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ESE – 2019 MAINS
OFFLINE TEST SERIES

ELECTRONICS & TELECOMMUNICATION ENGINEERING (E&T)

TEST – 3
SOLUTIONS

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1(a).

Sol: Face centered cubic structure (F.C.C.):

Figure shows the unit cell of the face centered cubic structure. In this structure, the eight corners of the cube are occupied by eight atoms and six atoms occupy the centres of six faces of the cube. Metals that crystallize into F.C.C. structure are nickel, aluminum, copper, silver, gold, platinum, lead and iron.

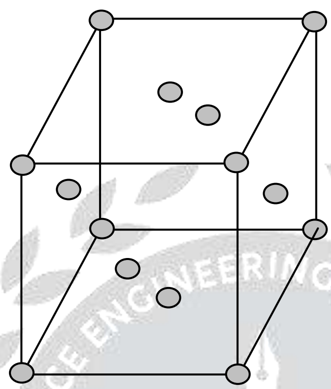


Fig. FCC

Number of atoms in the unit cell of F.C.C. structure:

In F.C.C. structure, the unit cell contains eight atoms at each corner of the cube and six atoms at the centres of six faces of the cube. Since each corner atom is shared by eight surrounding cubes and each of the face centered atom is shared by two adjacent cubes, the unit cell of F.C.C. structure contains.

8 atoms at the corners $\times \frac{1}{8}$ = 1 atom

6 face centered atoms $\times \frac{1}{2}$ = 3 atoms

$\therefore$ Total = 4 atoms

Therefore the unit cell of F.C.C. structure contains four atoms.

Atomic packing factor of F.C.C. structure:

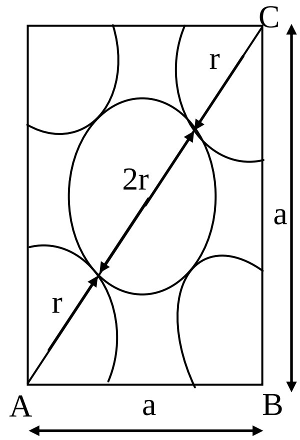


Fig. Atomic packing factor of FCC structure

From the figure

$(AC)^2 = (AB)^2 + (BC)^2$

$= a^2 + a^2 = 2a^2 \Rightarrow AC = a\sqrt{2}$

We have from the figure

$$AC = 4r \Rightarrow 4r = a\sqrt{2} \Rightarrow r = \frac{a\sqrt{2}}{4}$$

$\therefore$ The radius of the atom (sphere) in the F.C.C. structure is $\frac{a\sqrt{2}}{4}$. And the numbers of atoms in the unit cell of F.C.C. structure are four.

$\therefore$ Volume of atoms in the unit cell

$$= 4 \times \frac{4\pi r^3}{3} = \frac{16\pi}{3}\left(\frac{a\sqrt{2}}{4}\right)^3 = \frac{\pi a^3\sqrt{2}}{6}$$

Volume of unit cell = a^3

$\therefore$ Atomic packing factor

$$= \frac{\text{Volume of atoms in the unit cell}}{\text{Volume of unit cell}}$$

$$= \frac{\frac{\pi a^3\sqrt{2}}{6}}{a^3} = \frac{\pi\sqrt{2}}{6} = 0.74$$

1(b)

Sol: (i) Energy Consumed = $V_L I_L \cos\phi \times$ time

$= 240 \times 10 \times 0.8 \times 1$

$= \frac{1920}{1000} = 1.92$ kWh

Meter Constant (K) = $\frac{\text{rev}}{\text{kWh}}$

Rev = K × kWh

= 600 × 1.92 = 1152 rev

Speed, RPS = $\frac{\text{rev}}{\text{sec}} = \frac{1152}{3600} = 0.32$ rps

(a) Error = $P_m - P_t$

$= V_L I_L \sin(86^0 - \phi) - V_L I_L \sin(90 - \phi)$

$= 240 \times 10[\sin(86^0 - 0^0) - \sin(90 - 0^0)]$

$= 240 \times 10[0.9975 - 1]$

$= -5.84$ watt

(b) Error = $P_m - P_t$

$= 240 \times 10[\sin(86^0 - 60^0) - \sin(90 - 60^0)]$

$= 240 \times 10[0.4383 - 0.5]$

$= -148.08$ watt

1(b)

Sol: (ii) (a) The phenomena of slow but continuous rotation of the disc when there is no current flowing through the current coil when only pressure coil is energized is called creeping

Causes:

- Main reasons are over voltages and over static friction compensation
- Excessive lubrications, vibrations, stray magnetic field of Instrument.

(b) The disc revolves continuously in the field of the series magnet under load conditions and, therefore, there is a dynamically induced emf in the disc because of this rotation. This emf causes eddy currents which interact with series magnet, produces a self braking torque which is proportional to the square of the load current. Thus at high values of load current the registration tends to be lower than the actual. As a reason, an over-load compensating device is used, to minimize the self braking action.

1(c)

Sol: **Derivation:**

Method-1 :

In a dynamometer type wattmeter, the pressure coil connected across the supply is highly resistive.

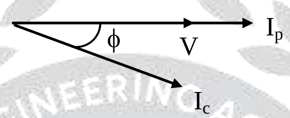
Now given, a capacitor of reactance equal to $\sqrt{3}$ times the pressure coil resistance is connected in series with the pressure coil.

Let pressure coil resistance = R

Before the capacitor is connected in series with the pressure coil:

$$I_P \propto \frac{V}{R}$$

$$\therefore P_1 \propto I_p I_c \cos\phi$$



$$P_1 \propto \frac{VI_C}{R}\cos\phi \;\ldots\ldots\; (1)$$

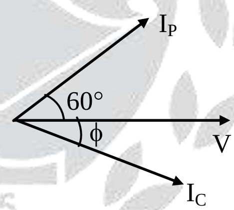
After the capacitor is connected:

X_C (Reactance of pressure coil) = $\sqrt{3}R$

$\therefore$ Impedance of pressure coil = $R - j\sqrt{3}R$

$$= 2R\angle -60°$$

$$\therefore P_2 \propto \left(\frac{V}{2R}\right) I_C \cos(60+\phi)$$



$$\frac{P_2}{P_1} = \frac{1}{2}\frac{\cos(60+\phi)}{\cos\phi}$$

$$\frac{P_2}{P_1} = \frac{1}{2}\frac{(\cos 60° \cos\phi - \sin 60° \sin\phi)}{\cos\phi}$$

$$\frac{P_2}{P_1} = \frac{1}{4}\left(1-\sqrt{3}\tan\phi\right)$$

$$\frac{4P_2}{P_1} = 1-\sqrt{3}\tan\phi$$

$$\tan\phi = \frac{1}{\sqrt{3}}\left(1-\frac{4P_2}{P_1}\right)$$

Method-2 :

In a dynamometer type wattmeter, the pressure coil connected across the supply is highly resistive.

Now given, a capacitor of reactance equal to $\sqrt{3}$ times the pressure coil resistance is connected in series with the pressure coil.

$Z = R_P + j(X_L - X_C) \approx R_P - j\,X_C$

Angle $\beta = \text{Tan}^{-1}\left(\frac{-X_C}{R_P}\right)$

Given $\sqrt{3}R_P = X_C$,

$\Rightarrow \beta = -60°$

Wattmeter reading $(P_1) = \frac{VI}{R_p}\cos\phi.(dM/d\theta)$

Wattmeter reading (P_2) due to angle β is $= \frac{VI}{R_p}\cos\beta\,\cos(\phi-\beta).(dM/d\theta)$

$$\frac{P_1}{P_2} = \frac{\frac{VI}{R_p}\cos\phi\,(dM/d\theta)}{\frac{VI}{R_p}\cos\beta\,\cos(\phi-\beta)\,(dM/d\theta)} = \frac{\cos\phi}{\cos\beta\,\cos(\phi-\beta)}$$

$$\frac{P_1}{P_2} = \frac{\cos\phi}{\cos(-60°)\cos(\phi+60°)}$$

$$\frac{P_2}{P_1} = \frac{\cos(\phi+60°)}{2\cos\phi}$$

$$\frac{P_2}{P_1} = \frac{\cos(\phi+60°)}{2\cos\phi}$$

$$\frac{P_2}{P_1} = \frac{\cos\phi\cos 60° - \sin\phi\sin 60°}{2\cos\phi}$$

$$\frac{P_2}{P_1} = \frac{1}{4} - \frac{\sqrt{3}}{4}\tan\phi$$

$$\therefore\ \tan\phi = \frac{1}{\sqrt{3}}\left(1 - \frac{4P_2}{P_1}\right)$$

1(d).

Sol: The magnetic flux density B is given by

$B = \mu_o (1 + \chi) H$

(i) Given Intensity of magnetization I = 2.8 A/m and

Susceptibility $\chi = 0.0025$;

Hence $H = (I/\chi) = (2.8/.0025) = 11.2 \times 10^2$ A/m

Therefore $B = 4\pi \times 10^{-7} \times 1.0025 \times 11.2 \times 10^2 = 1.41 \times 10^{-3}$ Wb/m^2

(ii) Given H = 1300 A/m and $\mu_r = 1.006$

Using the formula $B = \mu_o \mu_r H$, we get

$B = 4\pi \times 10^{-7} \times 1.006 \times 1300$

$= 1.64 \times 10^{-3}$ Wb/m^2

1(e).

Sol: (i) (a) Given data

$a_0 = 0.3294$ nm

For BCC metals,

$$r = \frac{(\sqrt{3})a_0}{4} = \frac{(\sqrt{3})(0.3294\,\text{nm})}{4} = 0.14256\,\text{nm} = 1.426 \times 10^{-8}\,\text{cm}$$

(b) Given data

$a_0 = 4.0862\ A^0$

For FCC metals,

$$r = \frac{(\sqrt{2})a_0}{4} = \frac{(\sqrt{2})\left(4.0862\ \mathring{A}\right)}{4} = 1.4447\ \mathring{A} = 1.4447 \times 10^{-8}\,\text{cm}$$

(ii) Interplanar spacing $d = \dfrac{a}{(h^2 + k^2 + l^2)^{1/2}}$

For FCC structure $a = \dfrac{4r}{\sqrt{2}}$

Given $r = 0.1278 \times 10^{-9}$m

Hence $a = \frac{4 \times 0.1278 \times 10^{-9}}{\sqrt{2}} = 0.3615\,\text{nm}$

Interplanar spacing for (110) plane:

$$d_{110} = \frac{0.3615}{\left[1^2 + 1^2 + 0^2\right]^{1/2}} = \frac{0.3615}{\sqrt{2}}\,\text{nm}$$

= 0.2556 nm

Interplanar spacing for (212) plane:

$$d_{212} = \frac{0.3615}{\left[2^2 + 1^2 + 2^2\right]^{1/2}} = \frac{0.3615}{9^{1/2}}$$

= 0.1205 nm

2(a).

Sol:(i) An expression for the torque of a moving iron instrument may be derived by considering the energy relations when there is a small increment in current supplied to the instrument. When this happens there will be a small deflection $d\theta$ and some mechanical work will be done.

Let T_d be the deflecting torque.

$\therefore$ Mechanical work done = $T_d.d\theta$

Alongside there will be a change in the energy stored in the magnetic field owing to change in inductance.

$$e = \frac{d}{dt}(LI) = I\frac{dL}{dt} + L\frac{dI}{dt}$$

The electrical energy supplied $eIdt = I^2dL + ILdI$

The stored energy changes from = $\frac{1}{2}I^2L$ to $\frac{1}{2}(I + dI)^2(L + dL)$

Hence the change in stored energy $\frac{1}{2}(I^2 + 2IdI + dI^2)(L + dL) - \frac{1}{2}I^2L$

Neglecting second and higher order terms in small quantities this becomes

$$ILdI + \frac{1}{2}I^2dL$$

From the principle of the conservation of energy. Electrical energy supplied = increase in stored energy + mechanical work done.

$$I^2dL + ILdI = ILdI + \frac{1}{2}I^2dL + T_d d\theta$$

$$T_d d\theta = \frac{1}{2}I^2dL$$

$$T_d = \frac{1}{2}I^2\frac{dL}{d\theta}$$

The moving system is provided with control springs and it turns the deflecting torque T_d is balanced by the controlling torque $T_C=K\theta$

K = spring constant Nm/rad

θ = deflection: rad

At equilibrium, $T_C = T_d$

$$\theta = \frac{1}{2}\frac{I^2}{K}\frac{dL}{d\theta}$$

Given data:

I = 5A,

$K = 24\times10^{-6}$ Nm/rad

$L = (20+10\theta-2\theta^2)$

$$\frac{dL}{d\theta} = (10-4\theta)\mu H/rad, K = 24\times10^{-6}\,Nm/rad$$

$$\theta = \frac{1}{2}\times\frac{5^2}{24\times10^{-6}}\times(10-4\theta)\times10^{-6}$$

$\theta(1+2.083) = 5.208$

$\theta = 1.689$ rad

$\theta = 96.77°$

(ii) Dynamometer reads rms value

$$I_{RMS} = \sqrt{\frac{1}{T}\int_0^T [i(t)]^2 dt}$$

$$= \sqrt{\frac{1}{T}\int_0^T \left[80-60\sqrt{2}\sin(\omega t+30^0)+60\sqrt{2}\cos(2\omega t-25^0)\right]^2 dt}$$

$$= \sqrt{80^2 + \left(\frac{60\sqrt{2}}{\sqrt{2}}\right)^2 + \left(\frac{60\sqrt{2}}{\sqrt{2}}\right)^2}$$

$$= \sqrt{80^2 + 60^2 + 60^2} = 116.619\text{A}$$

2(b).

Sol: (i) The intensity of magnetization (M) of a sample of a material is the magnetic moment per unit volume. It's unit is A m^{-1}. The intensity of magnetisation is directly related to the applied field H through the susceptibility of the medium χ by

$$\chi = \frac{M}{H}$$

Thus the magnetic susceptibility (χ) of a material is the ratio of the intensity of magnetization produced in the sample to the magnetic field intensity which produces the magnetization. It has no units.

$B = \mu H$

$= \mu_0 \mu_r H$

i.e., $B = \mu_0 \mu_r H + \mu_0 H - \mu_0 H$

$= \mu_0 H + \mu_0 H (\mu_r - 1) = \mu_0 H + \mu_0 M$

Where the magnetization M is equal to $H (\mu_r - 1)$

i.e. $B = \mu_0 (H+M)$ …….. (1)

The first term on the right side of Eq. (1) is due to external field. The second term due to the magnetization.

Thus the magnetic induction (B) in a solid is

$$B = \mu_0 (H+M)$$

Hence $\mu_0 = \dfrac{B}{H+M}$

The relative permeability,

$$\mu_r = \frac{\mu}{\mu_0} = \frac{B/H}{B/H+M} = \frac{H+M}{H} = 1 + \frac{M}{H}$$

$\mu_r = 1 + \chi$

(ii) Given data:

$M = 3300$ amp/meter

$H = 220$ amp/meter

$$\mu_r - 1 = \frac{M}{H}$$

$$\mu_r = \frac{M}{H} + 1$$

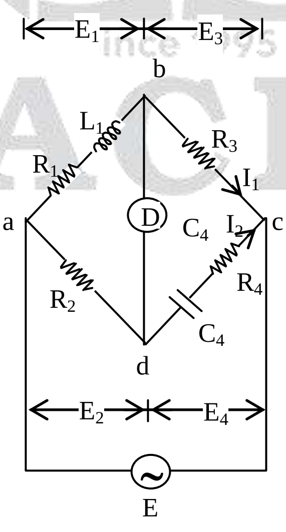
$$= \frac{3300}{220} + 1$$

$$= 15 + 1$$

$$= 16.$$

2 (c)

Sol: (i) In bridge circuits mainly errors are frequency errors. If a bridge is balanced for a fundamental frequency it should also be balanced for any harmonic and the waveform of the source need not be perfectly sinusoidal. On the other hand, it must be realized that the effective inductance and resistance for example, of a coil, vary with frequency, so that a bridge balanced at a fundamental frequency is never, in practice, truly balanced for the harmonics.



L_1 = unknown inductance having a resistance R_1

R_2, R_3, R_4 = known non inductive resistance

C_4 = standard capacitor

At balance,

$(R_1+j\omega L_1)(R_4-j/\omega C_4) = R_2R_3$

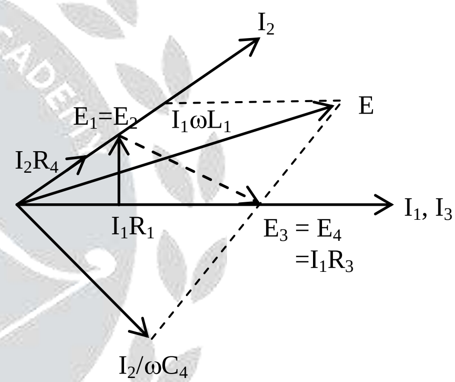
(Or)

$$R_1R_4+\frac{L_1}{C_4}+j\omega L_1R_4-\frac{jR_1}{\omega C_4}=R_2R_3$$

$$R_1R_4+\frac{L_1}{C_4}=R_2R_3 \text{ and } L_1=\frac{R_1}{\omega^2R_4C_4}$$

$$L_1=\frac{R_2R_3C_4}{1+\omega^2C_4^2R_4^2}$$

$$R_1=\frac{\omega^2R_2R_3R_4C_4^2}{1+\omega^2C_4^2R_4^2}$$



Phasor diagram

(ii) Given Data:

$R_3 = 1000\Omega$

$C_4 = 0.38\mu F$

$R_4 = 833\Omega$

$R_2 = 16800\Omega$

$L_X = ?$, $R_X = ?$

From the above formulas

$$L_X=\frac{R_2R_3C_4}{1+\omega^2C_4^2R_4^2}=\frac{16.8\times1\times0.38}{1+\left(0.38\times10^{-6}\right)^2\times(50\times2\pi)^2\times(833)^2}$$

$= 6.32$ H

$$R_X=\frac{\omega^2R_2R_3R_4C_4^2}{1+\omega^2C_4^2R_4^2}=\frac{(2\pi\times50)^2\times16800\times1000\times833\times\left(0.38\times10^{-6}\right)^2}{1+(2\pi\times50)^2\times\left(0.38\times10^{-6}\right)^2\times(833)^2}$$

$= 197.49\ \Omega$

3(a).

Sol: Solid insulating material

(i) Mica:

It is a mineral compound of silicate of aluminium with silicates of soda potash and magnesia. It is crystalline in nature and can be easily split into very thin flat sheets. It is rigid tough and strong. Its dielectric constant varies between 5 and 7.5 and dielectric strength between 700 and 1000 kV/mm.

Mica is widely used as an insulator for commutator segment separator in electrical machines, switch gears, armature winding, electrical heating devices like electric irons, hot plates etc. It is also used as a dielectric material for high frequency applications.

(ii) Ceramics:

They are generally non-metallic inorganic compounds such as silicates, aluminates, oxides, carbides, borides, nitrides and hydroxides. Ceramics are hard, strong, dense and brittle. They may be either crystalline or amorphous. The ceramics have excellent dielectric and mechanical properties. The dielectric constant of the commonly used ceramics varies between 4 and 10. The ceramics used as dielectric may be broadly described as porcelains, alumina, ceramics, titanates etc.

The ceramics are widely used as insulators for switches, plug holders, cathode heaters, vacuum type ceramic metal seals etc. They are very much used as dielectric materials in capacitors. These capacitors withstand very high temperature and very high voltage.

(iii) **Asbestos:**

It is a naturally occurring mineral of fibrous structure. Asbestos generally consists of magnesium silicate composition. Asbestos finds extensive use in electrical machines because of its ability to withstand very high temperature.

It is widely used as an insulator in the form of paper, tape, cloth and board. It is also used to manufacture panel boards, insulating tubes and cylinders used in the construction of air cooled transformers. It is used for covering/insulating the wire in electric heating devices, ovens, electric irons, etc.

(iv) **Rubber:**

They are organic polymers and may be natural or synthetic. Natural rubber has limited applications because of its poor stability at wide temperature range. The synthetic rubbers are produced artificially by copolymerization of isobutylene and isoprene. The rubbers have good electrical and thermal properties. The dielectric constant of rubber varies between 2.5 and 5. Rubber is widely used as an insulating material for electric wires, cables, tapes coatings, transformers, motor winding etc.

(v) **PVC materials**

Polyvinyl chloride (PVC) resin is produced when acetylene and hydrogen chloride are combinedin the presence of a catalyst at temperature of about 50°C wide variety of PVC materials are being manufactured and they have respectively good mechanical and electrical properties.

It is widely used in insulation for wires and cables. PVC films, tapes and sheets are commonly used as insulation for dry batteries.

(b) **Liquid insulating materials**

These can be divided into three groups:

(i) Mineral insulating oil,

(ii) Synthetic insulating oil and

(iii) Miscellaneous insulating oils

(i) Mineral insulating oil:

Transformer oil, cable oil, capacitor oil etc, come under this group. These oils are obtained from crude petroleum by distillation and have high oxidation resistance and thermal stability. Transformer oil is used for insulation and cooling of transformers. It has very high dielectric strength; it is highly viscous. It transfers heat from windings and core to the cooling surfaces by convection. The oil should be perfectly free from moisture, because presence of even a trace of water in it reduces its insulation strength considerably. The oil must undergo dehydration periodically to remove moist contents from it. Sludge formation takes place in the oil due to moisture and dirt content. Hence the oil is to be tested periodically for its quality.

(ii) Synthetic insulating oil:

Now-a-days synthetic oil is used as an insulator in transformers in the place of transformer oil (mineral oil) because synthetic oils are very much resistant to oxidation and fire hazards. Due to longer life and safety in operating conditions, synthetic oil is used as coolant and insulator in H.V. transformers. Askarels, aroclors, sovol and sovtol are few synthetic insulating oils widely used.

(iii) Miscellaneous insulating oils:

Vegetable oils, Vaseline and silicon liquids come under this group. Silicon liquids have thermal stability up to 200° C and are costly. The dielectric strength of these liquids is the same as that of mineral oils. They are used in H.V, transformers. Vaseline has high viscosity and high dielectric constant. It is used for impregnation of papers used in capacitors.

Gaseous insulating materials

(i) Air:

It is the most important insulating material available in nature. The dielectric constant of air increases linearly with the increase of pressure. It is used in air condensers. The power loss is practically zero. Air can be used for insulation only in low voltage applications since at higher field strengths air may get ionized.

(ii) Nitrogen:

Nitrogen is chemically inert. It prevents oxidation and reduces the rate of deterioration. In oil filled transformers, the nitrogen is used to replace oxidizing atmosphere. This is also used in capacitors and in cables under pressure.

(iii) Inert gases:

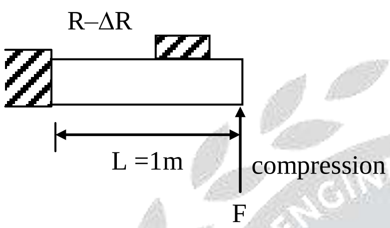
They are used in electronic tubes and discharge tubes as insulators.

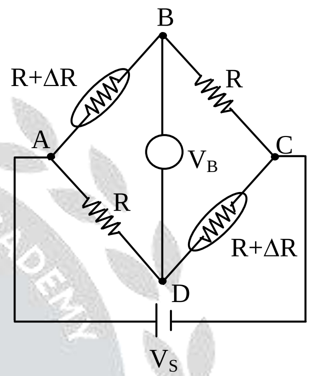
(iv) Sulphur hexafluoride:

It is produced when sulphur is burnt in fluorine atmosphere. It has high dielectric strength. It has superior cooling properties than those of air and nitrogen. It has high chemical stability. It is used in transformers, electric switches, Vande Graff generators, voltage stabilizer an X- ray apparatus.

03 (b)

Sol: (i) Strain gauges are devices, whose resistance changes under the application of force or strain. They can be used for measurement of force, strain, stress, pressure, displacement, acceleration etc. It is often easy to measure the parameters like length, displacement, weight etc., That can be felt easily by some senses. However, it is very difficult to measure the dimensions like force, stress and strain that cannot be really sensed directly by any instrument. For such cases, special devices called strain gauges are very useful





R = 200 Ω , L_1= 1m (Before compression)

ΔR = 0.7 Ω, L_2 = 999 mm (After compression)

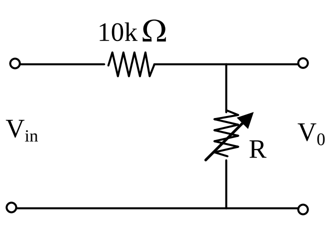
$\Delta L = L_1 - L_2 \Rightarrow 1\text{m} - 999\text{ mm}$

$\Delta L = 1\text{mm}$

$$G.F = \frac{\Delta R / R}{\Delta L / L} \Rightarrow \frac{0.7/200}{\dfrac{1\text{mm}}{1000\text{ mm}}} = 3.5$$

(ii) The output resistance of transducer = 10 kΩ

Let the input resistance of Amplifier = R



$$\therefore V_0 = \frac{R}{10+R} V_{in}$$

Error in the output voltage = $\dfrac{V_{in} - \dfrac{R}{10+R}V_{in}}{V_{in}} \times 100\%$

According to given data

$$1 - \frac{R}{10+R} \le 0.02$$

$$\frac{10}{10+R} \le 0.02$$

$10 \le 0.2 + 0.02R$

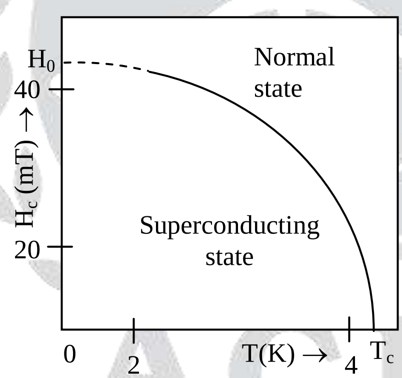
$0.02R \ge 9.8$

$R \ge 490$

$\therefore R_{min} = 490\ k\Omega$

3(c)

Sol: (i) (a) Effect of Magnetic Field



Superconducting state of a metal mainly depends on temperature and strength of the magnetic field in which the metal is placed. Superconductivity disappears if the temperature of the specimen is raised above T_c or a strong enough magnetic field is applied. This is illustrated show in Figure.

At temperatures below T_c, in the absence of any magnetic field, the material is in superconducting state. When the strength of the magnetic field applied reaches a critical value H_c the superconductivity disappears. At $T = T_c$, $H_c = 0$. At temperatures below T_c, H_c increases. The dependence of the critical field upon the temperature is given by

$$H_c(T) = H_c(0)\left[1-\left(\frac{T}{T_c}\right)^2\right]$$

Where $H_c(0)$ is the critical field at 0 K. $H_c(0)$ and T_c are constants and characteristic of the material.

(b) Effect of Current

The critical magnetic field required to destroy superconductivity need not necessarily be applied externally. An electric current flowing through the superconducting material itself may give rise to necessary magnetic field. For example, when a current flows through a superconducting ring. It gives rise to its own magnetic field. As the current is increased to a critical value I_c, the associated magnetic field becomes H_c and the superconductivity disappears. The critical current I_c flowing through a superconducting ring of radius r is given by

$$I_c = 2\pi r H_c$$

In the limits maximum possible current that flows through superconductor. Hence this is the main handle in producing high field superconducting magnets.

(ii) Industrial Applications of Superconductors

(a) Electric generators

Superconducting generators are very smaller in size and weight when compared with conventional generators. The low loss superconducting coil is rotated in an extremely strong magnetic field. Motors with very high powers as large as 2500 kW could be constructed at very low voltage as low as 450 V. This is the basis of new generation of energy saving power systems.

(b) Low loss transmission lines and transformers

Since the resistance is almost zero at superconducting phase, the power loss during transmission is negligible. Hence electric cables are designed with superconducting wires. The superconductors are used for winding of a transformer. The power losses will be very small. Using superconductor 2000 to 3000 mW portable transformers have been manufactured.

(c) Magnetic levitation

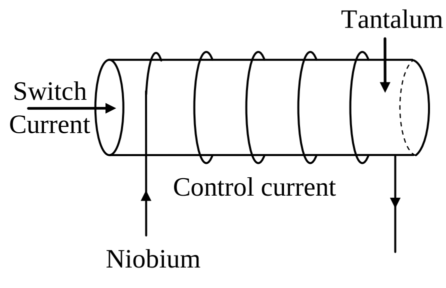
Diamagnetic property of a superconductor, namely, rejection of magnetic flux lines is the basis of magnetic levitation. A superconducting material can be suspended in air against the repulsive force from a permanent magnet. This magnetic levitation effect can be used for high speed transportation.

(d) Generation of high magnetic fields

Superconducting materials are used for producing very high magnetic fields of the order of 50 Tesla (Such high magnetic fields are required in MHD power generators). To generate such a high field power consumed is only 10 kW whereas in conventional method for such a high field generator power consumption used to be about 3 MW. Moreover in conventional method cooling of copper solenoid by water circulation is required to avoid burning of coil due to Joule heating.

(e) Fast electrical switching

A superconductor possesses two states, the superconducting and normal. The application of a magnetic field greater that H_c can initiate a change from superconducting to normal and removal of the field reverses the process. This principle is applied in development of switching element cryotron. This consists of a tantalum core around which is wound a niobium wire (both tantalum and niobium are superconductors Tantalum (T_c = 4.5K) is the gate and niobium (T_c = 9.5 K) is the control. As shown in figure current flows through Tantalum and this can be controlled by switching action. Now allowing a control current to pass through the niobium winding, magnetic field sufficient to change tantalum from its superconducting to normal state is produced. This closes the gate for the flow of current through tantalum.



(f) Logic and storage functions in computers

Superconductors are used to perform logic and storage functions in computers. The current voltage characteristics associated with the Josephson junction are suitable for memory elements. With this much faster switching times (of the order of 10 ps) have been measured.

(g) SQUIDS (Superconducting Quantum Interference Devices)

SQUID is a double junction quantum interferometer. Two Josephson junctions mounted on a superconducting ring forms this interferometer. The SQUIDs are based on the flux quantization in a superconducting ring. The total magnetic flux passing through the ring is quantized. Very minute magnetic signals are detected by these SQUID sensors. The SQUIDs are used to study tiny magnetic signals from the brain and heart. SQUID magnetometers are used to detect the paramagnetic response in the liver.

4(a)

Sol: Given that

Primary winding turns, $N_p = 1$

Secondary winding turns, $N_s = 98$

$\therefore$ Turns ratio, n = 98

Nominal ratio, $K_n = 500/5 = 100$

Magnetizing current component is in phase while the loss component is in quadrature with the flux.

$\therefore$ Magnetizing mmf = 8A

mmf equivalent to loss = 10A

Magnetizing current

$$= I_m = \frac{\text{Magnetizing mmf}}{\text{Primary winding turns}} = \frac{8}{1} = 8\text{A}$$

Loss component = I_e

$$= \frac{\text{loss mmf}}{\text{Primary winding turns}} = \frac{10}{1} = 10\text{A}$$

Output volt-ampere, VA = 15

Impedance of secondary load burden

$$= \frac{VA}{I_s^2} = \frac{15}{5^2} = 0.6\Omega$$

It is given that the external burden is purely resistive.

$\therefore$ Resistance of the external burden = 0.6Ω

Reactance of external burden = 0Ω

Resistance of total circuit burden = 0.6+0.35 = 0.95Ω

Reactance of total circuit burden

= 0+0.3 = 0.3Ω

Secondary phase angle

$$\delta = \tan^{-1}\frac{0.3}{0.95} = 17^\circ\,30'$$

So, cos δ = 0.95 and sin δ = 0.3

$$\text{Actual ratio, R} = \frac{I_e\cos\delta + I_m\sin\delta}{I_s} + n$$

$$= \frac{10\times0.95 + 8\times0.3}{5} + 98$$

= 100.38

$$\text{Ratio error} = \frac{100-100.38}{100.38}\times100 = -0.38\%$$

$$\text{Phase angle error} = \theta = \frac{180}{\pi}\left[\frac{I_m\cos\delta - I_e\sin\delta}{nI_s}\right]$$

$$= \frac{180}{\pi}\left[\frac{8\times0.95-10\times0.3}{98\times5}\right] = 0.537^\circ$$

(or) 9.372×10^{-3} rad

4(b)

Sol: (i) Current drawn by instrument when connected across 300 V.AC

I_{ac} = 100 mA = 0.1 A

At 50 Hz supply, Instrument reactance

$X_L = 2\pi fL = 2\pi \times 50 \times 0.8 = 251.33\ \Omega$

Instrument impedance, $Z = \frac{V_{ac}}{I_{ac}} = \frac{300}{0.1} = 3000\Omega$

Instrument resistance,

$$(R + r) = \sqrt{Z^2 - X_L^2} = \sqrt{(3{,}000)^2 - (251.33)^2} = 2{,}989.45\ \Omega$$

Instrument current when connected to 200 V dc supply,

$$I_{dc} = \frac{V_{dc}}{R + r} = \frac{200}{2{,}989.45} = 0.0669\,A$$

Reading of instrument when connected to 200 V dc supply = p

Current with 200 V dc supply $= \frac{p \times \text{reading with 300 Vac supply}}{\text{current with 300 Vac}}$

[$\because$ Deflection is proportional to operating current]

$$= 0.0669 \times \frac{300}{0.1} = 200.7\,V$$

Percentage error

$$= \frac{\text{Measured value} - \text{true value}}{\text{True value}} \times 100$$

$$= \frac{200.7 - 200}{200} \times 100 = 0.35\%$$

(ii) Given, P_i = 3650 W and P_0 = 3385 W

Uncertainty in the measurements = ± 10 W

Loss $P_L = P_i - P_0 = 3650 - 3385 = 265$ W

$$\frac{\partial P_L}{\partial P_i} = 1 \quad \text{and} \quad \frac{\partial P_L}{\partial P_0} = -1$$

Uncertainty in the losses

$$= \sqrt{\left(\frac{\partial P_L}{\partial P_i}\right)^2 \omega_{P_i}^2 + \left(\frac{\partial P_L}{\partial P_0}\right)^2 \omega_{P_0}^2}$$

$$= \sqrt{(1)^2(10)^2 + (-1)^2(10)^2}$$

$$= 10\sqrt{2}$$

$$\% \text{ uncertainty} = \frac{\pm 10\sqrt{2}}{265} \times 100$$

= 5.33 %

Efficiency:

$$\eta = \frac{P_0}{P_i} = \frac{3385}{3650} = 0.927$$

$$\frac{\partial \eta}{\partial P_0} = \frac{1}{P_i} = \frac{1}{3650}$$

$$\frac{\partial \eta}{\partial P_i} = P_0\left(\frac{-1}{P_i^2}\right) = \frac{-3385}{3650^2}$$

Uncertainty in efficiency

$$= \sqrt{\left(\frac{\partial \eta}{\partial P_0}\right)^2 \omega_{P_0}^2 + \left(\frac{\partial \eta}{\partial P_i}\right)^2 \omega_{P_i}^2}$$

$$= \sqrt{\left(\frac{1}{3650}\right)^2 (10)^2 + \left(\frac{-3385}{3650^2}\right)^2 (10)^2}$$

$$= \sqrt{7.5 \times 10^{-6} + 6.45 \times 10^{-6}}$$

$= 3.73 \times 10^{-3}$

$$\% \text{ uncertainty} = \frac{\pm 3.73 \times 10^{-3}}{0.927} \times 100$$

$= \pm\ 0.4029\%$

4(c)

Sol:(i) For resonant circuit frequency, $f_1 = \dfrac{1}{2\pi\sqrt{L_1C_1}}$

Inductance of circuit-1 $L_1 = \dfrac{1}{4\pi^2 f_1^2 C_1} = \dfrac{1}{4\pi^2 \times (60)^2 \times 1\times 10^{-6}} = 7.05$ H

Impedance of circuit 1 at 50 Hz, $Z_1 = R_1 + j\left(\omega L_1 - \dfrac{1}{\omega C_1}\right)$

$$= 100 + j\left(2\pi\times 50\times 7.05 - \frac{1}{2\pi\times 50\times 1\times 10^{-6}}\right)$$

$$= (100 - j971)\ \Omega$$

Impedance of circuit 2 at 50 Hz, $Z_2 = R_2 + j\left(\omega L_2 - \dfrac{1}{\omega C_2}\right)$

$$= 100 + j\left(2\pi\times 50\times L_2 - \frac{1}{2\pi\times 50\times 1.5\times 10^{-6}}\right)$$

$$= 100 + j\,(314\,L_2 - 2120)$$

For equal currents in two circuits, $Z_1 = Z_2$, or $314\,L_2 - 2120 = -971$

Inductance of circuit, 2, $L_2 = 3.658$ H

Resonant frequency of circuit 2, $f_2 = \dfrac{1}{2\pi\sqrt{L_2C_2}}$

$$f_2 = \frac{1}{2\pi}\sqrt{\frac{1}{3.658\times 1.5\times 10^{-6}}} = 67.94 \text{ Hz}$$

(ii) Given that: f_1 = 1MHz & C_1 = 1530 pF

f_2 = 3 MHz & C_2 = 162 pF

$$n = \frac{f_2}{f_1} = \frac{3\text{MHz}}{1\text{MHz}} = 3$$

After inserting the test coil into socket of Q – meter, the resonance is obtained for the first time at 1MHz with tuning capacitor adjusted to 1530pF. Then the frequency is tripled (i.e.,n = 3) and the resonance is obtained for the second time at 3MHz with tuning capacitor adjusted to 162 pF.

We know: $C_d = \frac{C_1 - n^2 C_2}{n^2 - 1}$

$$= \frac{1530\,pF - (3)^2 \times 162\,pF}{(3)^2 - 1}$$

$$= \frac{1530\,pF - 1458\,pF}{8}$$

$C_d = 9$ pF

$\therefore$ The self capacitance of the coil is 9 pF.

5(a)

Sol:(i) Digital voltmeter:

A digital voltmeter displays the value of a.c. or d.c. voltage being measured directly as discrete numerals in the decimal number system.

Numerical read out of DVMs is advantageous since it eliminates observational errors committed by operators

Resolution and Sensitivity of Digital Meter:

The resolution of digital meter is determined by the number of full digit used in it.

In general:

For $N\frac{1}{2}$ DVM

$$R = \frac{1}{10^N}$$

(where N shows no. of full digit in DVM)

or $R = \frac{\text{max .voltage}}{\text{total count}}$

Sensitivity of digital meter:

Sensitivity is the smallest change in input which a digital meter is able to detect. Hence it is the full scale value of the lowest voltage range multiplied by the meter resolution.

Sensitivity (S) = $V_{Fsmin.} \times R$

(ii) Given: $f_{clk} = 4 \times 106$Hz

$V_{in} = 10V$

$V_0 = -8V$

$C = 0.1\ \mu f$

For dual slope ADC output voltage is

$$V_0 = -\frac{1}{RC}\int V_i(t)dt$$

$$V_0 = -\frac{1}{RC} \times 10 \times T \times 2^n$$

$$= \frac{-1}{RC} \times 10 \times \frac{1}{f} \times 2^n$$

$$-8 = \frac{-1}{R \times 0.1 \times 10^{-6}} \times 10 \times \frac{1 \times 2^{16}}{4 \times 10^6}$$

R = 204.8 kΩ

5(b)

Sol: The crystal structure of NaCl is rock salt. The ionic radii are related to lattice parameter as

$2\,(r_a + r_c) = a$

No. of molecules per unit cell = 4

Volume of the molecules = $4\left[\frac{4}{3}\pi r_c^3 + \frac{4}{3}\pi r_a^3\right]$

Volume of unit cell = a^3

Packing factor = $\dfrac{4 \times \frac{4}{3}\pi\left[r_c^3 + r_a^3\right]}{8(r_a + r_c)^3}$

$$= \frac{\frac{2\pi}{3}\left[1 + \left(\frac{r_c}{r_a}\right)^3\right]}{\left(1 + \frac{r_c}{r_a}\right)^3} = \frac{\frac{2\pi}{3}\left[1 + (0.54)^3\right]}{(1.54)^3}$$

Packing factor = 0.663

5(c)

Sol: a) Error: The amount of deviation of measured value from true value is called error.

Error = measured value–true value.

$\varepsilon = A_M - A_t$

Types of Errors:

In any measuring instrument, there are three types of errors.

1. **Gross error**

- All human negligence errors, while using the instrument and operating the calculators, are called gross errors.

2. **Systematic error**: Systematic errors are of 3 types.

i) Instrumental error:- These errors are due to ageing, manufacturing defects.

ii) Environmental errors: These errors are due to the changes in environment
Ex: change in temperature.

iii) Observational errors: **-** These errors are due to parallax error i.e. observing the reading from sides.

- To avoid parallax errors, readings must be observed exactly at 90^0 to the display.

3. **Random errors:**

- There is no particular reason for occurrence of these errors.
- All instruments will have random errors. Random errors may be +Ve (or) –Ve.
- Random errors can be solved by using mathematical tool statistics like arithmetic mean and arithmetic mode and standard deviation.

Sources of errors:

i) Gross error: These type of errors mainly cover human mistakes in reading instruments and recording and calculating measurement results. The responsibility of the mistake normally lies with the experimenter.

ii) Systematic errors: These type of errors are of three types.

a) Instrumental errors: These errors are due to three main reasons

i) Due to inherent shortcomings in the instrument

ii) Due to misuse of the instruments and

iii) Due to loading effects of instruments

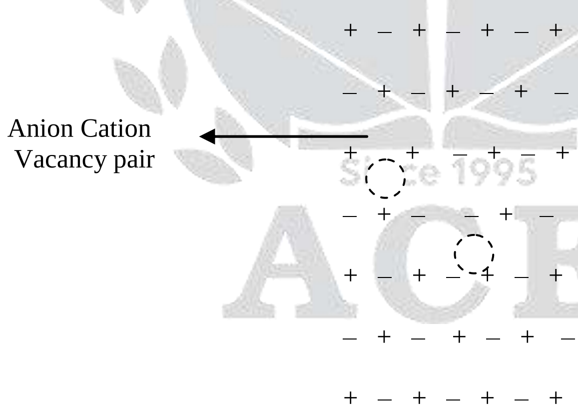
b) Environmental errors: These errors are due to conditions external to the measuring device, including conditions in the area surrounding the instrument. These may be effects of temperature, pressure, humidity, dust, vibrations or of external magnetic or electrostatic fields.

(c) Observational errors: There are many sources of observational errors. As an example, the pointer of a voltmeter rests slightly above the surface of the scale. Thus, an error on account of parallax will be incurred unless the line of vision of the observer is exactly above the pointer.

iii) Sources of Random error: These errors are due to a magnitude of small factors, which change or fluctuate from one measurement to another and are due surely to chance.

5(d)

Sol:(i) Schottky defect: In an ionic crystal, consider that an anion vacancy is created. Then to maintain charge neutrality, a cation vacancy will be created. The anion cation vacancy pair is called schottky defect. (see figure 2).



Frenkel defect: If an atom or ion is displaced from its normal lattice point (thereby creating a vacancy) and it occupies an interstitial site, the vacancy - interstitial pair formed is called Frenkel defect. This kind of defect is usually formed in ionic crystals only. It is rare in the normal close packed structure. (see figure 1).

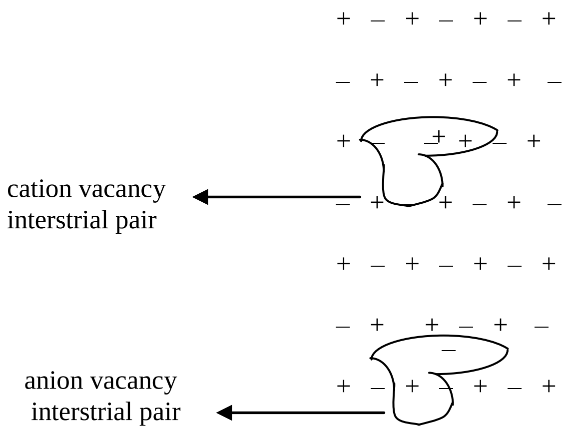
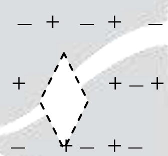


Figure 1

(ii) F-centre defect: The simplest colour centre is the F-centre. The name comes from German word for colour, “Farbe”. It is usually produced by heating crystal in excess alkali vapour or by x-irradiation.



F-centre has been identified by electron spin resonance as an electron bound at a negative ion vacancy. This occurs in alkali halides as well as in other ionic crystals.

When white light passes through the crystal, a fraction of the light corresponding to a narrow frequency region is absorbed, and the transmitted light is therefore coloured. Hence the name colour centre.

5(e)

Sol:(i) In sometimes it is necessary to measure the resistances to a precision of 1 part in 10,000 or even greater by comparing them with standard resistances. In such cases much more precautions are necessary in order to get the required accuracy.

Reasons:

- **Resistance of connecting leads:**

A lead of 22 SWG wire having a length of 25 cm has a resistance of about $0.012\,\Omega$ and this represents more than 1 part in 1000 for a$10\,\Omega$ resistance or more than one part in 10,000 for a $100\,\Omega$ resistance.

- **Thermo-electric effects:**

Thermoelectric emf is often in the measuring circuit and they must be taken into account since they affect the galvanometer deflection in the same way as an emf occurring because of unbalance.

- **Temperature Effects:**

The effect will be more in the case of resistances made up of materials having a large value of resistance temperature coefficient.

- **Contact Resistance:**

Serious errors may be caused by contact resistances of switches in binding post Another aspect of the contact resistance is that error caused by it is difficult to account for since its magnitude. i.e., magnitude of contact resistance is uncertain

ii) $V_{ac} = \frac{5\times 2K}{2K+2K} - \frac{5\times 2.05K}{2K+2.05K} = 2.5 - \frac{5\times 2.05}{4.05}$

$V_{ac} = 2.5 - 2.53086 = -30.86\text{ mV}$

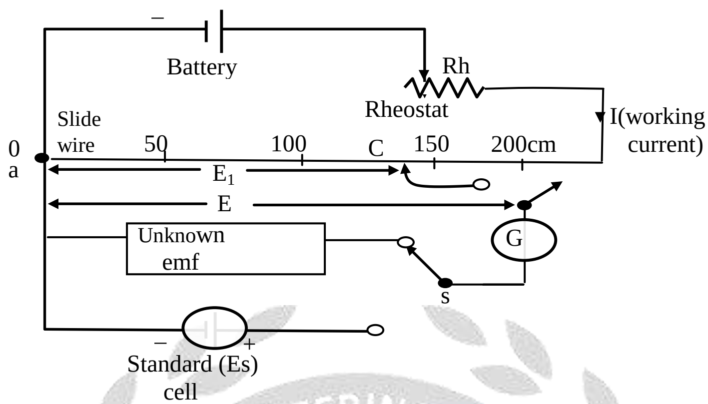
$\therefore V_{ca} = 30.86\text{ mV}$

$R_{th} = \left(\frac{2\times 2}{2+2}\right) + \left(\frac{2\times 2.05}{2+2.05}\right) = 2.0123\text{ k}\Omega$

$I_G = \frac{V_{th}}{R_{th}+R_G} = \frac{30.86\text{mV}}{2.0123\times 10^3 + 50} = 14.96\ \mu\text{A}$

6(a)

Sol:i) The principle of operation of all potentiometers is based on the below figure



The battery supplies the working current through, the rheostat R and the slide wire. The working current through the slide wire may be varied by changing the rheostat setting.

Zero galvanometer deflection or a null means that the unknown voltage E is equal to the voltage drop E1, across portion ac of the slide wire. Thus determination of the value of unknown voltage now becomes a matter of evaluating the voltage drop E1 along the portion ac of the slide wire.

The method of measuring the unknown voltage, E depends upon finding a position b for the sliding contact such that the galvanometer shows zero deflection, And hence there will be no current supplied by the unknown voltage source.

Standardization:

The process of adjusting the working current so as to match the voltage drop across the portion of sliding wire against a standard reference source is known as "standardization".

The equation for finding value of unknown voltage source is

$$E = \frac{ac}{ab} \times E_s$$

(ii) **LVDT:** is an inductive transducer which converts linear motion into electrical signals.

Features:

Advantages:

- LVDT has high range for measurement of displacement.
- As in LVDT core not came in contact with coils it is a frictionless device.
- Resolution of LVDT is purely infinite.
- As it is a transformer it maintains complete isolation between the excitation voltage given to the primary winding and output voltage produced from the second windings.
- Sensitivity of LVDT is high and it shows low hysteresis.

Disadvantages:

- Large displacements are required for measurable differential output.
- Performance of LVDT disturbs due to vibrations.
- The recoding instrument should operate on a.c.

Uses:

- Acting as a primary transducer LVDT converts displacement into an electrical output.
- Acting as a secondary transducer it can be used as a device to measure force, weight and pressure.

6(b)

Sol:(i) Assuming the conductor to be isotropic, the conductivity is given by Conductive Materials

$$\sigma = \frac{ne^2\tau}{m}$$

Relaxation time

$$\tau = \frac{m\sigma}{ne^2}; \left[\sigma = \frac{1}{\rho}\right]$$

$$= \frac{9.107\times10^{-31}}{1.54\times10^{-8}\times5.8\times10^{28}\times\left(1.601\times10^{-19}\right)^2}$$

$$= 4\times10^{-14}\text{s}$$

Mobility of the electrons

$$\mu_e = \frac{e\tau}{m}$$

$$= \frac{1.601\times10^{-19}\times4\times10^{-14}}{9.107\times10^{-31}}$$

$= 7.04 \times10^{-3}$ m^2 volt^{-1} s^{-1}

(ii) Drift velocity

$$v = \frac{e\tau}{m}E$$

$= 7.04 \times10^{-3} \times10^{2}$

$= 7.04$ ms^{-1}

(iii) We have

$$\frac{1}{2}mv_F^2 = W_F$$

Where V_F is the Fermi velocity and W_F is the Fermi energy.

$$v_F^2 = \frac{2W_F}{m}$$

$W_F = 5.5$ eV $= 5.5 \times1.6\times10^{-19}$ joule

$$v_F = \sqrt{\frac{2\times5.5\times1.6\times10^{-19}}{9.107\times10^{-31}}}$$

$= 1.39\times10^{6}$ ms^{-1}

(iv) The mean free path

$\lambda = v_F\tau_c$

$\lambda = 1.39\times10^{6}\times4\times10^{-14}$

$= 5.56 \times 10^{-8}$ m

6(c)

Sol: (i) Factors affecting the resistivity of electrical materials are listed below -

1. Temperature.
2. Alloying.
3. Mechanical stressing.
4. Age Hardening.
5. Cold Working.

1. Temperature The resistivity of materials changes with temperature. Resistivity of most of the metals increase with temperature. The change in the resistivity of material with change in temperature is given by formula given below-

$$\rho_{t_2} = \rho_{t_1}\left[1+\alpha_1\left(t_2 - t_1\right)\right]$$

Where,

ρ_{t_1} is the resistivity of material at temperature of t_1^o C

ρ_{t_2} is the resistivity of material at temperature of t_2^oC

α_1 is temperature coefficient of resistance of material at temperature of t_1^o C If the value of α_1 is positive, the resistivity of material increases. The resistivity of metals increase with increase of temperature. Means the metals are having positive temperature coefficient of resistance. Several metals exhibit the zero resistivity at temperature near to absolute zero. This phenomenon is called the “superconductivity”. The resistivity of semiconductors and insulators decrease with increase in temperature. Means the semiconductors and insulators are having negative temperature coefficient of resistance.

2. Alloying: Alloying is a solid solution of two or more metals. Alloying of metals is used to achieve some mechanical and electrical properties. The atomic structure of a solid solution is irregular as compared to pure metals. Due to which, the electrical resistivity of the solid solution increases more rapidly with increase of alloy content. A small content of impurity may increase the resistivity metal considerably. Even the impurity of low resistivity increases the resistivity of base metal considerably. For example, the impurity of silver (having lowest resistivity among all metals) in copper increases the resistivity of copper.

3. Mechanical stressing: Mechanical stressing of the crystal structure of material develops the localized strains in the material crystal structure. These localized strains disturb the movement of free electrons through the material. This results in an increase in resistivity of the material. Subsequently, annealing of metal reduces the resistivity of metal. Annealing of metal relieves the mechanical stressing of material, due to which the localized get removed from the crystal structure of the metal. Due to which the resistivity of metal decreases. For example, the resistivity of hard drawn copper is more as compared to annealed copper.

4. Age Hardening: Age hardening is a heat treatment process used to increase the yield strength and to develop the ability in alloys to resist the permanent deformation by external forces. Age hardening is also called "Precipitation Hardening". This process increases the strength of alloys by creating solid impurities or precipitate. These created solid impurities or precipitate disturb the crystal structure of metal, which interrupts the flow of free electrons through metal, due to which the resistivity of metal increases.

5. Cold Working: Cold working is a manufacturing process used to increase the strength of metals. Cold working is also known as "Work hardening" or "Strain hardening". Cold working is used to increase the mechanical strength of the metal. Cold working disturbs the crystal structure of metals, which interferes with the movement of electrons in metal, due to which, the resistivity of metal increases.

(ii) Conductivity $\sigma = n_i e(\mu_p + \mu_e)$

Resistance $R = \dfrac{\ell}{\sigma A} = \dfrac{\ell}{n_i e(\mu_p + \mu_e)A}$

Given

$l = 1\text{ cm} = 1\times10^{-2}\text{m}$

$A = 10^{-3}\times10^{-3} = 10^{-6}\text{m}^2$

$n_i = 2.5\times10^{19}/\text{m}^3$

$\mu_e = 0.39\ \text{m}^2\text{V}^{-1}\text{s}^{-1}$

$\mu_p = 0.19\ \text{m}^2\text{V}^{-1}\text{s}^{-1}$

Hence

$$R = \frac{10^{-2}}{2.5\times10^{19}\times(0.39+0.19)\times10^{-6}\times1.6\times10^{-19}}$$

$$= \frac{10^{-2}\times10^{6}}{2.5\times0.58\times1.6} = 4.31\times10^{3}\Omega$$

7(a)

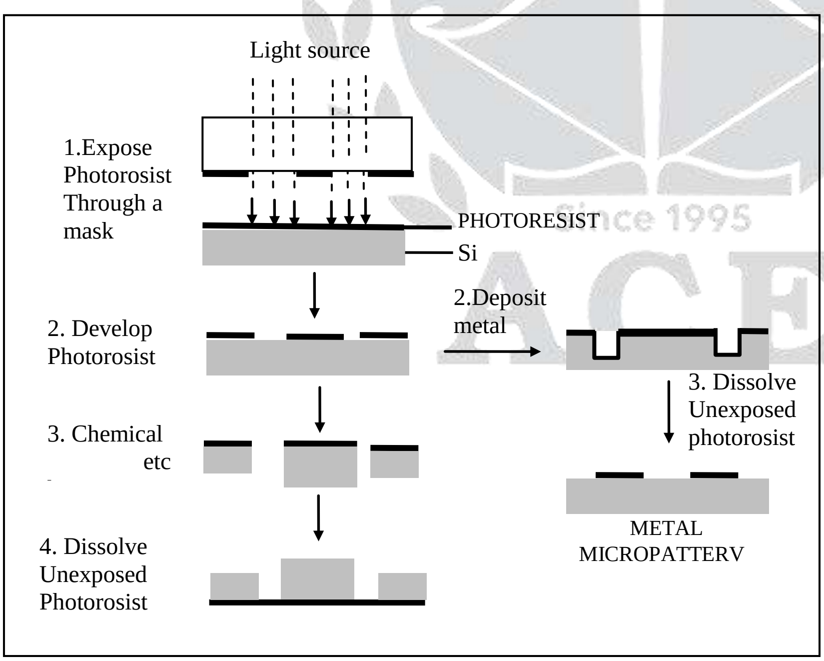
Sol:(i) Photo Lithography:

This technique follows the principle of transferring an image from a mask to a receiving substrate.

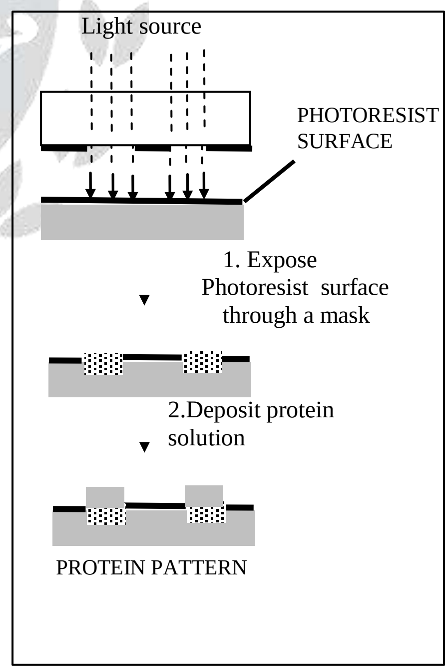
A typical lithographic process consists of three successive steps:

- Coating a substrate (Si wafer or glass) with a sensitive polymer layer (called resist)
- Exposing the resist to light, electrons or ion beams
- Developing the resist image with a suitable chemical (developer), which reveals a positive or negative image on the substrate depending on the type of resist used.(i.e. positive tone or negative tone resist).

(1) PHOTO LITHOGRAPHY



(2) PHOTOLIEOGRAPHY IN BIOPATTERNING



(ii) (1) Carbon Nano Tubes:

- Antibodies are added to carbon nanotubes to make them bacteria sensors.
- A composite of carbon nanotubes is coated on the surfaces of air craft wings. In flight, these bend and assume shapes which improve the flight characteristics of the air craft.
- Boron or gold powder is added to carbon nanotubes to give them the capacity of trapping oil spills.
- Small transistors can be made with carbon nanotubes
- Carbon nanotubes are used along with silicon to increase the capacity of Li-ion batteries by up to 10 times.

(2) Graphene:

- Graphene sheets are used as electrodes in ultracapacitors which will have as much storage capacity as batteries but will be able to recharge in minutes.
- Attaching strands of DNA to graphene will form sensors for rapid disease diagnostics.
- Indium in flat screen TVs is being replaced by graphene.
- Graphene is used in making high strength composite materials.

(3) Nano Composites:

- A nanotube-polymer nanocomposite is used to form a scaffold which speeds up the repair of broken bones.
- Graphene-epoxy nanocomposite with very high strength to weight ratio is used for bone transplantation.
- A nanocomposite made from cellulous and nanotubes is used to make a flexible battery.

(4) Nano fibers:

- Nano fibers are used to stimulate the production of cartilage in damaged joints.
- Piezoelectric nanofibers can be woven into clothing to produce electricity for cell phones or other devices.
- Carbon nanofibers can improve the flame resisting properties of furniture.

7(b)

Sol: (i) According to Meissner effect a superconductor expels completely the magnetic lines of force. But it was shown by F. London and H London that magnetic flux penetrates into a superconductor upto a few hundred layers according to the equation

$$B = B_0 \exp\left(\frac{-x}{\lambda_L}\right)$$

B_0 is the flux density at the surface of a superconductor and B is the flux density at a depth x from the surface. When $x = \lambda_L$ and $B = (B_0/e)$, λ_L is called the London penetration Depth. Thus it is the depth at which the flux density decreases by the factor e, i.e., by 67%.

The current in a superconductor is treated as made up of two parts as (i) normal current which is dissipative and (ii) super current which is non dissipative due to super electrons.

We can show that λ_L is given by $\lambda_L = \sqrt{\frac{m}{\mu_0 n_s c^2}}$

Where m = mass of electron, n_s = concentration of super electrons, and e- electron charge. An estimate of the above expression shows $\lambda_L \approx 100$ A°.

(ii) Given data:

The London presentation depth λ is given by the expression $\lambda = \sqrt{\frac{m}{\eta_s e^2 \mu_0}}$ where

m = mass of electron = 9.1×10^{-31} kg

η_s = concentrating (or) super electron

e = electron charge = 1.601×10^{-19} coulomb

μ_0 = Permeability of free space = $4\pi \times 10^{-7}$ H/m

Given the density of lead = 11.36 gm/cc

and atomic weight = 207.2

N- Avagadro number = 6.023×10^{23} per gm-mole

$$\eta_s = \frac{6.023\times10^{23}}{207.2}\times 11.38$$

$$= 3.3\times10^{22} \text{ per} - \text{cc}$$

$$= 3.3\times10^{28} \text{ per m}^3$$

$$\lambda = \sqrt{\frac{9.1\times10^{-31}}{3.3\times10^{28}\times2.56\times10^{-38}\times4\pi\times10^{-7}}}$$

$\lambda = 297A^0$

(iii) A Cooper pair is two (a pair) of electrons that attract each other and thereby make having the Cooper pair lower in total energy than the two electrons separately. Since a pair of electrons have an integral value of angular momentum, the Cooper pairs are bosons. As bosons, any number of Cooper pairs can exist, which means macroscopic superconductivity can exist.

Magnets act on superconductors to disrupt the attractive interaction of cooper pairs and thus destroy superconductivity. Since the super conducting gap (Δ) shrinks to zero as the material temperature approaches the critical temperature from below

7(c)

Sol: Curie – Weiss law:

The magnetization increase of paramagnetic material is

$$M = \frac{NP_m^2}{kT}\mu_0 H_i$$

$$M = \chi_m H$$

$$\chi_m = \frac{C}{T} \rightarrow \text{Curie's law for paramagnetic material}$$

In ferro magnetic material, due to magnetization, internal field in generated and assume internal field constant (γ). The total field (H_i) in Ferro magnets.

$H_i = H + \gamma M$

$$\text{magnetization } (M) = \frac{NP_m^2}{kT}\mu_0(H + \gamma M)$$

$$M = \frac{NP_m^2}{kT}\mu_0 H + \frac{NP_m^2}{kT}\mu_0 \gamma M$$

$$M\left(1 - \frac{NP_m^2}{kT}\mu_0\gamma\right) = \frac{NP_w^2}{kT}\mu_0 H$$

$$M = \frac{\frac{NP_m^2}{kT}\mu_0 H}{1 - \frac{NP_m^2}{kT}\mu_0\gamma} H$$

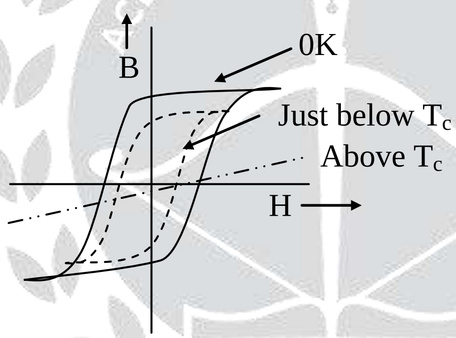
$M = \chi_m H$

$$\chi_m = \frac{\frac{NP_m^2}{k}\mu_0}{T - \frac{NP_m^2}{k}\mu_0\gamma} = \frac{C}{T-\theta}$$

$$\theta = \frac{NP_m^2}{k}\mu_0 = \text{curie constant}$$

8(a)

Sol:(i) These B-versus-H behaviours are sketched schematically below.



At 0 K, the saturation magnetization will be maximum, and the hysteresis loop will have the largest area. At a higher temperature (below the Curie temperature) the saturation magnetization will decrease and the size of the hysteresis loop will diminish. Finally, above the Curie temperature, ferromagnetic behaviour ceases, and the material becomes paramagnetic, with linear B-versus-H behaviour; the slope of this line segment is very gentle.

(ii) We know,

$\chi = \frac{M}{H}$ and $B = \mu_o(M + H)$

Hence $M = \chi H$

$= 3.7\times10^{-3}\times10^{4}$

$= 37\ Am^{-1}$

Hence magnetization = 37 Am^{-1}

Flux density $B = \mu_o(37 + 10^4)$

$= (4\pi\times10^{-7}\times10037)$

$= 126179.43\times10^{-7}$ T

$= 0.0126$ Wb/m^2

8(b)

Sol: (i) Sources of errors:

Pressure coil Inductance: If the pressure coils of the wattmeter has an inductance then the current in it will lag the voltage by an angle β. Due to this, the wattmeter reads high for lagging loads and low for leading loads. Very serious errors may be introduced by pressure coil inductance at low power factors.

Pressure coil capacitance: This capacitance is mainly due to inter turn capacitance of the series resistance. The phase angle between pressure coil current and applied voltage depends upon the reactance of the pressure coil circuit. The effect of capacitance is opposite to that produced by inductance.

Mutual inductance effect: Errors caused due to mutual inductance between current coils and pressure coils of the wattmeter. These errors are quite low at power frequencies but they increase and become more important as the frequency is increased.

Because of connections: Errors are introduced in the measurement owing to power loss in the current and the pressure coils. If the pressure coil is connected to the supply side, the wattmeter measures the power loss in its current coil in addition to the power consumed by load. If current coil is in supply side, the wattmeter reads the power consumed in the load plus the power loss in the pressure coil.

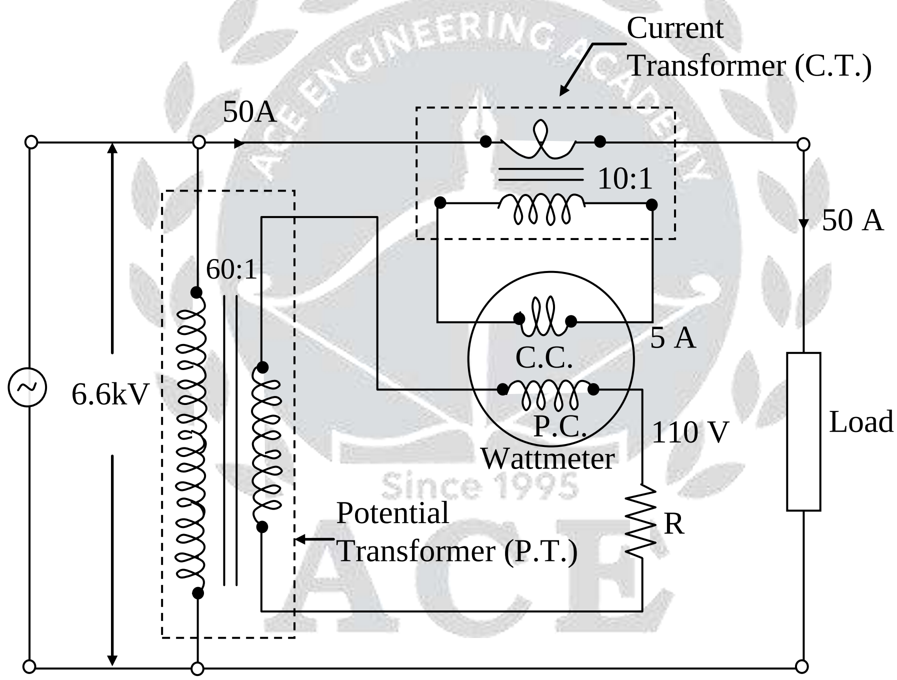
Eddy current errors: Eddy currents are induced in the solid metal parts and within the thickness of the conductors by alternating magnetic field of the current coil. These currents produce a field of their own and alter the magnitude and phase of the current coil field and thus cause errors.

Stray magnetic field errors: The electrodynamometer wattmeter has a relatively weak operating field and, therefore, it is particularly affected by stray magnetic fields resulting in the serious errors. Hence these instruments should be shielded against effects of stray magnetic fields.

Errors caused by vibration of moving system: The torque on the moving system varies cyclically with a frequency which is twice that of the voltage. If the pointer, spring or some other part of the moving system has a natural frequency which is in approximate resonance with the frequency of torque pulsation, the moving system would vibrate with considerable amplitude.

Temperature errors: This is because any change in room temperature changes the resistance of the pressure coil and the stiffness of the springs.

(ii)



Given :

Primary voltage, V_p = 6.6kV = 6600V; Secondary voltage, V_s = 110V; Primary current, I_p = 50 A; I_s = 5A

Transformation ratio of P.T. = $\frac{V_p}{V_s} = \frac{6600}{110} = 60$

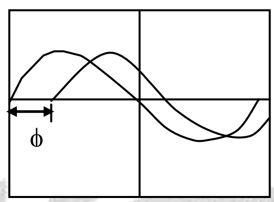
Transformation ratio of C.T. = $\frac{I_p}{I_s} = \frac{50}{5} = 10$

8(c)

Sol: (i) Phase difference between 2 sinusoidal signals can be measured by oscilloscope in its sweep mode of operation and X – Y display mode of operation

In sweep mode of operation, if both the signal waveform are displayed on the screen then phase difference can be measured by comparison.

$$\phi = \frac{2\pi}{T}(t_1 - t_2)$$

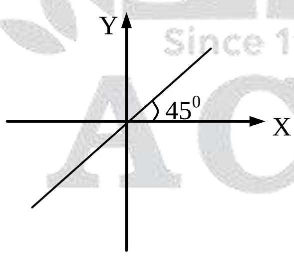


Phase measurement can also be measured using lissajious figures.

Consider two sinusoidal signal Vsinωt & Vsin (ωt + ϕ) are applied to both horizontal & vertical inputs of CRO then the lissajious figure displayed is ellipse represented by equation

$V_x^2 + V_y^2 - 2V_xV_y\cos\phi = V^2\sin^2\phi$ ---- (1)

Case 1. ϕ = 00



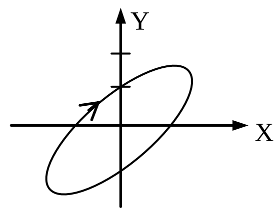
Eq. (1) reduces to: $V_x^2 + V_y^2 - 2V_xV_y = 0$

(Vx – Vy)2 = 0

Vx = Vy

This equation represents a straight line with slope 450 as given above

Case 2. 00 < ϕ < 900 $\Rightarrow$ say, ϕ = 450



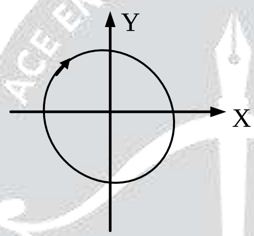
Eq (1) reduces to:

$$V_x^2 + V_y^2 - \sqrt{2}V_x V_y = \frac{V^2}{2}$$

This equation represents an ellipse as given above

This ellipse has major axis in 1st & 3rd Quadrants

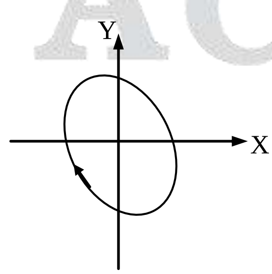
Case 3. ϕ = 900



Eq(1) reduces to : $V_x^2 + V_y^2 = V^2$

This equation represents a circle as given above

Case 4. 900 < ϕ < 1800, say ϕ = 1350

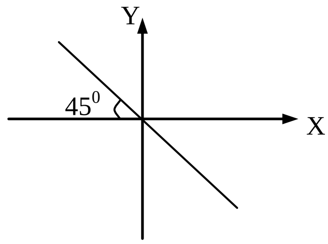


Eq.(1) reduces to :

$$V_x^2 + V_y^2 - \sqrt{2}V_x V_y = \frac{V^2}{2}$$

This equation represents an ellipse as given above

Case 5. ϕ = 1800



Eq. (1) reduces to : $V_x^2 + V_y^2 + 2V_xV_y = 0$

(Vx + Vy)2 = 0

Vx = –Vy

This equation represents a straight line with a slope of 450 with –ve X axis, as given above.

ii) The spot generating the patterns moves in clock wise direction

a) $\sin\phi = \frac{V_1}{V_2} = \frac{0}{5} = 0$

$\therefore \phi = 0°$

b) $\sin\phi = \frac{2.5}{5} = 0.5$

$\therefore \phi = 30°$

c) $\sin\phi = \frac{3.5}{5} = 0.7$

$\therefore \phi = 45°$

d) $\sin\phi = \frac{2.5}{5} = 0.5$

$\therefore \phi = 180° – 30° = 150°$