ions is possible that produces current & is termed as ionic conduction.

Joule's Law (Heat developed in a current carrying conductor)

Joule experimentally showed that heat developed in a conductor having resistance R & current I is given by I^2R

$$I^2R = \frac{V^2}{R} = \frac{(El)^2}{\rho l/A} = \sigma E^2 lA$$

Heat developed per unit volume per second is

$$\boxed{W = \sigma E^2}$$

WKT. $J = \sigma E$ $\qquad W = JE$ $\qquad (W \rightarrow watt/m^3)$

Thus, heat developed in a conductor is equal to energy supplied.

Let us consider an isotropic conductor & let at any instant $t = 0$, a particular e^- has suffered a collision with

b) Twin boundary
c) Stacking fault

4) Volume defect → three dimensional
1 defects such as cracks, precipitable particles, large voids etc.

Q.2 (iv) Miller indices → a set of three numbers used to indicate
2 the position of face or internal plane of crystal & ~~determined~~ represented by (h, k, l).

Miller indices can be determined by the following steps --

1 1) The coordinates of the intercepts made by plane along X, Y, Z axes are first determined.

1 2) Take reciprocal of these numbers.

1 3) These reciprocals are reduced to smallest set of integral numbers, then it is denoted by (h, k, l).