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ESE 2025 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Electronics & Telecommunication Engineering

Test-5 : Materials Science + Basic Electrical Engineering + Electronic Measurements and Instrumentation [All topics]

Name : ....

Roll No :

Test Centres				Student's Signature
Delhi ☐	Bhopal ☐	Jaipur ☐	Pune ☐	
Kolkata ☐	Hyderabad ☐			

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	40
Q.2	32
Q.3	—
Q.4	—
Section-B	
Q.5	17
Q.6	49
Q.7	51
Q.8	—
Total Marks Obtained	189

Signature of Evaluator: Chaithra A M

Cross Checked by: ....

* Good Performance.
* Keep it up.

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.

Do not write in this margin

Section A : Materials Science + Basic Electrical Engineering + Electronic Measurements and Instrumentation

1 (a) Strontium has an FCC crystal structure, an atomic radius of 0.215 nm, and an atomic weight of 87.62 g/mol. Calculate the theoretical density for strontium crystal.

[12 marks]

$a = \text{radius} = 0.215 \times 10^{-9}$ m ; $A = 87.62 \times 10^{-3}$ kg/mole

$N_A = 6.023 \times 10^{23}$ atoms/mole ; $\rho = ?$

∴ we know that

$$N = \frac{n}{V_c} = \frac{N_A \rho}{A} \quad [n = 4 \text{ for FCC}]$$

$$\Rightarrow \frac{4}{\frac{4}{3}\pi (a)^3} = \frac{N_A \rho}{A} \quad \rightarrow a^3$$

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$$\Rightarrow \rho = \frac{4 \times 3}{4\pi (a)^3} \times \frac{A}{N_A}$$

$$\Rightarrow \rho = \frac{4 \times 3 \times 87.62 \times 10^{-3}}{4 \times \pi \times (0.215 \times 10^{-9})^3 \times 6.023 \times 10^{23}}$$

$$\Rightarrow \rho = 1.397 \times 10^4 \text{ kg/m}^3$$

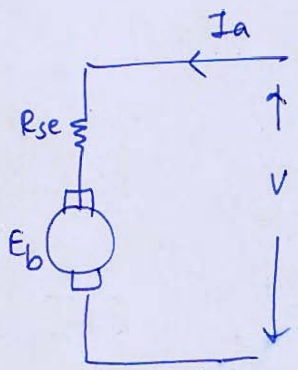
$\rho = 2.587$ g/cm^3

Q.1 (b) Define commutation. Also suggest methods to improve commutation in a DC machine.

[12 marks]

Q.1 (c) Prove that "the torque developed by a d.c. motor is directly proportional to the flux per pole and armature current".

[12 marks]



$\phi \rightarrow$ flux per pole

$I_a \rightarrow$ armature current

we know that

Back emf $\boxed{E_b = \frac{\phi Z N}{60} \times \frac{P}{A}}$ —(1)

Z = No. of conductors ; P = No. of poles

N = speed in rpm ; A = No. of parallel paths

Power developed $P = E_b I_a$

$\because \quad P = \vec{\tau} \cdot \vec{\omega}$

$\therefore$ Torque $(\tau) = \dfrac{\text{Power}}{\omega}$

$$\Rightarrow \boxed{\tau = \frac{E_b I_a}{(2\pi N/60)}} \quad -(2)$$

using eq^n (1) & eq^n (2)

$$\tau = \left(\frac{\phi Z N}{60}\right)\frac{P}{A} \times \frac{I_a}{2\pi N} \times 60$$

$$\Rightarrow \tau = \left(\frac{Z P}{2\pi A}\right)\phi I_a$$

$$\Rightarrow \boxed{\tau = K \phi I_a} \qquad \left(K = \frac{ZP}{2\pi A}\right)$$

Torque ∝ (Flux per pole) (Armature current)

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1 (d) An 1 kΩ resistance with an accuracy of ±10% carries a current of 10 mA. The current was measured by an analog meter of 20 mA range with an accuracy of ±2% of full scale. Compute the power dissipated in the resistor and determine the accuracy of the result.

[12 marks]

$R = 1k\Omega \pm 10\%$

$I = 10mA \pm x\%$ [accuracy of analog meter of 20mA rang is $\pm 2\% I_{fs}$]

error at 20mA $\longrightarrow$ $20mA \times \frac{2}{100} = \pm 0.4mA$

% error at $I = 10mA$

$x = \frac{\pm 0.4mA}{10mA} \times 100 = \pm 4\%$

$\therefore I = 10mA \pm 4\%$

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$P = I^2 R$

$\Rightarrow P = (10mA)^2 \times 1 \times 10^3$

$\Rightarrow P = 10^{-4} \times 10^3$

$\Rightarrow P = 0.1$ watt

error in $P = 2(x) +$ error in resister

$error_p = 2 \times 4 + 10$

$error_{power} = \pm 18\%$

$\Rightarrow$ Power $= 0.1 \pm 18\%$ watt

accuracy = 100 − error = 82%

Q.1 (e) A thermometer at room temperature of 30°C is dipped suddenly into a bath of boiling water at 100°C. It takes 30 seconds to reach 97°C. Calculate the time required to reach a temperature of 98°C.

[12 marks]

$T_i = 30^\circ C \quad ; \quad T_F = 100^\circ C$

$T = (T_i - T_F)e^{-t/\tau} + T_F$ ✓ $[\tau = \text{time constant}]$

$\Rightarrow$ at $t = 30$ sec ; $T = 97^\circ C$

$\therefore \quad 97 = (30 - 100)e^{-\frac{30}{\tau}} + 100$

$\Rightarrow \quad 97 = 100 - 70e^{-30/\tau}$

$\Rightarrow \quad 3 = 70e^{-30/\tau}$

$\Rightarrow \quad e^{30/\tau} = 70/3$

$\Rightarrow \quad \frac{30}{\tau} = \ln 70/3$ ✓

$\Rightarrow \quad \boxed{\tau = 9.524 \text{ sec.}}$

again for $T = 98^\circ C$

$98 = (30 - 100)e^{-\frac{t}{9.524}} + 100$

$\Rightarrow \quad 70e^{-\frac{t}{9.524}} = 2$

$\Rightarrow \quad e^{\frac{t}{9.524}} = \frac{70}{2}$

$\Rightarrow \quad t = 9.524 \ln 35$ ✓

$\Rightarrow \quad \boxed{t = 33.86 \text{ sec.}}$

(12)

2 (a) **(i)** A barium titanate pickup has dimensions of 5 mm × 5 mm × 1.25 mm. The force acting on it is 5 N. The charge sensitivity of barium titanante is 150 pC/N and its permittivity is 12.5×10^{-9} F/m. If the modulus of elasticity of barium titanate is 12×10^{6} N/m^2, calculate the strain. Also calculate the charge and the capacitance.

(ii) The inductance of a moving iron instrument is given by

$$L = (12 + 6\theta - \theta^2)\ \mu H$$

where θ is the deflection in radians from zero position. The spring constant is 12×10^{-6} Nm/radians. Calculate the deflection for a current of 8 A.

(iii) In a proximity inductive transducer, the coil has an inductance of 2 mH when the target made of Ferro-magnetic material is 1 mm away from the core. Calculate the value of inductance when a displacement of 0.02 mm is applied to the target in a direction moving it towards the core. Show that the change in inductance is linearly proportional to the displacement.

[8 + 6 + 6 marks]

(i) $d = 150 \times 10^{-12}$ C/N ; $\epsilon = 12.5 \times 10^{-9}$ F/m

$Y = 12 \times 10^{6}$ N/m^2 $= \dfrac{\text{stress}}{\text{strain}}$; $F = 5$ N

$$\text{Stress} = \frac{F}{\text{Area}} = \frac{5}{5\times10^{-3} \times 5\times10^{-3}} = \frac{10^{6}}{5}\ \text{N/m}^2$$

$$\Rightarrow \text{Strain} = \frac{\text{stress}}{Y} = \frac{10^{6}/5}{12\times10^{6}}$$

$$\Rightarrow \boxed{\text{Strain} = 0.0166}$$

Charge $Q = dF$

$$\Rightarrow Q = 150\times10^{-12} \times 5$$

$$\Rightarrow \boxed{Q = 7.5\times10^{-10}\ \text{columb}}$$

Capacitance $C = \dfrac{A\epsilon}{d}$

6

$\Rightarrow C = \dfrac{5\times10^{-3} \times 5\times10^{-3} \times 12.5\times10^{-9}}{1.25\times10^{-3}}$

$\Rightarrow \boxed{C = 2.5\times10^{-4} \text{ farad}}$

$C = 250\,pF$

(ii) $L = (12 + 6\theta - \theta^2)\,\mu H$

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

$\Rightarrow 12\times10^{-6}\,\theta = \dfrac{1}{2}\times I^2 \times (6 - 2\theta)$

$\Rightarrow$ (given $I = 8\,A$)

$\Rightarrow 12\times10^{-6}\times\theta = \dfrac{1}{2}\times 8^2 \times (6 - 2\theta)$

$\Rightarrow \dfrac{24\times10^{-6}\times\theta}{8^2} = 6 - 2\theta$

$\Rightarrow 3\times10^{-6}\,\theta = 6 - 2\theta$

$\Rightarrow \theta(3\times10^{-6} + 2) = 6$

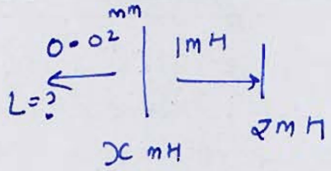
$\Rightarrow \boxed{\theta = 2.999 \text{ rad}}$

$\Rightarrow \boxed{\theta = 171.31^\circ}$

$\theta = 2.526$ rad $= 144.74^\circ$

Avoid calculation mistakes.

(iii)



$$L = 2\,mH + 0.02\,mm \times \frac{2\,mH}{1\,mH}$$

$$\boxed{L = 2.04\,mH}$$

5

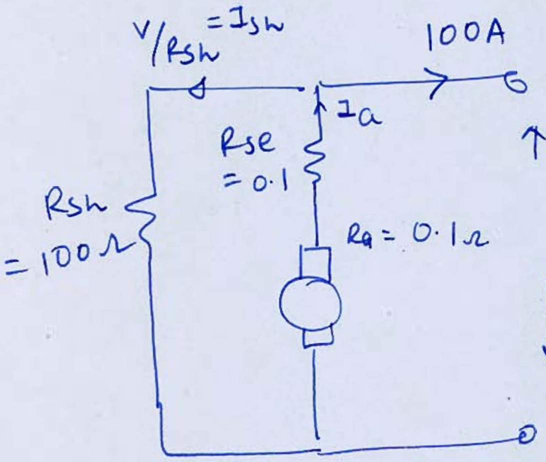
Q.2 (b) A 4-pole long shunt compound d.c. generator has 1200 armature conductors and running at a speed of 500 r.p.m. The diameter of the pole shoe circle is 0.35 m and the ratio of pole arc to pole pitch is 0.7 while the length of the shoes is 0.2 m.

Assume the shunt field, series field and armature resistance are 100 Ω, 0.1 Ω and 0.1 Ω respectively. If the flux density in the air gap is 0.65 T, load current is 100 A and voltage drop per brush is 1 V, then calculate load voltage when

(i) Armature winding is lap connected.

(ii) Armature winding is wave connected.

[20 marks]



$$V = E_b - I_a R_a - 2 - I_a R_{se}$$

$$E_b = \frac{\phi Z N}{60} \times \frac{P}{A}$$

$$\phi = \vec{B} \cdot d\vec{s}$$

$$\Rightarrow \phi = 0.65 \times 0.2 \times 0.7 \times \frac{\pi D}{P}$$

$$\phi = 0.65 \times 0.2 \times 0.7 \times \pi \times \frac{0.35}{4}$$

$$\boxed{\phi = 0.025 \text{ wb}}$$

$$\Rightarrow E = \frac{0.025 \times 1200 \times 500}{60} \frac{P}{A}$$

$$\Rightarrow \boxed{E = 250 \frac{P}{A}}$$

(i) Case :→ lap winding $A = P$

$\therefore$ $E = 250$ volt

$V = 250 - I_a \times 0.1 - 2 - I_a \times 0.1$

$\Rightarrow$ $V = 248 - 0.2 I_a$ — (1)

$I_a = 100 + \frac{V}{100}$ — (2)

$\therefore$ $V = 248 - 0.2\left[100 + \frac{V}{100}\right]$

$\Rightarrow$ $V = 248 - 20 - \frac{0.2V}{100}$

$\Rightarrow$ $V\left[1 + \frac{0.2}{100}\right] = 228$

$\Rightarrow$ $V = 227.54$ volt

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Good

(ii) $A = 2$ (wave) $E = 500$ volt

$\therefore$ $V = 500 - I_a \times 0.1 - 2 - I_a \times 0.1$

$V = 498 - 0.2 I_a$

$I_a = 100 + \frac{V}{100}$

$\Rightarrow$ $V = 498 - 0.2\left[100 + \frac{V}{100}\right]$

$\Rightarrow$ $V + \frac{0.2V}{100} = 478$

$\Rightarrow$ $V = 477.04$ Volt

Q.2 (c) An electrodynamometer wattmeter is used for measurement of power in a single phase circuit. The load voltage is 100 V and the load current is 9 A at a lagging power factor of 0.1. The wattmeter voltage circuit has a resistance of 3000 Ω and an inductance of 30 mH. Estimate the percentage error in the wattmeter reading when pressure coil is connected:

(i) on the load side, and

(ii) on the supply side.

The current coil has a resistance of 0.1 Ω and negligible inductance. The frequency is 50 Hz. Comment upon the result.

[20 marks]

.3 (a) (i) A steel cantilever is 0.25 mm long, 20 mm wide and 4 mm thick.

1. Calculate the value of deflection at the free end for the cantilever when a force of 25 N is applied at this end. The modulus of elasticity for steel is 200 GN/m^2.
2. An LVDT with a sensitivity of 0.5 V/mm is used. The voltage is read on a 10 V voltmeter having 100 divisions. Two-tenths of a division can be read with certainty.

Calculate the minimum and maximum value of force that can be measured with this arrangement.

(ii) An ac LVDT has the following data: Input = 6.3 V, Output = 5.2 V, range ±0.5 in.

1. Plot the output voltage vs core position for a core movement going from +0.45 in. to –0.30 in.
2. Determine the output voltage when the core is –0.25 in. from the centre.

[14 + 6 marks]

Q.3 (b) (i) State the applications of synchronous motors. Compare synchronous motor with induction motor.

(ii) Compare with neat sketches squirrel-cage and slip-ring three-phase induction motor with reference to construction, performance and applications.

[10 + 10 marks]

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Q.3 (c) (i) A solenoid is 0.25 m long having 1000 turns and has 2.5 A current flowing through it in a vacuum chamber. When placed in pure oxygen environment, the magnetic induction exhibits an increase of 1.04×10^{-8} Wb/m^2. Find the magnetic susceptibility of oxygen.

(ii) Write a short note on optical properties of semiconducting Nanoparticles.

[10 + 10 marks]

Q.4 (a) A 110 kW belt-driven shunt generator running at 400 r.p.m on 220 V bus bars continues to run as a motor when the belt breaks. As a motor it takes 11 KW. Find the speed at which it will run as a motor if the resistance of the armature and field are 0.025 Ω and 55 Ω respectively. Brush contact drop is 2 V.

[20 marks]

Q.4 (b) How frequency is measured with help of Wein's Bridge? Explain with mathematical derivation and circuit diagram. Enumerate other applications of Wein's bridge.

[20 marks]

Q.4 (c) Explain briefly the polarization occurring in dielectric materials. What are different types of polarization occurring in dielectric materials?

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 $\vec{E} = 10^4 \vec{a}_x$ V/m, then calculate the value of polarization and dipole moment of each molecule. (Consider all molecules have same dipole moment).

[20 marks]

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Section B : Materials Science + Basic Electrical Engineering + Electronic Measurements and Instrumentation

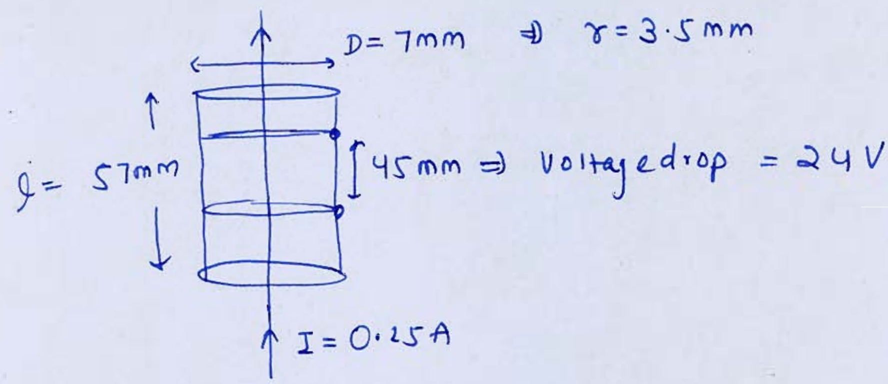
Q.5 (a) Consider a cylindrical silicon specimen 7.0 mm in diameter and 57 mm in length.

(i) A current of 0.25 A passes along the specimen in the axial direction. A voltage of 24 V is measured across the two probes that are separated by 45 mm. What is the electrical conductivity of the specimen?

(ii) Compute the resistance over the entire 57 mm of the specimen.

[12 marks]

(i)



Resistance (R) of 45 mm length = $\frac{V}{I} = \frac{24}{0.25}$

$\Rightarrow$ $\boxed{R = 96\,\Omega}$

$\therefore$ $R = \frac{l}{\sigma A}$ $\Rightarrow$ $96 = \frac{45\times10^{-3}}{\sigma\times\pi\times(3.5\times10^{-3})^2}$

$\Rightarrow$ $\sigma = \frac{45\times10^{-3}}{96\times\pi\times3.5^2\times10^{-6}}$

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$\Rightarrow$ $\boxed{\sigma = 12.18 \text{ mho/m}}$ ✓

(ii) Resistance of entire 57 mm

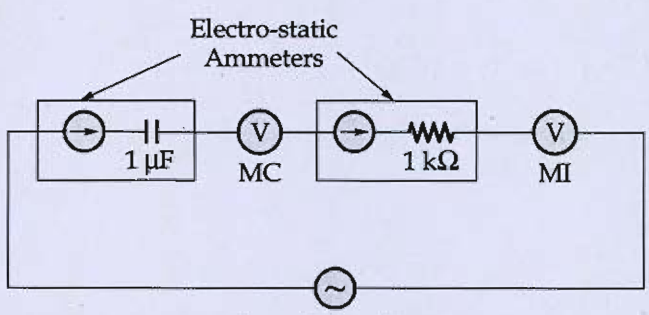
$R' = \frac{l}{\sigma A}$

$\Rightarrow$ $R' = \frac{57\times10^{-3}}{12.18\times\pi\times(3.5\times10^{-3})^2}$

$$\Rightarrow R' = \frac{57 \times 10^3}{12.18 \times \pi \times 3.5^2}$$

$$\Rightarrow \boxed{R' = 121.602\ \Omega}$$

5 (b) A voltage of (0.6 + 0.4 sin ωt – 0.1 sin $2\omega t$) volts is applied across the circuit shown below.



V, $\omega = 10^6$ rad/sec

Where, MC : Moving coil instrument

MI : Moving iron instrument

Determine the reading of each instrument. (Assume only one instrument is connected at a time)

[12 marks]

Since input voltage consists of three different voltage so we can treat them seperately :→

if V $V = 0.6 + 0.4 \sin \omega t - 0.1 \sin 2\omega t$

$V = V_1 + V_2 + V_3$

$V_1 = 0.6$ volt $\Rightarrow$ then $I_1 = 0$ —(1)

$(\because$ for $f = 0$; $X_C = \infty)$

for $V_2 = 0.4 \sin \omega t$

$$X_C = \frac{1}{j \times 10^6 \times 10^{-6}} = -j \,\Omega$$

$$Z = R - j = 1000 - j \,\Omega$$

$$\therefore I_2 = \frac{0.4 \sin \omega t}{1000 - j} = 3.99 \times 10^{-4} \sin(\omega t + \phi_1) \text{ Amp} \quad -(2)$$

for $V_3 = 0.1 \sin 2\omega t$

$$X_C = \frac{1}{j \times 2 \times 10^6 \times 10^{-6}} = -j0.5 \,\Omega$$

$$Z = 1000 - j0.5 \,\Omega$$

$$\therefore I_3 = \frac{0.1 \sin 2\omega t}{1000 - j0.5} = 9.999 \times 10^{-5} \sin(2\omega t + \phi_2) \text{ Amp} \quad -(3)$$

(3)

$$\therefore I = I_1 + I_2 + I_3$$

$$\Rightarrow I = 3.99 \times 10^{-4} \sin(\omega t + \phi_1) + 9.99 \times 10^{-5} \sin(2\omega t + \phi_2)$$

$\because$ For moving coil $\rightarrow$ only DC value

$$I = \frac{3.99 \times 10^{-4}}{2\pi} + \frac{9.99 \times 10^{-5}}{2\pi}$$

$$\Rightarrow \boxed{I = 7.94 \times 10^{-5} \text{ Amp}}$$

moving coil voltmeter given. $\Rightarrow V_{dc} = 0.6\,V$

for moving iron : $\rightarrow$ rms value

$$I = \frac{3.99 \times 10^{-4}}{\sqrt{2}} + \frac{9.99 \times 10^{-5}}{\sqrt{2}}$$

moving iron voltmeter reads rms value. $\Rightarrow V_{rms} = 0.667\,V$

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$I = 3.527 \times 10^{-4}$ amp

5 (c) (i) A linear resistance potentiometer is 50 mm long and is uniformly wound with a wire having a resistance of 10,000 Ω. Under normal conditions, the slider is at the center of the potentiometer. Find the linear displacement when the resistances of the potentiometer as measured by Wheatstone bridge for two cases are:

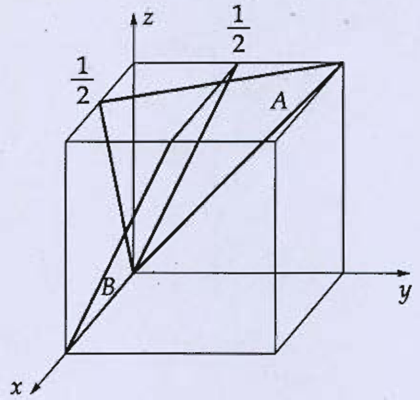
1. 3850 Ω.

2. 7560 Ω.

Are the two displacements in same direction?

If it is possible to measure a minimum value of 10 Ω resistance with the above arrangement, find the resolution of the potentiometer.

(ii) Determine the Miller indices for the planes shown in the following unit cell:



[6 + 6 marks]

(i) Sensitivity of potentiometer $= \frac{10,000\ \Omega}{50\text{ mm}}$

$S = 200\ \Omega/\text{mm}$

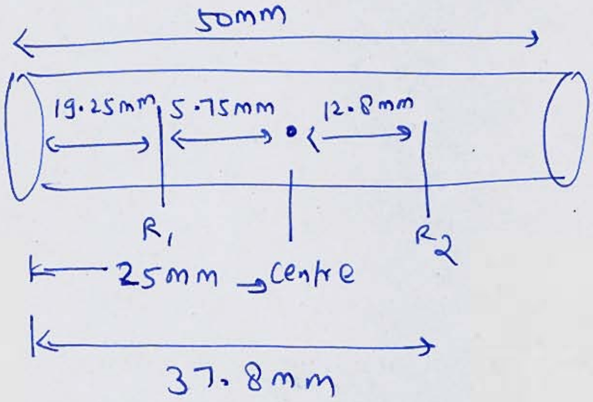
1. when $R = 3850\,\Omega$

$\text{length } (l_1) = \frac{3850}{200} = 19.25 \text{ mm}$ ✗

5000-3850

2. when $R = 7560\,\Omega$ → 7560-5000

$\text{length } (l_2) = \frac{7560}{200} = 37.8 \text{ mm}$ ✗



(2)

Both are in opposite direction ✓

For $10\,\Omega$:→ $\text{length} = \frac{10}{200} = 0.05 \text{ mm}$

$$\text{Resolution} = \frac{0.05 \text{ mm}}{10000} = 5\times10^{-6} \text{ mm}/\Omega$$

$= 0.05 \text{ mm}$

5 (d) State few advantages of Rotating Field Alternator over Rotating Armature Alternator.
[12 marks]

5 (e) A customer has to choose between two DVM machines with following specifications:

Machine A is a $4\frac{1}{2}$ digit DVM with error specification as 0.2% of reading +10 counts whereas machine B is 4 digit DVM with error specification as 0.2% of reading +2 digits.

If a dc voltage of 100 V is read on its 200 V full scale and customer decides to take the instrument with less percentage error, then which instrument is most suited to the customer?

[12 marks]

Q.6 (a) (i) A 100 kVA, 50 Hz, 440/11000 V, 1-phase transformer has an efficiency of 97.23% when supplying full load current at 0.83 power factor lagging and an efficiency of 98.72% when supplying half full load current at unity power factor. Find the core loss and the copper loss corresponding to the full load current. At what value of load current will maximum efficiency be attained?

(ii) A two pole, 50 Hz induction motor supplies 15 kW to a load at a speed of 2950 rpm. **Calculate:**

1. Motor's slip.
2. Induced torque in the motor.
3. Operating speed of the motor if its torque is doubled.
4. Power supplied to the motor when the torque is doubled.

[Assume friction and windage loss is zero.]

[10 + 10 marks]

10

(i) 100 kVA; 440/11000 V; 1ϕ

Case ① $\eta = 97.23\%$ → at full load; $\cos\phi = 0.83$ (lagging)

Case ② $\eta = 98.72\%$ → at half full load; $\cos\phi = 1$ (UPF)

$W_I = ?$ $W_{FL\,Culoss} = ?$

$$\eta = \frac{x[kV]\cos\theta}{x[kV]\cos\theta + x^2 W_{FL\,Culoss} + W_I}$$

for case ①

$$0.9723 = \frac{(1)(100\times10^3)\times0.83}{(1)(100\times10^3)\times0.83 + (1)^2 W_{FL\,cu} + W_I}$$

$$\Rightarrow \boxed{W_{FL\,cu} + W_I = 2364.599} \quad — ①$$

for case ②

$$0.9872 = \frac{(0.5)(100\times10^3)\times(1)}{(0.5)(100\times10^3)\times(1) + (0.5)^2 W_{FL\,cu\,loss} + W_I}$$

$$\Rightarrow \boxed{0.25\,W_{FL\,cu\,loss} + W_I = 648.298} \quad — ②$$

From eqn ① & ②

$$\boxed{\begin{aligned} W_{FL\,cu\,loss} &= 2288.40 \text{ watt} \\ W_I &= 76.1976 \text{ watt} \end{aligned}}$$

for maximum efficiency :- variable loss = constant loss

$$\Rightarrow x^2 (W_{FL\,cu\,loss}) = W_I$$

$$\Rightarrow x = \sqrt{\frac{W_I}{W_{FL\,cu}}} = \sqrt{\frac{76.1976}{2288.40}}$$

$$\Rightarrow \boxed{x = 0.182} \text{ of full load}$$

value of load current at η_{max} $= 0.182 \times \frac{100\times10^3}{11000}$

$$\boxed{I_{load} = 1.654 \text{ Amp}}$$

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(ii) $p = 2$; $f = 50Hz$; output power $P = 15kW$;
$N = 2950 rpm$

1. Slip :→ $S = \frac{N_S - N}{S}$; $N_S = \frac{120f}{p}$

$N_S = \frac{120 \times 50}{2}$

$N_S = 3000 rpm$

∴ $S = \frac{3000 - 2950}{3000}$

⇒ $S = 0.0166$

⇒ $S = 1.66\%$

2. Induced torque $= \frac{15 \times 10^3}{2\pi\left(\frac{2950}{60}\right)} = 48.55$ N-m

3. if Torque is doubled then Operating speed will be half ($\because P = \vec{\tau} \cdot \vec{\omega}$)

∴ $N = \frac{2950}{2} = 1475$ rpm

5

4. Power supplied to the motor $= \frac{\text{output power}}{1 - S}$

new value of $S = \frac{N_S - N}{N_S} = \frac{3000 - 1475}{3000}$

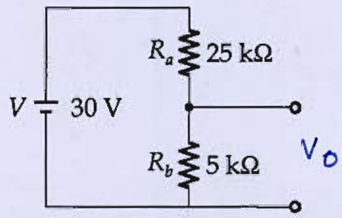
$S = 0.5083$

∴ power supplied to the motor $= \frac{15 \times 10^3}{1 - 0.5083}$

$P = 30.506$ kW

29.5kW

5 (b) Two different voltmeters are used to measure the voltage across R_b in the circuit of figure shown below.



Meter 1 : $S = 1\ k\Omega/V$, range 10 V
Meter 2 : $S = 20\ k\Omega/V$, range 10 V

Calculate:

(i) voltage across R_b without any meter across it,

(ii) voltage across R_b when meter 1 is used,

(iii) voltage across R_b when meter 2 is used, and

(iv) error in the voltmeters.

[20 marks]

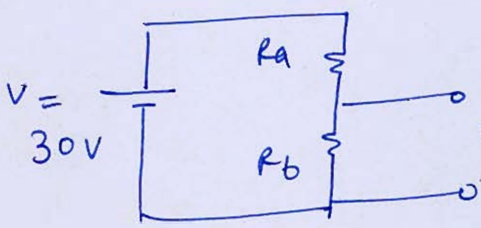
meter 1 resistance $R_1 = \frac{1\ k\Omega}{V} \times 10\ V$

$$\boxed{R_1 = 10\ k\Omega}$$

meter 2 resistance $R_2 = \frac{20\ k\Omega}{V} \times 10\ V$

$$\boxed{R_2 = 200\ k\Omega}$$

(i) without any meter :-

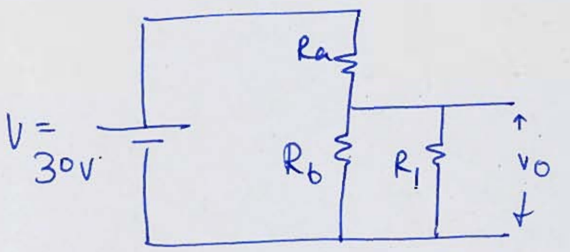


$V_O = \frac{R_b}{R_a + R_b} \times V$

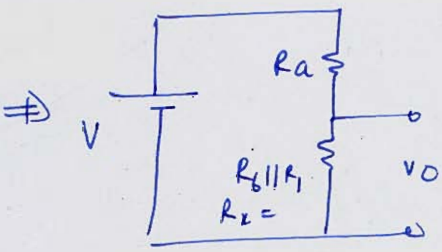
$\Rightarrow V_O = \frac{5k}{5k + 25k} \times 30$

$\Rightarrow \boxed{V_O = 5\ volt}$

(ii) When meter 1 is used :-



⇒



$$R_x = \frac{R_b R_1}{R_b + R_1} = \frac{5k \times 10k}{5k + 10k} = \frac{10}{3} k\Omega$$

$$\therefore \quad V_o = \frac{R_x}{R_x + R_a} \times V = \left(\frac{10/3}{10/3 + 25}\right) \times 30$$

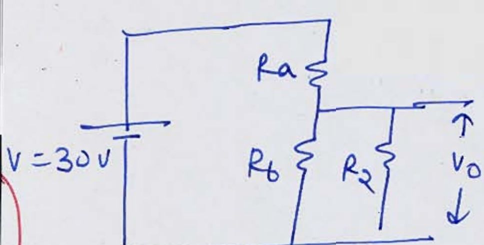
$$\Rightarrow \quad V_o = \frac{10}{55} \times 30$$

$$\Rightarrow \quad \boxed{V_o = 5.454 \text{ volt}}$$

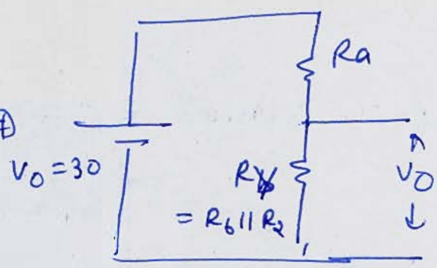
✗ → 3.53 V

(Avoid calculation mistakes).

(iii) When meter 2 is used :→



⇒



15

$$R_y = \frac{R_b R_2}{R_b + R_2} = \frac{5k \times 200k}{5k + 200k} = \frac{200}{41} k\Omega$$

$$\therefore \quad V_o = \frac{R_y}{R_y + R_a} \times V = \left(\frac{200/41}{200/41 + 25}\right) \times 30$$

$$\boxed{V_o = 4.897 \text{ Volt}}$$

✓

(iv) error in voltmeters :→

Voltmeter 1

$\% \epsilon_r = \frac{A_m - A_T}{A_T} \times 100$

$\Rightarrow \% \epsilon_r = \frac{5.454 - 5}{5} \times 100$

$\Rightarrow \boxed{\% \epsilon_r = \pm 9.08 \%}$

Voltmeter 2

$\% \epsilon_r = \frac{A_m - A_T}{A_T} \times 100$

$\% \epsilon_r = \frac{4.897 - 5}{5} \times 100$

$\boxed{\% \epsilon_r = \pm 2.06 \%}$

[Voltmeter 2 is more accurate because it's internal resistance is more. Resistance of ideal voltmeter should be infinite]

(c) (i) For a dielectric, establish an expression for the relationship between the polarizability and permittivity. How does this relation lead to Clausius-Mossotti equation?

(ii) When an NaCl crystal is subjected to an electric field of 1000 V/m, the resulting polarization is 4.3×10^{-8} C/m^2. Calculate the relative permittivity of NaCl.

[15 + 5 marks]

(i) $\vec{D} = \epsilon_0 \epsilon_r \vec{E}$ —(1)

and $\vec{D} = \epsilon_0 \vec{E} + \vec{P}$ —(2)

from (1) & (2)

$\epsilon_0 \vec{E} + \vec{P} = \epsilon_0 \epsilon_r \vec{E}$

$\Rightarrow \boxed{\vec{P} = \epsilon_0 (\epsilon_r - 1) \vec{E}}$ $[\epsilon_r - 1 = \chi_e]$

Clausius - Mossotti equation :→

Assumptions :→

(1) Polarizability is isotropic

(2) arrangement of molecules is isotropic

(3) polarization due to elastic displacement only

Further, this equation applicable only for cubic structure ($\gamma = 1/3$)

Now

$$P = N\alpha E_i$$

$$E_i = E + \frac{\gamma P}{\epsilon_0}$$

$$\boxed{E_i = E + \frac{P}{3\epsilon_0}}$$

$$\therefore \quad P = N\alpha\left(E + \frac{P}{3\epsilon_0}\right)$$

$$\Rightarrow \quad P\left[1 - \frac{N\alpha}{3\epsilon_0}\right] = N\alpha E$$

$$\Rightarrow \quad \epsilon_0(\epsilon_r - 1)E\left[1 - \frac{N\alpha}{3\epsilon_0}\right] = N\alpha E$$

$$\Rightarrow \quad \boxed{\epsilon_r - 1 = \frac{\frac{N\alpha}{\epsilon_0}}{1 - \frac{N\alpha}{3\epsilon_0}}} \quad \text{— eq}^n \text{ (3)}$$

5

add 3 to both sides

$$\Rightarrow \quad \epsilon_r + 2 = \frac{N\alpha/\epsilon_0}{1 - \frac{N\alpha}{3\epsilon_0}} + 3 = \frac{3}{1 - \frac{N\alpha}{3\epsilon_0}} \quad (4)$$

eq^n (3) ÷ (4)

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

4

(ii) $E = 1000\ V/m$; $P = 4.3 \times 10^{-8}\ C/m^2$; $\epsilon_r = ?$

$$\because \quad P = \epsilon_0(\epsilon_r - 1)E$$

$$\Rightarrow \quad \epsilon_r - 1 = \frac{4.3 \times 10^{-8}}{8.85 \times 10^{-12} \times 1000} = 4.858$$

$$\therefore \quad \boxed{\epsilon_r = 3.858}$$

~~[illegible]~~

$\epsilon_r = 5.86$

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7 (a) A 4-pole, 250 V, wave-connected shunt motor gives 10 kW when running at 1000 rpm and drawing armature and field current of 60 A and 1 A respectively. It has 560 conductors. Its armature resistance is 0.2 Ω, Assuming a drop of 1 V per brush, determine

(i) Total torque, (ii) Useful torque,

(iii) Useful flux per pole, (iv) Rotational losses,

(v) Efficiency.

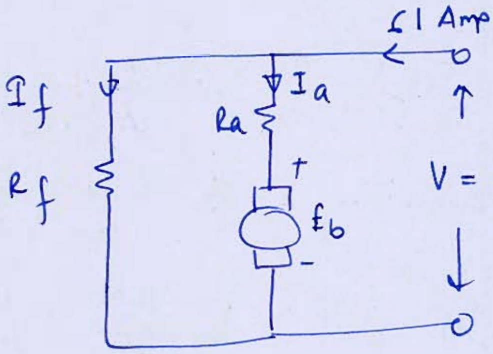
and also represent it through power-flow diagram.

[20 marks]

$P = 4$; $250V$; $N = 1000 rpm$; motor output = 10 kW

$I_a = 60A$; $I_f = 1A$; $Z = 560$; $r_a = 0.2\Omega$

drop across brush = 1 volt per brush



$E_b = V - I_a R_a -$ Brush drop

$\Rightarrow E_b = 250 - 60 \times 0.2 - 2 \times 1$

$\Rightarrow$ $\boxed{E_b = 236 \text{ volt}}$

$\Rightarrow \omega = \frac{2\pi N}{60} = \frac{2 \times \pi \times 1000}{60} = 104.719$ rad/sec.

(i) Total torque $= \frac{E_b I_a}{\omega}$

Total torque $= \frac{(236)(60)}{104.719}$

$\boxed{\text{Total torque} = 135.21 \text{ N-m}}$

(ii) Useful Torque = $\frac{\text{output power}}{\omega}$

Useful Torque = $\frac{10\times10^3}{104.719}$

Useful torque = 95.493 N-m

(iii) Useful flux per pole :-

$E_b' I_a = (\text{Useful Torque}) \times \omega$

$\Rightarrow E_b' = \frac{95.493 \times 104.719}{60} = 166.66$ volt

20

Good

$E_b' = \frac{\phi_{useful} Z N}{60} \times \frac{P}{A}$

for wave A = 2

$\Rightarrow E_b' = \frac{\phi_{use} \times 560 \times 1000}{60} \times \frac{4}{2}$

$\Rightarrow \phi_{use} = \frac{166.66 \times 60 \times 2}{560\times1000\times4}$

$\Rightarrow$ **$\phi_{use/pole} = 8.92\times10^{-3}$ weber**

$E_b = \frac{\phi Z N}{60} \times \frac{P}{A}$

for wave A = 2

$E_b = \frac{\phi \times 560 \times 1000}{60} \times \frac{4}{2}$

$\phi = \frac{236 \times 60 \times 2}{560\times1000\times4}$

$\phi_{/pole} = 12.64 \times 10^{-3}$ weber

(iv) Rotational loss = $E_b I_a - E_b' I_a$

$= 236\times60 - 10\times10^3 = 4160$ watt

(v) efficiency = $\frac{\text{output}}{\text{input}} = \frac{10\times10^3}{250\times(60+1)} \times 100$

$\eta = 66.66\%$

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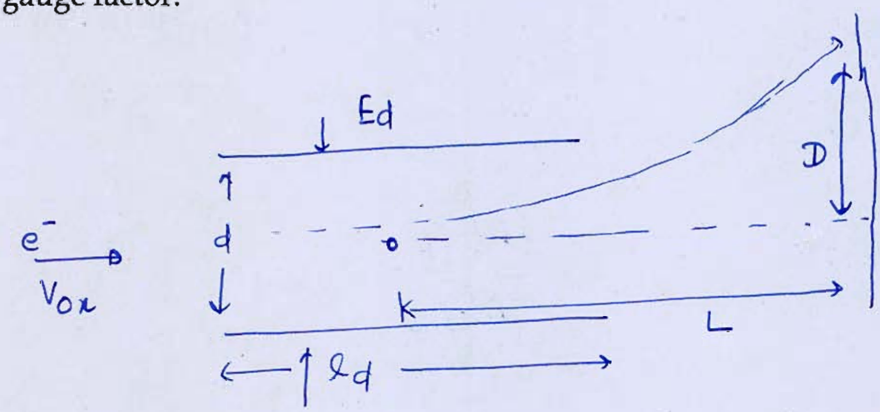
(b) (i) Draw a basic CRT arrangement to show electrostatic deflection and obtain relation for velocity of electron when entering field of deflecting plates. A CRT has an anode voltage of 2000 V and parallel deflecting plates 2 cm long and 5 mm apart. The screen is 30 cm from the centre of the plates. Calculate the input voltage required to deflect the beam through 3 cm. Assume the input voltage is applied to the deflecting plates through amplifiers having an overall gain of 100.

(ii) A single strain gauge having resistance of 120 Ω is mounted on a steel cantilever beam at a distance of 0.15 m from the free end. An unknown force *F* applied at the free end produces a deflection of 12.7 mm at the free end. The change in gauge resistance is found to be 0.152 Ω. The beam is 0.25 m long with a width of 20 mm and a depth of 3 mm. The Young's modulus for steel is 200 GN/m². Calculate the gauge factor.

[10 + 10 marks]

(i)



Anode voltage $E_a = 2000\,V$; $l_d = 2\times10^{-2}\,m$;

$d = 5\times10^{-3}\,m$; $L = 30\times10^{-2}\,m$

$E_d = 100\times(\text{input voltage})$; $D = 3\times10^{-2}\,m$;

we know that

$$\frac{1}{2}mV_{0x}^2 = eE_a$$

$$\Rightarrow \boxed{V_{0x} = \sqrt{\frac{2eE_a}{m}}\ m/sec.}$$

$$\Rightarrow V_{0x} = \sqrt{\frac{2\times1.6\times10^{-19}\times2000}{9.1\times10^{-31}}} = 2.651\times10^{7}\ m/sec$$

Now we know that deflection $D = \frac{L l_d E_d}{2 d E_a}$

10

$\Rightarrow 3 \times 10^{-2} = \frac{30 \times 10^{-2} \times 2 \times 10^{-2} \times E_d}{2 \times 5 \times 10^{-3} \times 2000}$

$\Rightarrow E_d = 100 \text{ volt}$

$\therefore$ Input voltage $= \frac{E_d}{100} = 1 \text{ volt}$

(ii) $R = 120\,\Omega$; $L = 0.15\text{ m}$; $\Delta L = 12.7 \times 10^{-3}\text{ m}$

$\Delta R = 0.152\,\Omega$

gauge factor $G_F = \frac{\Delta R / R}{\Delta L / L}$

$\frac{\Delta R}{R} = \frac{0.152}{120} = 1.266 \times 10^{-3}$

& $\frac{\Delta L}{L} = \frac{12.7 \times 10^{-3}}{0.15} = 0.08466$

$\therefore G_F = \frac{1.266 \times 10^{-3}}{0.08466}$

$\Rightarrow G_F = 0.0149$

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(c) What are the types of cubic crystal structure? Derive the atomic packing factor of all the cubic crystal structures.

[20 marks]

Cubic Structure are of three types :→

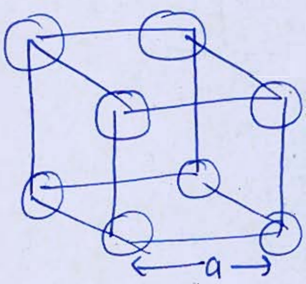
Simple cubic ; Body centered (BCC) ; Face centered (FCC)

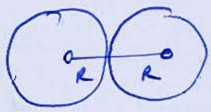
① Simple cubic :→

$$\text{Atomic packing Factor} = \frac{n \times \frac{4}{3}\pi R^3}{a^3}$$

[n = number of effective atoms in cell
R = Radius of atom ; a = lattice or cube dimension]

For





$a = 2R$

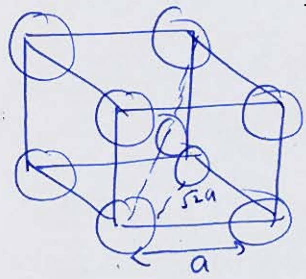
$n = 8 \times \frac{1}{8} = 1$

$$\therefore \quad APF = \frac{(1) \times \frac{4}{3}\pi\left(\frac{a}{2}\right)^3}{a^3}$$

$$\Rightarrow \quad APF = \frac{4}{3} \times \pi \times \frac{1}{8} = 0.5235$$

$$\Rightarrow \quad \boxed{APF = 52.35\%}$$

(ii) Body centered (BCC) : $\rightarrow$ $\boxed{n = 1 + 8 \times \frac{1}{8} = 2}$



$$4R = \sqrt{a^2 + 2a^2}$$

$$\Rightarrow \quad \boxed{4R = \sqrt{3}a}$$

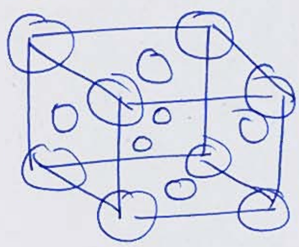
$$\therefore \quad APF = \frac{(2) \times \frac{4}{3}\pi\left(\frac{\sqrt{3}a}{4}\right)^3}{a^3}$$

$$\Rightarrow \quad APF = 2 \times \frac{4}{3}\pi \times \frac{3\sqrt{3}}{64} = 0.6801$$

$$\Rightarrow \quad \boxed{APF = 68.01\%}$$

(iii) Face centered : $\Rightarrow$ $n = 8 \times \frac{1}{8} + 6 \times \frac{1}{2} = 1 + 3$

$$\boxed{n = 4}$$



$$4R = \sqrt{a^2 + a^2}$$

$$\boxed{4R = \sqrt{2}a}$$

$$\therefore \quad APF = \frac{(4) \times \frac{4}{3}\pi\left(\frac{\sqrt{2}a}{4}\right)^3}{a^3}$$

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$$\therefore \quad APF = \frac{4 \times \frac{4}{3}\pi \times 2\sqrt{2}}{64} = 0.7404$$

$\therefore$ $\boxed{APF = 74.04\%}$

$APF(FCC) > APF(BCC) > APF(\text{simple cubic})$

$74.04\% > 68.01\% > 52.35\%$

(a) Explain the principle of operation and design a digital frequency meter.

[20 marks]

(b) (i) Calculate the linear atomic density in the [1 1 0] direction in BCC iron which has lattice constant of 2.89 Å.

(ii) The critical magnetic field for superconductor Niobium is 10^5 A/m at temperature 8 K and 2×10^5 A/m at a temperature of 0 K. Calculate the critical temperature of Niobium.

(iii) The following 10 observations were recorded when measuring a voltage:

1	2	3	4	5	6	7	8	9	10
41.7	42	41.8	42	42.1	41.9	42.5	42	41.9	41.8

Find:

1. mean,
2. standard deviation
3. probable error in a single observation.

[6 + 6 + 8 marks]

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(c) (i) A 12-pole, 3-phase alternator is coupled to an engine running at 500 rpm. It supplies an induction motor which has a full-load speed of 1440 rpm. Find the slip and the number of poles of the motor.

(ii) Draw the power flow diagrams of a DC generator and a DC motor.

[10 + 10 marks]

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OOOO

Space for Rough Work

Space for Rough Work

Space for Rough Work