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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

Delhi ☒ Bhopal ☐ Jaipur ☐ Pune ☐  
Kolkata ☐ Hyderabad ☐

#### Student's Signature

#### 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	46
Q.2	38
Q.3	—
Q.4	—
Section-B	
Q.5	23
Q.6	—
Q.7	35
Q.8	35
<b>Total Marks Obtained</b>	<b>177</b>

Signature of Evaluator

Cross Checked by

*Chaitanya . S.M*

*\* 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.



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

- Q.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.

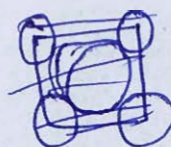
[12 marks]

Sol<sup>n</sup>

For an FCC crystal

$$4r = a\sqrt{2}$$

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



where 'r' is radius of atom & 'a' is lattice constant.

$$\text{Density} = \frac{N M}{N_A a^3}$$

where,  $N \rightarrow$  No. of atoms in FCC crystal (effective)

$N_A \rightarrow$  Avogadro's number =  $6.023 \times 10^{23}$

$M \rightarrow$  Molar mass of atom

Here,  $N = 4$

$M = 87.62 \text{ g/mol}$

$$a = \frac{4 \times 0.215 \times 10^{-7}}{\sqrt{2}} = 0.608 \times 10^{-7} \text{ cm}$$

$$\rho = \frac{4 \times 87.62}{6.023 \times 10^{23} \times (0.608 \times 10^{-7})^3}$$

$$= 258.76 \times 10^{-2} \text{ g/cm}^3$$

$$\text{Density } (\rho) = 2.587 \text{ g/cm}^3$$

12

Good

Q.1 (b) Define commutation. Also suggest methods to improve commutation in a DC machine. [12 marks]

*[Faint handwritten text and diagrams are visible through the paper, including a diagram of a DC machine's internal components and some illegible text.]*

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]

Soln

For a d.c. motor ,

Let  $E_b$  be the back emf generated .



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

Where,  $P$  = Number of poles

$\phi$  = Flux per pole

$N$  = Speed of motor in rpm

$Z$  = Number of conductors

$A$  = Number of parallel path .



Work done by motor in  
one rotation

$$= F \times 2\pi r$$



$$\therefore \text{Power output} = \frac{\text{Work done}}{\text{Time}}$$

$$\text{Total time taken in 1 rotation} = \frac{60}{N}$$

(as speed is 'N' rpm)

$$\therefore P_{out} = \frac{F \times 2\pi r}{(60/N)}$$

$$\text{Torque } (\tau) = F \times r$$

$$\Rightarrow P_{out} = \frac{\tau \times 2\pi \times N}{60}$$

$$P_{in} = E_b I_a$$

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

$$P_{in} = P_{out}$$

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

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

$$\Rightarrow \boxed{\tau \propto \phi I_a}$$

i.e., Torque proportional to flux per pole  
and armature current.

- Q.1 (d) An  $1\text{ k}\Omega$  resistance with an accuracy of  $\pm 10\%$  carries a current of  $10\text{ mA}$ . The current was measured by an analog meter of  $20\text{ mA}$  range with an accuracy of  $\pm 2\%$  of full scale. Compute the power dissipated in the resistor and determine the accuracy of the result.

[12 marks]

Soln

$$\text{Accuracy of analog meter} = \frac{2}{100} \times 20\text{ mA} \\ = 0.4\text{ mA}$$

Power dissipation across resistor is given by,

$$P = I^2 R$$

$$\Rightarrow \frac{\Delta P}{P} = 2 \left( \frac{\Delta I}{I} \right) + \frac{\Delta R}{R}$$

$$\frac{\Delta P}{P} \times 100 = 2 \times \left( \frac{\Delta I}{I} \right) \times 100 + \frac{\Delta R}{R} \times 100$$

$$= 2 \times \frac{0.4}{10} \times 100 + 10$$

$$= 8 + 10$$

$$= 18\%$$

$$\therefore \boxed{\text{Accuracy} = 18\%}$$

$$\begin{aligned} \text{Power dissipated} &= I^2 R \\ (P) &= (10^{-2})^2 \times 10^3 \\ &= 10^{-4} \times 10^3 \end{aligned}$$

$$= 0.1\text{ W}$$

$$\boxed{P = 0.1\text{ W}}$$



- Q.1 (e) A thermometer at room temperature of  $30^{\circ}\text{C}$  is dipped suddenly into a bath of boiling water at  $100^{\circ}\text{C}$ . It takes 30 seconds to reach  $97^{\circ}\text{C}$ . Calculate the time required to reach a temperature of  $98^{\circ}\text{C}$ .

[12 marks]

Soln

For thermometer,

$$\frac{d\theta}{dt} = -k(\theta - \theta_0)$$

where 'k' is a constant &  $\theta_0$  is ambient (surrounding temperature)

$$\theta = \theta_0 + (\theta_i - \theta_0)e^{-kt}$$

Here,  $\theta_0 = 100^{\circ}\text{C}$

$\theta_i = 30^{\circ}\text{C}$

$$\therefore \theta = 100 + (30 - 100)e^{-kt}$$

At  $t = 30 \text{ sec}$ ,  $\theta = 97^{\circ}\text{C}$

$$\therefore 97 = 100 + (-70)e^{-k \times 30}$$

$$\Rightarrow -3 = -70e^{-30k}$$

$$\Rightarrow e^{30k} = \frac{70}{3}$$

$$30k = \ln\left(\frac{70}{3}\right)$$

$$\Rightarrow k = 0.105$$

For  $\theta = 98^{\circ}\text{C}$

$$98 = 100 + (-70)e^{-0.105t}$$

$$\Rightarrow 0.105t = \ln \frac{70}{2}$$

$$t = 33.86 \text{ sec}$$

Total time required to reach  $98^{\circ}\text{C} = 33.86 \text{ sec}$



- Q.2 (a) (i) A barium titanate pickup has dimensions of  $5 \text{ mm} \times 5 \text{ mm} \times 1.25 \text{ mm}$ . The force acting on it is  $5 \text{ N}$ . The charge sensitivity of barium titanate is  $150 \text{ pC/N}$  and its permittivity is  $12.5 \times 10^{-9} \text{ F/m}$ . If the modulus of elasticity of barium titanate is  $12 \times 10^6 \text{ N/m}^2$ , calculate the strain. Also calculate the charge and the capacitance.
- (ii) The inductance of a moving iron instrument is given by
- $$L = (12 + 6\theta - \theta^2) \mu\text{H}$$
- where  $\theta$  is the deflection in radians from zero position. The spring constant is  $12 \times 10^{-6} \text{ Nm/radians}$ . Calculate the deflection for a current of  $8 \text{ A}$ .
- (iii) In a proximity inductive transducer, the coil has an inductance of  $2 \text{ mH}$  when the target made of Ferro-magnetic material is  $1 \text{ mm}$  away from the core. Calculate the value of inductance when a displacement of  $0.02 \text{ mm}$  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.

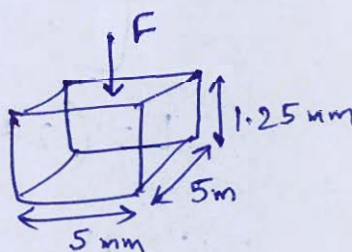
[8 + 6 + 6 marks]

Soln

(i)

From the Hooke's law

$$\frac{F}{A} = Y \frac{\Delta l}{l}$$



$$\frac{F}{A} \rightarrow \text{Stress}, \quad \frac{\Delta l}{l} = \text{Strain}$$

$$\therefore \frac{5}{5 \times 5 \times 10^{-6}} = 12 \times 10^6 \frac{\Delta l}{l}$$

$$\Rightarrow \frac{\Delta l}{l} = \frac{1}{60}$$

$$\boxed{\text{Strain} = 0.0167}$$

$$Q = d F$$

where  $Q \rightarrow$  charge developed

$d \rightarrow$  charge sensitivity

$$Q = \left(150 \frac{\text{pC}}{\text{N}}\right) \times 5 \text{ N} = 750 \text{ pC}$$

$$\text{Capacitance } (C) = \frac{\epsilon_0 \epsilon_r A}{t} \quad \begin{array}{l} A \rightarrow \text{Area} \\ t \rightarrow \text{thickness} \end{array}$$

$$= \frac{12.5 \times 10^{-9} \times 25 \times 10^{-6}}{1.25 \times 10^{-3}}$$

$$= 250 \times 10^{-12} \text{ F}$$

$$\boxed{C = 250 \text{ pF}}$$

ii) For a moving iron instrument

$$\left[ \theta = \frac{I^2}{2K} \frac{dL}{d\theta} \right]$$

$$L = (12 + 6\theta - \theta^2) \text{ mH}, \quad I = 8 \text{ A}$$

$$\therefore \frac{dL}{d\theta} = (6 - 2\theta) \times 10^{-6} \text{ H/radian}$$

$$\therefore \theta = \frac{64}{2 \times 12 \times 10^{-6}} (6 - 2\theta) \times 10^{-6}$$

$$\theta = \frac{8}{3} (6 - 2\theta)$$

$$\Rightarrow 3\theta = 48 - 16\theta$$

$$19\theta = 48 \Rightarrow \theta = 2.526$$

$$\boxed{\theta = 2.526 \text{ radian}}$$



iii)

$$\frac{L_2}{L_1} = \frac{x_2}{x_1}$$

$$\frac{L_2}{2 \text{ mH}} = \frac{1.02}{1}$$

$$L_2 = 2.04 \text{ mH}$$

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  $100\ \Omega$ ,  $0.1\ \Omega$  and  $0.1\ \Omega$  respectively. If the flux density in the air gap is  $0.65\ \text{T}$ , load current is  $100\ \text{A}$  and voltage drop per brush is  $1\ \text{V}$ , then calculate load voltage when
- Armature winding is lap connected.
  - Armature winding is wave connected.

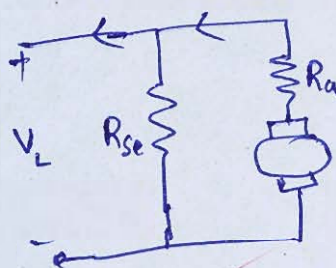
[20 marks]

Sol<sup>n</sup>

(i) Lap connected

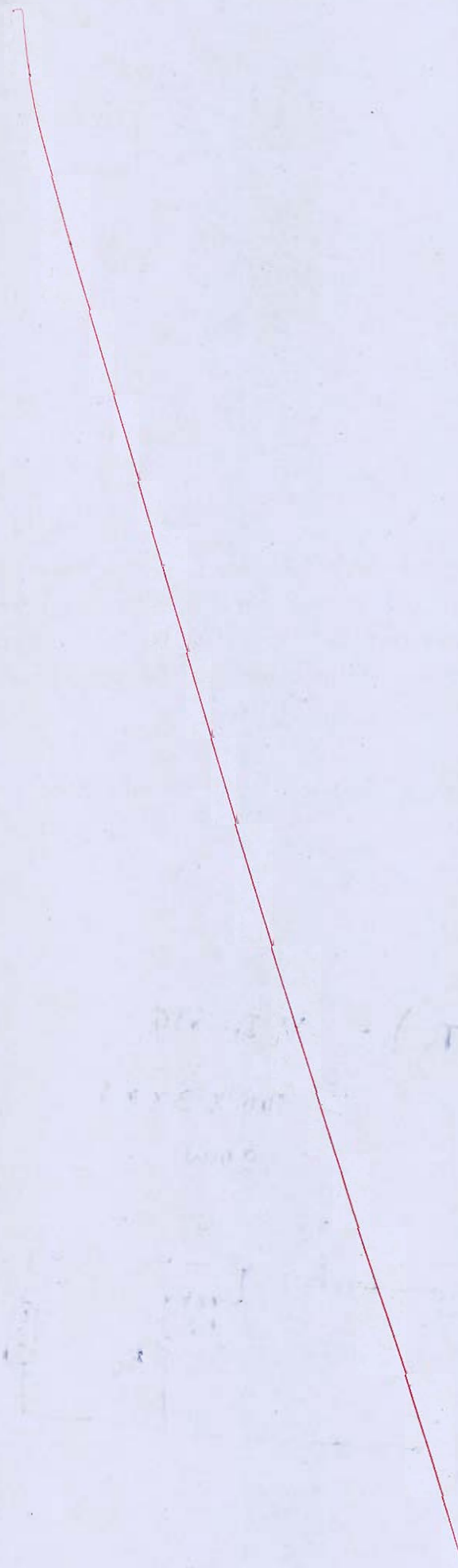
$$A = P = 4$$

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



①



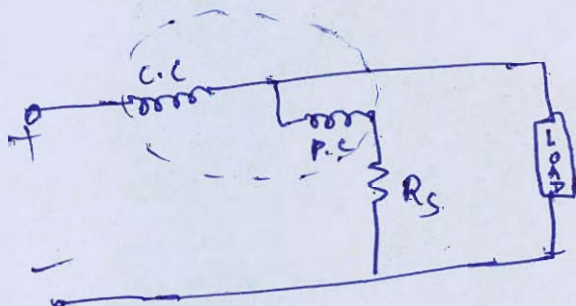


- Q.2 (c) An electrodynameometer wattmeter is used for measurement of power in a single phase circuit. The load voltage is 100 V and the load current is 9 A at a lagging power factor of 0.1. The wattmeter voltage circuit has a resistance of 3000  $\Omega$  and an inductance of 30 mH. Estimate the percentage error in the wattmeter reading when pressure coil is connected:
- on the load side, and
  - on the supply side.
- The current coil has a resistance of 0.1  $\Omega$  and negligible inductance. The frequency is 50 Hz. Comment upon the result.

[20 marks]

soln

$$\begin{aligned}
 (i) \quad \text{Power } (P_T) &= V_L I_L \cos \phi \\
 &= 100 \times 9 \times 0.1 \\
 &= 90 \text{ W}
 \end{aligned}$$





$$\text{Power loss} = \frac{V^2}{R_s}$$

$$= \frac{(100)^2}{3000} = 3.33 \text{ W}$$

$$\therefore \text{Power loss due to Pressure coil resistance} = 3.33 \text{ W}$$

$$\text{Power loss due to inductance} = (\tan \phi \cdot \tan \beta) \times \text{True Power}$$

$$\tan \beta \cdot \tan \phi = \frac{2\pi \times 50 \times 30 \times 10^{-3}}{3000} = 3.141 \times 10^{-3}$$

$$\cos \phi = 0.1 \Rightarrow \tan \phi = 9.949$$

$$\therefore \text{Power loss due to inductance of Pressure coil}$$

$$= 31.25 \times 9.949 \times 10^{-3}$$

$$= 2.81 \text{ W}$$

$$\therefore \text{Total Power loss} = 2.81 + 3.33$$

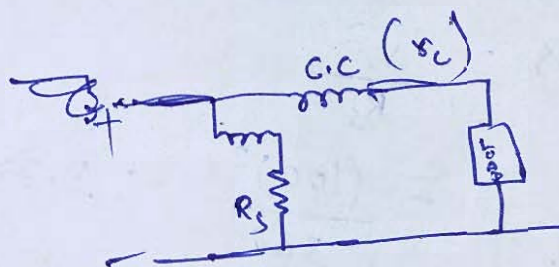
$$= 6.142 \text{ W}$$

Good

$$\therefore \text{Error} = \frac{6.142}{90} \times 100$$

$$= 6.825 \%$$

ii)



For this connection, Power loss due to resistance of current coil  $= I^2 r_c$

$$= (9)^2 \times 0.1$$

$$= 8.1 \text{ W}$$

Power loss due to inductance of pressure coil

$$= (\tan \phi \cdot \tan \phi) \times \text{True Power}$$

$$= 2.81 \text{ W}$$

$$\therefore \text{Total Power loss} = 8.1 + 2.81$$

$$= 10.91 \text{ W}$$

$$\therefore \text{Error} = \frac{10.91}{90} \times 100$$

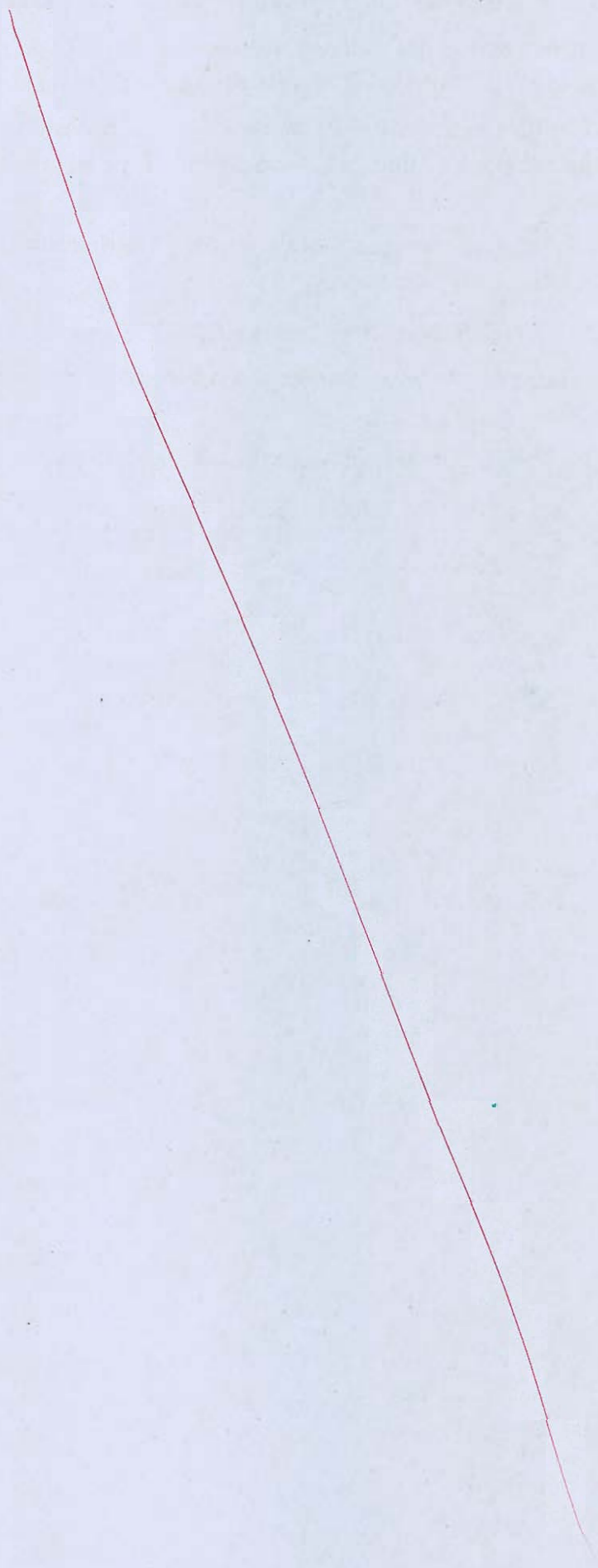
$$= 12.12 \%$$

Percentage error is more when pressure coil is connected on the supply side.



- Q.3 (a) (i) A steel cantilever is 0.25 m 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  $200 \text{ GN/m}^2$ .
  2. An LVDT with a sensitivity of  $0.5 \text{ V/mm}$  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  $\pm 0.5 \text{ in}$ .
1. Plot the output voltage vs core position for a core movement going from  $+0.45 \text{ in}$ . to  $-0.30 \text{ in}$ .
  2. Determine the output voltage when the core is  $-0.25 \text{ in}$ . from the centre.

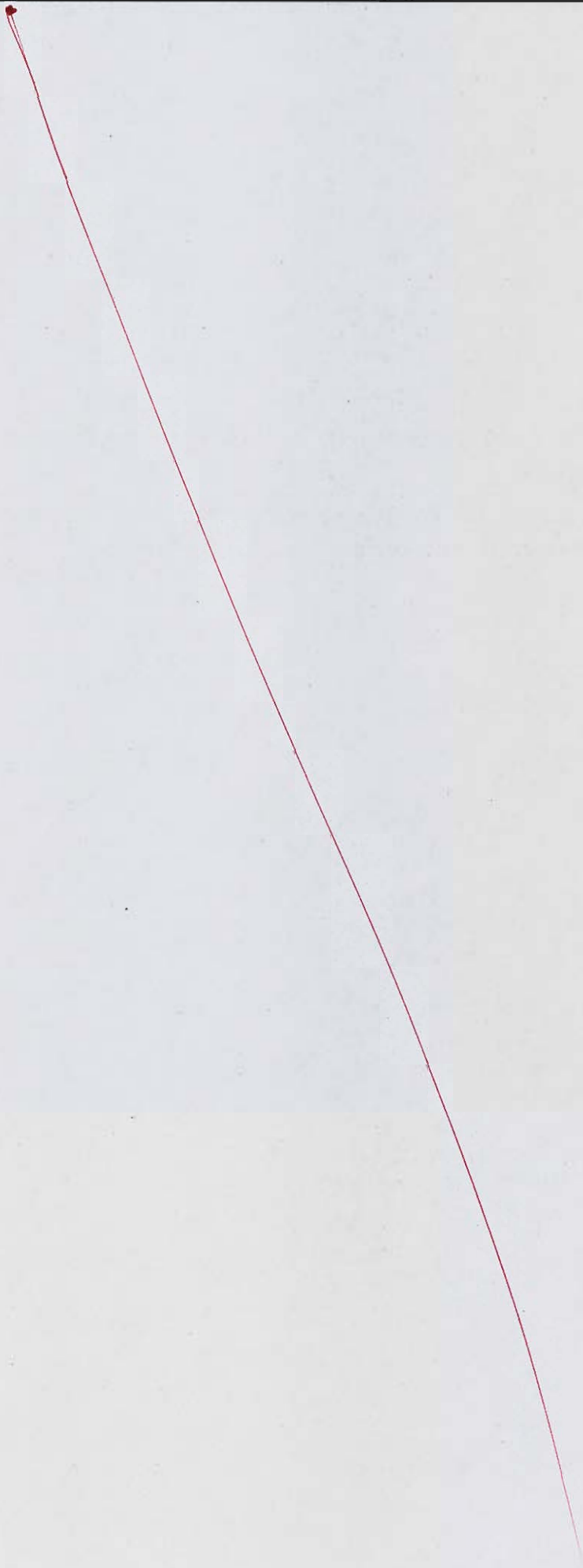
[14 + 6 marks]



- 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]



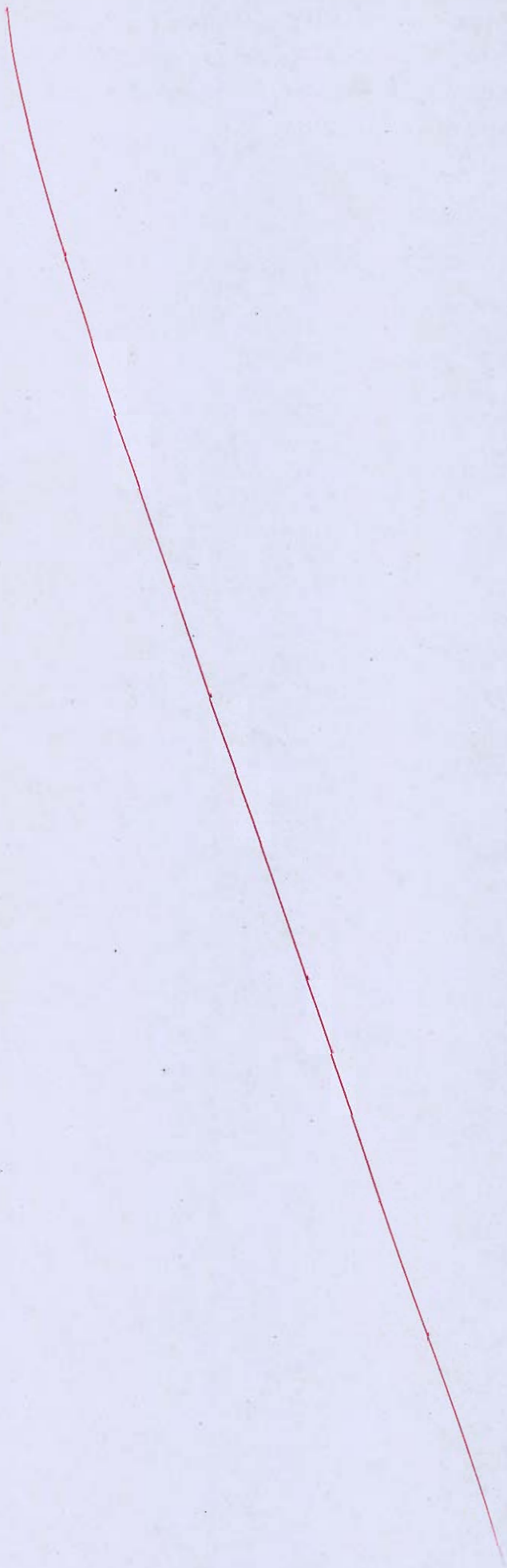






- Q.3 (c) (i) A solenoid is 0.25 m long having 1000 turns and has 2.5 A current flowing through it in a vacuum chamber. When placed in pure oxygen environment, the magnetic induction exhibits an increase of  $1.04 \times 10^{-8} \text{ Wb/m}^2$ . Find the magnetic susceptibility of oxygen.
- (ii) Write a short note on optical properties of semiconducting Nanoparticles.

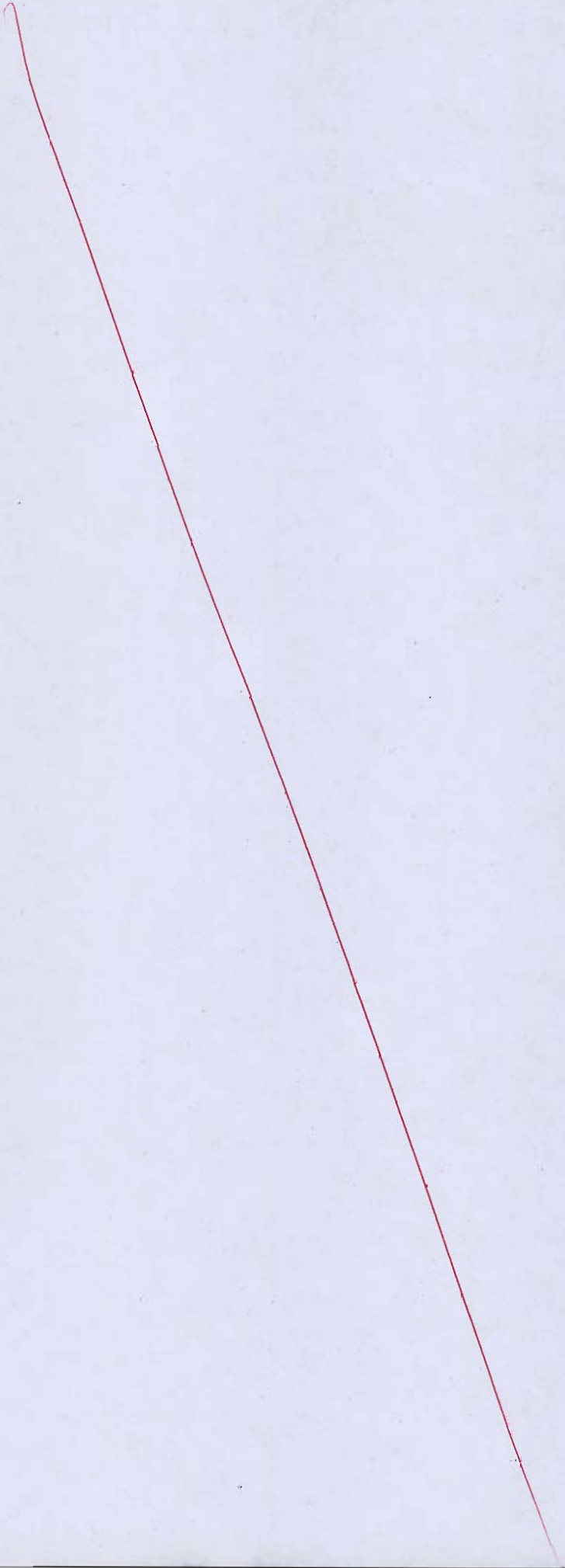
[10 + 10 marks]





- 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  $0.025 \Omega$  and  $55 \Omega$  respectively. Brush contact drop is 2 V.

[20 marks]

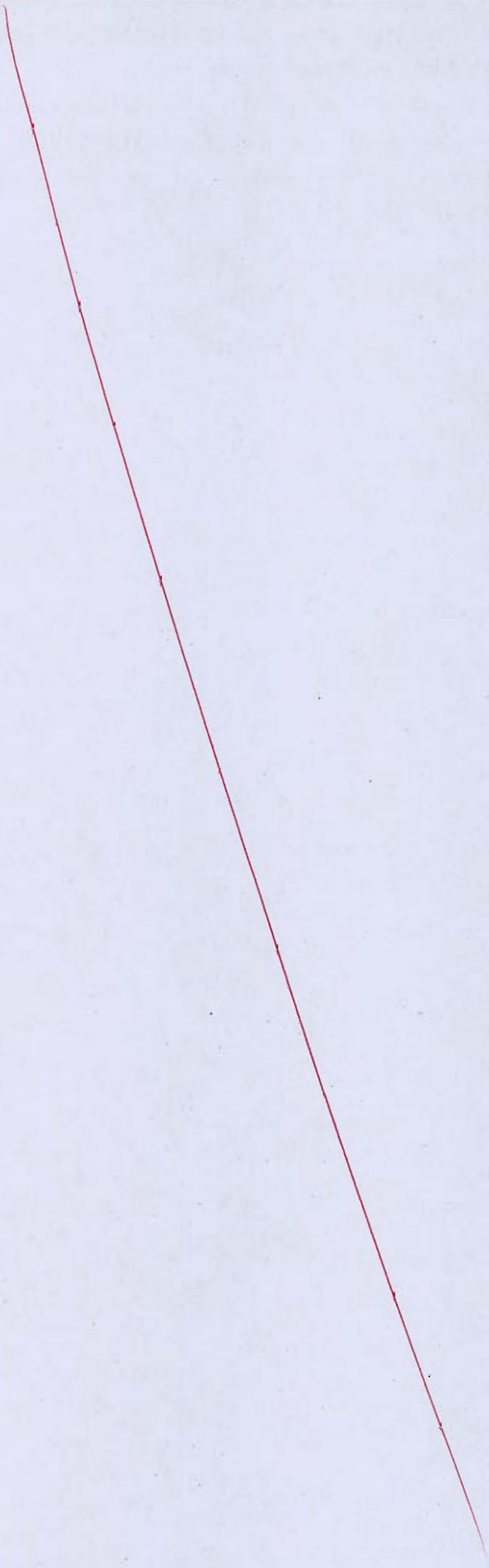




Q.4 (b) How frequency is measured with help of Wein's Bridge? Explain with mathematical derivation and circuit diagram. Enumerate other applications of Wein's bridge.

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

[20 marks]





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

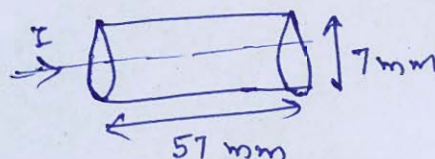
**Q.5 (a)** Consider a cylindrical silicon specimen 7.0 mm in diameter and 57 mm in length.

- (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]

Soln

i)  $I = 0.25 \text{ A}$



$$\text{Electric field } (E) = \frac{V}{d}$$

$$= \frac{24}{45 \times 10^{-3}} \text{ V/m}$$

From the Ohm's law

$$J = \sigma E$$

$J \rightarrow$  current density  
 $\sigma \rightarrow$  conductivity  
 $E \rightarrow$  Electric field

$$\Rightarrow \frac{I}{A} = \sigma E$$

$$\therefore \sigma = \frac{I}{AE}$$

$$= \frac{0.25}{\left( \pi \times \frac{49 \times 10^{-6}}{4} \right) \times \frac{24}{45} \times 10^{-3}}$$

$$\sigma = \frac{0.25 \times 4 \times 4.5}{\pi \times 49 \times 24} \times 10^9$$

$$\left[ \sigma = 1.218 \times 10^6 \text{ } \Omega^{-1} \text{ cm}^{-1} \right]$$

$$\text{or } \sigma = 1.218 \times 10^6 \text{ Siemens}$$

ii) Resistance ( $R$ ) =  $\frac{1}{\sigma} \frac{l}{A}$

or  $R = \frac{V}{I}$

Here,  $V = E \times l = \frac{24}{4.5 \times 10^{-3}} \times 57 \times 10^{-3}$   
 $= 30.4 \text{ V}$

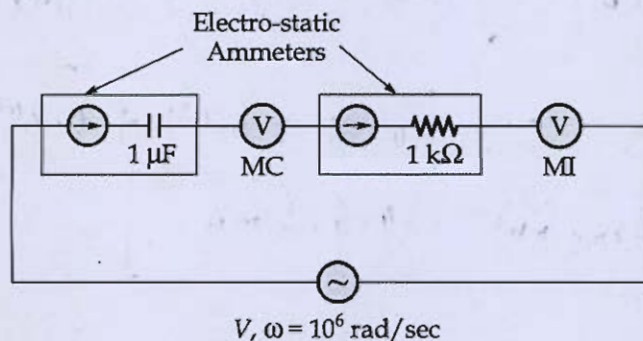
$\Rightarrow$  Total voltage = 30.4 V

Current = 0.25 A

$\therefore$  Resistance ( $R$ ) =  $\frac{30.4}{0.25} = 121.6 \Omega$

12

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



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]

Sol<sup>n</sup>

(i) When Moving coil instrument is connected  
~~MC~~ MI reads rms value

$$V_{\text{rms}}^2 = (0.6)^2 + \frac{(0.4)^2}{2} + \frac{(0.1)^2}{2}$$

$$= 0.445$$

$$V_{\text{rms}} = 0.667 \text{ V}$$



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

$$Z_1 = 1 \text{ k}\Omega$$

$$Z_2 = \cancel{j \times 10^6} \times 1 - \frac{j}{10^6 \times 10^{-6}} = 1 - j$$

$$Z_3 = 1 - \frac{j}{2 \times 10^6 \times 10^{-6}} = 1 - 0.5j$$

$$I(mA) = \frac{0.6}{1} + \frac{0.4}{\sqrt{2}} \sin(\omega t + \frac{\pi}{4}) - \frac{0.1}{1.118} \sin(2\omega t + 0.46)$$

For

$$I_{rms} = (0.6)^2$$

$$I_{rms} (mA) = \sqrt{(0.6)^2 + \left(\frac{0.4}{\sqrt{2}}\right)^2 \times \frac{1}{2} + \left(\frac{0.1}{1.118}\right)^2 \times \frac{1}{2}} = 0.667$$

$$= \sqrt{0.36 + 0.04 + 0.004}$$

$$I_{rms} (mA) = 0.635 \text{ mA}$$

Reading of Moving coil instrument  
MI reads average value  
 $\Rightarrow V_{avg} = 0.6 \text{ V}$   
 $= 0.635 \text{ mA}$

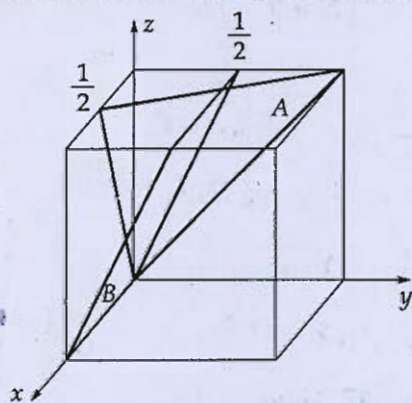
Reading of Moving iron instrument  
 $= I_{rms} = 0.635 \text{ mA}$

- (c) (i) A linear resistance potentiometer is 50 mm long and is uniformly wound with a wire having a resistance of  $10,000 \Omega$ . 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.  $3850 \Omega$ .
  2.  $7560 \Omega$ .

Are the two displacements in same direction?

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

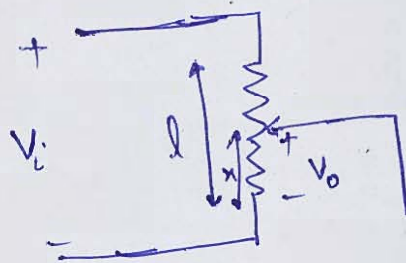
- (ii) Determine the Miller indices for the planes shown in the following unit cell:



[6 + 6 marks]

Soln

(i)



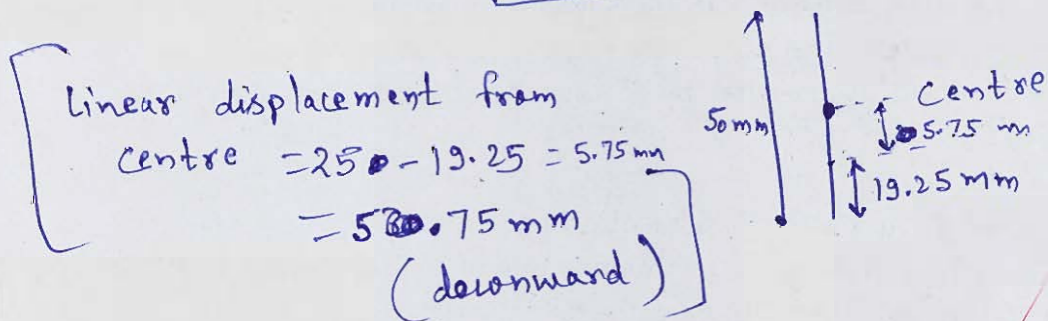
$$l = 50 \text{ mm}$$

$$\frac{V_o}{V_i} = \frac{x}{l} \Rightarrow \frac{V_o}{x} = \frac{V_i}{l}$$

$$\text{When } R_o = 3850 \Omega$$

$$\Rightarrow \frac{x}{3850} = \frac{50}{10000}$$

$$\Rightarrow \boxed{x = 19.25 \text{ mm}}$$

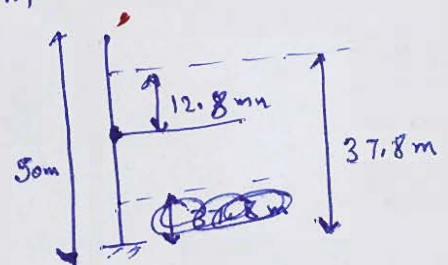


$$\text{When } R_o = 7560 \Omega$$

$$\frac{x}{7560} = \frac{50}{10000}$$

$$x = 37.8 \text{ mm}$$

Linear displacement from  
centre =  $37.8 - 25$   
=  $12.8 \text{ mm}$   
(upward)



The two displacements are in opposite direction.



$$\text{Sensitivity} = \frac{V_o}{x} = \frac{V_i}{l} = \frac{R_i}{l} = \frac{10000}{50 \text{ mm}} = 200 \text{ } \Omega/\text{mm}$$

$$\text{Resolution} = \frac{R_{\min}}{\text{Sensitivity}} = \frac{10}{200} \text{ mm} = 0.05 \text{ mm}$$

ii) For Plane A:

$$x\text{-intercept} = \frac{a}{2} = \frac{1}{2} \text{ [Normalised]}$$

$$y\text{-intercept} = b = 1 \text{ [Normalised]}$$

$$z\text{-intercept} = c = 1 \text{ [Normalised]}$$

$$\therefore \text{Miller indices} = (2 \ 1 \ 1)$$

Converting to integers,

$$\boxed{\text{Miller indices} = (2 \ 1 \ 1)}$$

For Plane B:

$$x\text{-intercept} : 1$$

$$y\text{-intercept} : \frac{1}{2}$$

$$z\text{-intercept} : \frac{1}{2}$$

$$\therefore \text{Miller indices} = (2 \ 2 \ 2)$$

5 (d) State few advantages of Rotating Field Alternator over Rotating Armature Alternator.

[12 marks]

*[Faint, illegible handwritten text is visible across the page, likely bleed-through from the reverse side. A prominent red diagonal line is drawn across the page.]*

- 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?

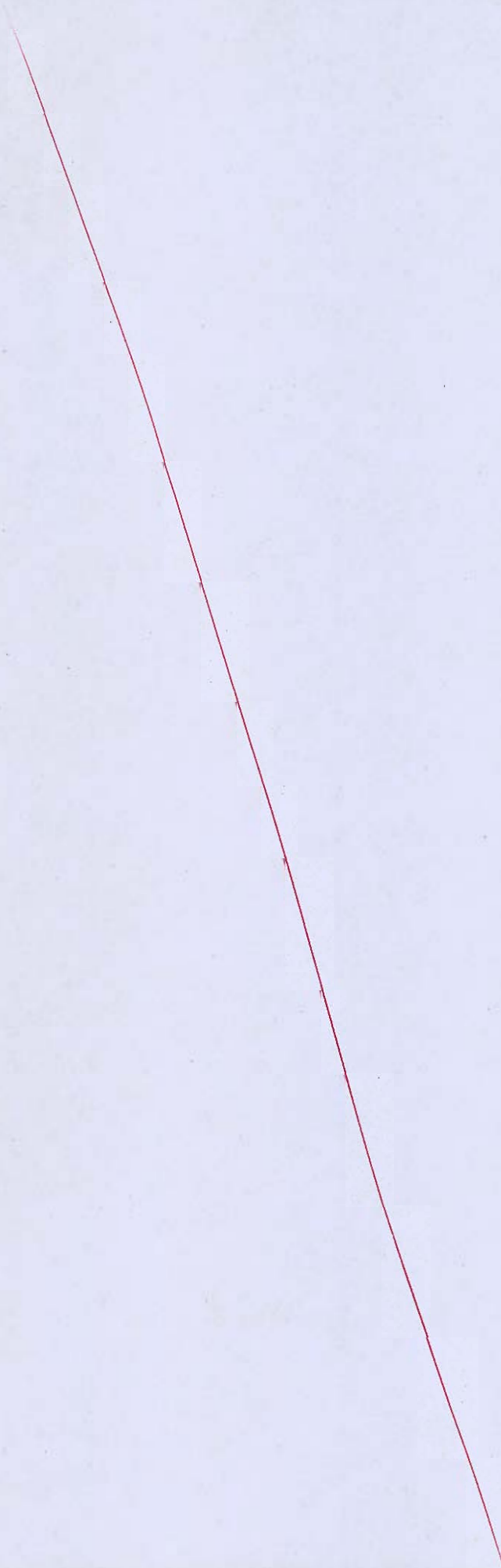
[12 marks]

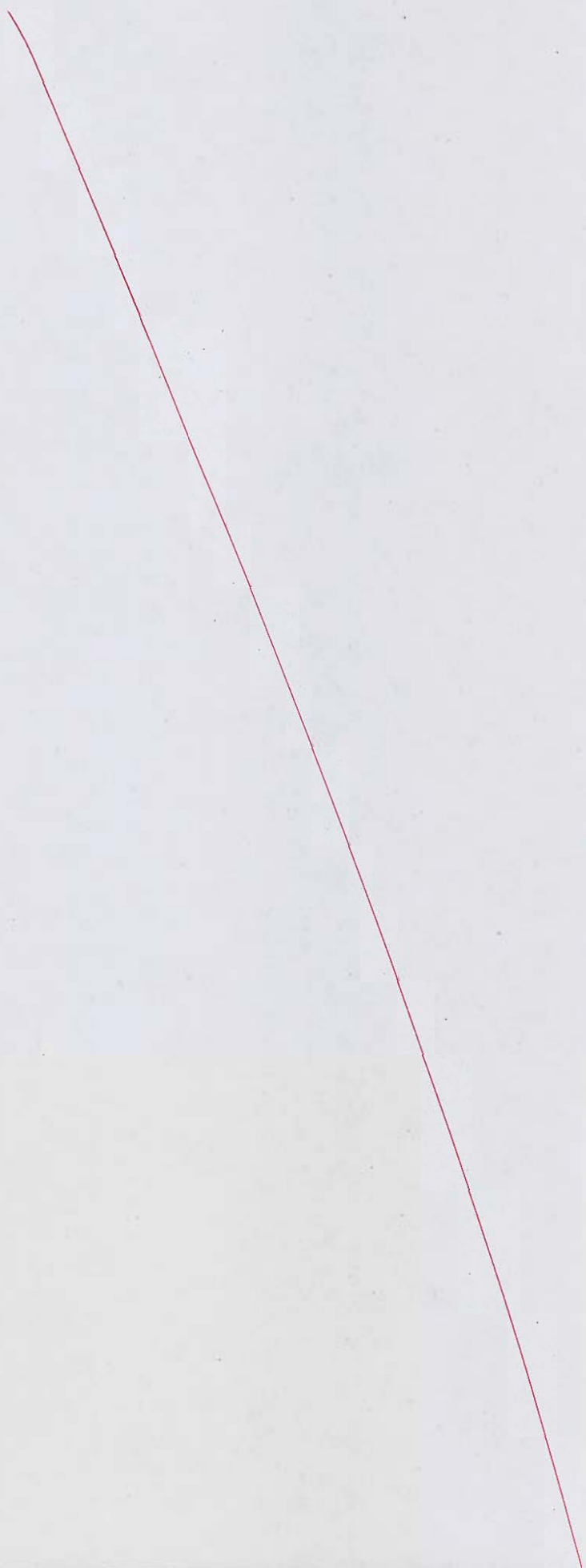
Sol<sup>n</sup>



- 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.]

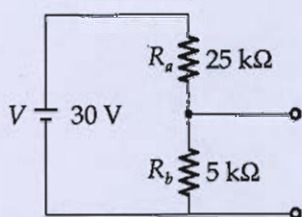
[10 + 10 marks]







- p) Two different voltmeters are used to measure the voltage across  $R_b$  in the circuit of figure shown below.



Meter 1 :  $S = 1\text{ k}\Omega/\text{V}$ , range  $10\text{ V}$

Meter 2 :  $S = 20\text{ k}\Omega/\text{V}$ , range  $10\text{ V}$

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.

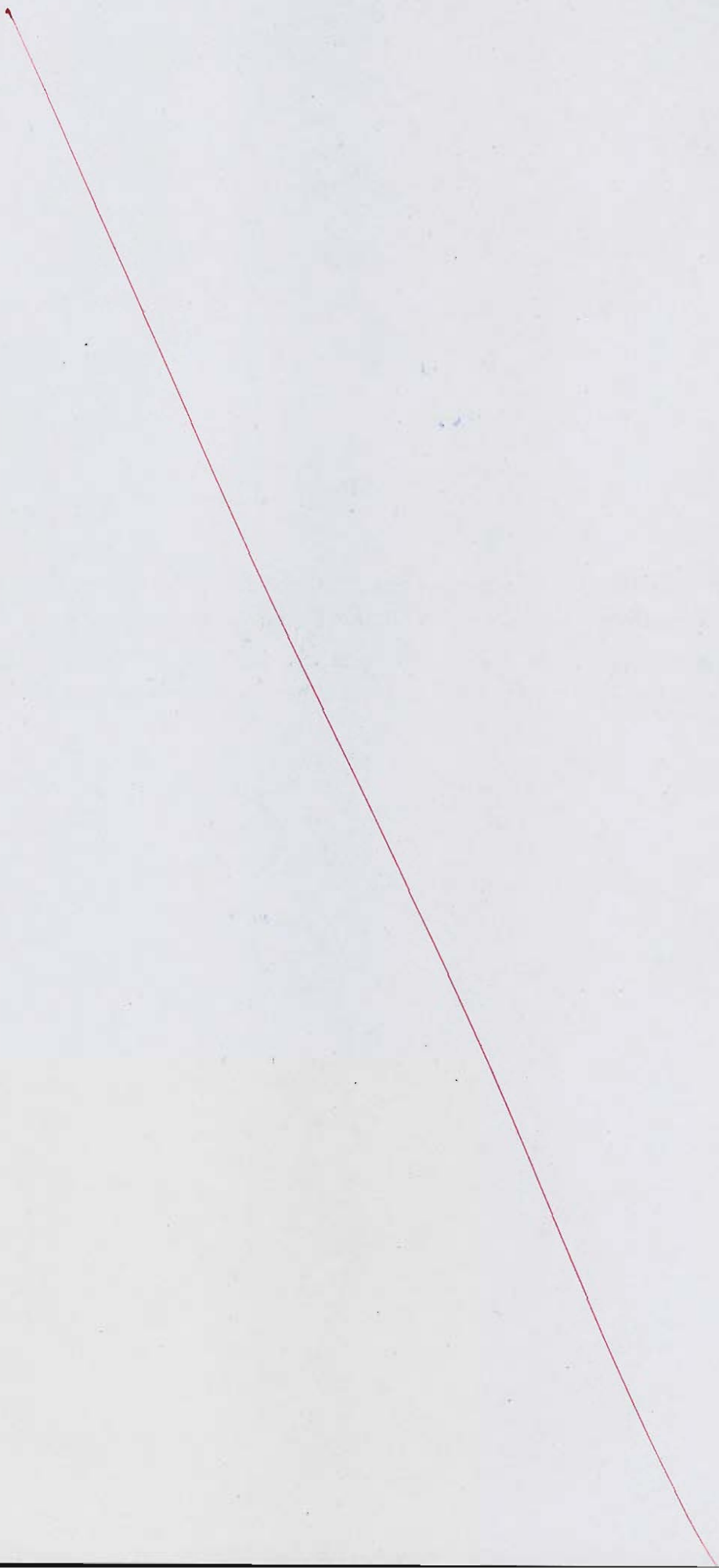
[20 marks]



- e) (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  $4.3 \times 10^{-8} \text{ C/m}^2$ . Calculate the relative permittivity of NaCl.

[15 + 5 marks]





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  $0.2 \Omega$ , 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]

Sol<sup>n</sup>

(ii)

Total Torque

$$N = 1000 \text{ rpm}$$

$$A = 2 \text{ (wave connected)}$$

$$P = 4$$

$$E_b = P \phi \left( \frac{N}{60} \right) \frac{Z}{a}$$

$$E_b I_a = 10 \times 10^3$$

$$E_b \times 60 = 10 \times 10^3$$

$$\frac{10^4}{60} = 4 \times \phi \times \frac{1000}{60} \times \frac{50}{2}$$

$$\phi = \frac{10^4 \times 120}{60 \times 200 \times 10^3} = \frac{1200}{200 \times 60}$$

$$\phi = 0.1 \text{ wb} \quad \times \quad 0.0126 \text{ wb}$$

$$\therefore \text{Flux per pole} = 0.1 \text{ weber.}$$

(i)

$$\text{Total Torque} = \frac{P \phi Z}{2\pi A} (I_a)$$

$$= \frac{4 \times 0.1}{2\pi} \times \frac{560}{2} \times 60$$

$$= 1069.52 \text{ N-m}$$

ii)

$$\text{Useful Torque} = \frac{P_{\text{gen}}}{\omega}$$

$$\text{Armature loss} = (60)^2 \times 0.2$$

$$= 360 \times 2$$

$$= 720 \text{ W}$$

$$\text{Brush loss} = 60 \times 1 \times 2$$

$$= 120 \text{ W}$$

$$\text{Total loss} = 840 \text{ W}$$

$$\therefore P_{\text{net}} = 10000 - 840$$

$$= 9160 \text{ W}$$

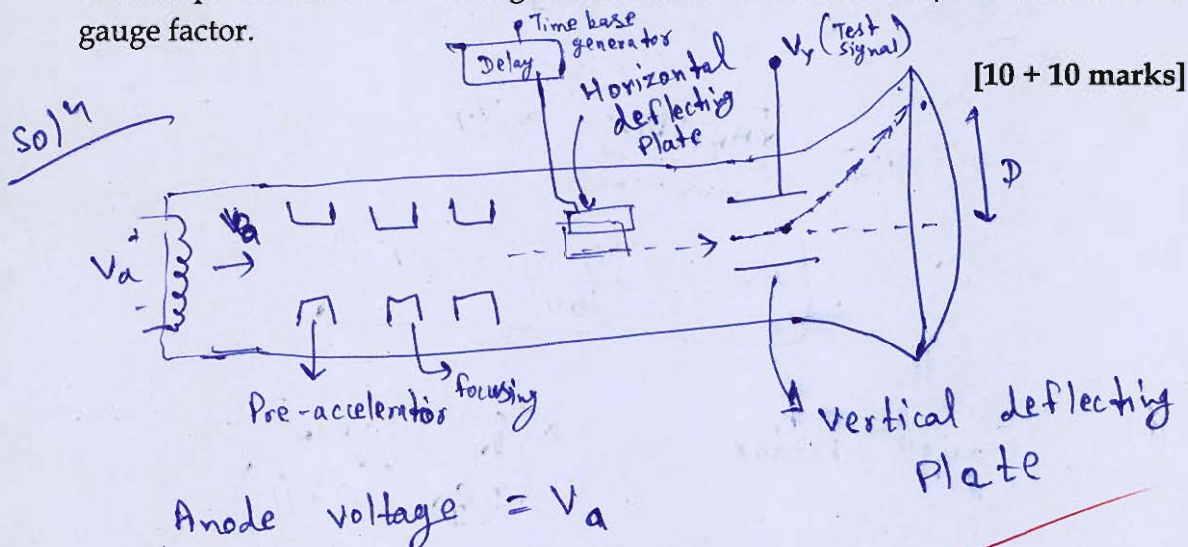
$$\text{Useful Torque} = \frac{9160 \times 60}{2\pi \times 1000}$$

$$= 87.47 \text{ N-m}$$

$$T_{\text{useful}} = 95.5 \text{ N-m}$$



- (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  $120\ \Omega$  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  $0.152\ \Omega$ . 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  $200\ \text{GN/m}^2$ . Calculate the gauge factor.



From Work-Energy Theorem

$$e V_a = \frac{1}{2} m v^2 - 0$$

$$\Rightarrow v = \sqrt{\frac{2 e V_a}{m}} \rightarrow \text{Velocity of electron just before entering the vertical deflecting plates.}$$

$$\text{Deflection } (D) = \frac{L l_d}{2d} \frac{V_y}{V_a} \quad , \quad V_y \rightarrow \text{Applied voltage}$$

$L \rightarrow$  Distance of screen from centre of deflecting plate

$l_d \Rightarrow$  length of vertical deflecting plate

$d \rightarrow$  separation between plates

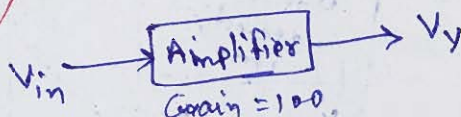
$V_a \rightarrow$  Anode voltage

$$\therefore \quad \cancel{30 \times 10^{-2}} \times 3 \times 10^{-2} = \frac{30 \times 10^{-2} \times 2 \times 10^{-2}}{2 \times 5 \times 10^{-3} \times 2000} V_y$$

$$V_y = \frac{3 \times 2 \times 5 \times 10^{-5} \times 2000}{60 \times 10^{-4}} \quad \checkmark$$

$$= 10^3 \times 10^{-1}$$

$$V_y = 100 \text{ V}$$



$$V_{in} = \frac{V_y}{100} = 1 \text{ V}$$

ii) Gauge factor =  $\frac{\frac{\Delta R/R}{\Delta l/l}}{\frac{\Delta l/l}{\Delta l/l}}$   $\checkmark$

$$\Delta R = 0.152 \, \Omega, \quad R = 120 \, \Omega$$

$$\frac{F}{A} = Y \frac{\Delta l}{l} \quad \checkmark \quad (\text{Hooke's law})$$

$$\frac{\Delta l}{l} = \frac{12.7 \times 10^{-3}}{0.15}$$

$$\therefore \text{Gauge factor} = \frac{0.152 \times 0.15}{120 \times 12.7 \times 10^{-3}} = 0.015 \quad \times$$



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

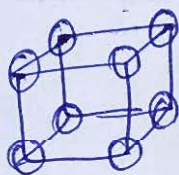
[20 marks]

Sol<sup>n</sup>

There are ~~four~~ three types of cubic crystal structure.

(i) Simple Cubic  $\rightarrow$  Atoms present at the corners of the cube.

Effective number of  
atoms =  $\frac{1}{8} \times 8$   
= 1

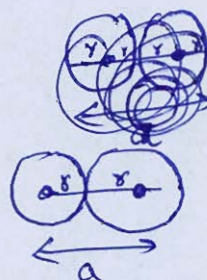


Also, for simple cubic

$$2r = a$$

Total volume of atom =  $1 \times \frac{4}{3} \pi r^3$

Volume of unit cell =  $a^3$

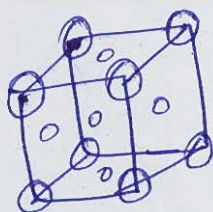




$$\begin{aligned}
 \text{Packing fraction} &= \frac{1 \times \frac{4\pi}{3} r^3}{a^3} \\
 &= \frac{4\pi}{3} \times \frac{1}{8} \\
 &= \frac{\pi}{6} \\
 &= 0.52
 \end{aligned}$$

ii) FCC (face centre cubic)

Atoms are present at corners and ~~face~~ at the face centre of the cell.



Effective number of atoms present in the unit cell

$$= \frac{1}{8} \times 8 + 6 \times \frac{1}{2}$$

$$= 1 + 3 = 4$$

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

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



Packing fraction =  $\frac{\text{Volume occupied by atoms}}{\text{Volume of unit cell}}$

$$= \frac{4 \times \frac{4\pi}{3} \times r^3}{a^3}$$

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

$$= \frac{16\pi}{3} \times \frac{2\sqrt{2}}{64}$$

$$\boxed{P.F = 0.74}$$

19

(iii) Body centred Cubic (BCC)

Atoms are present all the corners and at the body centre.

$$\text{Effective number of atoms} = \frac{1}{8} \times 8 + 1 \times 1 = 2$$

$$C_e \text{ for BCC : } 4r = a\sqrt{3} \Rightarrow \frac{r}{a} = \frac{\sqrt{3}}{4}$$

$$\text{Packing fraction} = \frac{2 \times \frac{4\pi}{3} r^3}{a^3} = \frac{8\pi}{3} \times \frac{3\sqrt{3}}{64} = 0.68$$

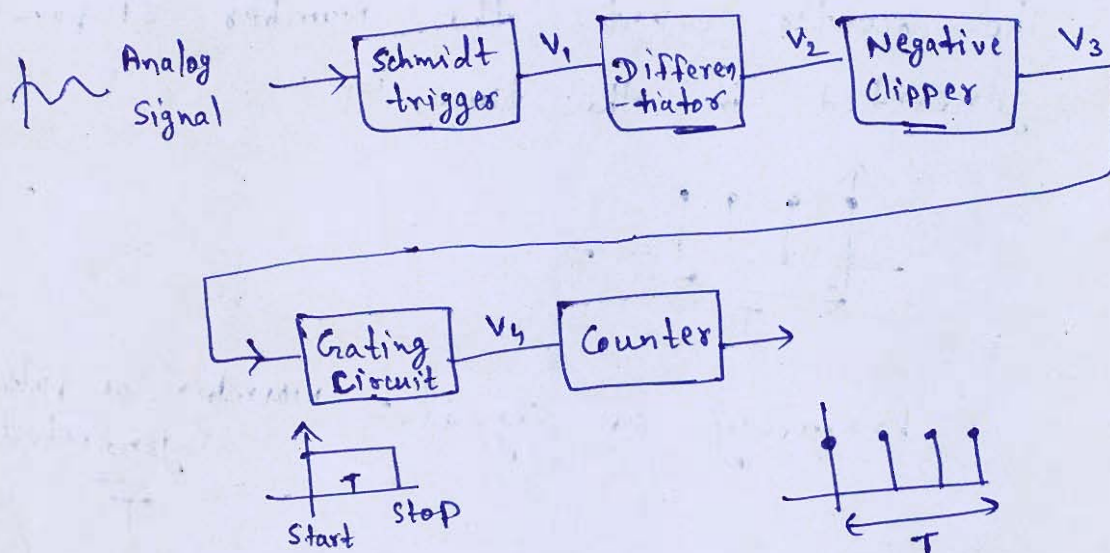
$$P.F_{BCC} = 0.68$$

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

[20 marks]

Soln

Digital frequency meter

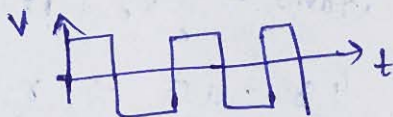


$$\text{No. of Pulse} = P$$

$$\therefore \text{frequency} = \frac{P}{T}$$



The input analog signal is passed through Schmidt trigger so that square wave is generated based on the input.



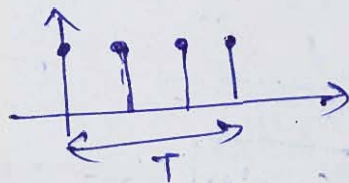
Output of Schmidt Trigger is passed through differentiator so that it can be converted to pulse.



Negative clipper is applied so that only positive pulse can be passed.

Grating circuit of time period  $T$  is applied to the output of negative clipper.

The counter counts the number of pulse generated in the time ' $T$ '.



Frequency of signal =  $\frac{\text{Number of pulse generated}}{T}$

$$f = \frac{P}{T}$$



- (i) Calculate the linear atomic density in the  $[1\ 1\ 0]$  direction in BCC iron which has lattice constant of  $2.89\text{ \AA}$ .
- (ii) The critical magnetic field for superconductor Niobium is  $10^5\text{ A/m}$  at temperature  $8\text{ K}$  and  $2 \times 10^5\text{ A/m}$  at a temperature of  $0\text{ K}$ . 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

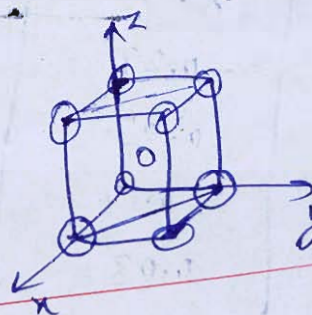
Find:

- mean,
- standard deviation
- probable error in a single observation.

[6 + 6 + 8 marks]

Sol<sup>n</sup>

i)

Number of atom  
along the line $= 2$  $\left(\frac{1}{2} + \frac{1}{2}\right)$  atomLength of the line  $= a\sqrt{2}$   $\left[ a = \text{lattice constant} \right]$ 

$$\therefore \text{Linear atomic density} = \frac{2}{a\sqrt{2}} = \frac{1}{\sqrt{2}a}$$

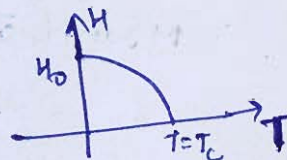
$$= \frac{\sqrt{2}}{a}$$

$$= 0.489 \times 10^{10} / \text{m}$$

ii)

$$H_0 = 10^5 \text{ A/m}$$

$$H = H_0 \left[ 1 - \left( \frac{T}{T_c} \right)^2 \right]$$


 $H_0 = \text{critical temperature at } T = 0\text{ K}$

$$H = 10^5 \text{ A/m}, T = 8 \text{ K}$$

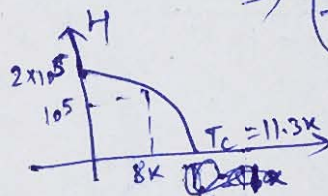
$$H_0 = 2 \times 10^5 \text{ A/m}$$

$$\therefore 10^5 = 2 \times 10^5 \left[ 1 - \left( \frac{8}{T_c} \right)^2 \right]$$

$$0.5 = 1 - \left( \frac{8}{T_c} \right)^2$$

$$\Rightarrow \left( \frac{8}{T_c} \right)^2 = 0.5 \Rightarrow$$

$$\boxed{T_c = 16 \text{ K}}$$



$$T_c^2 = \frac{64}{0.5} \Rightarrow T_c^2 = 128$$

$$\boxed{T_c = 11.31 \text{ K}}$$

ii)

$x$	$x - \bar{x}$	$(x - \bar{x})^2$
41.7	-0.27	0.0729
42	0.03	0.0009
41.8	-0.17	0.0289
42	0.03	0.0009
42.1	0.13	0.0169
41.9	-0.07	0.0049
42.5	0.53	0.2809
42	0.03	0.0009
41.9	-0.07	0.0049
41.8	-0.17	0.0289

$$\text{Mean } (\bar{x}) = \frac{41.7 + 42 + 41.8 + 42 + 42.1 + 41.9 + 42.5 + 42 + 41.9 + 41.8}{10}$$

$$\bar{x} = 41.97$$

$$\sum_{i=1}^{10} (x_i - \bar{x})^2 = 0.441$$



$$\text{standard deviation} = \sqrt{\frac{0.414}{9}} = \sqrt{\frac{0.414}{9}} = 0.2214 \text{ V}$$

$$\sigma = 0.046$$

$$\text{iii) Probable error} = 0.6745 \times 0.046 \approx 0.031$$

5

(Avoid silly mistakes)

- (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]

Soln

$$N = \frac{120 f}{P}$$

$$500 = \frac{120 f}{12}$$

$$\Rightarrow \boxed{f = 50 \text{ Hz}}$$

$$N_r = 1440 \text{ rpm}$$

$$N_s = 1440 \text{ rpm}$$

$$\frac{120 f_s}{P} = 1440$$

$$\frac{120 \times 50}{P} =$$



$$N_s = 1440 \text{ rpm}$$

$$N_r = 500 \text{ rpm}$$

$$N_r = (1-s) N_s$$

$$\frac{500}{1440} = 1-s$$

$$s = 1 - \frac{5}{144}$$

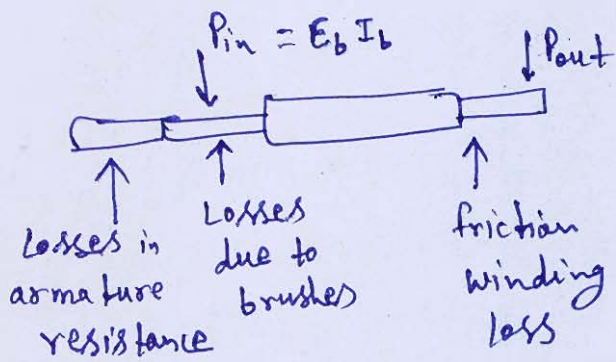
$$s = 0.965$$

$$s = 0.04 \\ = 4\%$$

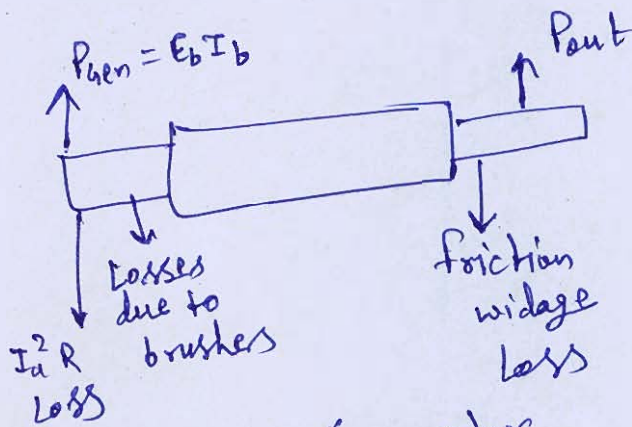
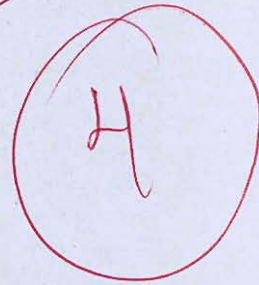
$$\frac{120 \times 50}{P} = 1440$$

$$P = \frac{120 \times 50}{1440} = 4$$

$$\text{No. of Poles} \approx 4$$



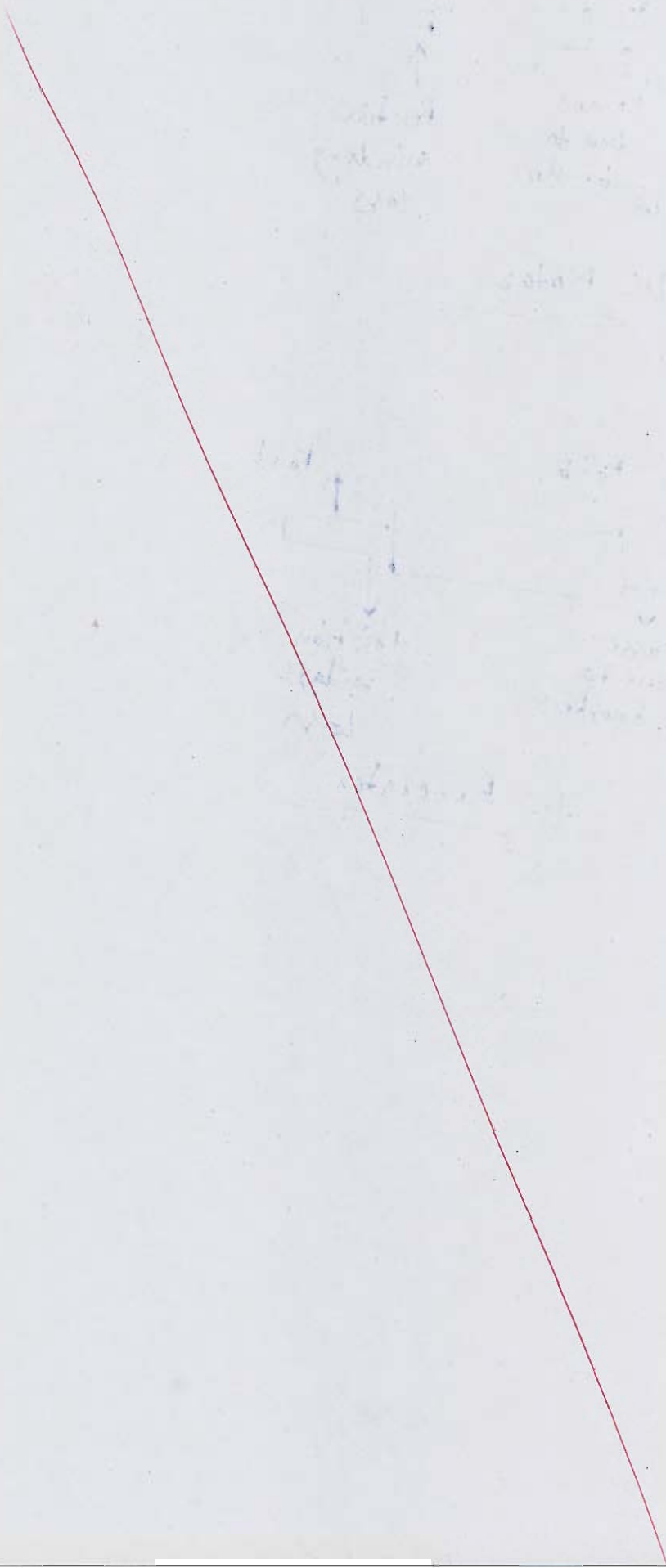
DC Motor



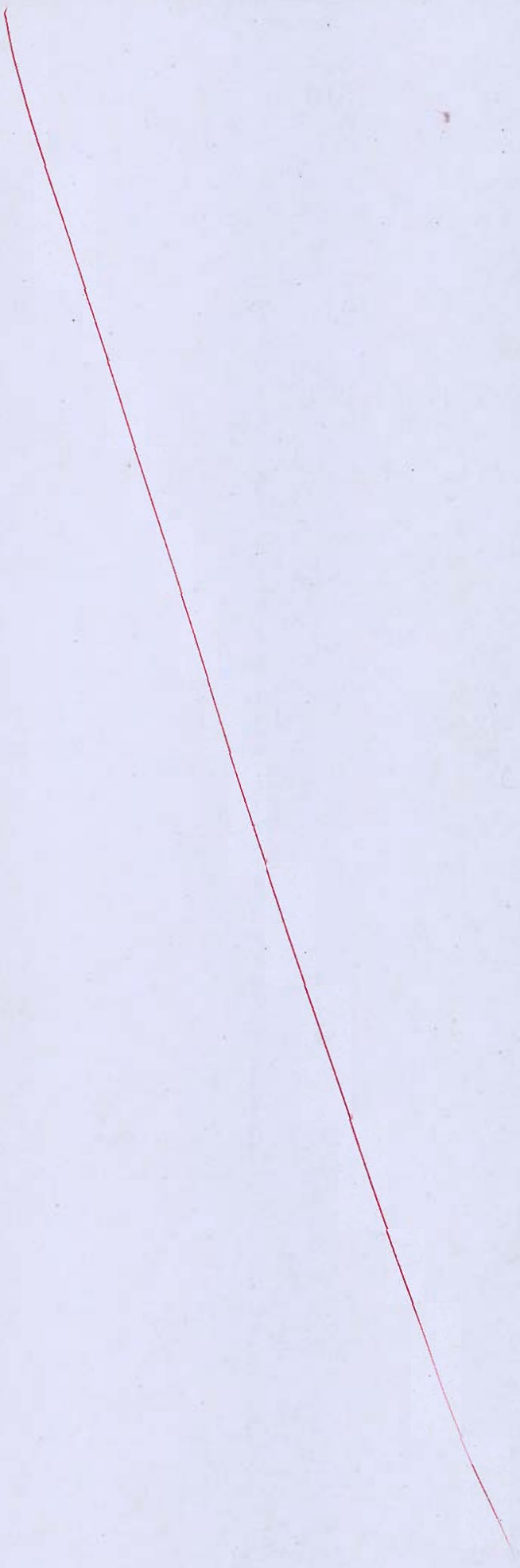
DC Generator

## Space for Rough Work

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$$\frac{F \times 2\pi r}{2\pi N} \quad (0.607)$$

$$\tan \phi \cdot \tan \beta \times \text{Trupaceu}$$

$$\frac{I}{A} = \sigma E$$

$$\frac{V}{I} = R = \frac{\rho l}{A}$$

$$\sigma = \frac{1}{R A} l$$

$$= \frac{1}{(\text{ohm-cm}^{-1})}$$

$$\frac{16\pi}{3} \times \frac{752}{642}$$

$$\left( \frac{752}{6} \right)$$