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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	46
Q.2	—
Q.3	—
Q.4	57
Section-B	
Q.5	25
Q.6	41
Q.7	—
Q.8	20
Total Marks Obtained	189

Signature of Evaluator: Chaithra. N. M

Cross Checked by: .....

* Good performance
* Avoid calculation mistakes.

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

.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]**

Solution:- given strontium is fcc structure

n = 4 atoms/unit cell

A (atomic weight) = 87.62 g/mol

N_A (Avagadro number) = 6.023×10^{23} atoms/mole

$$\text{Density } (\rho) = \frac{n \times A}{V_c \times N_A} \text{ gm/cm}^3 \quad \text{--- (1)}$$

V_c (unit cell volume) = a^3 [a = unit cell edge length]

As we know atomic radius (R) = $\frac{a}{2\sqrt{2}}$

$a = 2\sqrt{2}R$

So $V_c = (2\sqrt{2}R)^3$

$= (2\sqrt{2} \times 2.15 \times 10^{-8} \text{ cm})^3$

$V_c = 22.487 \times 10^{-23} \text{ cm}^3$

12

Good

from equation (1)

$$\rho = \frac{4 \times 87.62}{22.487 \times 10^{-23} \times 6.023 \times 10^{23}}$$

$\rho = 2.58 \text{ gm/cm}^3$

Ans density (ρ) = 2.58 gm/cm^3

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

Solution-:

Commutation-:

Actual emf induced in armature conductors is in AC (bidirectional nature). but in DC machine output required is in form of DC (unidirectional waveform). Hence commutator is used. which convert bidirectional waveform i.e. AC into unidirection waveforme i.e. DC. This process is called as commutation.

To improve commutation in a DC machine-:

To improve commutation in a DC machine following methods can be used.

(1) By using field winding. which placed upon pole core. They connected in definite direction so that it generate electromagnet torque.

(2) Armature conductor is conneted 'g' different method to improve commutation.

(a) in Lap winding arrangment

(b) in WAVE winding arrangment.

5

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]

Solution :-

Torque is twisting or bending moment about axis called Torque.

Hence Torque is given by (T = Torque)

$P' = T \times \omega$ - (1)

P' = power, $\omega = \frac{2\pi N}{60}$ (N = speed of Rotor)

T = Torque.

$P' = E_b I_a$ - (2) (E_g = ~~generated~~ back emf, I_a = armature conductor

As we know $E_b = \frac{P\phi N}{60} \times \frac{Z}{A}$ - (3)

P = Number of poles

ϕ = flux per pole

A = Number of parallel path

Z = Number of conductor

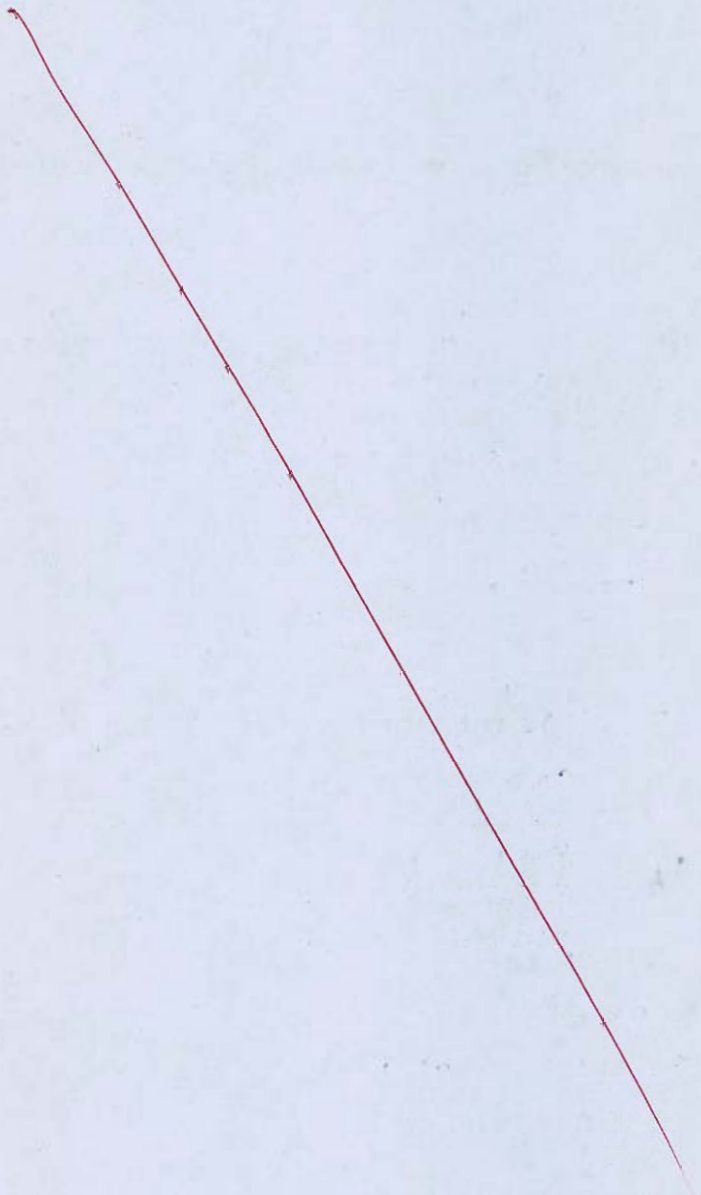
from equation (3), (2) putting into (1)

$$I_a \times \frac{P\phi N}{60}\frac{Z}{A} = T \times \frac{2\pi N}{60}$$

$$T = 0.159\,\phi I_a \frac{PZ}{A}$$

Hence T (Torque) $\propto \phi I_a$

Hence it is proved that 'Torque developed by a DC m.c. motor is proportional to the flux per pole and armature conductor



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]**

Solution given

Resistance (R) = 1 KΩ ± 10% ~~on full scale~~

current (I) = 20 mA ± 2% on full scale.

power dissipated (P) = I^2R

$$\frac{\delta P}{P} \times 100 = \pm \left[2 \times \frac{\delta I}{I} + \frac{\delta R}{R}\right] \times 100 \quad - (1)$$

Now $\frac{\delta R}{R} \times 100 = 10$ (given)

when R = 1 KΩ

$$\frac{\delta R}{R} = \pm 0.1 \quad - (2)$$

$$\frac{\delta I}{I} \times 100 = 2 \quad \text{when } I = 20 \text{ mA}$$

$$\frac{\delta I}{20} \times 100 = 2$$

$$\delta I = \pm 0.4 \text{ mA}$$

Now when I = 10 mA

then $\frac{\delta I}{I} \Rightarrow \frac{\pm 0.4}{10}$

$$\frac{\delta I}{I} = 0.04 \quad - (3)$$

from (2), (3), substituting in (1)

$$\frac{\delta P}{P} \times 100 = \pm \left[2 \times 0.04 + 0.1\right] \times 100$$

$$= \pm \left[0.18\right] \times 100$$

$$\frac{\delta P}{P} \times 100 = 18\%$$

$P = (10 \times 10^{-3})^2 \times 1 \times 10^3$

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

$= 10 \text{ W} \pm 1$ → 0.1 W

Ans $P = 10 \text{ W} \pm 1$, Accuracy = 18%

0.1 W

"Avoid calculation mistakes"

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]

Solution :-

Thermometer temperature $\theta(t)$ is given by

$$\theta(t) = [\theta_{initial} - \theta_{final}]\, e^{-t/\tau} + \theta_{final}$$

Given

$\theta_{initial} = 30°C$, $\theta_{final} = 100$

Now $\theta(t) = 100 - 70e^{-t/\tau}$

[τ = time constant]

At $\theta(t) = 97°C$, time $(t) = 30$

Now $97 = 100 - 70e^{-\frac{30}{\tau}}$

$$\frac{-30}{\tau} = \ln\frac{3}{70}$$

$$\tau = 9.5248\ sec$$

Let t_1 time is required to reach 98°C

So $98 = 100 - 70e^{-\frac{t_1}{9.524}}$

$$t = 33.86\ sec$$

Ans time required to

Ans time $(t) = 33.86$ sec is required to reach 98°C

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.

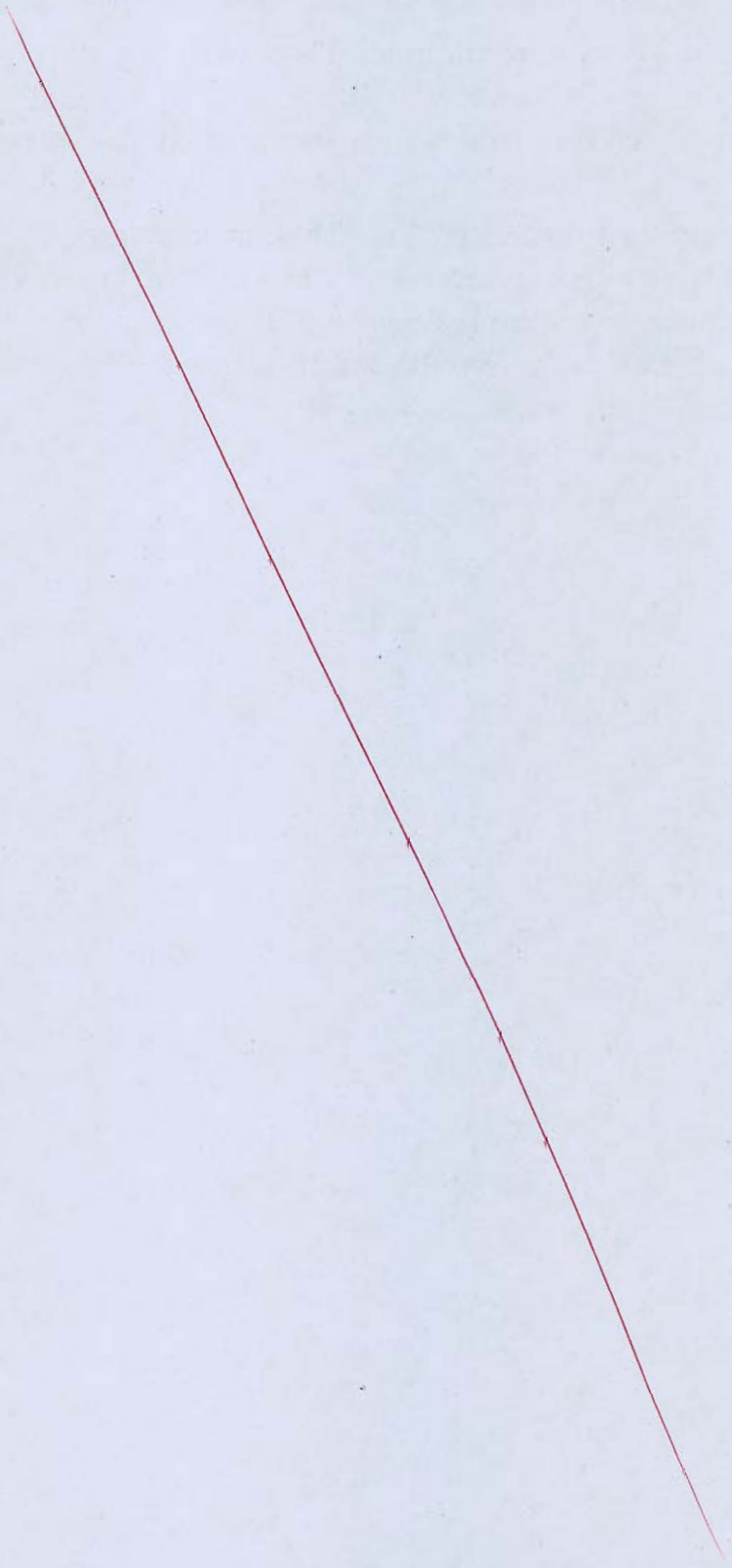
(ii) The inductance of a moving iron instrument is given by

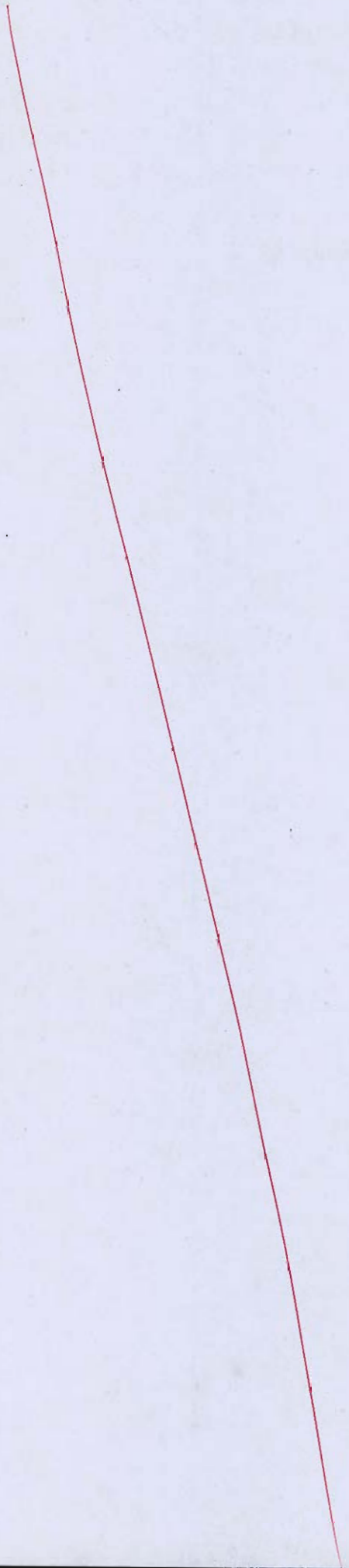
$$L = (12 + 6\theta - \theta^2)\ \mu H$$

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]





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]

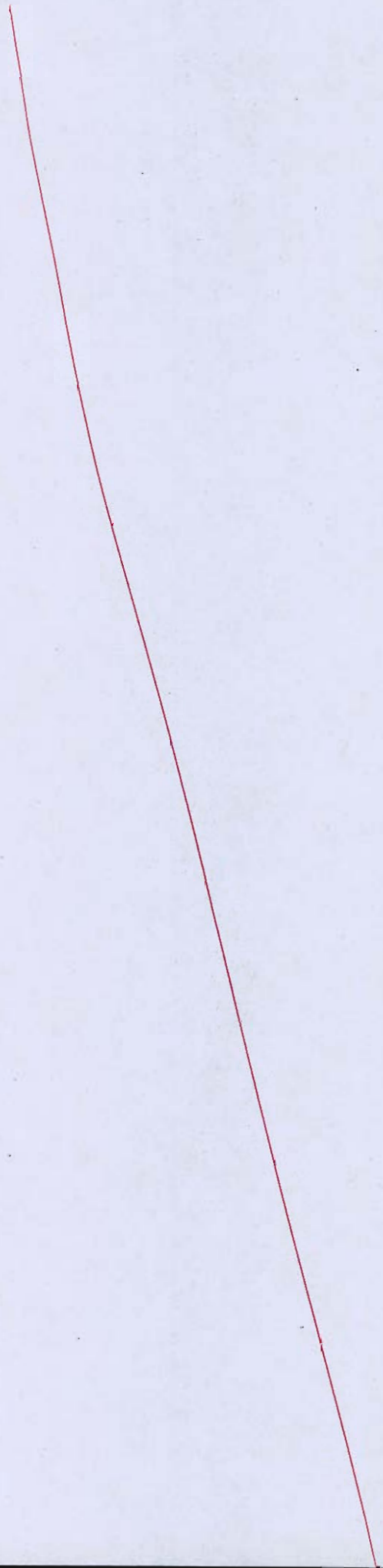
Q.2 (c) An electrodynamometer wattmeter is used for measurement of power in a single phase circuit. The load voltage is 100 V and the load current is 9 A at a lagging power factor of 0.1. The wattmeter voltage circuit has a resistance of 3000 Ω and an inductance of 30 mH. Estimate the percentage error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

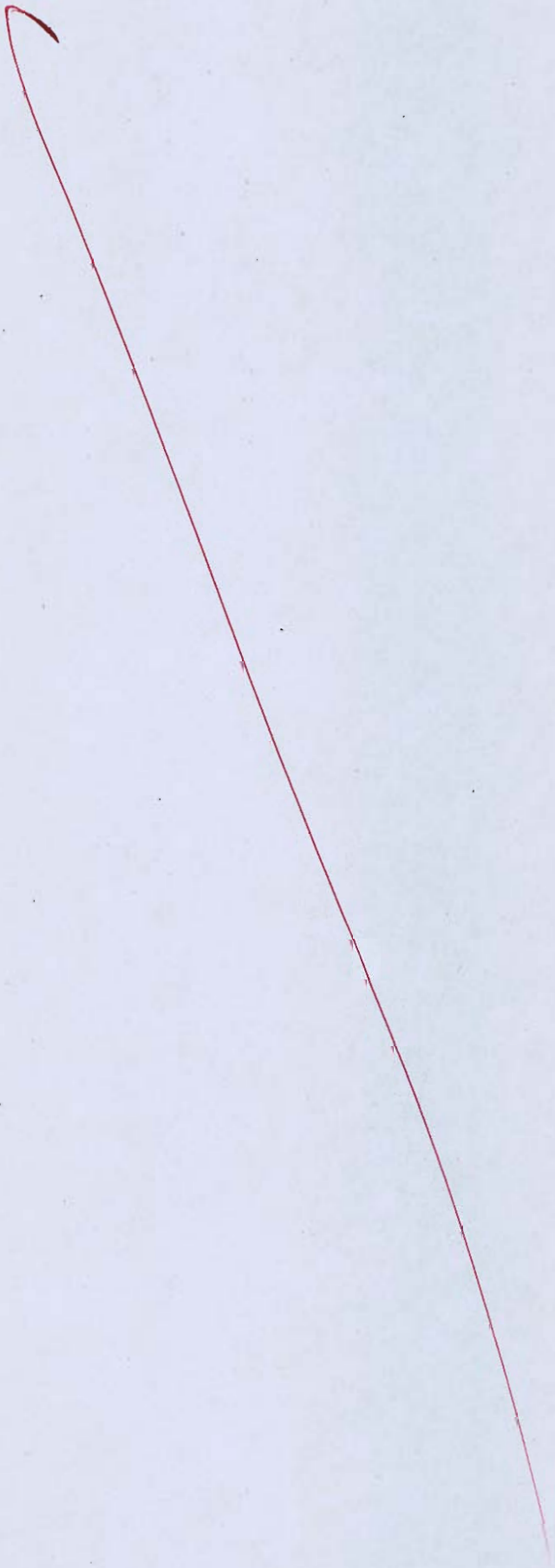
(i) on the load side, and

(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.

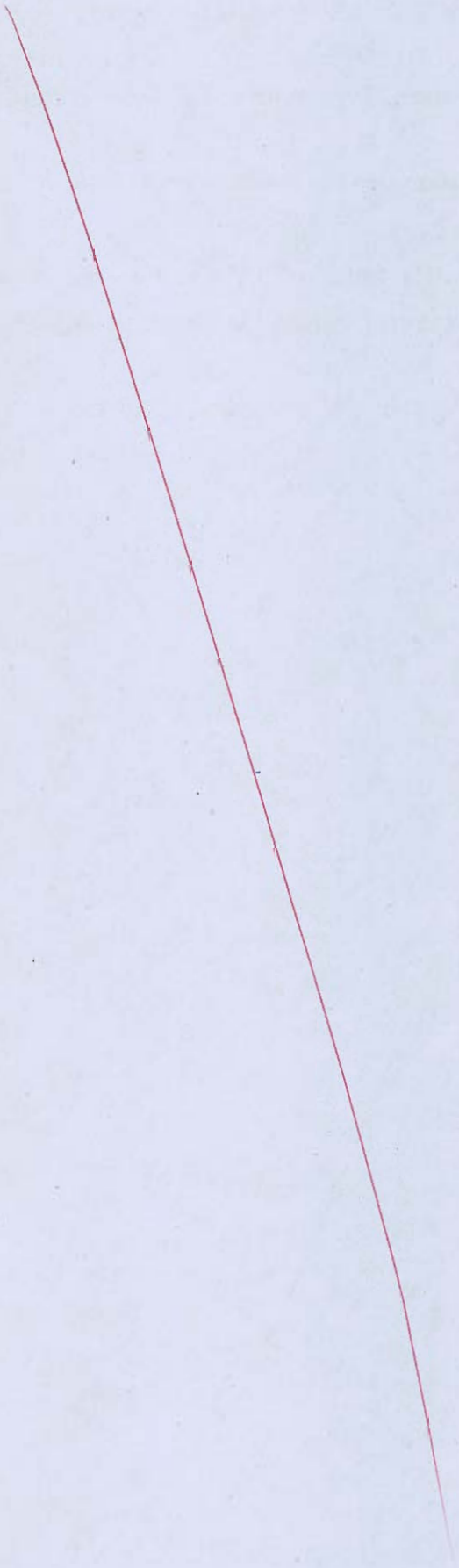
1. Calculate the value of deflection at the free end for the cantilever when a force of 25 N is applied at this end. The modulus of elasticity for steel is 200 GN/m^2.
2. An LVDT with a sensitivity of 0.5 V/mm is used. The voltage is read on a 10 V voltmeter having 100 divisions. Two-tenths of a division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

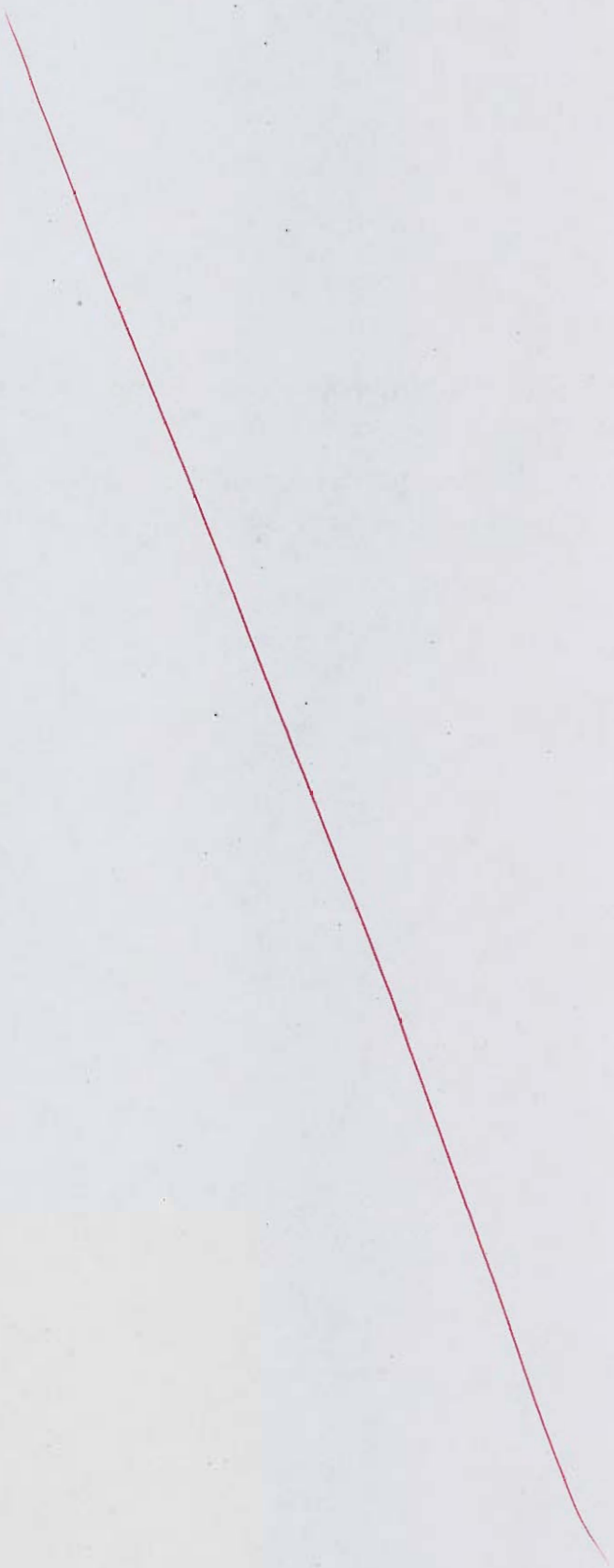
[14 + 6 marks]



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]



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]

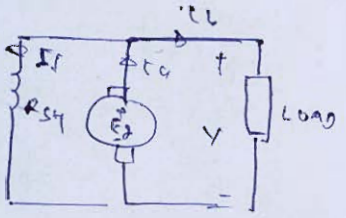
Solution-8 given for shunt Generator

Speed (N_1) = 400 RPM, Voltage (V) = 220 V

Power (P_{out}) = 110 KW

Armature resistance (R_a) = 0.025 Ω

field resistance (R_{sh}) = 55 Ω



Load current (I_L) = $\frac{P_{out}}{V}$

$I_L = \frac{110 \times 10^3}{220}$

$I_L = 500$ A

field current (I_f) = $\frac{V}{R_{sh}}$

$I_f = \frac{220}{55}$

$I_f = 4$ A

Armature current (I_a) = $I_L + I_f$

$I_a = 500 + 4$

$I_a = 504$ A

generated emf (E_g) = $V + I_a R_a$ + Brush drop

$E_g = 220 + 504 \times 0.025 + 2$

$E_g = 234.6$ Volt – (1)

For shunt Motor

given output power of motor when belt breaks

$P_{out} = 11$ KW

19

Good

$V = 220$ volt

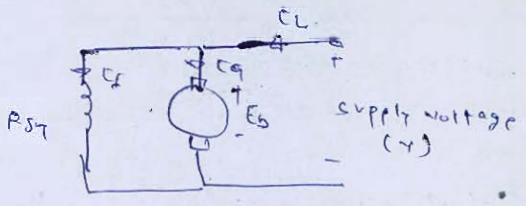
$I_L = \frac{P_{out}}{V}$

$I_L = \frac{11 \times 10^3}{220}$

$I_L = 50\ A$

$I_f = \frac{V}{R_{sh}} = \frac{220}{55}$

$I_f = 4\ A$



Armature current (I_a) = $I_L - I_f$

$I_a = 50 - 4$

$I_a = 46\ A$

back emf (E_b) = $V - I_a R_a$ - brush drop.

$E_b = 220 - 46 \times 0.025 - 2$

$E_b = 216.85$ volt

Let motor is running (N_2) RPM when belt breaks

As we know $E_g \propto N$ (speed)

and $E_b \propto N$ (speed)

Now $\frac{N_2}{N_1} = \frac{E_b}{E_g}$

$N_2 = N_1 \times \frac{E_b}{E_g}$

$= 400 \times \frac{216.85}{234.6}$

$N_2 = 369.74$ RPM

Ans Motor speed (N_2) = 369.74 RPM

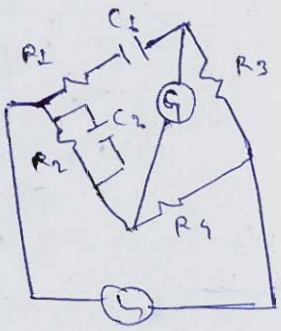
Q.4 (b) How frequency is measured with help of Wein's Bridge? Explain with mathematical derivation and circuit diagram. Enumerate other applications of Wein's bridge.

[20 marks]

Solution:-

Wein's Bridge:- Wein's bridge is used to measured high frequency. in (KHz - MHz range)

Wein's Bridge diagram is shown below.



Wein-bridge

Let $Z_1 = \left(R_1 - \frac{j}{\omega C_1}\right)$

$Z_2 = R_2 \| \frac{1}{j\omega C_2}$

$Z_2 = \frac{R_2}{1 + j\omega R_2 C_2}$

$Z_3 = R_3$

$Z_4 = R_4$

At Bridge balance condition

$Z_1 \cdot Z_4 = Z_2 \cdot Z_3$

$\left(R_1 - j/\omega C_1\right) R_4 = \left(\frac{R_2}{1 + j\omega R_2 C_2}\right) \times R_3$

$R_1 R_4 - j\frac{R_4}{\omega C_1} = \frac{R_2 R_3}{1 + \omega^2 R_2^2 C_2^2} - j\frac{R_2^2 R_3 C_2}{1 + \omega^2 R_2^2 C_2^2}$

comparing Real and imaginary part.

we get $\frac{R_1}{R_2} + \frac{C_2}{C_1} + 1 =$

$$\boxed{\frac{R_1}{R_2} + \frac{C_2}{C_1} = \frac{R_3}{R_4}} \text{ condition}$$

And frequency of oscillation is given by

$$\boxed{\omega_0 = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}}$$

~~Applicatio~~

Disadvantage-& Wein-bridge is balance only single frequency (i.e. fundamental frequency). If hormonics present then bridge is never balanced.

Application of Wein-bridge-&

Application is listed below-

(1) It is used as total hormonic distortion in Notch filter.

(2) It is used as oscillator in analog circuits.

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]

Solution-:

Polarization-:

Polarization is not but electric flux density developed in material on application of electric field.

total electric flux is due to 2 two reason-

(1) Due to applied electric field

(2) Due to polarization

$$\vec{D} = \epsilon \cdot \vec{E} + \vec{P}$$

P = polarization, ϵ = permittivity

E = electric field, D = electric flux density

Type of polarization in dielectric material-:

(1) electronic polarization or electric induced polarization

(2) Ionic polarization or Molecular polarization

(3) orientational polarization

(4) space charge polarization or interfacial polarization

(1) Electronic polarization-: This type of polarization found in those materials who ~~have~~ does not have interaction among them.

Example - Inert gas, Diamond, H_2 etc.

(2) Ionic polarization-: This type of polarization is found in those materials, having net positive and negative charge.

Example Alkali-Halide

(3) Orientational polarization-: This type polarization found in those material, having polar co-valent bond

Example H_2O, CO, HCl

(4) space charge polarization:- In some material free electrons is found. On application of electric field they travel one end to other ends. If in material vaccancies found. Then electron is trapped by vaccanies and crey negative charge. And other end equal amount of positive charge is created. Hence due to positive and negative ions it's creat dipole. Hence this type of polarization called space charge polarization.

Given $N = 3.2 \times 10^{19}$ polar molecules/m3

$\epsilon_r = 2.4$

applied electric field $(\bar{E}) = 10^9 a\hat{x}$ V/m

As we know

polarization $(\bar{P}) = \epsilon_0(\epsilon_r - 1)\bar{E}$

$|\bar{P}| = 8.85 \times 10^{-12} (2.4-1) \times 10^9 a\hat{x}$ C/m2

$\bar{P} = 12.39 \times 10^{-8} a\hat{x}$ C/m2

As we know $\bar{P} = N\bar{p}$

$\bar{p}$ = dipole moment of each molecules

$12.39 \times 10^{-8} a\hat{x} = 3.2 \times 10^{19} \times \bar{p}$

$\bar{p} = 3.87 \times 10^{-27} a\hat{x}$ C-m

Ans polarization $(\bar{P}) = 12.39 \times 10^{-8} a\hat{x}$ C/m2.

dipole moment $(\bar{p}) = 3.87 \times 10^{-27} a\hat{x}$ C-m

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]

Solution

given cylindrical silicon

diameter(D) = 7mm, length(l) = 57mm

(i) current(I) = 0.25A, voltage(V) = 24V

probes separation(d) = 45mm

let electrical conductivity = (σ) Ω-m

As we know Resistance(R) = $\frac{l}{\sigma A}$

A = $\frac{\pi D^2}{4}$ (area) and R = V/I

Now $\frac{V}{I} = \frac{l}{\sigma A}$

$\sigma = \frac{lI}{V \times A}$

$\sigma = \frac{57 \times 10^{-3} \times 0.25}{24 \times \frac{\pi}{4}(7 \times 10^{-3})^2}$ → 45×10^{-3}

$\sigma = 15.42\ \Omega$-m

Ans (electrical conductivity(σ) = 15.42 Ω-m)

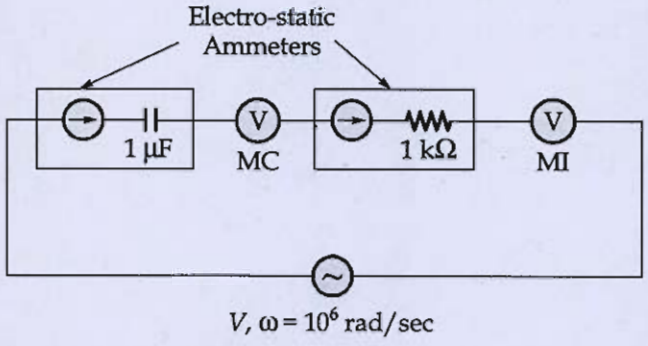
(ii) Resistance(R) = $\frac{V}{I}$

$R = \frac{24}{0.25}$

$R = 96\ \Omega$

Ans (Resistance(R) = 96 Ω)

Q.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.

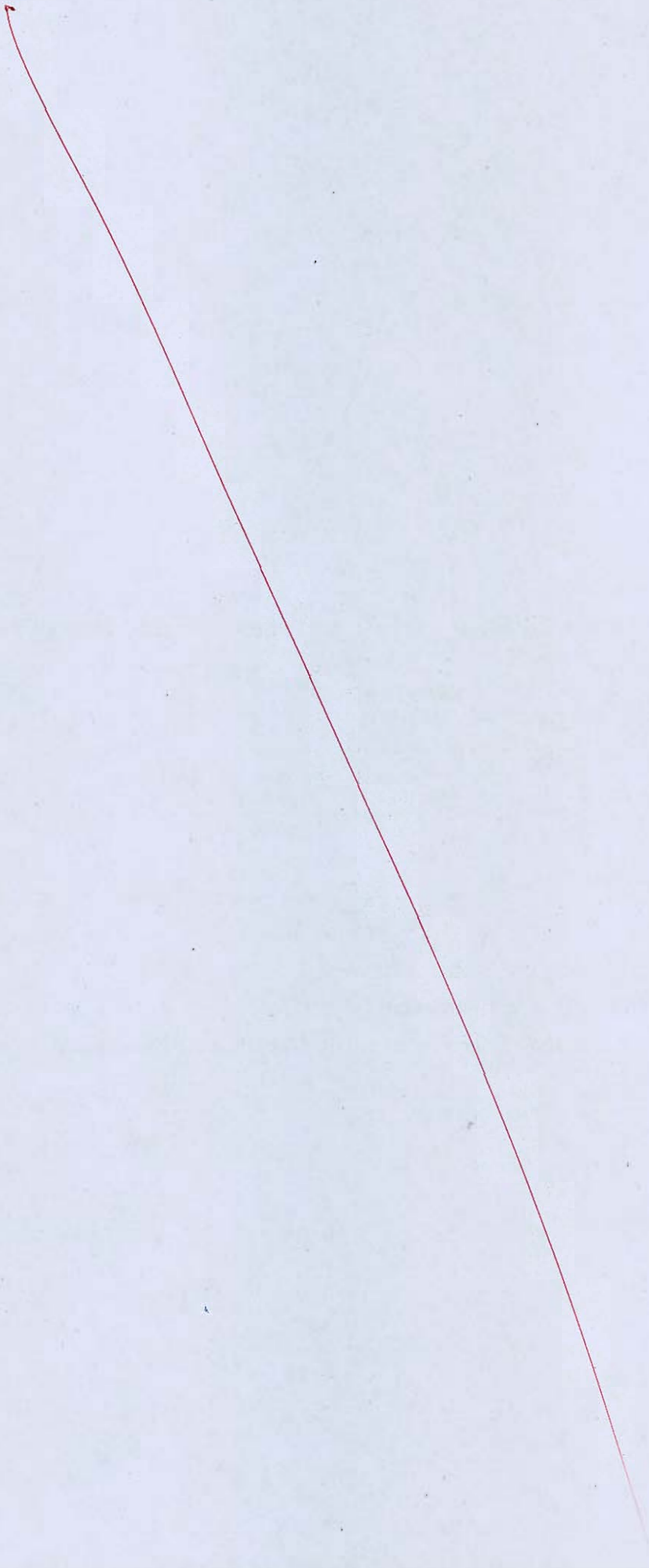


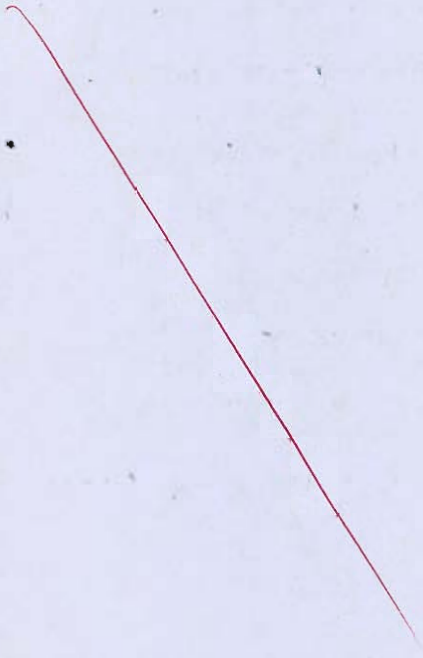
Where, MC : Moving coil instrument

MI : Moving iron instrument

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

[12 marks]





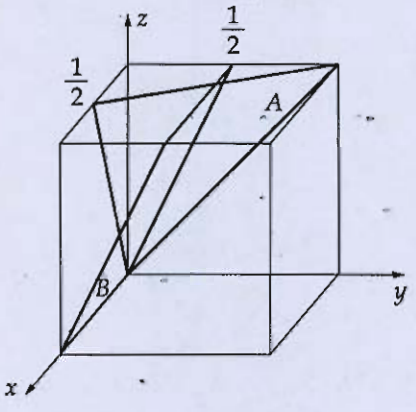
Q.5 (c) (i) A linear resistance potentiometer is 50 mm long and is uniformly wound with a wire having a resistance of 10,000 Ω. Under normal conditions, the slider is at the center of the potentiometer. Find the linear displacement when the resistances of the potentiometer as measured by Wheatstone bridge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

Solution (i) :- potentiometer is linear device. which is used to measured ~~unknown resistance~~ and displacement comparing of ~~known~~ resistance.

given when length (ℓ) = ~~50mm~~, it is when resistance (R) = 10,000Ω is balanced on length (ℓ) = 50mm

Let linear displacement = x in each case.

(i) when $R' = 3850\Omega$, displacement = x

As we know 'Resistance $\propto$ length or displacement

So $$\frac{R'}{R} = \frac{\ell}{x}$$

$$x = \frac{R\ell}{R'}$$

$$x = \frac{R}{R'} \times \ell \quad - (1)$$

Now $$x = \frac{10,000}{3850} \times 50\text{mm}$$

$$x = 129.87\text{ mm}$$

Ans displacement (x) = 129.87 mm

(ii) ~~when $R' = 7560\Omega$~~

~~by using equation (1) $x = 10,$~~

$$\frac{R'}{R} = \frac{x}{\ell} \Rightarrow x = \frac{R'}{R}\ell \quad - (1)$$

(i) when $R' = 3850\Omega$, displacement = x mm

from (1) $$x = \frac{3850}{10,000} \times 50 \Rightarrow 19.25\text{mm}$$

Ans displacement (x) = 19.25 mm

(ii) when $R' = 7560\Omega$, displacement = x mm

from equation (1) $$x = \frac{7560}{10,000} \times 50$$

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

Ans displacement (x) = 37.8 mm

Resolution is output / input. i.e. Resolution = $\frac{x}{R}$ (when R=1Ω)

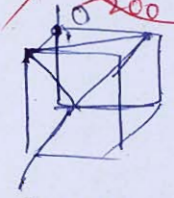
from (1) Resolution = $\frac{2}{R} \Rightarrow \frac{50}{1000} \Rightarrow 5\times10^{-3}$ mm/Ω

Ans Resolution = 5×10^{-3} mm/Ω

~~$\frac{10}{200} = 0.05$mm~~

(ii) For plane-A

Let origin 'O' shown figure. Which is not lies on plane.



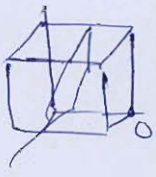
Intercepts of plane on x axis, y axis, z-axis

Intercepts	x-axis	y-axis	z-axis
	a/2	b	-c
Intercepts in terms of a, b, c	1/2	1	-1
Reciprocal	2	1	-1
enclosed	(2, 1, $\bar{1}$)		

Ans plane-A Miller Indices (2 1 $\bar{1}$)

For plane-B

Intercepts	x-axis	y-axis	z-axis
	a	-b/2	∞c
Intercepts in terms of a, b, c	1	-1/2	∞
Reciprocal	1	-2	0
enclosed	(1 $\bar{2}$ 0)		



O (origin)

Ans Miller Indices for plane B (1 $\bar{2}$ 0)

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

[12 marks]

Solution

Advantage of Rotating field Alternator over Rotating Armature Alternator is given below.

(1) It is more economical because less slip ring, brushes is required.

(2) Temperature Rise is will be low.

(3) Due to small size of Rotor, rotor rotational losses will be less. Hence efficiency will be high.

(4) Due to small size of Rotor, Rotor can run at very high speed. Hence more output can be taken.

(5) It is easy to provide required insulation.

(6) It is easy to provide cooling of rotor.

(7) Connection of armature conductor to rotor will be easy.

There are some advantage of Rotating field alternator over Rotating Armature Alternator

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]

Solution DVM machines

Machine-A

$4\frac{1}{2}$ digit DVM, error specification 0.2% of reading +10 count.

sensitivity (S) = 1 9 9.9 9

sensitivity (S) = 0.01 Volt on 200 V scale.

total error (e_A) = 0.2% × Reading value + sensitivity × count

$= \frac{0.2}{100} \times 100 + 0.01 \times 10$

total error (e_A) = ±0.3

Relative error (ε%) = $\frac{\pm 0.3}{100} \times 100$

= 0.3%

For Machine-B

4 digit DVM, error = 0.2% of reading ± 2 digit.

Largest count 1 9 9 9

sensitivity (S) = 0.1 Volt (on 200 V scale)

total error = 0.2% × reading value + sensitivity × digit

$= \frac{0.2}{100} \times 100 + 0.1 \times 2$

= 0.2 + 0.2

= ±0.4

Relative error = $\frac{\pm 0.4}{100} \times 100 \Rightarrow$ 0.4%

→ 0.24%

Since relative error of machine A is less than machine B.

Hence customer select machine A ✗

Machin B has less % error as compared to machine A.

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]

Solution (i):-

given 100 KVA, 440/11000 V

efficiency (η) = 97.23%, at 0.83 power factor lagging (i.e. $\cos\theta = 0.83$)

$$\text{efficiency } (\eta) = \frac{x(\text{VA})\cos\theta}{x(\text{VA})\cos\theta + x^2 W_{cu} + W_i} \times 100 \quad \text{--- (1)}$$

x = fraction of load, W_{cu} = full load Cu loss

W_i = iron loss, VA = kVA rating of transformer

Case-1 when full load current $x = 1$

$$0.9723 = \frac{1 \cdot (10^5) \times 0.83}{1 \cdot (10^5) \times 0.83 + W_{cu} + W_i}$$

$89 \times 10^3 + W_{cu} + W_i = 85.365 \times 10^3$

$W_{cu} + W_i = 2.365 \times 10^{+3}$ — (2)

case-2 when half full load current $x = 1/2$, $\eta = 98.72\%$

from equation (1) . unity power factor i.e. $\cos\phi = 1$

$$0.9872 = \frac{1/2\,(100 \times 10^3) \times 1}{\frac{1}{2}(100 \times 10^3) + (1/2)^2 W_{cu} + W_i}$$

$0.25 W_{cu} + W_i = 0.648 \times 10^3$ — (3)

After solving equation (2) and (3)

we get

$W_{cu} = 2.289$ KW,

$W_i = 75.667$ watt

For maximum efficiency condition

variable loss = constant loss

let load current = I corresponding to maximum efficiency

$I^2 R_{01} = W_i$ — (4)

AS $W_{cu} = I_q^2 R_{01}$ [I_q = Rated current]

$\therefore I_q = \frac{100 \times 10^3}{440}$

$I_q = 227.27$ A

so $R_{01} = \frac{2.289 \times 10^3}{(227.27)^2}$

$R_{01} = 4.43 \times 10^{-2}\ \Omega$

from (4) $I = \sqrt{\frac{W_i}{R_{01}}} \Rightarrow \sqrt{\frac{75.667}{4.43 \times 10^{-2}}}$

$I = 41.32$ Amp

Ans Full load cu loss $W_{cu} = 2.289$ KW,
Iron loss (W_i) = 75.667 watt
current corresponding maximum efficiency (I) = 41.32 Amp

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At maximum Efficiency,

$I_m = I_{FL}\sqrt{\frac{P_i}{P_{cu}}}$

(ii) for induction motor

poles (P) = 2, frequency (f) = 50 Hz

speed (N) = 2950 RPM, power (P) = 2.5 KW

Synchronous speed $(N_S) = \frac{120f}{P} \Rightarrow \frac{120 \times 50}{2}$

$N_S = 3000$ Rpm

(i) $\text{Slip}(S) = \frac{N_S - N}{N_S} \times 100 \Rightarrow \frac{3000 - 2950}{3000} \times 100$

$S = 1.667\%$

Ans $\boxed{\text{Slip}(S) = 1.667\%}$

(ii) As we know power $(P) = T \times \omega$

T = torque, $\omega = 2\pi N/60$

Now $15 \times 10^3 = T \times \frac{2\pi \times 2950}{60}$

$T = 48.56$ N-m

Ans $\boxed{\text{Torque}(T) = 48.56 \text{ N-m}}$

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(iii) As $P = T \times \omega$ (N = speed)

$T \times \frac{2\pi N}{60} = P$ Hence $T \times N$ = constant

If $T_2 = 2T_1$, Let speed N_2

$\frac{T_2}{T_1} = \frac{N_1}{N_2} \Rightarrow N_2 = \frac{T_1}{T_2} \times N_1$

$N_2 = \frac{T_1}{2T_1} \times (2950)$

$N_2 = 1475$ Rpm

Ans $\boxed{\text{Speed}(N_2) = 1475 \text{ Rpm}}$

(iv) power $(P_2) = T_2 \times \frac{2\pi N_2}{60}$

$P_2 =$

$T_2 = 2 \times 48.56$

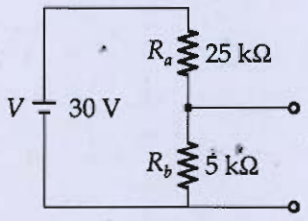
$T_2 = 97.12$ N-m

$P_2 = 97.12 \times \frac{2\pi \times 1475}{60}$

$P_2 = 15$ KW

Ans $\boxed{\text{power}(P) = 15 \text{ KW}}$

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



Meter 1 : $S = 1$ kΩ/V, range 10 V
Meter 2 : $S = 20$ kΩ/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]

(i) Let voltage across R_b is V_b volt.

(i) when without any meter used.

by using voltage divider

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

$$V_b = 30 \times \frac{5}{25+5} \Rightarrow V_b = 5 \text{ volt}$$

Ans Voltage (V_b) = 5 volt

(ii) when meter-1 is connected.

for meter-1 $S = 1\text{K}\Omega/\text{V}$, range 10 V

meter resistance (R_m) = $1\text{K}\Omega/\text{V} \times 10\text{V}$

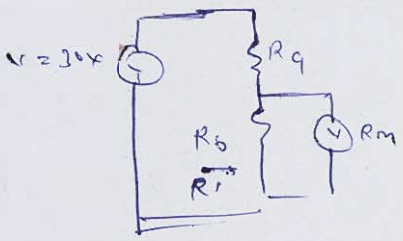
$R_m = 10\ \text{K}\Omega$

In this case loading occurs.

effective resistance across R_5 is R'

$$R' = R_5 \| R_m = 5 \| 10$$

$$R' = 3.33\ K\Omega$$



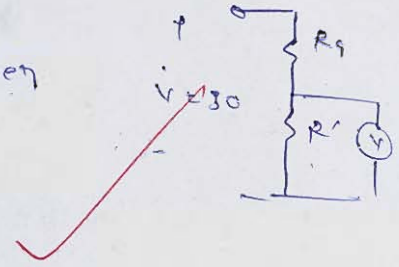
Now by using voltage divider

$$V_5 = V \times \frac{R'}{R' + R_q}$$

$$V_5 = 30 \times \frac{3.33}{3.33 + 25}$$

$$V_5 = 3.53 \text{ Volt}$$

Ans Voltage (V_5) = 3.53 Volt



(iii) When meter-1 connected across R_5

Meter resistance (R_m) = 5 × range ⇒ 20 × 10 = 200 Ω

effective resistance across R_5 i.e. R'

$R' = R_5 \| R_m \Rightarrow 5 \| 200 \Rightarrow R' = 4\ K\Omega$ → $R' = 4.88K$

Voltage divider $V_5 = V \times \frac{R'}{R' + R_q}$

$$V_5 = 30 \times \frac{4}{4 + 25}$$

$$V_5 = 4.14 \text{ Volt}$$

4.9V

Ans Voltage (V_5) = 4.14 Volt

Avoid calculation mistak

13

On

(iv) When meter-1 is connected

True voltage (V_5) = 5 Volt

Measured voltage (V_5') = 3.53 Volt

$$\text{error} = V_5 \cdot \frac{\text{Measured value} - \text{True value}}{\text{True value}} \times 100$$

$$= \frac{3.53 - 5}{5} \times 100$$

$$= -29.4\ \%$$

for meter-2

Measured voltage (V_2) = 4.14 volt

$$\text{error} = \frac{\text{measured value} - \text{True value}}{\text{True value}} \times 100$$

$$= \frac{4.14 - 5}{5} \times 100$$

$$= -17.2\% \rightarrow -2\%$$

Ans: Meter-1 error = −29.4%

Meter-2 error = −17.2%

6 (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]

Solution-(i) for dielectric

We know polarization $(\bar{P}) = \epsilon_0(\epsilon_r - 1)\bar{E}$ — (1)

ϵ_r = Relative permittivity

and $\bar{p} = \alpha \bar{E}$ α = polarizability

$\bar{p}$ = dipole moment

$\bar{P} = N\bar{p}$

$\bar{P} = N\alpha\bar{E}$ — (2)

from (1) and (2) $N\alpha E = \epsilon_0(\epsilon_r - 1)E \Rightarrow \alpha = \frac{\epsilon_0(\epsilon_r - 1)}{N}$

$\alpha = \frac{\epsilon_0(\epsilon_r - 1)}{N}$ Ans

Clausius Mossotti equation-

Assumptions

(1) polarization of molecules is isotropic.

(2) Absence of short range interactions

(3) Polarizability of molecules is isotropic.

(4) Polarization due to elastic displacement only.

It is applicable only cubic crystal.

As we know $\bar{E}_i = E + \frac{\bar{P}}{3\epsilon_0}$ - (1)

$\bar{P} = N\alpha E_i$ - (2)

Put equation (1) in to (2)

$\bar{P} = N\alpha\left[E + \frac{\bar{P}}{3\epsilon_0}\right]$

$\frac{P}{E} = \frac{N\alpha}{1 - \frac{N\alpha}{3\epsilon_0}}$

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

Hence $\epsilon_r - 1 = \frac{N\alpha/\epsilon_0}{1 - \frac{N\alpha}{3\epsilon_0}}$ - (3)

Adding three in equation (3) both side.

we get $\epsilon_r + 2 = \frac{3}{1 - \frac{N\alpha}{3\epsilon_0}}$ - (4)

(4)

divide equation (3) ÷ (4)

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

(ii) given electric field (E) = 1000 V/m

polarization (P) = 4.3×10^{-8} C/m²

As we know $P = \epsilon_0(\epsilon_r - 1)E$

So $\epsilon_r - 1 = \frac{P}{\epsilon_0 E}$

(2)

$\epsilon_r - 1 = \frac{4.8 \times 10^{-8}}{8.85 \times 10^{-12} \times 1000}$ → 4.3

$\epsilon_r - 1 = 5.424$

$\epsilon_r = 6.424$ ✗

$\epsilon_0 = 5.86$

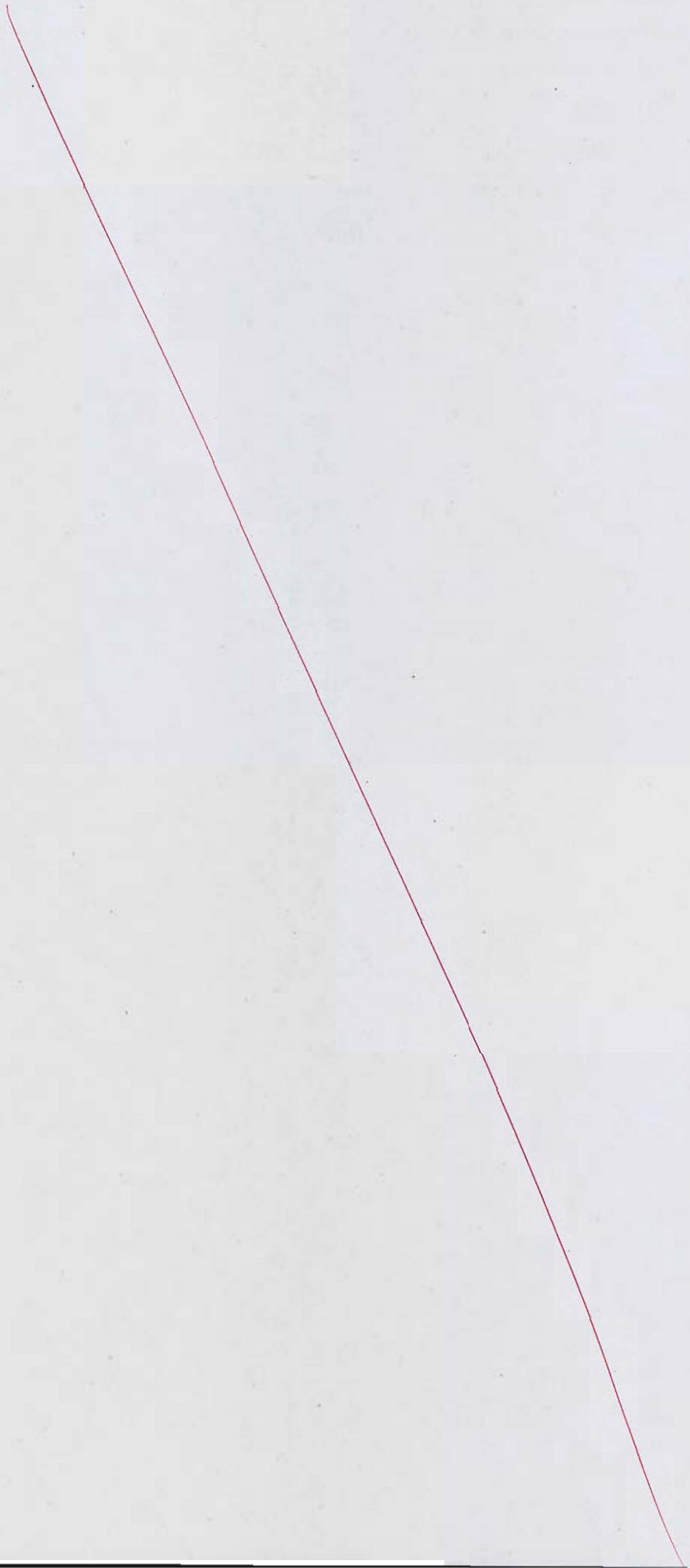
Ans [Relative permitivity (ϵ_r) = 6.424] ✗

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]



(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/m^2. Calculate the gauge factor.

[10 + 10 marks]

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

[20 marks]

8 (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]

Solution(i) BCC crystal

direction [1 1 0]

Linear density (LD) = $\frac{\text{effective atoms lies on [1 1 0] direction vector}}{\text{length of vector}}$

Length = a

As we know $R = \frac{\sqrt{3}}{4}a$

6

$\therefore$ $LD = \frac{1 \text{ atoms}}{\sqrt{2}a} \Rightarrow \frac{1}{\sqrt{2} \times 2.89 \times 10^{-7}}$

$LD = 2.45 \times 10^6$ atom/cm

Ans $(LD = 2.45 \times 10^5$ atoms/cm$)$ ✓

(ii) critical Magnetic field (H_C) = 10^5 A/m at

critical temperature (T_C) = 8K

at $T = 0$, $H_0 = 2 \times 10^5$ A/m

Let critical temperature $= T_C$

As we know $H_C = H_0\left(1 - \left(\frac{T}{T_C}\right)^2\right)$

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

$\frac{8}{T_c} = 0.707$

$T_c = 11.313\,K$

Ans (critical temperature (T_c) = 11.213 K)

6

(iii) $\text{Mean} = \frac{\Sigma x}{n_i} = \frac{41.7 + 42 + 41.8 + 42 + 42.9 + 42.5 + 42 + 41.9 + 41.8}{10}$

$\text{Mean} = \frac{419.7}{10}$

(Mean = 41.97)

2

probable error = $0.6745\,\sigma$

σ = standard deviation.

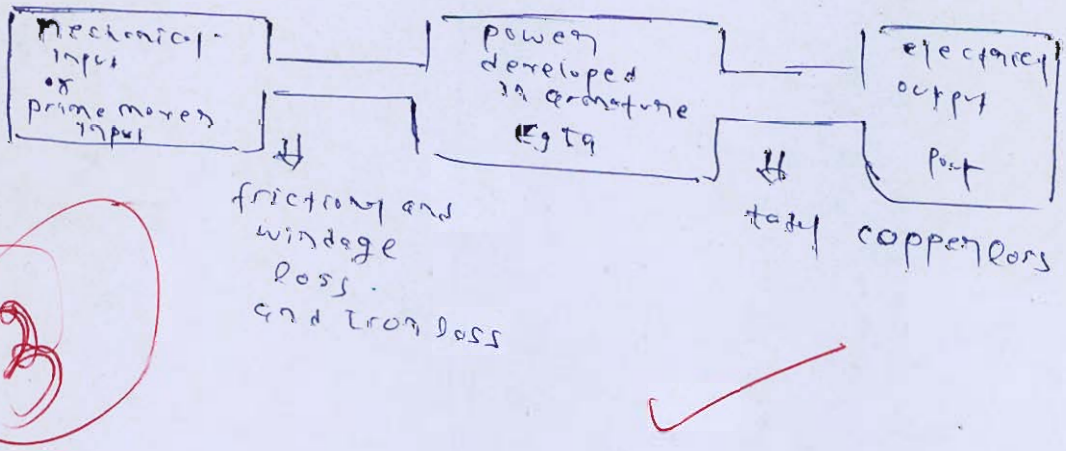
(c) (i) A 12-pole, 3-phase alternator is coupled to an engine running at 500 rpm. It supplies an induction motor which has a full-load speed of 1440 rpm. Find the slip and the number of poles of the motor.

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

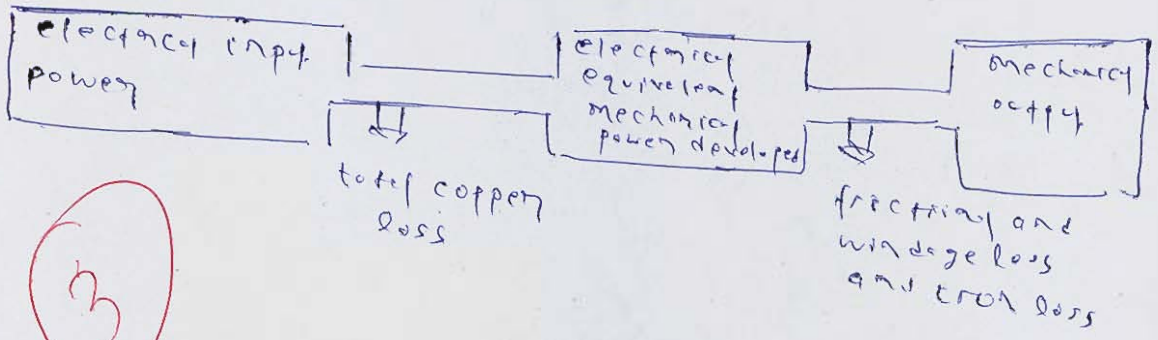
[10 + 10 marks]

Solutn (ii)

power flow diagram of DC Generator



Power flow diagram of DC motor



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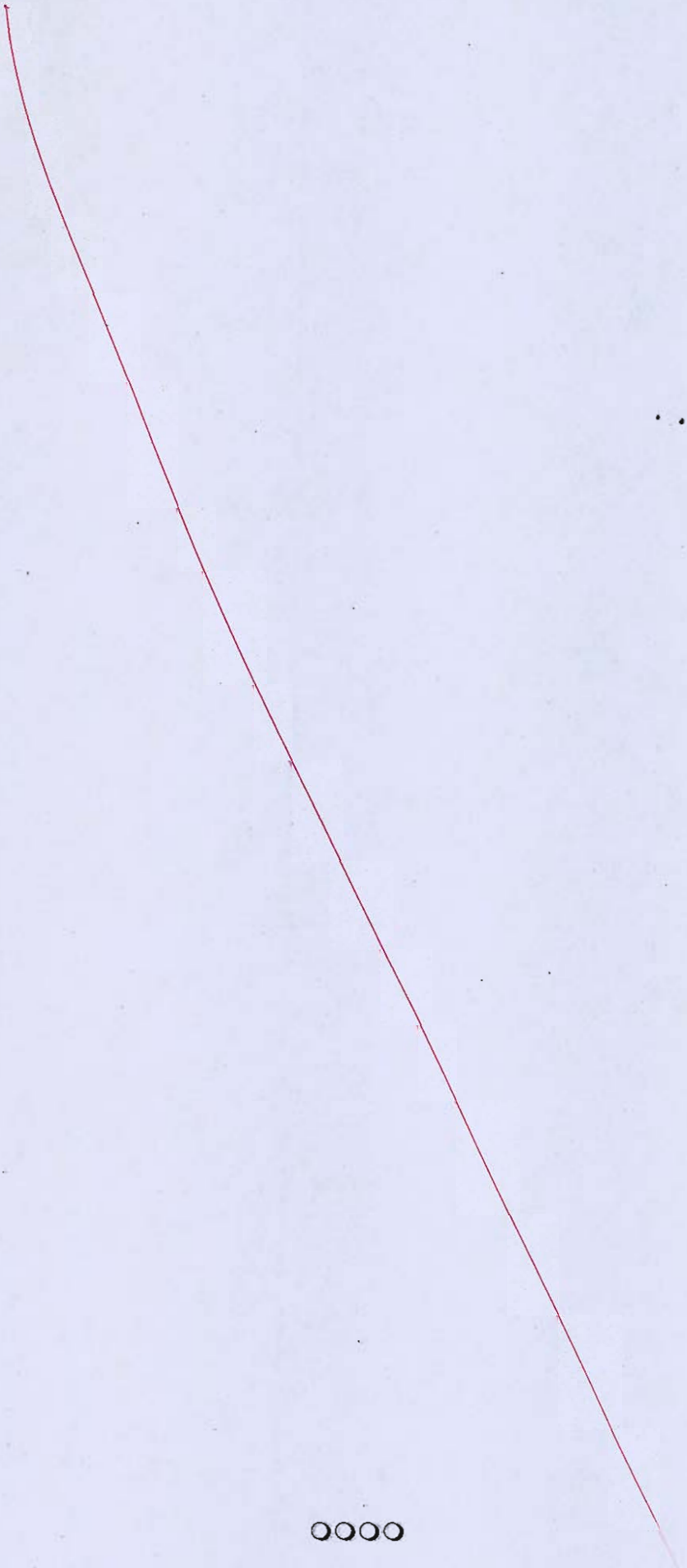
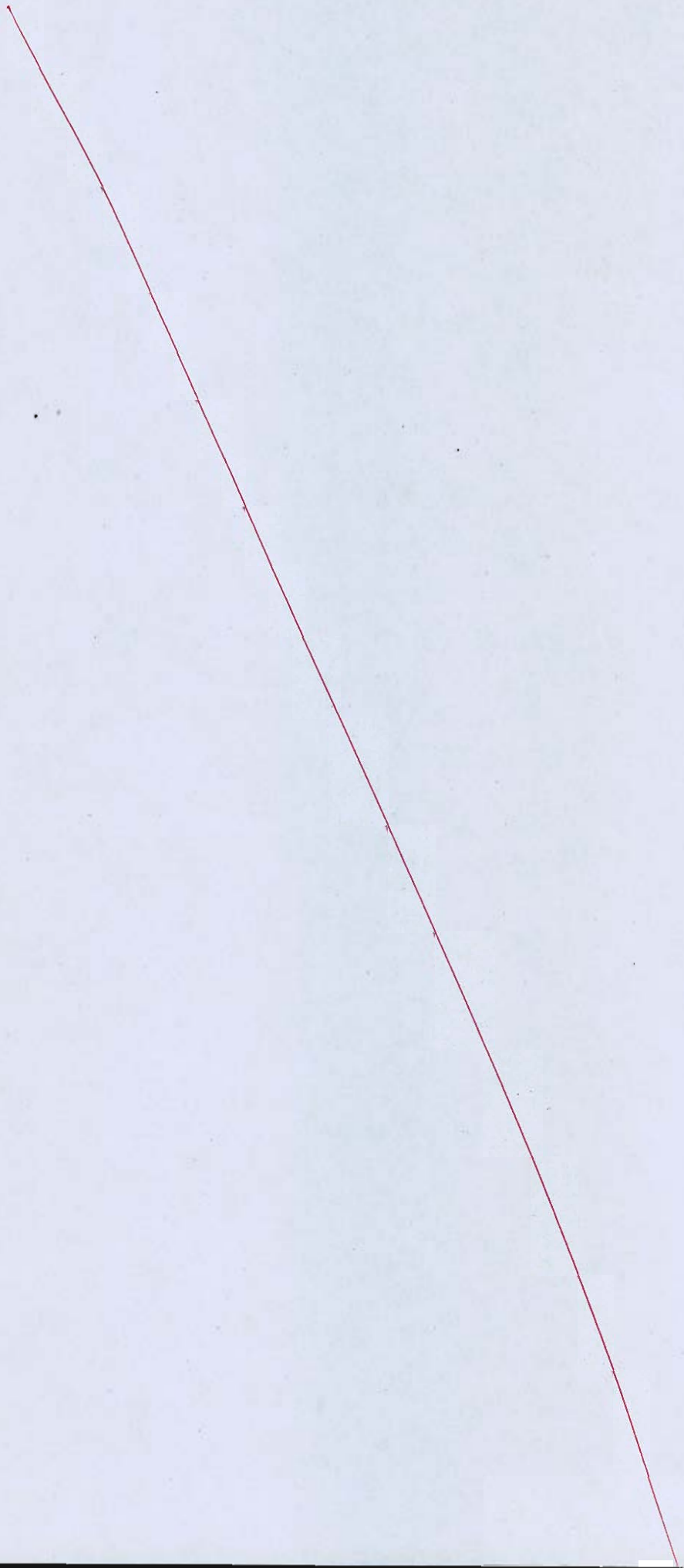
Solution (i)



OOOO

Space for Rough Work



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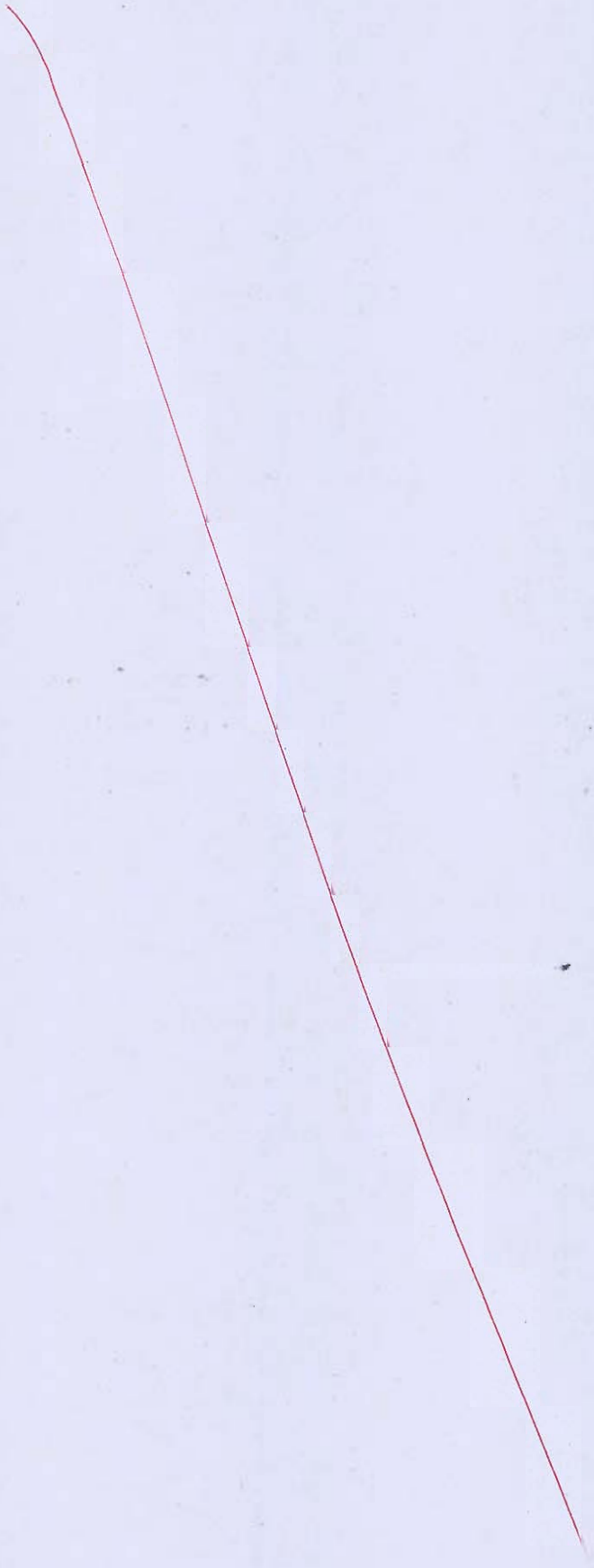

Space for Rough Work