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Highlights your answer

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ESE 2025 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Electrical Engineering

Test-3 : Electrical and Electronic Measurements + Electrical Materials

Name : ....

Roll No :

Test Centres			Student's Signature
Delhi ☑	Bhopal ☐	Jaipur ☐	
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Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. There are Eight questions divided in TWO sections.
3. Candidate has to attempt FIVE questions in all in English only.
4. Question no. 1 and 5 are compulsory and out of the remaining THREE are to be attempted choosing at least ONE question from each section.
5. Use only black/blue pen.
6. The space limit for every part of the question is specified in this Question Cum Answer Booklet. Candidate should write the answer in the space provided.
7. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
8. There are few rough work sheets at the end of this booklet. Strike off these pages after completion of the examination.

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	38
Q.2	41
Q.3	
Q.4	
Section-B	
Q.5	39
Q.6	42
Q.7	
Q.8	54
Total Marks Obtained	214

Signature of Evaluator: Sourabh kumar

Cross Checked by: ....

IMPORTANT INSTRUCTIONS

CANDIDATES SHOULD READ THE UNDERMENTIONED INSTRUCTIONS CAREFULLY. VIOLATION OF ANY OF THE INSTRUCTIONS MAY LEAD TO PENALTY.

DONT'S

1. Do not write your name or registration number anywhere inside this Question-cum-Answer Booklet (QCAB).
2. Do not write anything other than the actual answers to the questions anywhere inside your QCAB.
3. Do not tear off any leaves from your QCAB, if you find any page missing do not fail to notify the supervisor/invigilator.
4. Do not leave behind your QCAB on your table unattended, it should be handed over to the invigilator after conclusion of the exam.

DO'S

1. Read the Instructions on the cover page and strictly follow them.
2. Write your registration number and other particulars, in the space provided on the cover of QCAB.
3. Write legibly and neatly.
4. For rough notes or calculation, the last two blank pages of this booklet should be used. The rough notes should be crossed through afterwards.
5. If you wish to cancel any work, draw your pen through it or write "Cancelled" across it, otherwise it may be evaluated.
6. Handover your QCAB personally to the invigilator before leaving the examination hall.

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Section A : Electrical and Electronic Measurements

Q.1 (a) What is a Digital Voltmeter? What are its merits? Explain Ramp type digital voltmeter technique along with suitable block diagram. Also show the functioning of ramp type DVM with the help of timing diagram.

[12 marks]

Soln.

Digital Voltmeter:— It is an electrical instrument which is used to measure voltage and show the result on display digitally. It is an op amp circuit design to measure voltage (on the basis of comparator use).

Merits:

(1) accurate

(2) no parallax error (due to analog meter)

(3) very fast compared to analog meter

(4) High sensitivity

(5) easily usable

(6) error is less

(7) no calibration required

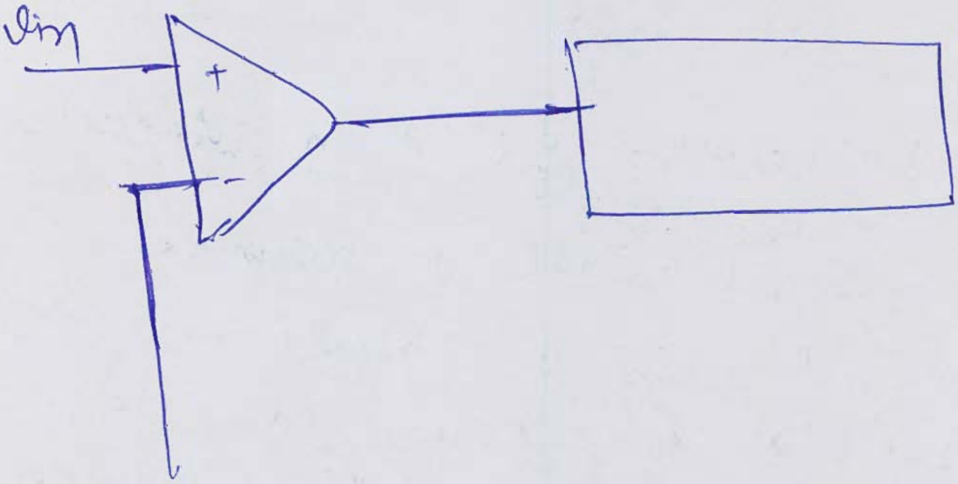
(8) Simple construction

(9) less expensive

6

Incomplete solution

Ramp type Voltmeter



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Q.1 (b) A single phase, watt-hour meter has a constant load of 6 A at 230 V passing through it for 10 hours at unity power factor. If the meter constant is 520 revolutions per kWh, how many revolutions does the meter disc makes during this period? If the same meter makes 1722 revolutions when operated at 230 V and a constant load of 9 A passing through it for certain duration with a power factor of 0.707, determine the duration of operation of the meter in hour.

[12 marks]

Soln:

given:

$K_e = 520$ rev/kWh

$I = 6A$, $V = 230V$, $T = 10$ hours, $\cos\phi = 1$

So $P = VI\cos\phi = 230 \times 6 \times 1 = 1380$ watt

total energy in 10 hours $= P \times T = 1380 \times 10$

$= 13.8$ kWh

meter constant $= \frac{\text{total no. of revolution}}{\text{total energy (kWh)}}$

$\Rightarrow$ total no. of revolution $= 13.8 \times 520$

$= 7176$

Revolution made by disc during this period $= 7176$ revolution Ans

(ii) no. of revolution $= 1722$

$V = 230$ Volt, $I = 9A$, $\cos\phi = 0.707$

$K = \frac{\text{no. of revolution}}{\text{kWh}}$

$K = \frac{1722 \times 1000}{230 \times 9 \times 0.707 \times T}$ $\Rightarrow$

$$T = \frac{1722 \times 1000}{520 \times 230 \times 9 \times 0.707} = 2.26 \text{ hours}$$

duration of operation of the meter in hrs
= 2.26 hours

Ans

11

Good Approach

Q.1 (c) The coil of a 150 V moving iron voltmeter has a resistance of 400 Ω and an inductance of 0.75 H. The coil is made of copper which has a resistance temperature coefficient of 0.004/°C. The current consumed by the instrument when placed on a 150 V dc supply is 0.05 A. The series resistance of the voltmeter is of Manganin with a resistance temperature coefficient 0.00015/°C. Estimate:

(i) The temperature coefficient of the instrument.

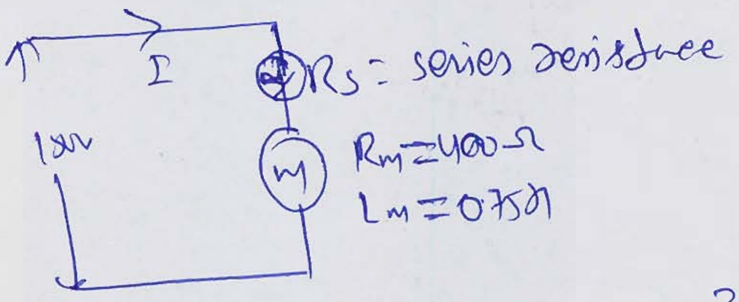
(ii) The alternation of the reading between direct current and alternating current at 100 Hz.

(iii) The capacitance of the capacitor necessary to eliminate the frequency error.

[12 marks]

Soln

(i)



$I = 0.05A \Rightarrow R_S + R_M = \frac{150}{0.05} = 3000\,\Omega$

$R_S = 3000 - R_M = 2600\,\Omega$

⇒ So temperature coefficient of the instrument is

given $\alpha_T = \frac{(\alpha_s \times R_s + \alpha_m \times R_m)}{R_s + R_m}$

$\Rightarrow \alpha_T = \frac{0.00015/°C \times 2600 + 0.004 \times 400}{3000}$

$\alpha_T = 6.633 \times 10^{-4}/°C$

temperature coefficient of the instrument

$\boxed{\alpha_T = 0.00066/°C}$ B

(ii) On DC

$I_{DC} = \frac{150}{3000} = 0.05$ Ampere

On AC, $f = 100Hz$

$Z = R_s + R_m + j\omega L = 3000 + j\,2\pi \times 100 \times 0.75$

$= (3000 + j471.238)\Omega = 3036.78 \angle 8.92° \ \Omega$

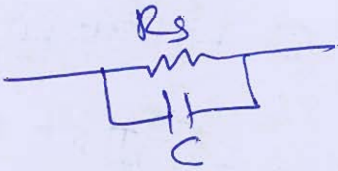
$|I_{AC}| = \frac{V}{|Z|} = \frac{150}{3036.78} = 0.0494$ Ampere

Change in current

$|I_{DC}| - |I_{AC}| = 0.05 - 0.0494 = 6.055 \times 10^{-4}$ A

$\boxed{\Delta I = 0.605 mA}$ 3

(iii) Capacitance required to eliminate the frequency error



$C_s = 0.41 \times \frac{L_m}{R_s^2} = 0.41 \times \frac{0.75}{(2600)^2}$

$C_s = \frac{0.41 \times 0.75}{(2600)^2} = 45.48 nF$

$\boxed{C_s = 45.48 nF}$ 3

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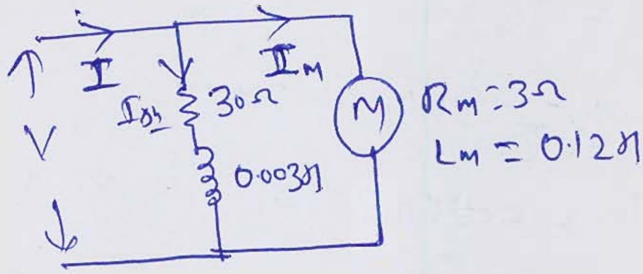
Q.1 (d) A dynamometer ammeter is fitted with two fixed coils having a total resistance of 3.0 Ω and a total inductance of 0.12 H, and a moving coil of resistance 30 Ω and an inductance of 0.003 H. Calculate the error in reading when the instrument is calibrated with d.c. and used on a.c. 50 Hz with moving coil shunted directly across the field coils. Comment upon the results.

[12 marks]

Soln



On D.C

$I_M = \frac{I \times 30}{33} = 0.909\,I$ Ampere

5

On-AC

$f = 50\,Hz$

$Z_M = R_M + j\omega L_M = 3 + j \times 2\pi \times 50 \times 0.12 = (3 + j\,37.7)\,\Omega$

$Z_{sh} = R_{sh} + j\omega L_{sh} = 30 + j \times 2\pi \times 100 \times 0.003 =$

$(30 + j\,1.885)\,\Omega$

$I_{M_{AC}} = \frac{I \times Z_{sh}}{Z_{sh} + Z_M} = \frac{I \times (30 + j\,1.885)}{(30 + j\,1.885) + (3 + j\,37.7)}$

$|I_{M_{AC}}| = 0.5832\,I$

$\%\,error = \frac{I_{MAC} - I_{DC}}{I_{DC}} \times 100$

$\%\,\varepsilon_r = \frac{0.5832\,I - 0.909\,I}{0.909\,I} \times 100$

$\boxed{\%\,\varepsilon_r = -35.84\,\%}$

B

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⇒ On AC Supply

Current through Ammeter measure low as compared to DC supply. hence error is (−ve).

Q.1 (e) An electrostatic voltmeter is constructed with six parallel, semicircular fixed plates equivalent is 4 mm intervals and 5 interleaved semicircular movable plates that move in planes midway between the fixed plates in air. The movement of the movable plates is about an axis through the center of the circles of the plates system perpendicular to the planes of the plates. The instrument is spring-controlled. If the radius of the movable plates is 40 mm calculate the spring constant if 10 kV corresponds to a full-scale deflection of 100°. Neglect fringing edge effects and plate thickness. The permittivity of air is 8.85×10^{-12} F/m.

[12 marks]

Soln:

$T_d = \frac{1}{2} C V^2$ – deflecting force

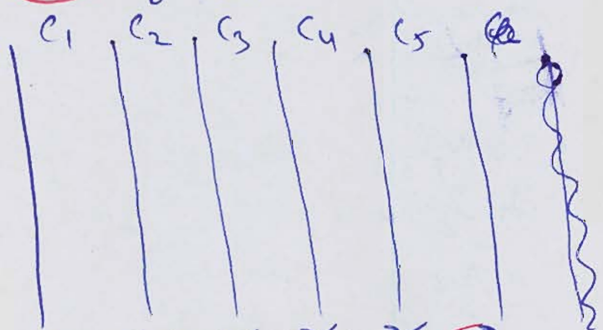
$T_c = K\theta$ – controlling force
↳ spring constant

⇒

$K\theta = \frac{1}{2} C V^2$ (∵ $T_d = T_c$ at steady state)

$$K = \frac{\frac{1}{2} C V^2}{\theta} \quad \text{—— (1)}$$

Arrangement of Capacitor



$d = 4\,mm = 4 \times 10^{-3}$ m

$A = \pi r^2 = \pi \times 40 \times 40 \times 10^{-6}$ m²

Capacitance of each plate = $\varepsilon_0 A / d$

$$C_1 = \frac{8.854 \times 10^{-12} \times \pi \times 40 \times 40 \times 10^{-6}}{4 \times 10^{-3}}$$

$C_1 = 1.1126 \times 10^{-18} \times 10^{+7} = 1.1126 \times 10^{-11}$ F

Total Capacitance $\Rightarrow C_T = C_1 + C_2 + C_3 + C_4 + C_5$

$C_T = 5 \times C_1 = 5 \times 1.1126 \times 10^{-11} = 5.56 \times 10^{-11} F$

Now putting ~~eq (4)~~ C_T in eq (1) then

$$K = \frac{\frac{1}{2} \times 5.56 \times 10^{-11} \times (10 \times 10^3)^2}{100^\circ}$$

$$K = \frac{5.56}{2} \frac{\times 10^{-11} \times 10^8}{100} = 2.78 \times 10^{-5} \text{ N/degree}$$

$K = 2.78 \times 10^{-5}$ N/degree

~~$K = 1.59 \times 10^{-3}$ N/rad~~

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Q.2 (a) (i) The power flowing in a 3-phase, 3-wire balanced load system is measured by two wattmeter method. The reading of wattmeter-A is 9000 W and of wattmeter-B is –1800 W.

1. What is the power factor of the system?
2. If the voltage of the circuit is 440 V, what is the value of capacitance which must be introduced in each phase in series, which causes the whole of the power measured to appear on wattmeter A? (The frequency is 60 Hz).

[14 marks]

Soln

(i) $P_1 = 9000\,W$, $P_2 = -1800\,W$

$P_1 + P_2 = 7200\,W$, $P_1 - P_2 = 10800\,W$

So we know

$$\tan\phi = \frac{\sqrt{3}(P_1 - P_2)}{P_1 + P_2}$$

$$\Rightarrow \tan\phi = \frac{\sqrt{3}(10800)}{7200} = 2.598$$

$\phi = \tan^{-1}(2.558) = 68.94°$

$p.f = \cos\phi = \cos(68.94) = 0.359$

Hence, $p.f = \cos\phi = 0.359$

(ii) $V_{L-L} = 440\,V$, $f = 60\,Hz$

Total power can be calculated as

$$\sqrt{3} \times V_L \times I_L \times \cos\phi = P_1 + P_2$$

$$\Rightarrow I_L = \frac{7200}{\sqrt{3} \times 440 \times 0.359} = 26.31 \text{ Ampere}$$

$I_L = I_{ph}$ (for A- star connection)

$\frac{V_{ph}}{Z} = I_{ph}$

$\Rightarrow I_{ph} = \frac{440/\sqrt{3}}{Z}$

$Z = \frac{440/\sqrt{3}}{26.31} = 9.655$

$Z = R + j\omega L = R + jX_L$

$= 9.655 (\cos^{-1} 0.359 = (3.469 + j9.01)\Omega$

whole power to appear on wattmeter A

$P_1 = 7200$ Watts, and $P_2 = 0$, it is possible when

So ~~cos~~ $\phi = 60^\circ$, $\cos\phi = 1/2$

$P_1 = \sqrt{3} V I \cos(30^\circ - \phi)$

$P_2 = \sqrt{3} V I \cos(30^\circ + \phi)$

↳ putting $\phi = 60^\circ$, $P_2 = 0$

$\tan\phi = \left(\frac{X_L + X_C}{R}\right)$ $\left(\because \phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)\right)$

$\Rightarrow X_C = -(\sqrt{3} \times R) + X_L$

$\Rightarrow X_C = -\sqrt{3} \times 3.469 + 9.01 = 3.21\,\Omega$

$X_C = 1/\omega C = 3.21$

$C = \frac{1}{3.21 \times 2\pi \times 60} = 0.825\,mF$

$\boxed{C = 0.825\,mF}$

↳ required capacitance value.

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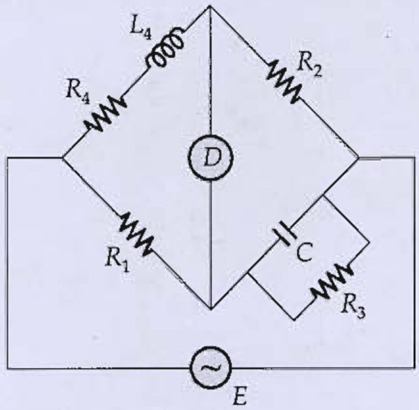
Q.2 (a) (ii) In a Maxwell's bridge, the fixed - value bridge components have the following values:

$R_3 = 5\,\Omega$, $C = 1$ mF

If $R_1 = 159\ \Omega$ and $R_2 = 10\ \Omega$ at balance then find the Q-factor for the unknown impedance (L_4 and R_4 unknown impedance) at a supply frequency of 50 Hz.



[6 marks]

Soln: At Balanced condition

$$(R_4 + jwL_4) \times \left(\frac{R_3 \times 1/jwC}{R_3 + 1/jwC}\right) = R_1 \cdot R_2$$

$$\Rightarrow (R_4 + jwL_4)\left(\frac{R_3}{1 + jwCR_3}\right) = R_1 \cdot R_2$$

$$\Rightarrow R_3 R_4 + jwR_3 L_4 = R_1 R_2 + jwCR_1R_2R_3$$

On equating real part and imaginary part separately then

$$R_3 R_4 = R_1 R_2 \Rightarrow R_4 = \frac{R_1 R_2}{R_3} \quad -(I)$$

$$w R_3 \times L_4 = wCR_1R_2R_3$$

$$L_4 = R_1 R_2 C \quad -(II)$$

Now putting value, $R_4 = \frac{159 \times 10}{5} = 318\,\Omega$

$L_4 = 159 \times 10 \times 1 \times 10^{-3} = 1.59$ H

Quality factor $\Rightarrow Q = \frac{w_0 L_4}{R_4} = \frac{2\pi \times 50 \times 1.59}{318}$

$Q = \pi/2 = 1.57$

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Good Approach

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Q.2 (b) (i) A current transformer having a 1 turn primary is rated at 500/5 A, 50 Hz with an output of 15 VA. At rated load with non-inductive burden, the inphase and quadrature components (referred to the flux) of the exciting mmf are 8 and 10 A respectively. The number of turns in the secondary is 98, and the resistance and leakage reactance of the secondary winding are 0.35 Ω and 0.3 Ω respectively. Calculate the ratio and phase angle error.

(ii) What are the advantages and disadvantages of PMMC instruments?

[12 + 8 marks]

Soln :—

(i) $500/5 = K = 100$

$I_W = 8A, \quad I_w = 10A$

$n = 98 = N_2/N_1$ — turn ratio

$r_s = 0.35\Omega, \quad X_s = 0.3\Omega$

$\tan^{-1}\delta = \frac{j\omega L_s}{r_s} = \frac{0.3}{0.35}$

$\delta = 40.6^\circ$

$I_0 = \sqrt{I_m^2 + I_w^2} = \sqrt{10^2 + 8^2} = 12.8$ ampere

$\tan\alpha = \frac{I_w}{I_m} = \frac{10}{8} = 1.25$

$\alpha = 51.34^\circ$

$R = n + \frac{I_0(\sin(\alpha+\delta))}{I_s}$

$= 98 + \frac{12.8 \sin(51.34 + 40.6^\circ)}{5} = 100.558$

% Ratio error $= \frac{K - R}{R} \times 100 = \frac{100 - 100.558}{100.558} \times 100$

% ratio error $= -0.555\%$

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(ii) phase angle error $\sigma_\theta = \frac{I_0 (\sin(\alpha+\delta))}{n I_s}$

$\sigma_\theta = \frac{12.8 \times \cos(51.34° + 40.6)}{500} \times \frac{180}{\pi}$

$\boxed{\sigma_\theta = -0.05°}$

→ phase angle error

B2

(ii) Advantage of PMMC instruments—

(1) Higher torque/weight ratio.

(2) Very accurate device

(3) due to higher torque/weight ratio, sensitivity is very high

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(4) Suitable for DC quantities measurement

(5) It is a linear instrument

(6) It does not affected by frequency error or stray mf. etc

(7) It measure DC quan directly proportional to given quan

Disadvantage of PMMC

(1) It is not suitable for AC measurement

(2) It does not measure rms value of given quantity.

(3) If frequency is applied then its ~~three~~ pointer show zero deflection.

(4) It is costly instrument.

(5) It does not measure the quantity of high frequency.

(6) It dissipates energy.

Q.2 (c) (i) An ac bridge with terminals ABCD has following components:

Arm AB : A resistance of 800 Ω in parallel with a capacitor of 0.5 μF.

Arm BC : A resistance of 400 Ω in series with a capacitor of 1 μF.

Arm CD : A resistance of 1000 Ω

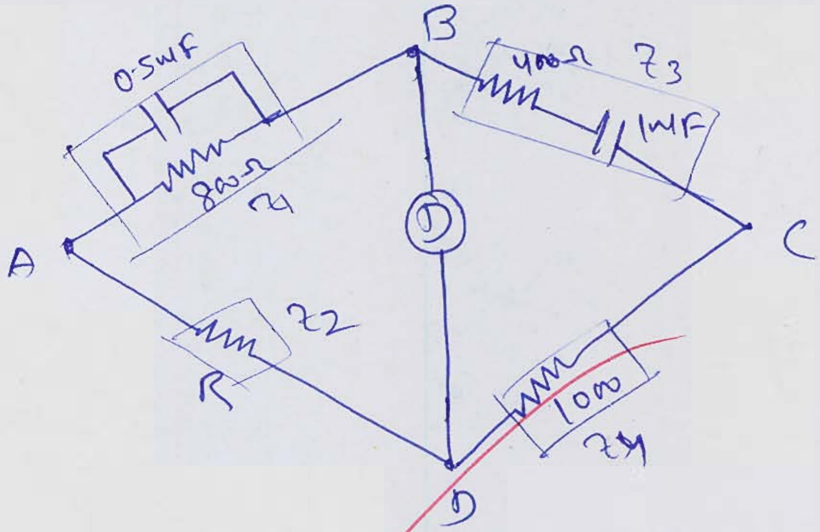
Arm DA : A pure resistance R.

Find the value of the frequency at which the bridge will balance.

(ii) A moving coil instrument whose resistance is 25 Ω gives a full scale deflection with a voltage of 25 mV. This instrument is to be used with a series multiplier to extend its range to 10 V. Calculate the error caused by 10°C rise in temperature. (The temperature coefficient of copper is 0.004/°C and that of manganin is 0.00015/°C).

[12 + 8 marks]

Soln:



At Balanced condition

$$|Z_2| \cdot |Z_3| = |Z_1| |Z_4|$$

$$\Rightarrow Z_1 = \frac{800 * 1/j\omega C}{800 + 1/j\omega C} = \frac{R_1 \times 1/j\omega C_1}{R_1 + 1/j\omega C_1} = \frac{R_1}{j\omega C_1 R_1 + 1}$$

$$Z_3 = R_3 + 1/j\omega C_3$$

$$Z_2 = R_2, \quad Z_4 = R_4$$

$$\Rightarrow \left(R_4 \times \frac{R_1}{j\omega C_1 R_1 + 1}\right) = (R_3 + 1/j\omega C_3) \times R_2$$

$$\Rightarrow \frac{R_1 R_4}{1 + j\omega C_1 R_1} = \frac{(j\omega R_3 C_3 + 1) R_2}{j\omega C_3}$$

$$\frac{R_1 R_4 j\omega C_3}{R_2} = (j\omega C_3 R_3 + 1)(1 + j\omega C_1 R_1)$$

$$\Rightarrow j\frac{R_1 R_4}{R_2}\omega C_3 = j\omega C_3 R_3 + 1 - \omega^2 C_3 R_3 R_1 C_1 + j\omega C_1 R_1$$

for balanced galvanometer ⇒

real parts and imaginary parts are seperated then

$$1 = \omega^2 C_3 R_3 R_1 C_1 \quad \text{— (1)}$$

$$\boxed{\omega = \frac{1}{\sqrt{R_1 R_3 C_1 C_3}} \text{ rad/s}}$$

$$\omega = \frac{1}{\sqrt{800\times 400 \times 1\times10^{-6} \times 0.5\times10^{-6}}}$$

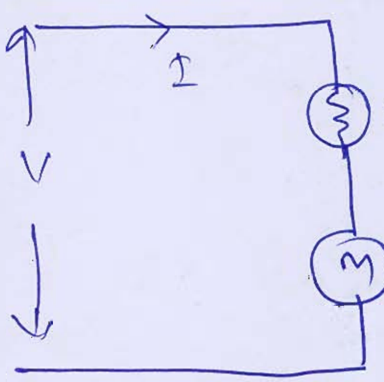
$$\omega = \frac{10^6}{\sqrt{800\times400\times0.5}} = \frac{10^6}{400} = 2.5\times10^3 \text{ rad/s}$$

$$f_0 = \frac{\omega}{2\pi} = 397.88 \text{ Hz}$$

$$\boxed{f_0 = 397.88 \text{ Hz}}$$

(11) Good Approach

(ii)



$R_M = 25\Omega$

$I_m = \frac{V}{R_m} = \frac{25\text{mV}}{25} = 1\text{mA}$

$V' = 10$ Volt

$m = \frac{10}{25} \times 1000 = 400$

$R_s = (m-1) \times R_m = 399 \times 25 = 9975\ \Omega$

↳ series multiplier Resistance

$R_m + R_s = 9975 + 25 = 10000\ \Omega$

On temperature changed by 10°

$R_s' = 9975(1 + 0.00015 \times 10) = 9989.9625\ \Omega$

$R_m' = 25(1 + 0.004 \times 10) = 26\ \Omega$

$R_s' + R_m' = 10015.9625\ \Omega$ $\left(\because \frac{10}{10k\Omega} = I_m = 1mA\right)$

$I_M' = \frac{10}{10015.9625} = 0.998\ mA$, $I_m = 1mA$

$\%\ error = \frac{0.998 - 1.0}{1.0} \times 100 = \frac{I_m' - I_m}{I_m} \times 100$

$\boxed{\%\ error = -0.2\ \%}$

7

Q.3 (a) A PMMC voltmeter with resistance of 25 Ω has a full scale deflection of 150° for a voltage of 90 mV across it. The coil dimensions are 25 mm × 25 mm having number of turns equal to 120. Current carrying turns are made of conductor with specific resistivity $= 1.7 \times 10^{-8}$ Ω-m. The control spring constant is 0.45×10^{-6} N-m/degree. The coil resistance is 40% of total instrument resistance. The value of diameter of conductor wire used in coil winding and flux density in air gap will be respectively

[20 marks]

Q.3 (b) (i) A current transformer has a single turn primary and 400 turns on secondary winding. The resistance and reactance of the secondary circuit are 2 Ω and 3 Ω respectively including transformer winding. When 6 A current is flowing in the secondary winding, the magnetizing mmf is 100 AT and iron loss is 2 W, find the value of ratio error.

(ii) Give a generalized diagram of digital data acquisition system. Also explain the various components and their functions.

[14 + 6 marks]

Q.3 (c) Explain in detail the working principle of linear variable differential transducer (LVDT). Write down its advantages.

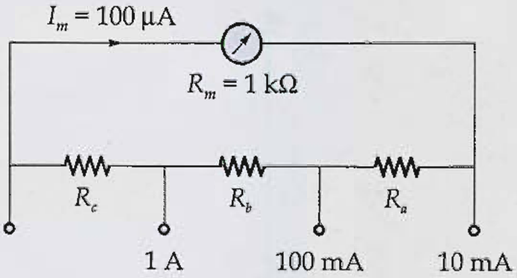
[20 marks]

(a) (i) The variable 'A' is related to three other variables B, C and D as $A = \frac{B}{CD}$. The variables B, C and D are measured with meters of accuracy ± 0.5% of reading, ±1.2% of full scale value and ±1.5% of reading respectively. If actual readings are respectively 90, 20 and 60 with 100 being full scale value for B, C and D, then find the maximum limiting error in reading of A.

(ii) Derive the expression for force developed by an electrostatic instrument.

[12 + 8 marks]

Q.4 (b) Calculate the value of the shunt resistors for the circuit shown below:



[20 marks]

Q.4 (c) (i) A dynamometer type wattmeter with pressure coil angle of 2° measure 800 W for 1 - ϕ inductive load supplied by 230 V. If this wattmeter is replaced by another wattmeter with pressure coil angle 1° reading obtained is 640 W, find the value of current drawn by load.

(ii) Calculate the constants of a shunt to extend the range of 0 - 5 A moving iron armature to 0 - 50 A. The instrument constants are $R = 0.09\ \Omega$ and $L = 90$ mH. If the shunt is made non-inductive and the combination is correct on d.c., find the full scale errors at 50 Hz.

[10 + 10 marks]

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Section B : Electrical Materials

(a) Consider a parallel-plate capacitor having an area of 6.45×10^{-4} m^2 and a plate separation of 2×10^{-3} m across which a potential of 10 V is applied. If a material having a dielectric constant of 6.0 is positioned within the region between the plates, compute:

(i) The capacitance.

(ii) The magnitude of the charge stored on each plate.

(iii) The dielectric displacement D.

(iv) The polarization.

[12 marks]

Soln:

Given $A = 6.45 \times 10^{-4}$ m^2, $d = 2 \times 10^{-3}$ m

$V = 10V$, $\varepsilon_r = 6$

(i) Capacitance $= \dfrac{\varepsilon_0 \varepsilon_r A}{d}$

$$C = \frac{8.854 \times 10^{-12} \times 6 \times 6.45 \times 10^{-4}}{2 \times 10^{-3}}$$

$$\boxed{C = 17.13 \times 10^{-12}\ F = 17.13\ pF}$$ 3

(ii) magnitude of charge $Q = C \cdot V$

$Q = 17.13 \times 10^{-12} \times 10 = 171.3\ pC$

$$\boxed{Q = 171.3\ pC}$$ 3

(iii) $D = \varepsilon_0 \varepsilon_r E$

$E = V/d = \dfrac{10}{2} \times 10^3 = 5 \times 10^3$ V/m

$D = 8.854 \times 6 \times 10^{-12} \times 5 \times 10^3$

$= 265.62 \times 10^{-9} = 2.656 \times 10^{-7}$ C/m^2

$$\boxed{D = 2.656 \times 10^{-7}\ C/m^2}$$ 3

(iv) Polarisation $\vec{P} = \varepsilon_0(\varepsilon_r - 1)\vec{E}$

$\vec{P} = 8.854 \times 10^{-12} \times (6-1) \times 5 \times 10^{3}$

$= 8.854 \times 10^{-9} \times 25 = 2.213 \times 10^{-7}\ C/m^2$

$\boxed{\vec{P} = 2.213 \times 10^{-7}\ C/m^2}$

B

11

Good Approach

(b) What is magnetic anisotropy? Explain the importance of magnetic anisotropy in transformer cores.

[12 marks]

Soln:

Magnetic Anisotropy :- It is a properties of an magnetic material which show different magnetic properties like permeability, area law Hysteresis loop, losses in different direction on measurement along different different direction.

Importance of magnetic anisotropy

(1) The transformer cores is made up of magnetic material, like CRGO, steel rolled etc. for to avoid saturation of magnetic core of transformer it is used.

(2) due to magnetic isotropy, magnetic saturation of transformer core can be avoided.

(3) losses becomes less in core of T/F (losses due to hysteresis loss and eddy losses.

(4) Breakdown voltage of oil of core of T/F gets increased. Saved tripping from any fault.

7

(c) (i) The Burgers vector of a mixed dislocation line is $\frac{1}{2}[1 \quad 1 \quad 0]$. The dislocation line lies along the $[1 \quad 1 \quad 2]$ direction. Find the slip plane on which this dislocation lies.

(ii) Explain, why end centered tetragonal geometry does not exist.

[8 + 4 marks]

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(d) The magnetic field intensity $H = 2400$ A/m in a material when $B = 4$ Wb/m^2. When $\overrightarrow{H}$ is reduced to 800 A/m, $B = 2.8$ Wb/m^2, calculate the change in Magnetization M.

[12 marks]

Soln:

Given

$H_1 = 2400$ A/m , $B_1 = 4$ Wb/m^2

$H_2 = 800$ A/m , $B_2 = 2.8$ Wb/m^2

from Data 1

($\mu_0 = 4\pi \times 10^{-7}$)
↳ permeability constant)

$B_1 = \mu_0 \mu_r \cdot H_1$

$\mu_0 \mu_r = \frac{4}{2400}$

$\mu_r = \frac{4}{2400 \times 4\pi \times 10^{-7}} = 1326.3$

$M_1 = \overrightarrow{M}_1 = \chi_{m_1} \cdot H_1 = (1325.3 \times 2400)$
↳ magnetisation

$= 3.18 \times 10^6$ A/m

from Data-2

$B_2 = \mu_0 \mu_{r_2} \times H_2$

$\Rightarrow \mu_{r_2} = \frac{2.8}{800 \times 4\pi \times 10^{-7}} = 2785.21$

$\chi_{m_2} = (\mu_{r_2} - 1) = 2784.21$

$M_2 = \overrightarrow{M}_2 = 2784.21 \times 800 = 2.227 \times 10^6$ A/m

Change in magnetisation $= (M_1 - M_2)$

$\Delta M = M_1 - M_2 = 0.953 \times 10^6$ N/m

$\Delta M = 0.953 \times 10^6$ N/m

10

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(e) Molybdenum has the BCC crystal structure, a density of 10.22 $g\,cm^{-3}$ and an atomic mass of 95.94 g mol^{-1}. Find the atomic concentration, lattice parameter a and atomic radius of molybdenum.

[12 marks]

Soln: -

BCC crystal structure

Atoms are present at corner and one atom at center.

So total no. of effective atom per unit

$= 1+1 = 2 \quad (1 + 1/8 \times 8 = 2)$

$n = 2$

(i)

Density = $\frac{mass}{Volume}$

$\Rightarrow \rho = \frac{n \times A}{N_A \times Volume}$

$\Rightarrow n/V_m = N = \frac{\rho \times N_A}{A} = \frac{10.22 (g/cm^3) \times 6.023 \times 10^{23}}{95.94\ g}$

$N = \frac{10.22 \times 6.023 \times 10^{23}}{95.94} = 6.41 \times 10^{22}$ atm/cm^3

N = atomic concentration $= 6.41 \times 10^{22}$ atm/cm^3

3

(ii)

$\frac{n}{Volume} = N \Rightarrow Volume = \frac{2}{6.41 \times 10^{22}}\ cm^3$

$Volume = a^3 = \frac{2}{6.41} \times 10^{-22}$

$a = 3.148 \times 10^{-10} m = 3.148 \times 10^{-8} cm$

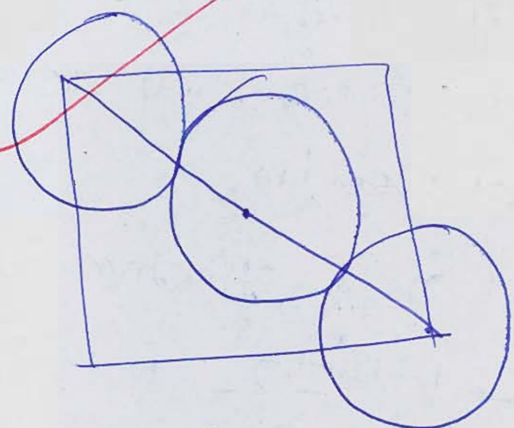
Lattice parameter

$$a = 3.148\ \text{Å}$$

2

(viii)

in BCC



$4r = \sqrt{3}a$

$r = \frac{\sqrt{3}}{4} \times a$

radius $= \frac{\sqrt{3}}{4} \times a = \frac{\sqrt{3}}{4} \times 3.148\ \text{Å}$

$$r = 1.363\ \text{Å} = 1.363 \times 10^{-10}\ m$$

2

11

Good Approach

(a) Define dielectric strength. Discuss different types of dielectric breakdowns in solids.
[20 marks]

Soln:

Dielectric strength:— dielectric strength is defined as the max allowable voltage that can be sustained by an insulator material without breakdown.

→ It means max voltage that a dielectric material sustain without breakdown.

~~Different Breakdown in~~ S

Different types of dielectric breakdowns—

(1) Voltage breakdown:— As we increase voltage across a dielectric material or stress of voltage, the solids material get breakdown, and the property of that material loss.

(2) moisture/humidity: Sometime due to excess moisture or humidity the dielectric material does not bear stress of normal voltage and get breakdown into loss.

(3) mechanical stress :- Sometime due to excessive mechanical stress ~~or~~ pressure the dielectric material lost its property and gets breakdown into ions. ~~and~~ It does not show the proper function for which they are used.

(4) Temperature :- Sometimes in the core of transformer, the oil gets breaked due to excessive heating of oil. they breakdown and loose its ~~pro~~ dielectric properties. so alway there is cooling method invested to cool down of oil temperature.

14

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Q.6 (b) (i) The resistivity of a doped silicon sample is 9×10^{-3} Ωm. The hall coefficient was measured to be 7.2×10^{-4} m^3 $columb^{-1}$. Assuming single carrier conduction, find the mobility and density of charge carrier.

(ii) What are type-I and type-II superconductors? Draw the magnetization versus magnetic field characteristic for type-I and type-II superconductors. Why superconductivity is observed for signals upto radio frequencies?

[12 + 8 marks]

Soln

(i) $\rho = 9 \times 10^{-3}\ \Omega\text{-m}$

$R_H = 7.2 \times 10^{-4}\ m^3/C$

$R_H = 1/ne = 7.2 \times 10^{-4}$

$ne = \frac{1}{7.2 \times 10^{-4}} = 1.389 \times 10^{3}\ C/m^3$

4

$\sigma = ne\mu$ (as we know)

$\mu = \frac{ne}{\sigma} = ne\rho = 9 \times 10^{-3} \times 1.389 \times 10^{3}$

$\boxed{\mu = 12.50\ \frac{m^2}{V\text{-}s}}$

(b)

$n = 1/7.2 \times 10^{-4} \times 1.6 \times 10^{-19} = \frac{10^{23}}{7.2 \times 1.6} = 8.68 \times 10^{21}$

$\boxed{n = 8.68 \times 10^{21}\ \text{atoms}/m^3}$

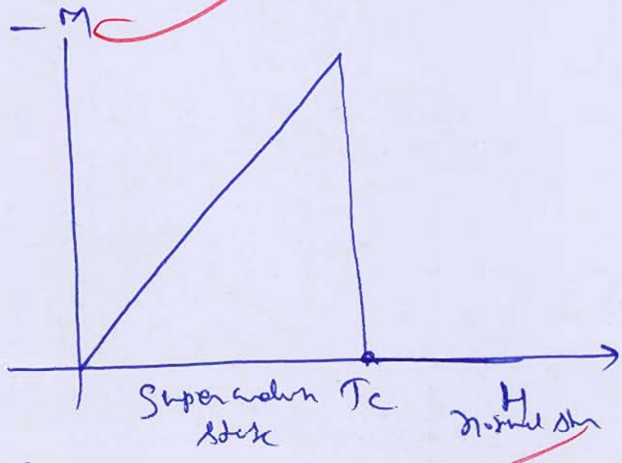
↳ density of charge carrier

Type-1 Superconductor or ideal Superconductor

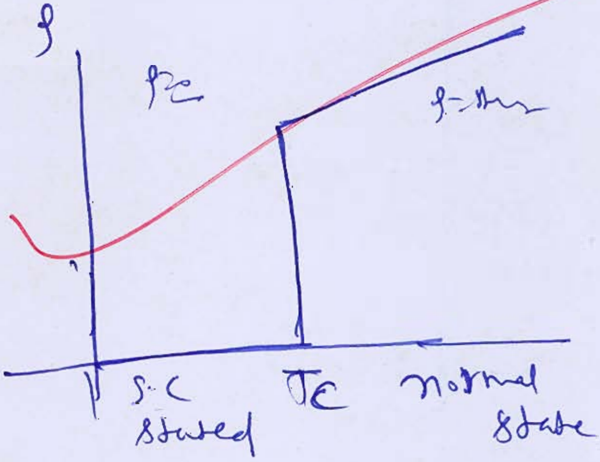
(1) It follows Silsbee rule and meissner effect truly.

(2) The changes from superconductivity state to normal state is abrupt or sharp transition.

(3)



(4)

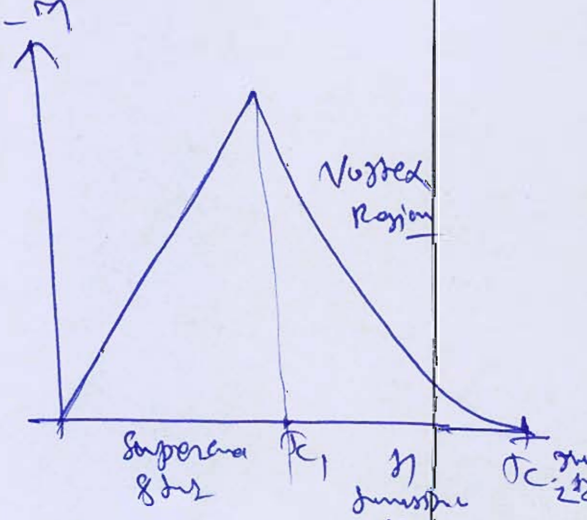


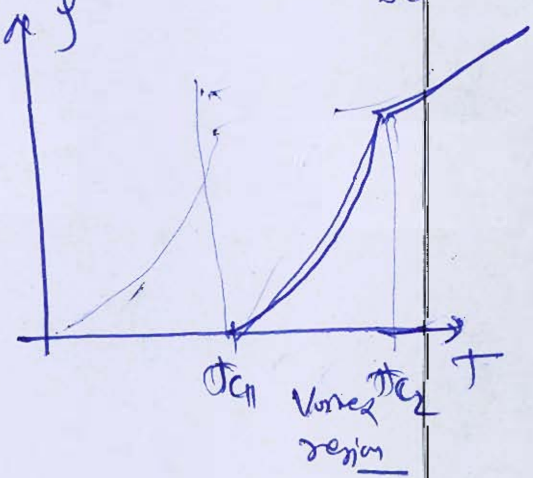
Type-II Superconductor or real Superconductor

(1) It does not follow Silsbee rule and meissner effect truly.

(2) The changes from superconductor state to normal state is gradual.

(3)





⇒ Super conductivity is observed upto radio frequency

after increasing frequency, f ↑ → S-C ↓

for ac power the material dissolved

follow inductance & resistivity increases

since f ≠ 0. at very high frequency.

6

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(c) (i) Explain the features of soft-magnetic materials with suitable examples and uses.

(ii) A material with magnetic property such that when it was placed in a magnetic field, $B = 4\ Wb/m^2$, magnetic field intensity was found to be 4800 A/m. If $\vec{H}$ is reduced to 640 A/m and $B = 1.8\ Wb/m^2$, then calculate the percentage change in magnetization M of the material.

[8 + 12 marks]

⇒ feature of soft magnetic material :-

(i) Low Hysteresis losses and eddy losses

(2) narrow and small hysteresis loop

(3) High permeability

(4) low retentivity, ~~[illegible]~~ low coercivity

(5) easy to magnetise and demagnetise

(6) eg:- (i) Si - Fe alloy

(ii) Si - Ni alloy

(iii) Si - permalloy

Applications -

(i) used for electromagnets.

(ii) used in cores of Transformer and reactor

(iii) used in high frequency ~~transformer~~ transformers.

(ii) $H_1 = 4800$ A/m, $B_1 = 4$ wb/m²

$H_2 = 640$ A/m $B_2 = 1.8$ wb/m²

from Data set-1

$B_1 = \mu_0 \cdot \mu_{r1} \times H_1$ $(\mu_0 = 4\pi \times 10^{-7})$

$\mu_{r1} = \dfrac{4}{4\pi \times 10^{-7} \times 4800} = 663.15$

$\chi_{m1} = (\mu_{r1} - 1) = 662.15$

$M_1 = \chi_{m1} \cdot H_1 = 662.15 \times 4800$
$= 3.178 \times 10^6$ A/m

from Data set-2

$B_2 = \mu_0 \mu_{r2} \times H_2$

$\mu_{r2} = \dfrac{1.8}{4\pi \times 10^{-7} \times 640} = 2238.11$

$\chi_{m2} = 2237.11$

$M_2 = \chi_{m2} \cdot H_2 = 2237.11 \times 640 = 1.431 \times 10^6$ A/m

% Change in magnetization $= \dfrac{M_1 - M_2}{M_1} \times 100$

$= \dfrac{3.178 \times 10^6 - 1.431 \times 10^6}{3.178 \times 10^6} \times 100$

$\% \Delta M = 54.97\%$ B

18 Good Approach

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Q.7 (a) Explain the phenomenon of superconductivity. Briefly explain its salient features, mechanism and applications.

The periphery of a copper disk 50 cm in radius and 10^{-3} mm in thickness is maintained at a potential of 50 V. A thin rod 1 cm in radius is soldered to the disk at its centre (at right angles to the plane of the disk) and maintained at a potential of 49 V. If the resistivity of copper is 1.7×10^{-8} Ωm, calculate the current through the disk.

[20 marks]

(b) (i) What is magnetoresistance effect? Calculate the current produced in a small germanium plate of area 1 cm^2 and thickness 0.3 mm when a potential difference of 2 V is applied across the faces.
(Given: Concentration of free electrons in germanium is $2 \times 10^{19}/m^3$ and mobilities of electrons and holes are 0.40 m^2/V-sec and 0.20 m^2/V-sec respectively).

(ii) Explain why end-centred tetragonal geometry does not exist in Bravais crystal structures.

[12 + 8 marks]

Q.7 (c) Explain briefly the polarization occurring in dielectric materials. What are different types of polarization occurring in dielectric material?

If a dielectric material contains 3.2×10^{19} polar molecules/m^3 and the relative permittivity of material is $\epsilon_r = 2.4$ with applied external electric field $\vec{E} = 10^4 \overrightarrow{a_x}$ V/m, then calculate the value of polarization and dipole moment in each molecule. (Consider all molecules have same dipole moment).

[20 marks]

Q.8 (a) (i) Derive the Clausius-Mossotti equation in case of non polar dielectric material in presence of dc field relating polarization (α) and dielectric constant of the material. Take number of molecules per unit volume of dielectric 'N'.

(ii) The Hall coefficient of a certain silicon specimen was found to be $-8.25 \times 10^{-5}\ m^3/C$ at 300° K. If the conductivity is 2.50 ℧/cm, then find :

1. type of semiconductor.
2. density of charge carrier.
3. mobility of charge carrier.

[10 + 10 marks]

Soln

Clausis mossotti eqn have five Assumptions —

(1) the polarisibility of molecules is isotropic in nature

(2) the arrangemnt of molecules is isotropic

(3) the polarization is only by elastic displacment only

(4) this eqn is applicable to crystal cubic structure.

As we know

$P = N\alpha E_i$ where P = polarisation

α = polarisibility

N = no. of atoms/molecules

E_i = External electric field

$E_i = E + \frac{\gamma P}{\varepsilon_0}$

$\gamma = 1/3$ for Lorentz factor

$P = N\alpha\left(E + \frac{\gamma P}{\varepsilon_0}\right)$

$P = N\alpha E + \frac{N\alpha\gamma P}{\varepsilon_0}$

$P\left[1 - \frac{N\alpha\gamma}{\varepsilon_0}\right] = N\alpha E$

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$$P = \frac{N\alpha E}{1 - \frac{N\alpha \gamma}{\varepsilon_0}} \quad \text{--- (II)}$$

As We know

$$P = \varepsilon_0 (\varepsilon_r - 1) \vec{E} \quad \text{--- (III)}$$

eq (II) = eq (III) then

$$\varepsilon_0 (\varepsilon_r - 1) \vec{E} = \frac{N\alpha E}{1 - \frac{N\alpha \gamma}{\varepsilon_0}}$$

$$\varepsilon_r - 1 = \frac{N\alpha / \varepsilon_0}{1 - \frac{N\alpha}{3\varepsilon_0}} \quad \text{--- (IV)} \quad (\gamma = 1/3 \text{ put})$$

Now add (+3) in eq (iv) then

$$\varepsilon_r - 1 + 3 = \frac{N\alpha/\varepsilon_0}{1 - \frac{N\alpha}{3\varepsilon_0}} + 3 = \frac{N\alpha/\varepsilon_0 + 3 - \frac{N\alpha}{\varepsilon_0}}{1 - \frac{N\alpha}{3\varepsilon_0}}$$

$$\varepsilon_r + 2 = \frac{3}{1 - N\alpha/3\varepsilon_0} \quad \text{--- (V)}$$

$$\frac{\text{eq (IV)}}{\text{eq (V)}} = \frac{\varepsilon_r - 1}{\varepsilon_r + 2} = \frac{N\alpha}{3\varepsilon_0}$$

9

Good Approach

Here

$$\boxed{\frac{\varepsilon_r - 1}{\varepsilon_r + 2} = \frac{N\alpha}{3\varepsilon_0}}$$

→ required clausius-mossotti eqn.

(ii) $R_H = -8.25 \times 10^{-5}\ m^3/C$

$\sigma = 2.50\ \mho/cm$

(1) As Hall coefficient is (-ve), Here it is **n-type** semiconductor.

(2) $R_H = 1/nq$

$\Rightarrow n = \frac{1}{R_H \times q} = \frac{1}{8.25 \times 10^{-5} \times 1.6 \times 10^{-19}}$

$n = \frac{10^{24}}{8.25 \times 1.6} = 7.5 \times 10^{22}$ atoms/m^3

$n = 7.5 \times 10^{22}$ atoms/m^3

↳ density of charge carrier

(3) $\sigma = nq\mu$

$\mu = \frac{\sigma}{nq} = \frac{2.5 \times 10^2}{1.6 \times 10^{-19} \times 7.5 \times 10^{22}}$

$\mu = \frac{2.5 \times 10^2 \times 10^{-3}}{1.6 \times 7.5} = 0.208 \times 10^{-1}\ \frac{m^2}{V\text{-}s}$

$\mu = 0.208 \times 10^{-1} \times 10^4 = 2.08 \times 10^2\ \frac{cm^2}{V\text{-}s}$

$\mu = 2.08 \times 10^2\ \frac{cm^2}{V\text{-}s}$

↳ mobility

9

Good Approach

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b) (i) Differentiate between different types of magnetic materials on the basis of magnetic dipoles and hysteresis loops.

(ii) The following data refers to a dielectric material having $\varepsilon_r = 4.94$, $n^2 = 2.69$, where n is the index of refraction. Calculate the ratio between electronic and ionic polarization for this material.

[12 + 8 marks]

Soln

On the basis of magnetic dipoles, different types of magnetic materia is classified –

(1) Diamagnetic material:– this material repel from magnetic field. It does not have spontaneous polarisation.

χ_m – (–ve) and very less (-10^{-3} to -10^{-2})

$\mu_r < 1$ – relative permeability

eg – Cu, Au, Ni etc

(2) paramagnetic material:– these material show net magnetic dipole on the effect of magnetic field applied across it.

χ_m = (+ve) (10^{-3} to 10^{-2})

$\mu_r > 1$ – relative permeability

It show very small magnetic dipoles.

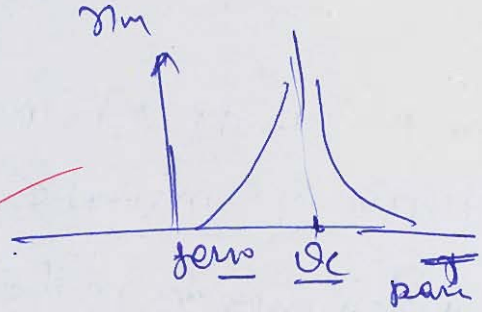
(3) ferromagnetic material:– this magnetic material show spontaneous magnetisation. When M.f applied then all the dipoles domain rotate in the direction

of M.f, and show a large magnetic dipole.

χ_m — very large (+ve)

$\mu_r >> 1$ — very large

$$\chi_m = \frac{C}{T-\theta}$$
↓
Curie Weiss law



(4) Ferrimagnetic material :- This material also shows high magnetic dipoles on application of M.f

↑↓ ↑↓ ↑↓ ↑↓

antiparallel dipoles present of unequal values. Hence this shows net magnetic dipoles.

χ_m — very large (+ve)

$\mu_r >> 1$

(5) Antiferromagnetic material :- This magnetic material have equal and opposite spin magnetic dipoles so it cancel out each other

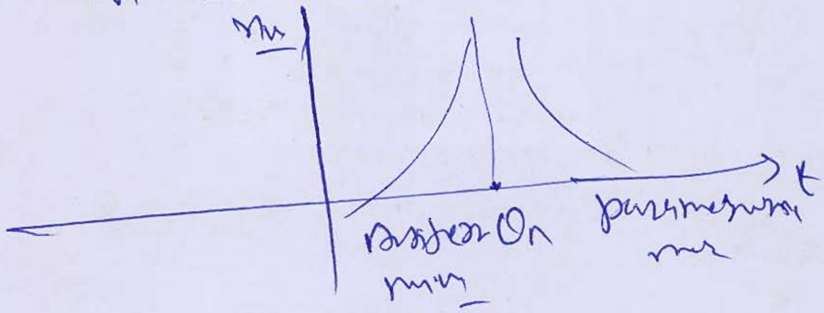
↑↓ ↑↓ ↑↓ ↑↓

So does not show spontaneous behaviour

it behave as paramagnetic material above Neel temp.

$$\chi_m = \frac{C}{T+\theta_N}$$

Where θ_N - Neel temperature.



ON the Basis of hysteresis loop, m.m are divided into two groups -

(1) Hard magnetic material

(2) Soft magnetic material

Hard M.M	Soft M.M
(1) Hard to demagnetize or magnetize	(1) easy to demagnetize and magnetize
(2) High value of coercivity, retentivity	(2) Low value of coercivity, retentivity
(3) Low permeability	(3) high permeability
(4) wide and large hysteresis loop	(4) narrow and small hysteresis loop

18

(ii) $\varepsilon_r = 4.94$, $n^2 = 2.69$

$$\frac{\varepsilon_r - 1}{\varepsilon_r + 2} = \frac{N(\alpha_i + \alpha_e)}{3\varepsilon_0} \quad -①$$

$$\frac{n^2 - 1}{n^2 + 2} = \frac{N\alpha_e}{3\varepsilon_0}$$

$$\Rightarrow \frac{eq(1)}{eq(2)} = \frac{\frac{4.94-1}{4.94+2}}{\frac{2.69-1}{2.69+2}} = \frac{\alpha_i + \alpha_e}{\alpha_e}$$

on solving

$$\frac{\alpha_e}{\alpha_i} = 1.735$$

Q.8 (c) **(i)** A ferromagnetic material of 20 kg mass and 7200 kg/m^3 density is subjected to an AC supply of 60 Hz frequency. The hysteresis loop area of the material is 180 cm^2. The scale factors on ordinate and abscissa are 1 cm = 0.004 Wb/m^2 and 1 cm = 10 AT/m respectively. Calculate the energy loss per hour in the specimen due to the hysteresis phenomena in the specimen.

(ii) What is a soft magnetic material? Give examples of soft magnetic materials and list their applications.

[10 +10 marks]

(i) Soln total mass = 20 kg

density = 7200 kg/m^3

$f = 60$ Hz

energy density = $B \times H$ = $0.004 \times 10 = 0.04$ J/m^3

energy density per unit area

$= 0.04 \times 180 = 7.2$

total energy loss in one hour

$E = \frac{7.2 \times 20}{7200} \times 60 \times 60 \times 60$

E = 4320 watt per hour

9

(ii) Soft magnetic material: It is a type of magnetic material based on hysteresis losses.

Characteristic of soft magnetic material

(1) narrow and small hysteresis loop

(2) low hysteresis losses

(3) High permeability

(4) low retentivity and low coercivity.

(5) easy to demagnetize or magnetize.

e.g: (1) Si-Fe alloy

(2) Si – Ni Alloy

(3) Si - permalloy

Application

(1) It is used in making of electromagnets.

(2) It is used in the core of transformer & reactor (manufacturing)

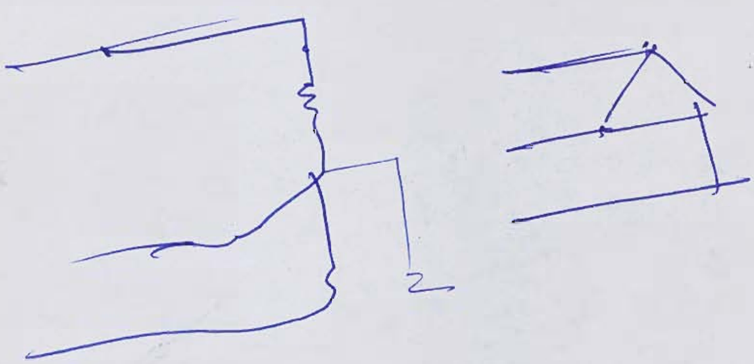
(3) It is also used for High frequency frequency transformer and reactor.

9

OOOO

Space for Rough Work

Space for Rough Work



$V_s = \frac{15VA}{300}$