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ESE 2026 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Mechanical Engineering

Test-6 : Section A : Renewable Sources of Energy + Industrial & Maintenance Engg.

Section B : Production Engineering & Material Science-1 + Theory of Machines-2

Name : .....

Roll No :

Test Centres			Student's Signature
Delhi ☑	Bhopal ☐	Jaipur ☐	
Pune ☐	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	44
Q.2	—
Q.3	52
Q.4	18
Section-B	
Q.5	37
Q.6	—
Q.7	17
Q.8	—
Total Marks Obtained	168

Signature of Evaluator ..... Cross Checked by .....

Keep up this Consistent effort

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 : Renewable Sources of Energy + Industrial and Maintenance Engg.

Q.1 (a) A PV system feed a dc motor to produce 2 hp power at the shaft. The motor efficiency is 90%. Each module has 36 multicrystalline silicon solar cells arranged in 9 × 4 matrix. The cell size is 135 × 135 mm and the cell efficiency is 14%. Calculate the number of modulus required in the PC array. Assume global radiation incident normally to the panel as 1 kW/m^2.

[12 marks]

Given

Power on shaft (P_s) = 2hp = 2 × 736 = 1472 Watt (746)

Motor efficiency (η_m) = 0.9

Number of cell in each module (n) = 36

Size of cell = 135 × 135 mm^2

Cell efficiency (η_c) = 14%

global radiation (G_s) = 1 KW/m^2

$\therefore$ motor efficiency (η_m) = $\frac{\text{Shaft power } (P_s)}{\text{Power supplied to motor } (P_m)}$

$\Rightarrow$ $P_m = \frac{1472}{0.9} = 1635.5556$ Watt

$\Rightarrow$ the power supplied by pv cell = 1635.5556 Watt to run the motor.

Now power produced by one module of pv cell is

$P_{\text{one module}} = \eta_c \times G_s \times A \times (n)$

$= 0.14 \times 1000 \times 135 \times 135 \times 10^{-6} \times 36$

$= 91.854$ Watt/module.

let the Number of module required is N

$\therefore$ $N \times 91.854 = 1635.5556$ (10)

$N = 17.806$

$\Rightarrow$ $N \simeq 18$ Answer.

Q.1 (b) Calculate the volume of a cooking based biogas plant required for cooking needs of a family of five adults and lighting needs with three 100 CP lamps for five hour daily. Also calculate the required number of cows to feed the plant. Use the data provided if required

- Biogas required for cooking - 0.227 m^3/person/day
- Biogas required for lighting 100 CP (candle power) mantle lamp - 0.126 m^3/hr
- Dung produced - 10 kg/cow/day
- % of dung that can be collected - 70%
- Solid content in cow dung - About 18%
- Gas yield (m^3 per kg dry matter) - 0.34 m^3/kg dry matter
- Density of slurry - 1090 kg/m^3
- Required retention time - 50 days
- Volume of digester - 90% of slurry and 10% empty space for gas formed

[12 marks]

Given

Number of family member = 5

lighting power used 100 CP 3 lamp 5 hr daily

Now

total biogas required daily = Biogas required for cooking + Biogas required lighting needs

(BG) daily

$\Rightarrow (BG)_{daily} = 5 \times 0.227\ m^3 + 3 \times 0.126 \times 5$

$\text{Person} \times \frac{m^3}{\text{Person-day}} \quad \text{lamp} \times \frac{m^3}{hr} \times \frac{hr}{day}$

$= 3.025\ m^3/day$

Now calculate the number of cows required

The biogas produced by single cow in a day is

$= 10 \times 0.7 \times 0.18 \times 0.34$

$\frac{kg\ matter}{cow\text{-}day} \times \frac{m^3}{kg\ dry\ matter}$

$= 0.4284\ \frac{m^3}{kg\ cow\text{-}day}$

Now to supply the required amount of Biogas, let the Number of cow required is N

$$\therefore \quad N \times 0.4284 \text{ cows} \times \frac{m^3}{\text{day-cow}} = 3.025 \frac{m^3}{\text{day}}$$

$$\Rightarrow N = 7.061$$

$$\Rightarrow \boxed{N \approx 8}$$ Number of cow required

Total mass of cow dung produced daily (m_1) $= 10 \times 0.7 \times 8$

$$= 56 \frac{Kg}{day}$$

Now assuming equal amount of water added

$\therefore$ the total mass of slurry (m_s) = cow dung mass + water mass

$$= 56 + 56$$

$$= 112 \text{ Kg/day}$$

Volume of slurry added in digester daily (V_s) $= \frac{m_s}{1090}$

$$= 0.1027 \frac{m^3}{\text{daily}}$$

$\therefore$ Retention time $= \frac{\text{Volume of slurry in digester}}{\text{Volume of slurry added daily}}$

$$50 = \frac{0.9 \times V}{0.1027}$$

$$\boxed{V = 5.705 \ m^3}$$

↳ Volume of digester of biogas plant required.

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Q.1 (c) (i) Why do we need inventory? Also, explain why the order quantity should be optimized.

(ii) A particular item has a demand of 10,000 units/yr. The cost of one procurement is Rs.100 and the holding cost per unit is Rs.2.5 per year. The replacement is instantaneous and no shortages are allowed. Determine:

1. The economic lot size
2. The number of orders per year and time between orders.
3. The total cost per year if the cost of one unit is Rs.1

[6 + 6 = 12 marks]

(i) Inventory is needed to meet the supply of items, in order to produce the final product. In case of unusual circumstances like strike, price hike, Government policy change. All these factors influence the normal supply of items and that can impact our productivity rate and performance. So in order to minimize that risks we should kept an extra storage of required essential items.

Order quantity is one of the most important parameter of inventory control, therefore optimization in order quantity is required because if the quantity of order is too large than requirement that it create storage issues and leads to increase in holding costs, depreciation cost etc. and if we order in too low or low quantity that will leads to shortage of items when demand arrived. and cause potential profit loses associated with inventory shortage and Good will too.

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(ii) Given

Annual demand (D) = 10,000 units.

Procurement cost (C_o) = ₹ 100

Holding cost (C_h) = ₹ 2.5 / unit / yr

(1) Economic lot size in case of instantaneous replacement is

$$Q^* = \sqrt{\frac{2DC_o}{C_h}}$$

$$= \sqrt{\frac{2 \times 10000 \times 100}{2.5}}$$

$Q^* = 894.4272$ units/order → Economic lot size

$\simeq$ 895 units/order

(2) Number of order (N^*) $= \frac{D}{Q^*}$

$$= \frac{10\,000 \text{ unit/year}}{894.4272}$$

$N^* = 11.1803$ order/year

Time between two reorder (T^*) $= \frac{1}{N^*} = \frac{1 \times 12}{11.1803}$ year/order

$T^* = 1.074$ months.

(3) unit cost (c) = ₹

Total annual cost = Purchase cost + procurement cost + Holding cost

$$= Dxc + \frac{D}{Q^*} C_o + \frac{Q^*}{2} C_h$$

Total Annual cost = $10000 \times 1 + \frac{10000}{894.4272} \times 100 + \frac{894.4272 \times 2.5}{2}$

Total annual cost = ₹ 12236.0679

6

Q.1 (d) Estimate the monthly average of the daily global solar radiation on a horizontal surface at Agra (27°10′ N, 78°05′E) during the month of February. If the average sunshine duration is 8 hour per day.

Use the following correlation:

$$\frac{\overline{H}_g}{\overline{H}_0} = a + b\left(\frac{\overline{n}}{\overline{N}}\right)$$

where, a = 0.25 and b = 0.57 and $\overline{H}_g$ = monthly average, daily total radiation on a horizontal surface at a location; $\overline{H}_0$ = monthly average, daily extra-terrestrial radiation that would fall at the location on a horizontal surface; $\overline{n}$ = monthly average, daily hours of bright sunshine obtained from actual records at the location; $\overline{N}$ = monthly average of maximum possible daily hours of sunshine.

For the month of February, use the 16th day of the month as the day for which H_0 is equal to $\overline{H}_0$.

[12 marks]

Given

average sunshine Duration ($\overline{S}$) = 8 hour/day. = $\overline{n}$

latitude angle (ϕ) = 27° 10' N = 27.1667° N

∴ monthly average, daily extra terrestrial radiation ($\bar{H}_0$) is given as

$$\bar{H}_0 = 3600 \times \frac{12}{\pi} \times I_{sc}\left(1 + 0.033 \cos\left(\frac{360}{365} n\right)\right) \times 2\left(\cos\phi \cos\delta \sin\omega_s + \sin\phi \sin\delta \omega_s\right)$$

where

$n = 31 + 16 = 47$ day (upto 16th February)

δ = declination angle.

$= 23.45 \sin\left[\frac{360}{365}(284+n)\right]$

$= 23.45 \sin\left[\frac{360}{365}(284+47)\right]$

$= -12.9546^\circ$

ω_s = Sunshine hour angle.

$= \cos^{-1}\left(-\tan\phi \tan\delta\right)$

$= \cos^{-1}\left(-\tan(27.1667)\tan(-12.9546)\right)$

$= 83.2203^\circ = 1.4525$ radian

I_{sc} = solar constant $= 1.367$ kW/m^2

$$\Rightarrow \bar{H}_0 = 3600 \times \frac{24}{\pi} \times 1.367\left(1 + 0.033 \cos\left(\frac{360}{365} \times 47\right)\right) \times \{\cos(27.1667)\cos(-12.9546)\sin(83.2203) + \sin(27.1667)\sin(-12.9546) \times 1.4525\}$$

$$= 37595.14869 \times 1.0228 \times 0.7123$$

$$\Rightarrow \bar{H}_0 = 27389.6226 \ \frac{kJ}{m^2\text{-day}}$$

Now

monthly average of maximum possible daily hours of sunshine

$$(\bar{N}) = \frac{2}{15}\omega_s = \frac{2}{15} \times 83.2203$$

$= 11.096$ hour/day.

Now using given equation

$$\frac{\bar{H}_g}{\bar{H}_0} = 0.25 + 0.57\left(\frac{\bar{n}}{N}\right)$$

$$\frac{\bar{H}_g}{27389.6326} = 0.25 + 0.57 \times \frac{8}{11.096}$$

$$\bar{H}_g = 18103.4149 \text{ kJ/m}^2\text{-day}$$

12

Q.1 (e) What is the basic purpose of Production Planning and Control? Also, briefly mention its various functions.

[12 marks]

Q.2 (a) (i) With the help of a neat sketch, explain the working of a Vertical Axis Wind Turbine (VAWT). Describe the function of its main components. Also, discuss the key advantages of VAWTs.

(ii) A propeller type wind turbine has following data

Speed of free wind at a height of 10 m = 15 m/s ; Air density = 1.23 kg/m^3; $\alpha = 0.15$; Height of tower = 120 m; Diameter of rotor = 85 m;

Wind velocity at the turbine reduces by 25%; Generator efficiency = 90%

Find :

(i) Total power available in wind.

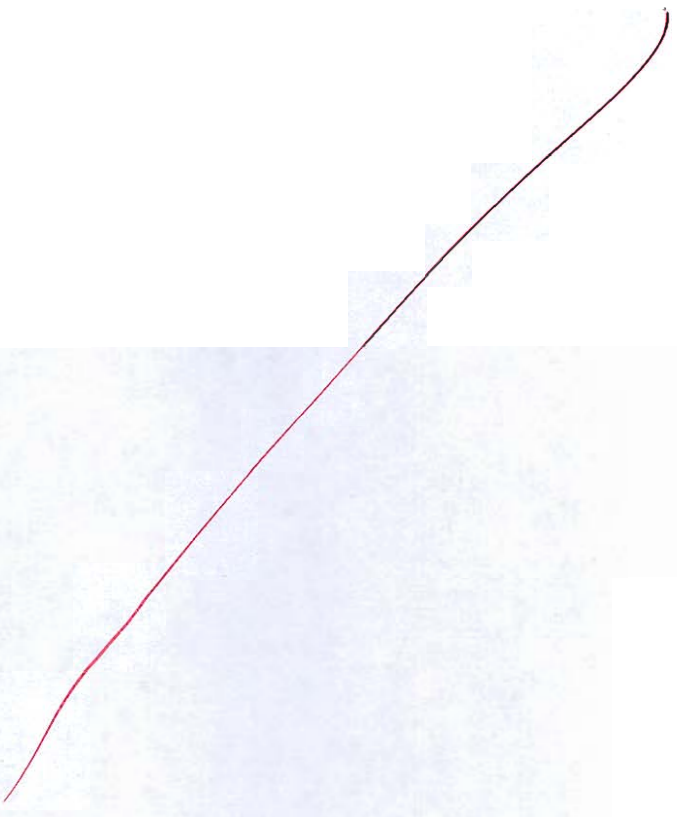
(ii) Power extracted by the turbine.

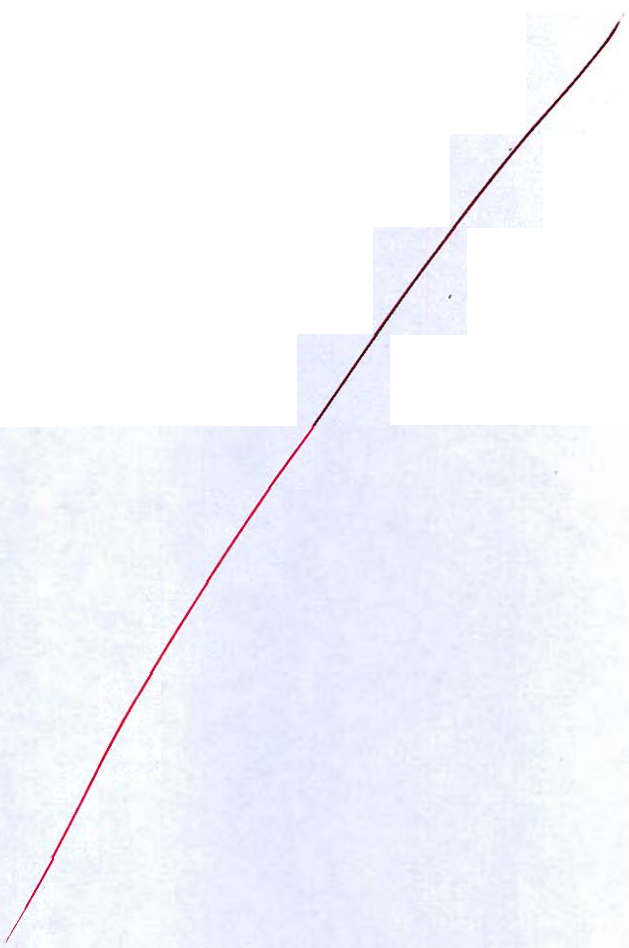
(iii) Electrical power generated.

(iv) Axial thrust on the turbine.

(v) Maximum axial thrust on the turbine.

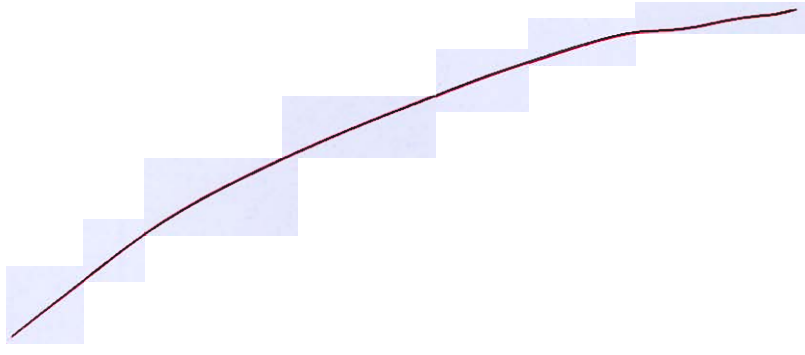
[10 + 10 = 20 marks]

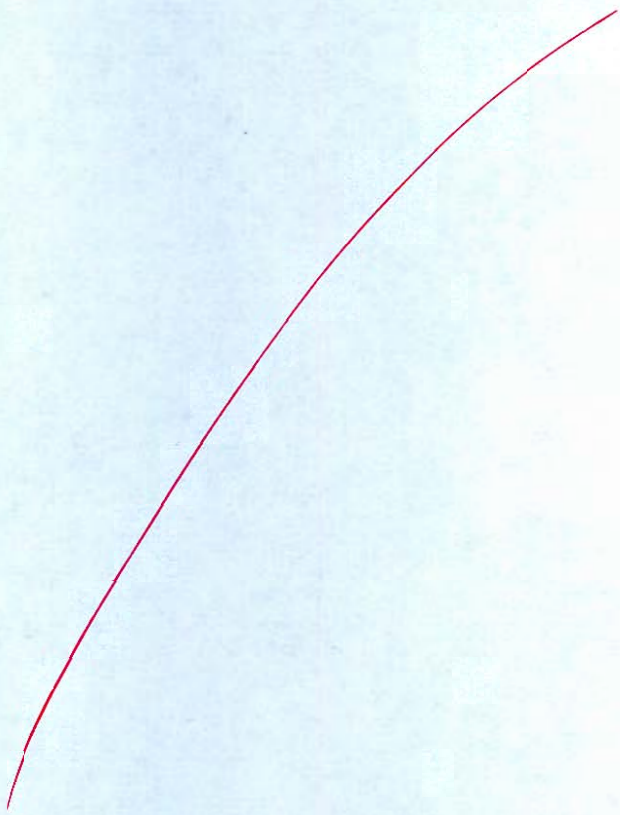


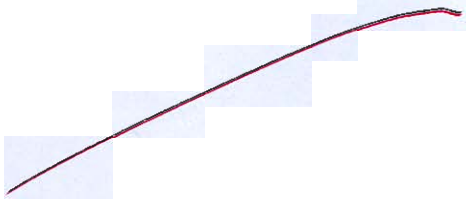


Q.2 (b) What are the differences between destructive and non-destructive tests? Explain with examples. Also, briefly explain various non-destructive testing methods used in engineering practice.

[20 marks]



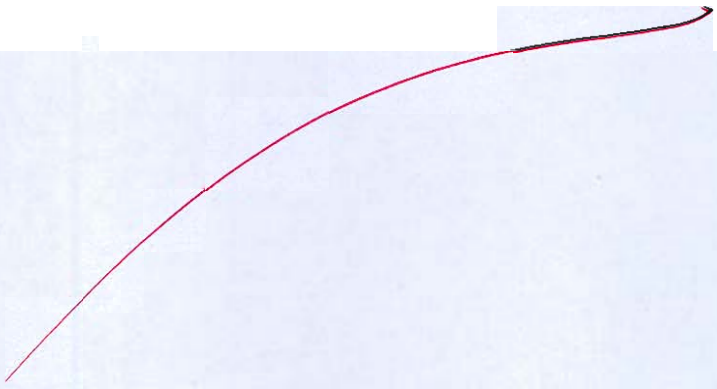


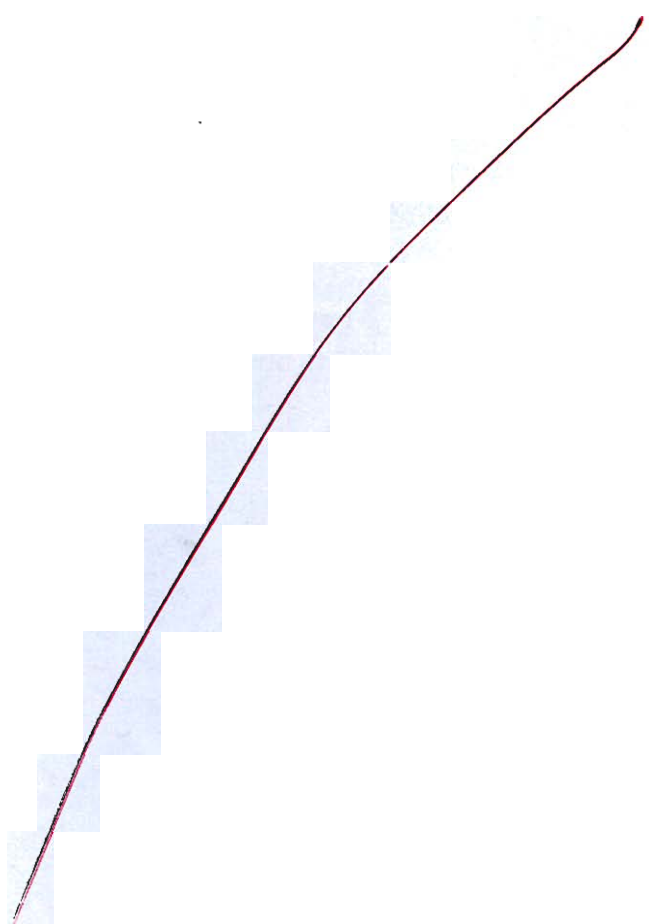


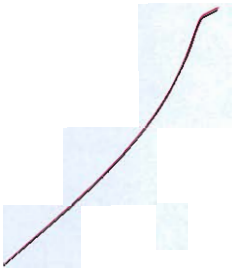
Q.2 (c) (i) Discuss the various condition monitoring technique used in engineering systems. Explain the principles and application of vibration, noise and wear debris monitoring.

(ii) What is a Flexible Manufacturing System (FMS)? What are its importance and advantages in manufacturing and automation?

[10 + 10 = 20 marks]







Q.3 (a) Using actuator disk theory, derive the expression for thrust and power developed by horizontal axis wind turbine. Obtain the power coefficient C_p as a function of axial induction factor and determine the condition for maximum power extraction. Hence, prove that the maximum power coefficient (Betz limit) is $\frac{16}{27}$ and show that the corresponding maximum thrust coefficient, C_f is $\frac{8}{9}$. Clearly, state the all the assumptions involved in the analysis.

[20 marks]

let,

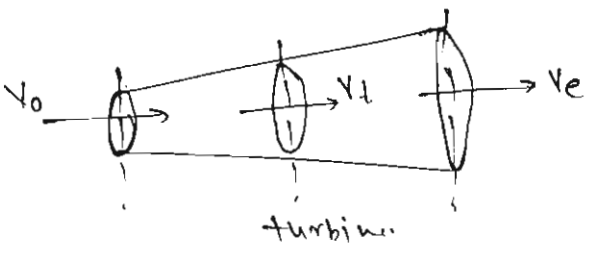
undisturbed wind speed = V_0 , A_t – turbine swept area

wind speed at turbine = V_t ρ – air density.

wind speed downstream = V_e

Now

∴ mass flow of air is constant but wind speed decrease there for flow area increases



Now the maximum power available at turbine is

$$\Rightarrow P_0 = \frac{1}{2} \dot{m} V_0^2 = \frac{1}{2} (\rho A_t V_t) V_0^2 \quad \text{—— (1)}$$

Now using, Energy balance

the power extracted from turbine (P_t) is equal to the change in kinetic energy of wind across the turbine.

$$\Rightarrow P_t = \frac{1}{2} \dot{m} (V_0^2 - V_e^2) = \frac{1}{2} (\rho A_t V_t) (V_0^2 - V_e^2) \quad \text{——(2)}$$

and

Axial thrust force (F_A) on the turbine blade is given in terms of change in momentum of wind

$$\Rightarrow F_A = \dot{m} (V_i - V_e) = \dot{m} (\rho A_t V_t) (V_0 - V_e) \quad \text{—(3)}$$

Power extracted at turbine can also be given as -

$$P_t = F_A \cdot V_t = \rho A_t V_t (V_0 - V_e) V_t$$

$$= \rho A_t V_t^2 (V_0 - V_e) \quad \text{—— (4)}$$

Now from equation (2) and (4)

$$\rho A_t V_t^2 (V_0 - V_e) = \frac{1}{2} \rho A_t V_t (V_0^2 - V_e^2)$$

$$\Rightarrow V_t = \frac{V_0 + V_e}{2}$$

$\therefore$ Axial induction factor (a) $= \dfrac{V_i - V_t}{V_i} = \dfrac{V_0 - V_t}{V_0}$

Now express V_t, V_e, P_t in terms of a and V_0

$$\Rightarrow V_t = (1-a) V_0 \quad \text{and}$$

$$V_e = (1-2a) V_0$$

Now using V_t and V_e in equation —(2)

$$P_t = \frac{1}{2} \rho A_t (1-a) V_0 \left(V_0^2 - (1-2a)^2 V_0^2 \right)$$

$$= \frac{1}{2} \rho A_t V_0^3 (1-a) \left[1 - 4a^2 - 1 + 4a \right]$$

$$= \frac{1}{2} \rho A_t V_0^3 (1-a) (4a - 4a^2)$$

$$= \frac{1}{2} \rho A_t V_0^3 \, 4a (1-a)^2$$

$$\Rightarrow \boxed{P_t = 4a(1-a)^2 \times \frac{1}{2} \rho A_t V_0^3}$$

↳ Power developed by turbine.

$$\therefore P_t = C_p \times \frac{1}{2} \rho A_t V_0^3$$

where $\boxed{C_p = 4a(1-a)^2}$

= power coefficient

Now for a constant wind speed (V_0)

For maximum power $\frac{dP_t}{da} = 0$

$$\Rightarrow 4a(1-a)(-2) + 4(1-a)^2 = 0$$

$$+ 8a(1-a) = 4(1-a)^2$$

$$\Rightarrow a = 1 \quad \text{or} \quad 8a = (1-a)4$$

$$3a = 1$$

$$a = 1/3$$

$\Rightarrow$ For maximum power, induction factor $(a) = \frac{1}{3}$

Now at $P_{t\max}$, power coefficient ($C_{p\max}$) is

$$C_{p\max} = 4a(1-a)^2 = 4 \times \frac{1}{3} \left(1 - \frac{1}{3}\right)^2$$

$$= \frac{4}{3} \times \frac{4}{9}$$

$$\boxed{C_{p\max} = \frac{16}{27}}$$ Hence prove.

↳ this is known a Betz limit.

From equation, (3) and V_t and V_e

$$F_A = \rho A_t V_t (V_0 - V_e)$$

$$= \rho A_t (1-a) V_0 (V_0 - (1-2a) V_0)$$

$$= \rho A_t V_0^2 (1-a) \frac{(2a)}{2} \times 2$$

$$f_A = 4a(1-a) \frac{1}{2} \rho A_t V_0^2$$

Here $4a(1-a) = C_f$ = ~~thrust~~ Force coefficient. (thrust coefficient)

$\because$ C_F value at $a = \frac{1}{3}$ for P_{max}

$\therefore (C_f)_{max} = 4a(1-a) = 4 \times \frac{1}{3} \left(1 - \frac{1}{3}\right)$

$$= \frac{4}{3} \times \frac{2}{3}$$

$$\boxed{C_{f\,max} = \frac{8}{9}}$$ Hence prove.

Expression of Power developed in terms of a and V_0 is

$$P_t = 4a(1-a)^2 \times \frac{1}{2} \rho A_t V_0^3$$ and

Expression of thrust in terms of a and V_0 is

$$F_A = 4a(1-a) \frac{1}{2} \rho A_t V_0^2$$

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Q.3 (b) Discuss the classification of fuel cells based on electrolyte type, chemical nature of electrolyte and operating temperature. With the help of a neat labelled diagram, describe the construction and working of a Proton Exchange Membrane Fuel Cell (PEMFC). Also, state the electro-chemical reactions occurring at the electrodes.

[20 marks]

Based on electrolyte the classification of fuel cell is

(i) proton Exchange membrane fuel cell (PEMFC)

(ii) Phosphoric acid fuel cell (PAFC)

(iii) Alkaline fuel cell (AFC)

(iv) molten carbonate fuel cell (MCFC)

(v) Solid oxide fuel cell (SOFC)

(vi) Direct methane Fuel cell (DMFC)

Based on Chemical nature of electrolyte.

(1) Acidic type of electrolyte

(2) Alkaline type of electrolyte

(3) Neutral type of electrolyte.

Based on temperature range of operation

(1) low temperature operation (upto 150°C)

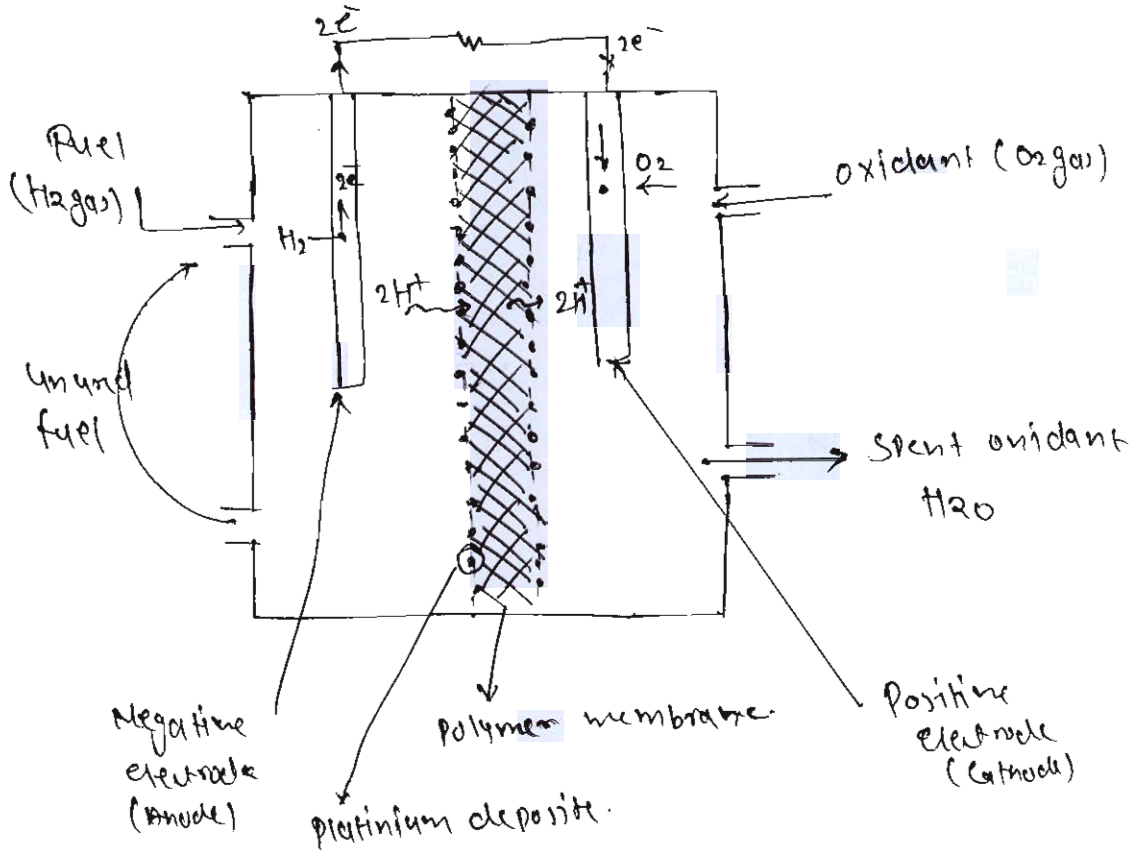
(2) medium temperature operation (150°C to 250°C)

(3) High temperature operation (500°C to 1000°C)

Proton Exchange membrane fuel cell

Polymer membrane

- It is a solid porous membrane made of organic material and coated with finly divided platinum powered in order to accelerate the reaction.
- It is porous for H^+ ion to transport from −ve to +ve electrode but non conductive for electrons.



- PEMFC used two electrode made up of Nickel (commonly) as an anode and cathode.

- Working.

Reaction

At anode

Hydrogen atom will dissociated in H^+ ion and equal number of electron

$$H_2 \xrightarrow[Pt]{\text{Catalyst}} 2H^+ + 2e^-$$

Now the electron is migrated toward positive electrode through external circuit and H^+ is transported toward positive electrode through polymer membrane.

At Cathode

The H^+ ion, oxygen and e^- from external load react to produce H_2O.

At $\frac{1}{2}O_2 + 2H^+ + 2e^- \longrightarrow H_2O$

⇒ Overall reaction

$H_2 + \frac{1}{2}O_2 \xrightarrow[Pt.]{\text{Catalyst}} H_2O$

Application : Residential, Cellular phone, portable laptops, buses, Cars etc.

18

Q.3 (c) (i) A microwave transmitter has exhibited a constant failure-rate of 0.00034 failure per operating hour. The reliability function is given by

$R(t) = e^{-0.00034t}$

1. Determine the reliability over a 30 day continuous period.
2. If a second redundant transmitter is added in parallel to the system, then find the reliability function for the parallel system and its hazard rate function. Also calculate the reliability over a 30 day continuous period.

(ii) Old hens can be bought for Rs 2 but young ones cost Rs 5 each. The old hens lay 3 eggs/week and the young ones lay 5 eggs/week. Each egg being worth 30 paise. A hen cost Rs 1 per week to feed. If a person has only Rs 80 to spend on the hens, how many of each kind should he buy to get a profit of more than Rs. 5.8 per week assuming that he cannot use more than 20 hens. Solve using graphical method.

[10 + 10 = 20 marks]

(i) Given reliability function

$R(t) = e^{-0.00034t}$

(i) $t = 30 \text{ day} \times 24 \frac{\text{hr}}{\text{day}} = 720 \text{ hours.}$

a) $R_1(t = 720\,hr) = \exp(-0.00034 \times 720)$

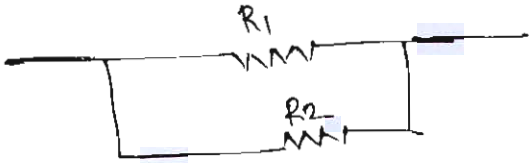
$= 0.78286$

or

78.286%

(2) if redundant transmitter is added parallel

a)



Now reliability of system $(R_s) = R_1 + (1 - R_1) R_2$

and $R_1 = R(t) = \exp(-0.00034t)$

a) $R_s(t) = \exp(-0.00034t) + (1 - \exp(-0.00034t)) \times \exp(-0.00034t)$

$R_s(t) = \exp(-0.00034t)\left(2 - \exp(-0.00034t)\right)$

↳ Reliability function. ——(1)

Now hazard rate $(\lambda(t)) = \dfrac{f(t)}{R(t)}$

where $f(t)$ = probability density function

$= -\dfrac{d\,R(t)}{dt}$

$= +\dfrac{1}{+0.00034} \exp(-0.00034t) - \exp(-0.00034t) \times \left(\dfrac{1}{0.00034} \exp(-0.00034t)\right)$

$= \dfrac{\exp(-0.00034t)}{0.00034}\left[1 - \exp(-0.00034t)\right]$

a) $\lambda(t) = \dfrac{\exp(-0.00034t)\left(1 - \exp(-0.00034t)\right)}{(0.00034)\exp(-0.00034t)\left(2 - \exp(-0.00034t)\right)}$

→ Hazard rate $(d(t)) = \dfrac{2941.1764\left[1 - \exp(-0.000341t)\right]}{\left[2 - \exp(-0.000341t)\right]}$

Now $R(t=720\text{ hr}) = \exp(-0.000341 \times 720)\left[2 - \exp(-0.000341 \times 720)\right]$

$= 0.95285$.

or

$95.285\ \%$.

10

(ii) let,

Number of old hens $= x$

Number of young hens $= y$

objective function, maximization $Z = 3 \times 30\, x + 5 \times 30 \times y$

$= 90x + 150y$

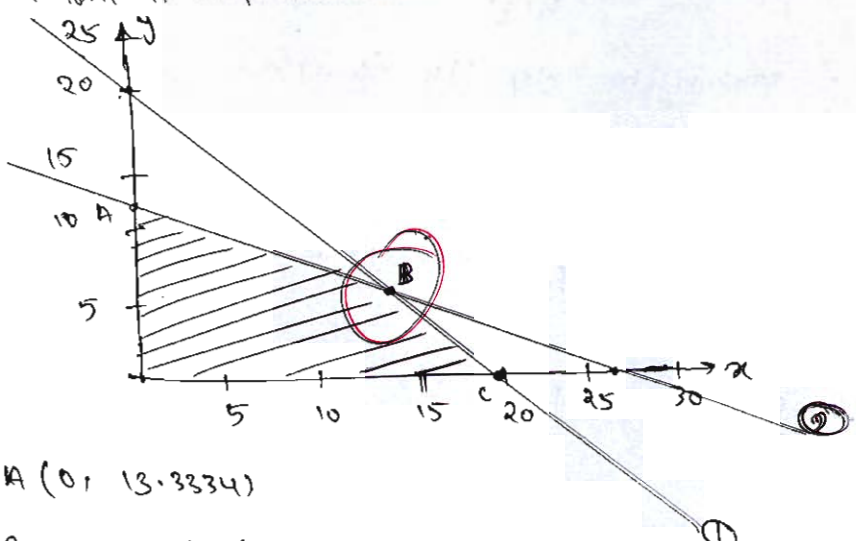
Constraints;

$x + y \leq 20$ —①

$2x + 5y + 1 \times (x+y) \leq 80$

$3x + 6y \leq 80$ —②

Graphical representation



A (0, 13.3334)

Point-B is intersection on equation (1) and (2)

B (13.3334, 6.6667)

C (20, 0)

Now

Z_A = 2000.67 Paisa

Z_B = 2200.671 Paisa

Z_C = 1800 Paisa.

∴ the number of old hens he can buy x = 13 hens

y = 7 hens

4

Q.4 (a) The time estimates (in weeks) for the activities of a PERT network are given below:

Activity	t_0	t_m	t_p
1 - 2	1	1	7
1 - 3	1	4	7
1 - 4	2	2	8
2 - 5	1	1	1
3 - 5	2	5	14
4 - 6	2	5	8
5 - 6	3	6	15

(i) Draw the project network and identify all the paths through it.

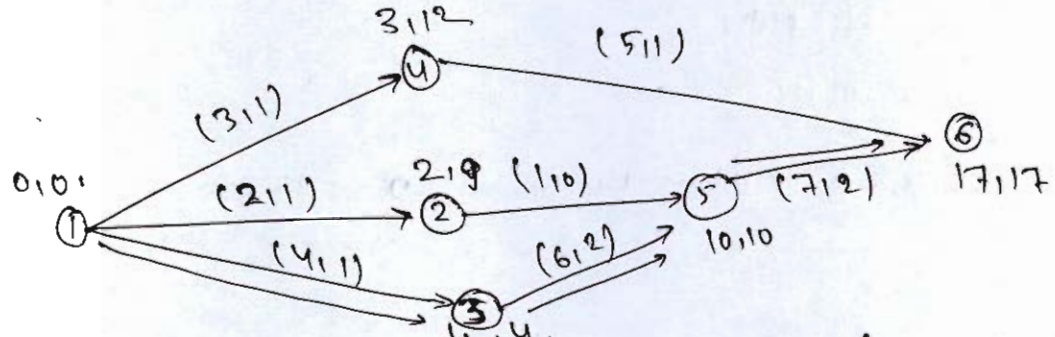
(ii) Determine the expected project length and calculate the standard deviation and variance of the project length.

(iii) What is the probability that the project will be completed

1. at least 4 week earlier than expected time.
2. no more than 4 week later than expected time.

[20 marks]

(i) Network diagram



Activity	to	tm	tp	$t_E = \frac{t_o + 4t_m + t_p}{6}$	$\sigma = \frac{t_p - t_o}{6}$
1-2	1	1	7	2	1
1-3	1	4	7	4	1
1-4	2	2	8	3	1
2-5	1	1	1	1	0
3-5	2	5	14	6	2
4-6	2	5	8	5	1
5-6	3	6	15	7	2

(ii) Expected project length (T_E) = 17 weeks.

Critical path : 1–4–5–6

Standard deviation along Critical path (σ) = $\sqrt{1^2 + 2^2 + 2^2}$

= 3 weeks

Variance of the project length (σ^2) = 3^2 = 9 weeks

(iii) Probability of project completion

(1) If scheduled time (T_S) = 13 weeks

$\therefore$ Normal variant (Z) = $\frac{T_S - T_E}{\sigma}$

= $\frac{13 - 17}{3}$

= $-\frac{4}{3}$

∴ The probability of completion = 0.09121
or
9.121 %

(2) If scheduled time (T_S) = 21 weeks

∴ $Z = \frac{T_S - T_E}{\sigma} = \frac{21 - 17}{3}$

$= \frac{4}{3}$

∴ Probability of completion = 0.90878
or
90.878 %

18

Q.4 (b) A manufacturer of complex electronic equipment has just received a sizable contract and plans to subcontract part of the job. He has solicited bids for 6 subcontracts from 3 firms. Each job is sufficiently large and any firm can take only one job. The table below shows the bids as well as the cost estimates (in thousands of Rs) for doing the job internally. Not more than three jobs can be performed internally.

Firm \ Job	1	2	3	4	5	6
1	44	67	41	53	48	64
2	46	69	40	45	45	68
3	43	73	37	51	44	62
Internal	50	65	35	50	46	63

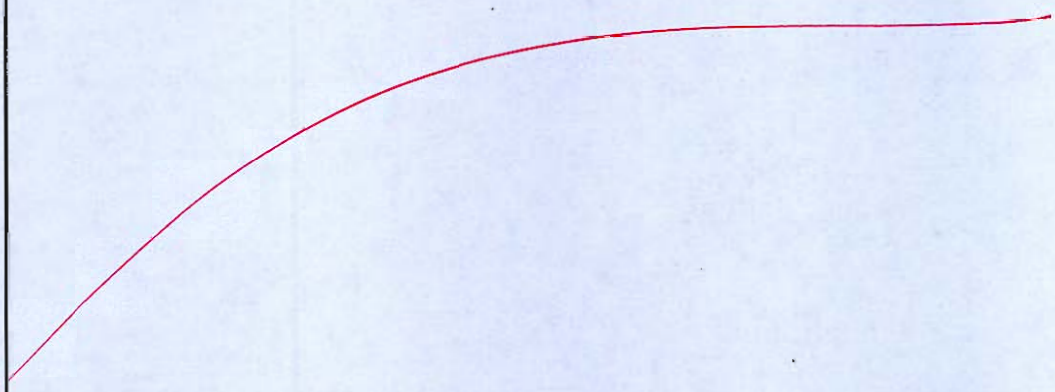
Find the optimal assignment that will result in minimum total cost. Also find total minimum cost.

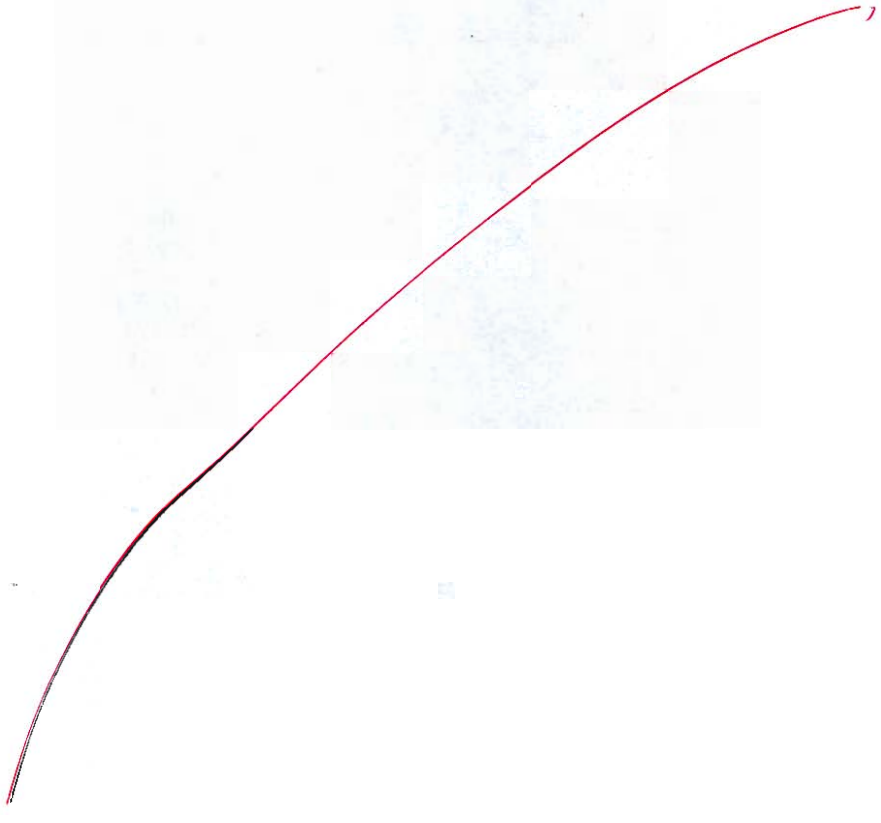
[20 marks]

Given matrix

Firms Jobs →

↓

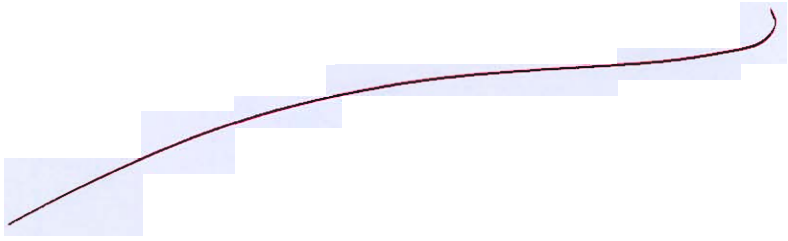


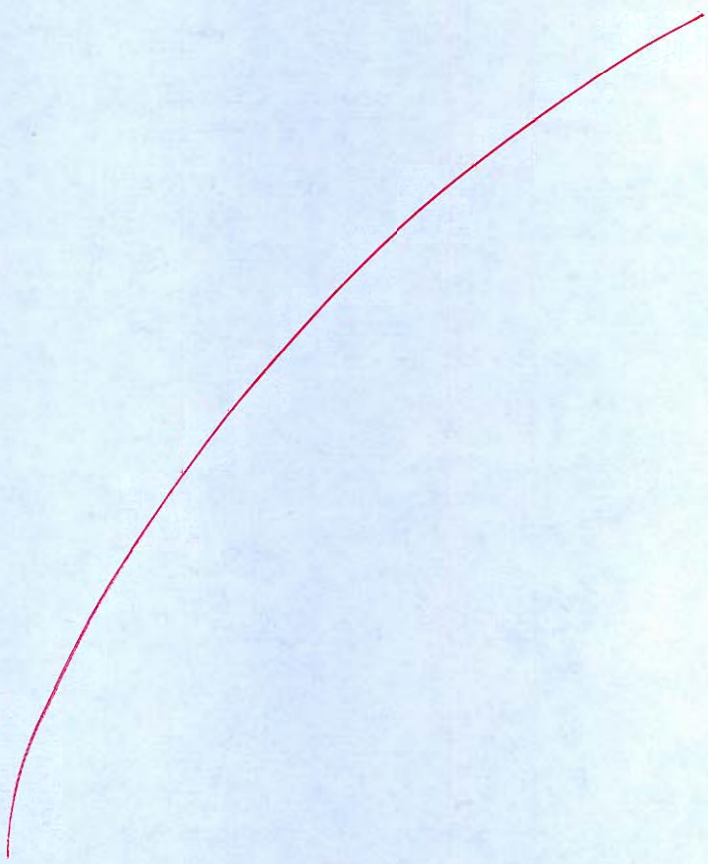


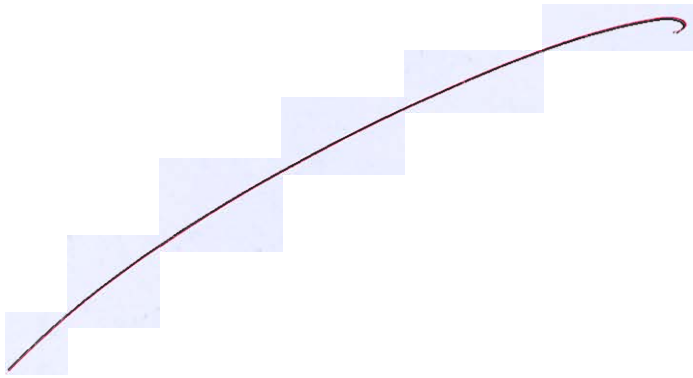
Q.4 (c) Classify tidal power plants based on their mode of operation and basin arrangement. With the help of a neat schematic diagram, explain the working principle of a double-basin tidal power plant with linked-basin operation.

Also, describe the important components of a tidal power plant and list the types of turbines commonly used in tidal energy conversion systems.

[20 marks]







Section B : Production Engineering & Material Science-1 + Theory of Machines-2

Q.5 (a) A cylindrical billet of 40 mm diameter and 110 mm length is reduced by backward extrusion to a diameter of 15 mm. If the Johnson's equation constants are $a = 0.8$ and $b = 1.5$, the strength coefficient of material is 800 MPa and the strain hardening exponent $n = 0.17$. Determine the Extrusion ratio, Extrusion strain, Ram force.

[12 marks]

Given

Initial dia (d_0) = 40 mm

Final dia (d_f) = 15 mm

Billet length (L) = 110 mm.

Johnson's equation constant $a = 0.8$, $b = 1.5$

Strength coefficient (K) = 800 MPa and

Strain hardening exponent (n) = 0.17

* Power law equation is

$$\sigma = K \epsilon^n = 800\, \epsilon^{0.17}$$

$\therefore$ true Strain (ϵ) = $\ln\left(\frac{d_0}{d_f}\right)^2$

$= 2 \ln\left(\frac{40}{15}\right) = 1.9616$

$\because$ Average flow stress $(\bar{\sigma}_0) = \dfrac{K\epsilon^n}{n+1}$

$= \dfrac{800 \times (1.9616)^{0.17}}{1.17} = 766.7396$ MPa.

Now according Johnson's equation

$\sigma_E = \bar{\sigma}_0 (a + b \ln R)$ where R = extrusion ratio $= \dfrac{A_0}{A_f} = \left(\dfrac{d_0}{d_f}\right)^2$

$= 766.7396 \left[0.8 + 1.5 \ln \left(\dfrac{d_0}{d_f}\right)^2\right]$

$= 766.7396 \left[0.8 + 3 \ln \left(\dfrac{40}{15}\right)\right]$

$= 2869.5135$ MPa.

Now ramforce $(F_E) = \sigma_E \times A_0 = \sigma_E \times \dfrac{\pi}{4} d_0^2$

$= 2869.5134 \times \dfrac{\pi}{4} \times (40)^2$

$= \underline{3605.936 \text{ KN}}$ Ans.

11

Extrusion ratio $(R) = \left(\dfrac{d_0}{d_f}\right)^2 = \left(\dfrac{40}{15}\right)^2 = 7.1111$

Extrusion Strain $(\epsilon) = 1.9616$

Q.5 (b) (i) Calculate the gating dimensions with gating ratio of 1 : 2 : 3 for ductile iron-casting of section thickness 12 mm weighing 30 kg. Assume a sprue height of 200 mm. Given pouring time (t) = $k\sqrt{w}$, k = 2.3, for thickness = 12 mm, flow/discharge factor, C_d = 0.9, w = weight of casting(kg), density of iron = 7900 kg/m^3.

(ii) For BCC iron, compute the interplanar spacing and the differaction angle for the (220) set of planes. The lattice parameter for Fe is 0.28 nm. Also, assume that monochromatic radiation having a wavelength of 0.18 nm is used and order of reflection is 1.

[6 + 6 = 12 marks]

(i) Given

Weight of casting (w) = 30kg = 30×9.81 N = 294.3N

Sprue height (h_s) = 200 mm = 0.2m

discharge factor (C_d) = 0.9

density of iron (δ) = 7900 kg/m3

Now: Choke area (C_A) = $\dfrac{m}{\delta C_d t_f \sqrt{2gh_s}}$

$\therefore t_f$ = filling time / Pouring = $\dfrac{\text{Kg}}{\text{Kg/sec}}$ $K\sqrt{w}$ = 2.3$\sqrt{30}$

= 12.5976

$\therefore C_A = \dfrac{30}{7900 \times 0.9 \times 12.5976\sqrt{2\times 9.81\times 0.2}}$ = 1.6908×10^{-4} m^2

= 169.0827 mm^2

$\therefore$ gating ratio 1 : 2 : 3

$A_S : A_R : A_g$

Where A_S – sprue end area

A_R – runner area

A_g – Ingate area.

$\Rightarrow A_S = C_A$ = minimum area.

$\Rightarrow$ A_S = 169.0827 mm^2

and $\dfrac{A_S}{A_g} = \dfrac{1}{3}$

$A_g = 3A_S$

A_g = 507.2483 mm^2

and $\dfrac{A_S}{A_R} = \dfrac{1}{2}$ $\Rightarrow$ $A_R = 2A_S$ =

A_R = 338.1655 mm^2

(ii) Given plane ~~(200)~~ (220) ≡ (h k l)

lattice parameter (a) = 0.28 nm

radiation wavelength (λ) = 0.18 nm

order of reflection (n) = 1

∴ Interplanar spacing $(d) = \frac{a}{\sqrt{h^2+k^2+l^2}}$

$= \frac{0.28}{\sqrt{2^2+2^2+0}}$

$\boxed{d = 0.09899 \text{ nm}}$

and, from Bragg's law

∴ $n\lambda = 2d \sin\theta$ where θ - diffraction angle

$1 \times 0.18 = 2 \times 0.09899 \sin\theta$

$\Rightarrow \boxed{\theta = 65.3926^\circ}$

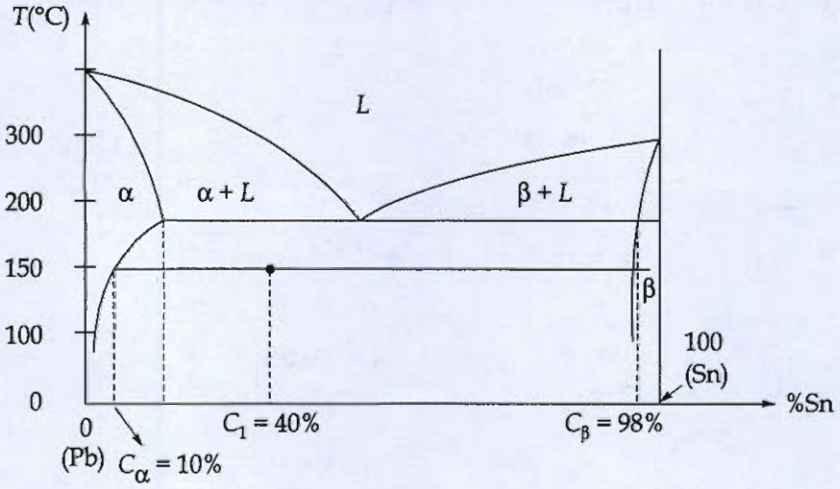
↳ Diffraction angle.

Diffraction angle is 2θ.

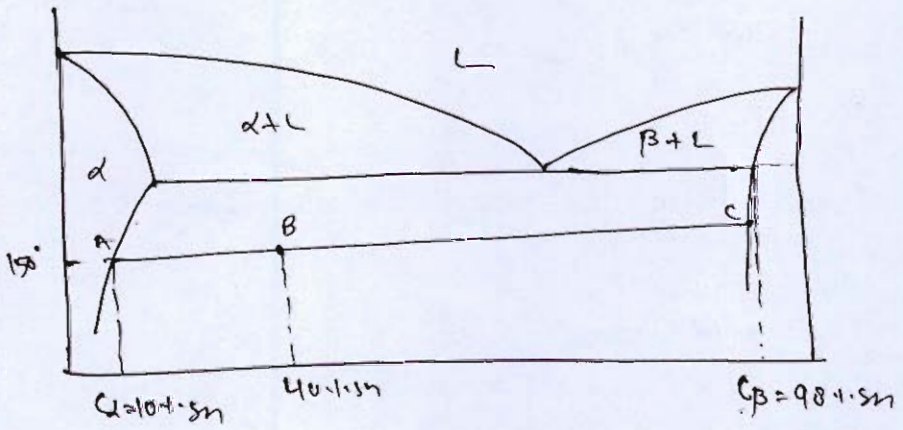
5

Q.5 (c) Determine the mass fraction and volume fraction of each phase for a 40% by wt. Sn. and 60% by wt. Pb alloy at 150°C.

Take; $\rho_{Sn} = 7.24\ g/cm^3$; $\rho_{Pb} = 11.23\ g/cm^3$



[12 marks]



Now

mass fraction of α-phase (m_α) $= \frac{BC}{AC} = \frac{98-40}{98-10} = 0.65909$

mass fraction of β-phase (m_β) $= \frac{AB}{AC} = \frac{40-10}{98-10} = 0.3409$

Now volume fraction of α-phase (V_α) $= \frac{\text{Volume of } \alpha\text{-phase}}{\text{Volume of } \alpha\text{-phase} + \text{Volume of } \beta\text{ phase}}$

where

ρ_α, ρ_β are density of α, β phase.

$$= \frac{\frac{m_\alpha}{\rho_\alpha}}{\frac{m_\alpha}{\rho_\alpha} + \frac{m_\beta}{\rho_\beta}}$$

$$\therefore \frac{100}{\rho_\alpha} = \frac{(C_{Sn})_\alpha}{\rho_{Sn}} + \frac{(C_{Pb})_\alpha}{\rho_{Pb}}$$

Similarly $\frac{100}{\rho_\beta} = \frac{(C_{Sn})_\beta}{\rho_{Sn}} + \frac{(C_{Pb})_\beta}{\rho_{Pb}}$

$$\frac{100}{\delta_\alpha} = \frac{10}{7.24} + \frac{90}{11.23} \qquad \frac{100}{\delta_\beta} = \frac{98}{7.24} + \frac{2}{11.23}$$

$$\delta_\alpha = 10.6434 \text{ g/cm}^3 \qquad \delta_\beta = 7.2918 \text{ g/cm}^3$$

$$\therefore \text{Volume of } \alpha\text{-phase} = \frac{\frac{0.65909}{10.6434}}{\frac{0.65909}{10.6434} + \frac{0.3409}{7.2918}} = 0.5698$$

and

similarly

$$\text{Volume of } \beta\text{-phase} = \frac{\frac{m_\beta}{\delta_\beta}}{\frac{m_\beta}{\delta_\beta} + \frac{m_\alpha}{\delta_\alpha}} = \frac{\frac{0.3409}{7.2918}}{\frac{0.65909}{10.6434} + \frac{0.3409}{7.2918}}$$

$$= 0.4302$$

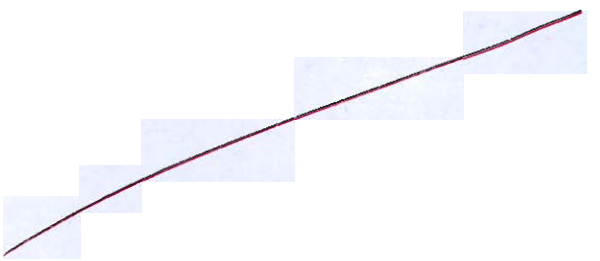
12

Q.5 (d) Define the following terms commonly used in laying out the cam profiles **with** a neat sketch.

(a) Base circle (b) Trace point

(c) Pitch curve (d) Pressure angle

[12 marks]



Q.5 (e) A pinion of 20° involute teeth rotating at 300 rpm meshes with a gear and provides a gear ratio of 2.4. The number of teeth on the pinion is 20 and module is 8 mm. If the interference is just avoided, determine (i) addenda on the wheel and the pinion (ii) path of contact and (iii) the maximum velocity of sliding on both sides of the pitch point.

[12 marks]

Given

Pressure angle (ϕ) = 20°

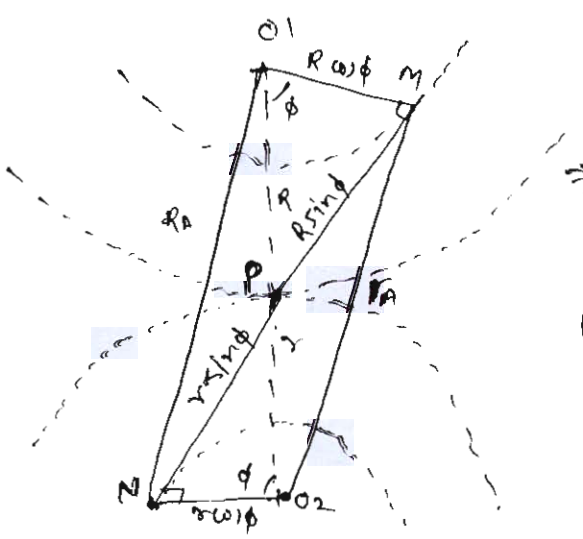
Pinion speed (N_p) = 300 rpm

Gear ratio (G) = 2.4 = $\frac{T}{t} = \frac{\omega_p}{\omega_G}$

Number of teeth on pinion (t) = 20 $\Rightarrow \frac{T}{t} = 2.4$

$T = 48$ teeth on Gear

module (m) = 8 mm



$\Rightarrow$ Configuration at point, just avoid interference

$\Rightarrow$ point of contact

$(PQ)_{max} = \max [R \sin\phi, r \sin\phi]$

$= \max [64.9838, 27.7616]$

$= 64.9838$ mm.

Here

O_1 – Gear Centre

O_2 – Pinion centre.

R_A / r_A – Gear and pinion addendum radius

R, r – Gear and pinion pitch circle radius.

$\therefore m = \frac{2R}{T}$ and $m = \frac{2r}{t}$

$\Rightarrow R = \frac{mT}{2} = 192\,mm$, $r = \frac{mt}{2} = 80\,mm$.

Now, From figure shown above

(i) in $\Delta O_1 M N$

$R_A^2 = (R\cos\phi)^2 + (R\sin\phi + r\sin\phi)^2$

$= 192^2 \cos^2(20) + (192 + 80)^2 \times \sin^2(20)$

$R_A = 213.3526\,mm$

$\therefore R_A = R + A_G \Rightarrow$ Gear Addendum $(A_G) = R_A - R$

$= 21.3526\,mm$

Similarly

In $\Delta O_2 N M$

$r_A^2 = (r\cos\phi)^2 + (R\sin\phi + r\sin\phi)^2$

$= 80^2 \cos^2(20) + (192 + 80)^2 \sin^2 20$

$r_A = 122.7\,mm$

$\therefore r_A = r + A_p \Rightarrow$ Pinion addendum $(A_p) = r_A - r$

$= 42.7\,mm$

(ii) Path of contact (PoC) $= R\sin\phi + r\sin\phi$

$= (192 + 80)\sin(20) = 93.0294\,mm$.

(iii) maximum Sliding Velocity $= (\omega_p + \omega_G) \times (OP)_{max}$

$= \left(\frac{2\pi N_P}{60} + \frac{2\pi N_G}{60}\right) \times \frac{64.9838\,m}{1000}$

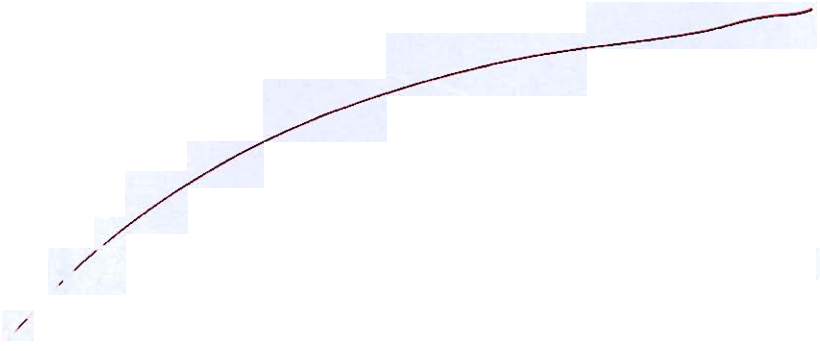
$= \frac{2\pi}{60}\left(3000 + \frac{3000}{2.4}\right) \times \frac{64.9838}{1000}$

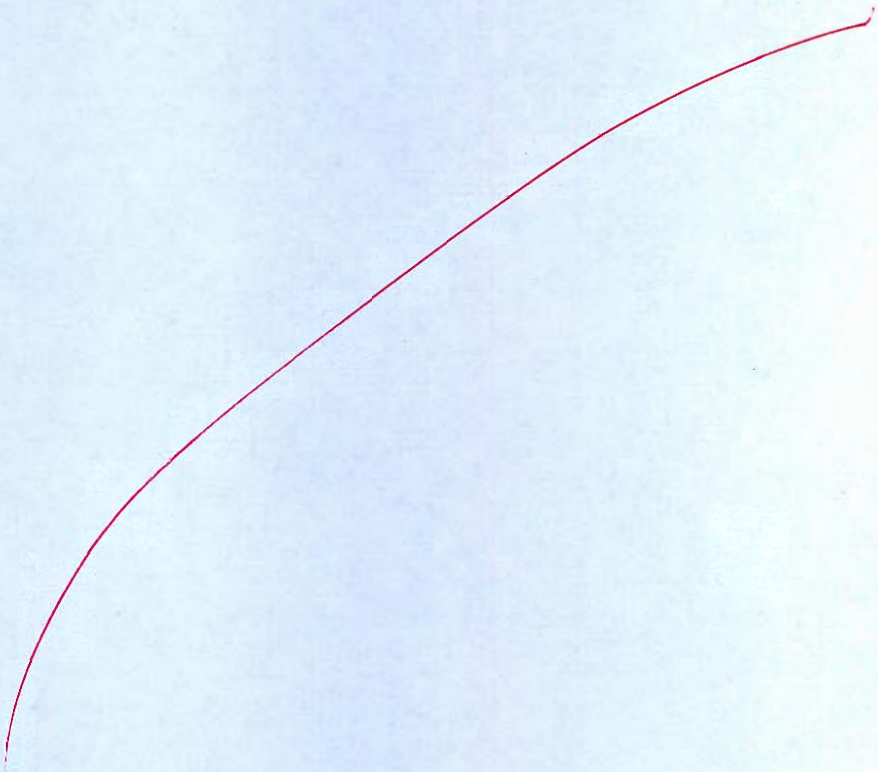
$= 28.9216\,m/sec$

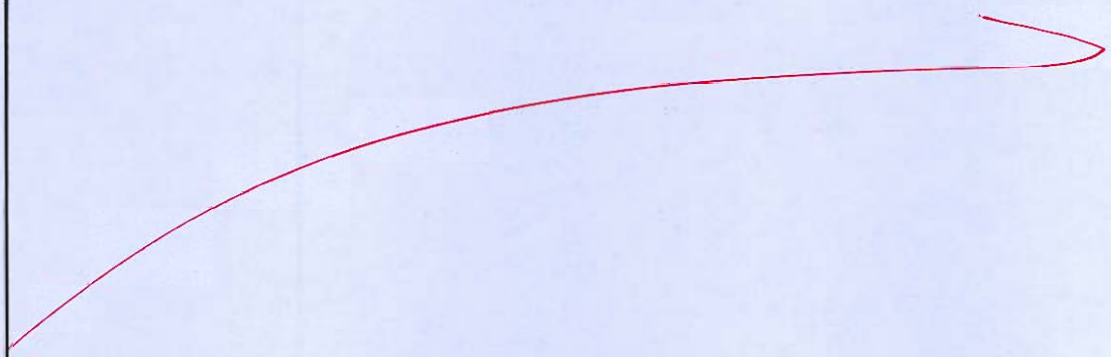
Ans

Q.6 (a) The intermediate cranks of a four-cylinder symmetrical engine, which is in complete primary balance, are at 90° to each other and has a reciprocating mass of 400 kg. The centre distance between intermediate cranks is 600 mm and between extreme cranks, it is 1800 mm. Length of the connecting rods and the cranks are 900 mm and 200 mm respectively. Calculate the masses fixed to the extreme cranks with their relative angular positions. Also, find the magnitude of the secondary forces and couples about the centre line of the system if the engine speed is 150 rpm.

[20 marks]



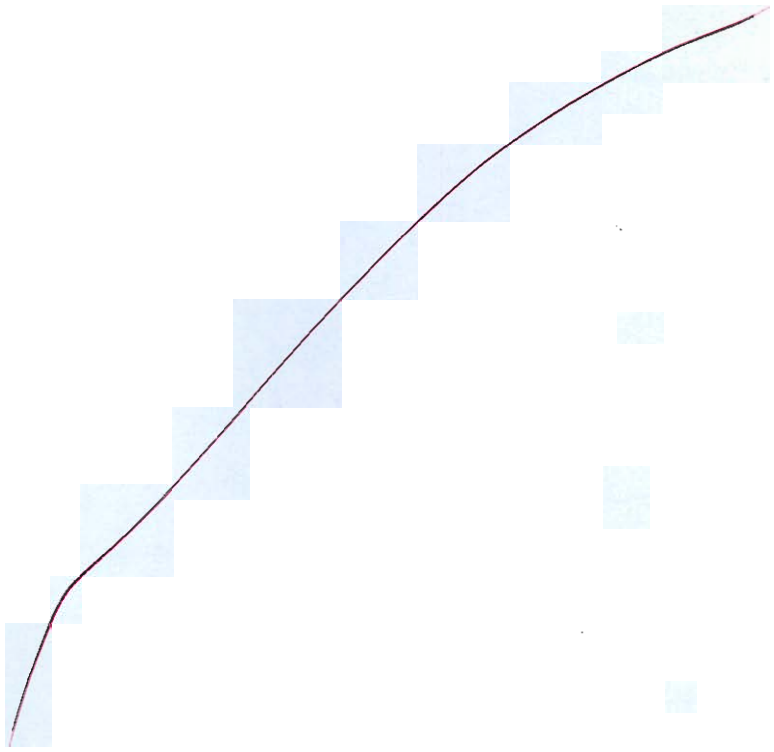


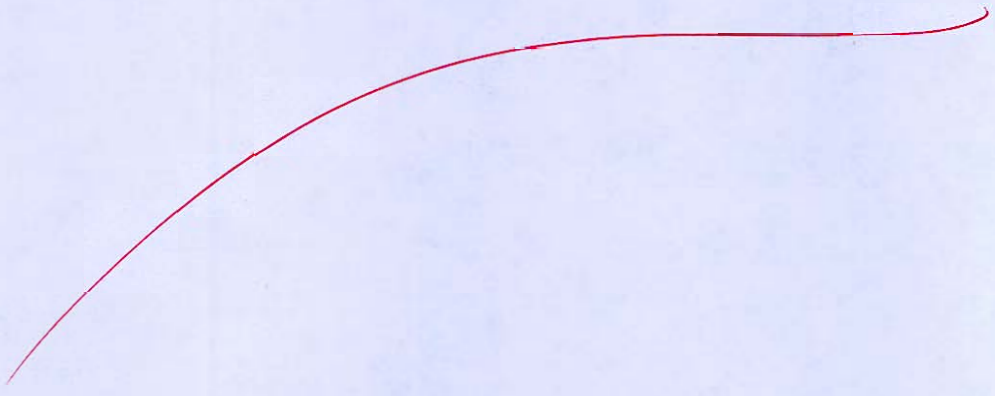


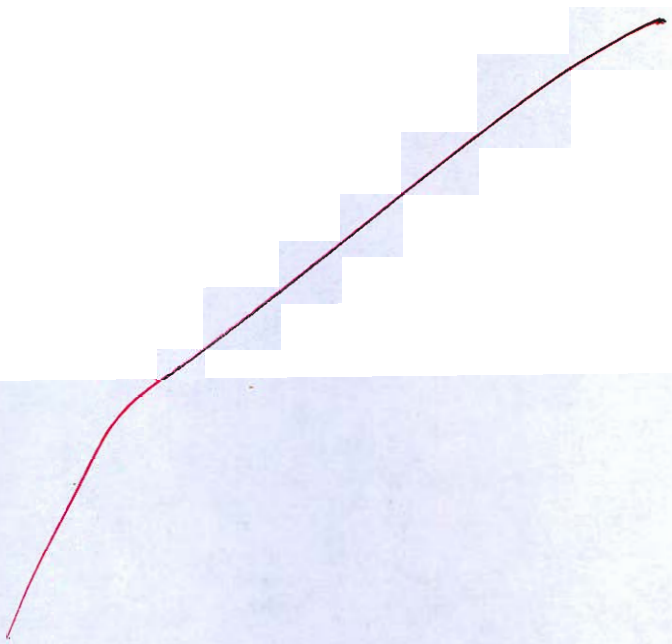
Q.6 (b) **(i)** Write the various characteristics of miller indices of plane as well as direction.

(ii) Define planar and linear density. Also calculate the planar and linear density of 111 plane and direction respectively of BCC and FCC crystal structure along with suitable diagrams.

[8 + 12 = 20 marks]

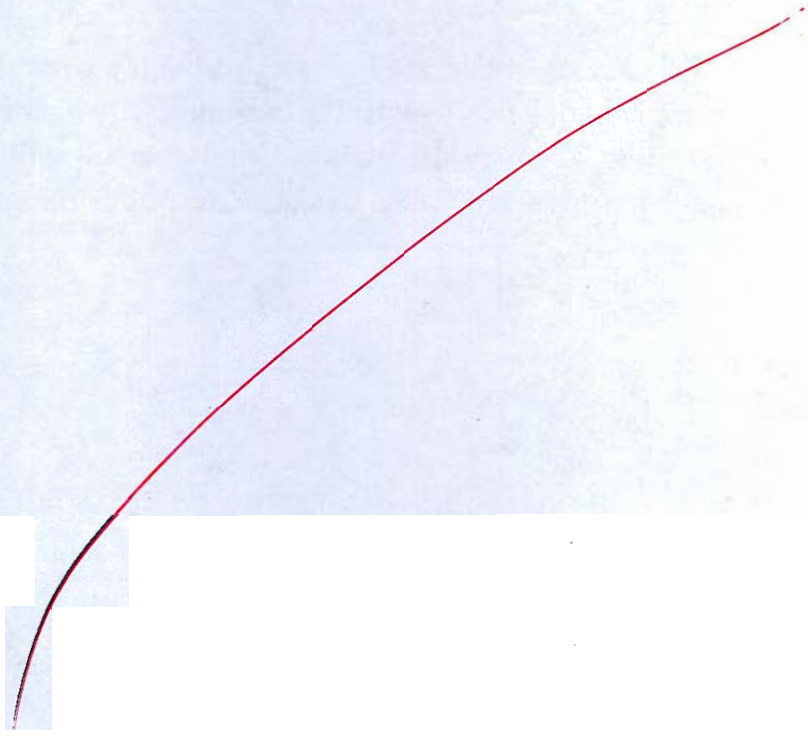


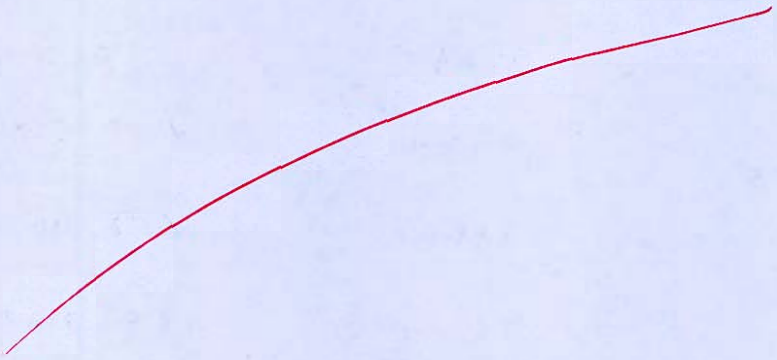




Q.6 (c) In a wire drawing operation after passing through a conical portion, the wire passes through a die land of 4 mm length. The incoming wire diameter is 8 mm and outgoing diameter is 6 mm. The semi-die angle is 8° and co-efficient of friction is 0.05. If nominal strength of the material is 30 MPa. Calculate the pull required to draw the wire.

[20 marks]





Q.7 (a) (i) What are the basis of Bravais crystal structures? Enlist different unit cell and space lattices under Bravais crystal systems.

(ii) Zinc has atomic radius of 0.133 nm and atomic weight of 65.39 g/mol. Calculate the theoretical density of zinc [HCP structure]

[10 + 10 = 20 marks]

(i)

Bravais Crystal Structure represents the arrangement of crystal atoms in different shape of unit cells and in different - different location.

Bravais lattice are classified into 7 different types based on X-diffraction technique

The 7 known bravais lattic and their lattice parameter relations are.

let, a, b, c are lattic dimension

α, β, γ are angle between lattice axis.

lattice type	lattice dimension	lattic angle.
Cubic	$a=b=c$	$\alpha=\beta=\gamma=90$
tetragonal	$a=b\neq c$	$\alpha=\beta=\gamma=90$
orthorhombic	$a\neq b\neq c$	$\alpha=\beta=\gamma=90$
monoclinic	$a\neq b\neq c$	$\alpha=\gamma=90$, $\beta\neq 90$
Triclinic	$a\neq b\neq c$	$\alpha\neq\beta\neq\gamma\neq 90$
Hexagonal	$a=b\neq c$	$\alpha=\beta=90$, $\gamma=120$
Rhombohedral	$a=b=c$	$\alpha=\beta=\gamma\neq 90$

7

(ii) Given

atomic radius (r) = 0.133 nm

atomic weight (A) = 65.39 g/mol

$$\therefore \text{theoretical density} = \frac{\text{total atomic weight}}{\text{Volume of unit cell}}$$

$$= \frac{A \times N_{av}}{6.023 \times 10^{-23} \times \text{Volume of unit cell}}$$

where

N_{av} = Average number of atom in a unit cell

= 6

$$\text{Volume of unit cell} = 6 \times \frac{\sqrt{3}}{4} a^2 \times c = 6 \times \frac{\sqrt{3}}{4} a^2 \times 1.633\, a$$

$$= 6 \frac{\sqrt{3}}{4} \times 1.633\, a^3$$

4

$$\therefore \text{theoretical density} = \frac{65.39 \times 6}{6.023 \times 10^{-23} \times \left(6 \frac{\sqrt{3}}{4} \times 1.633 \times a^3\right)}$$

$$= \frac{1.53536 \times 10^{2}\, g}{a^3}$$

∴ In case of HCP structure.

$a = 2r$ ⇒ $a = 2 \times 0.133$ nm. = 0.266 nm.

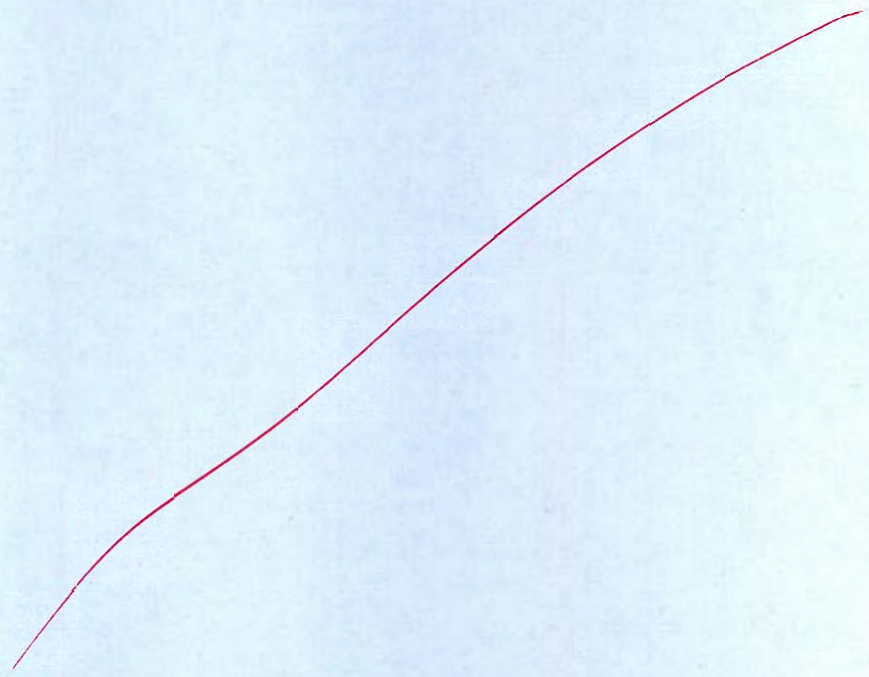
$$\therefore \text{theoretical density} = \frac{1.53536 \times 10^{-22}}{(0.266 \times 10^{-9})^3}$$

$$= 81.5765 \times 10^5 \frac{g}{m^3}$$

$$\text{theoretical density} = 8157.65 \frac{kg}{m^3}$$ Ans.

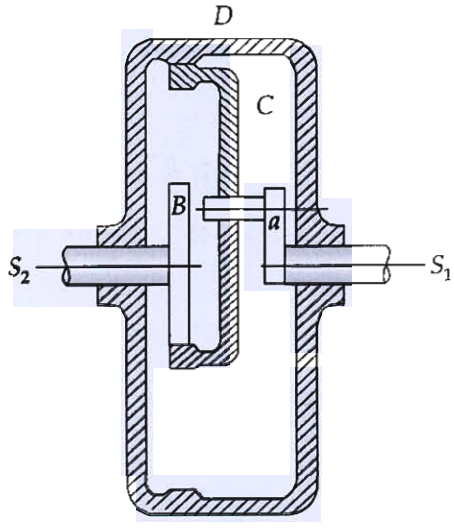
Q.7 (b) What are various Rapid-Prototyping techniques? Briefly explain Stereolithography and Selective-Laser Sintering. Also mention their advantages and disadvantages.

[20 marks]



Q.7 (c) **(i)** Each wheel of a motorcycle is of 650 mm diameter and has a moment of inertia of 1.3 kg.m^2. The total mass of motorcycle and the rider is 200 kg and the combined centre of mass is 590 mm above the ground level when the motorcycle is upright. The moment of inertia of the rotating parts of the engine is 0.2 kgm^2. The engine speed is 6 times the speed of the wheels and is in the same sense. Determine the angle of heel necessary when the motorcycle takes a turn of 30 m radius at a speed of 50 km/h.

(ii) In the epicyclic gear train shown in figure, a gear C which has teeth cut internally and externally is free to rotate on a arm driven by the shaft S_1. It meshes externally with the casing D and internally with the pinion B. The gears have the following number of teeth:



$T_B = 24$, $T_C = 30$ and 36, $T_D = 44$

Find the velocity ratio between

1. S_1 and S_2 when D is fixed
2. S_1 and D when S_2 is fixed

What will be the torque required to fix the casing D, if a torque of 300 Nm is applied to the shaft S_1?

[10 + 10 = 20 marks]

(i) Given

diameter of wheel $(d_w) = 650$ mm

moment of inertia of wheel $(I_w) = 1.3$ kg-m^2

total mass $(m) = 200$ kg

height of centre of mass $(h) = 590$ mm

moment of inertia of rotating part $(I_E) = 0.2$ kg-m^2

Engine speed $(\omega_E) = 6 \times$ wheel speed (ω_w)

radius of turn $(R) = 30$ m

Speed of turn (V) = $\frac{50}{} \frac{km}{hr}$ = 13.8889 m/s

$\therefore$ Angular velocity of precision (ω_p) = $\frac{V}{R} = \frac{13.8889}{30}$

= 0.46296 rad/sec

and

Angular velocity of wheel (ω_w) = $\frac{V}{\left(\frac{dw}{2}\right)}$

= $\frac{13.8889 \times 2}{650 \times 10^{-3}}$

= 42.7351 rad/sec

$\therefore$ Angular velocity of engine (ω_E) = 6 x ω_w

= 256.4104 rad/sec.

(4)

$\therefore$ Angle of heel (α) is,

$$\tan\alpha = \frac{(2 I_w \omega_w \pm I_E \omega_E)\omega_p + \frac{mV^2}{R} \times h}{mgh}$$

$$= \frac{(2 \times 1.3 \times 42.7351 + 0.2 \times 256.4104) \times 0.46296 + \frac{200 \times (13.8889)^2}{30} \times 0.59}{200 \times 9.81 \times 0.58}$$

$\tan\alpha$ = 0.75899

$\Rightarrow$ $\alpha = 37.1984^\circ$

$\hookrightarrow$ Angle of heel necessary.

(ii) Using tabular method

motion	Gear - B (24)	Gear (30)	Gear - D (64)	Arm
With respect to arm	$+x$	$+\frac{24x}{30}$	$-\frac{24x}{30}\times\frac{30}{44}$	0
With respect to ground	$y+x$	$y+\frac{4x}{5}$	$y-\frac{12x}{22}$	y
	N_B	N_C	N_D	

(1) $\because$ D - fixed

$N_D = 0 \Rightarrow y = \frac{12x}{22}$

$\therefore \frac{N_B}{N_C} = \frac{y+x}{y+\frac{4x}{5}} = \frac{\frac{12x}{22}+x}{\frac{12x}{22}+\frac{4x}{5}} = \frac{12+22}{12\times5+22\times4}$

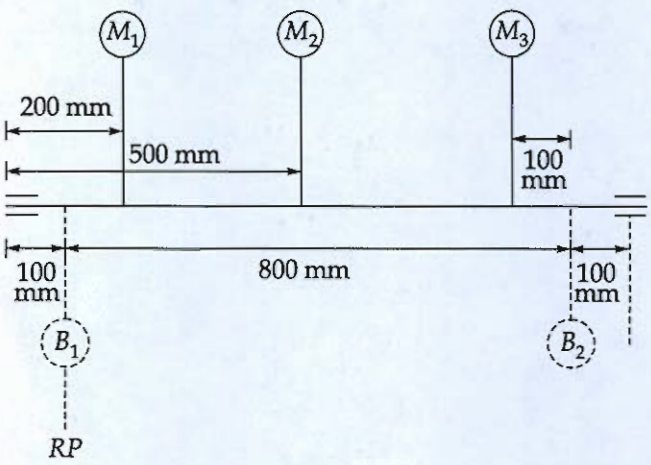
$= 0.2297$

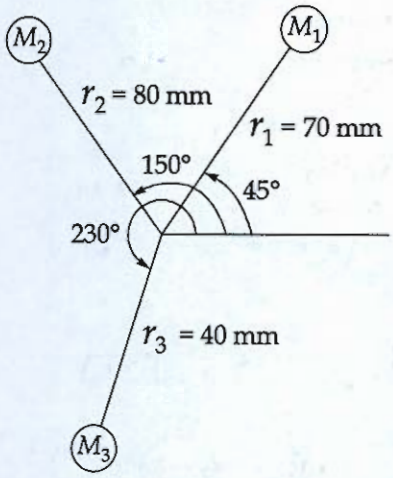
(2) When Gear B - fixed

$\because N_B = 0 \Rightarrow y = -x$

$\therefore \frac{S_1}{D} =$

Q.8 (a) Three masses M_1 = 5 kg, M_2 = 6 kg and M_3 = 5 kg are rotating in different planes as shown in figure. Two balancing masses are B_1 and B_2 are placed at 100 mm from each at 80 mm radius. Find the magnitude and angular positions of the balancing masses.

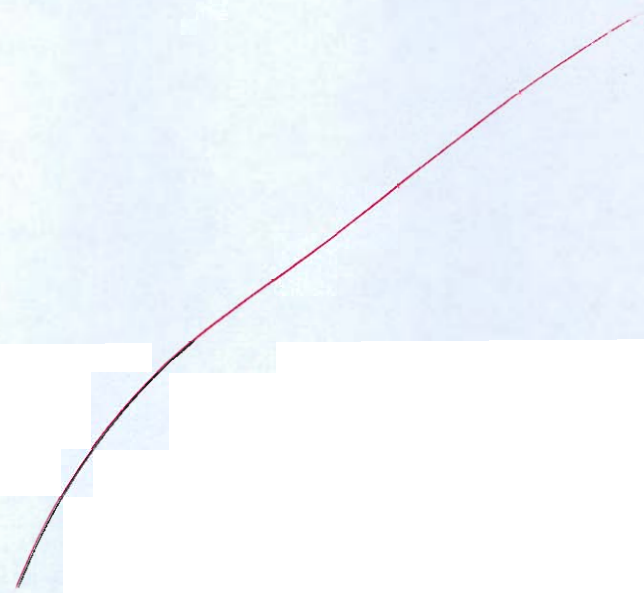


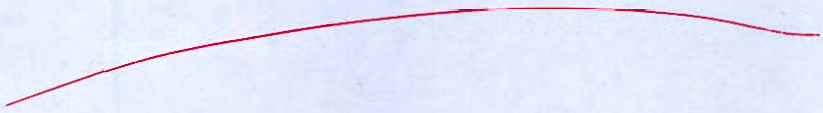


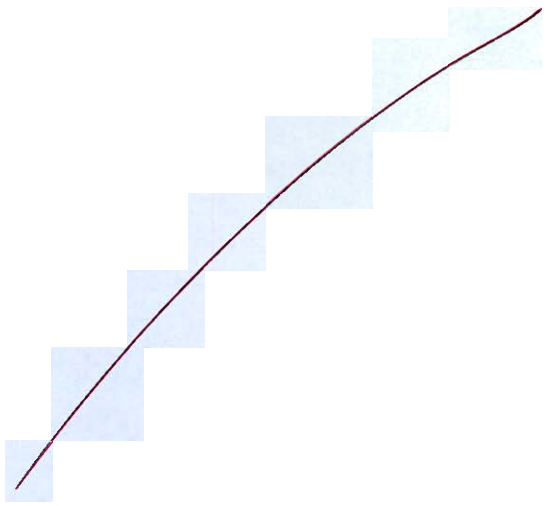
[20 marks]

Q.8 (b) For a continuous and oriented fiber reinforced composite, the moduli of elasticity in longitudinal and transverse directions are 33 GPa and 3.65 GPa, respectively. If the volume fraction of fibers is 0.30. Determine the moduli of elasticity of fiber and matrix phases. Derive the relation used for modulus of elasticity in transverse direction.

[20 marks]

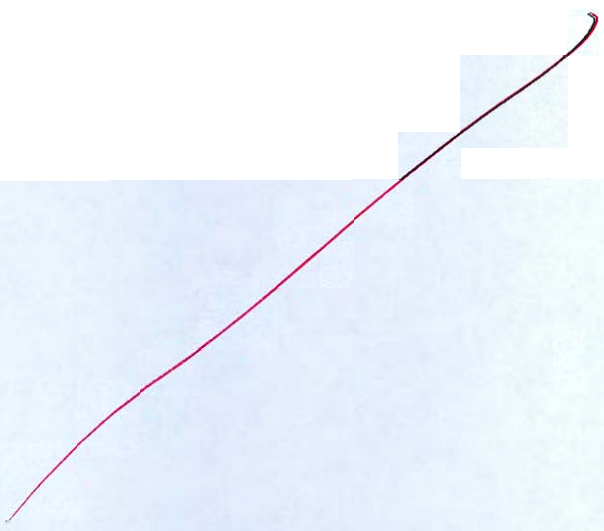


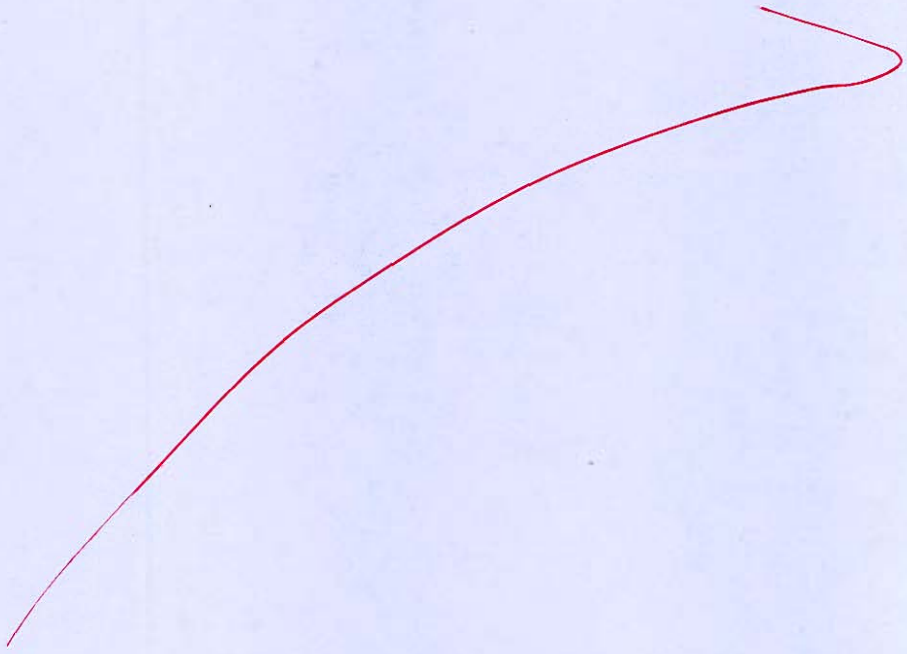


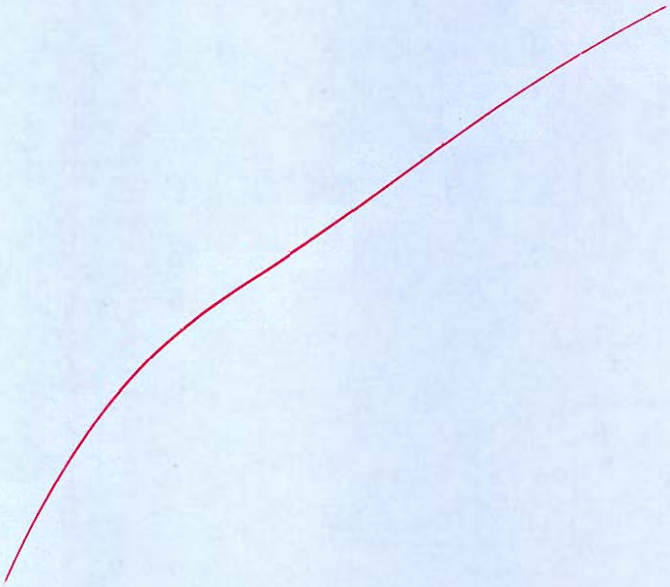


Q.8 (c) Why are Non-Ferrous Materials Important in engineering applications? Briefly discuss Aluminium, Copper, Zinc and Magnesium.

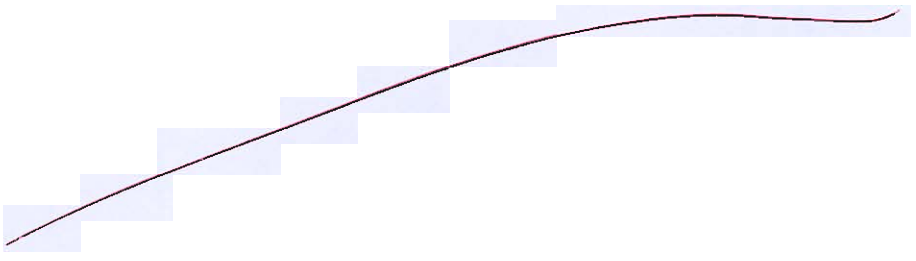
[20 marks]







Space for Rough Work



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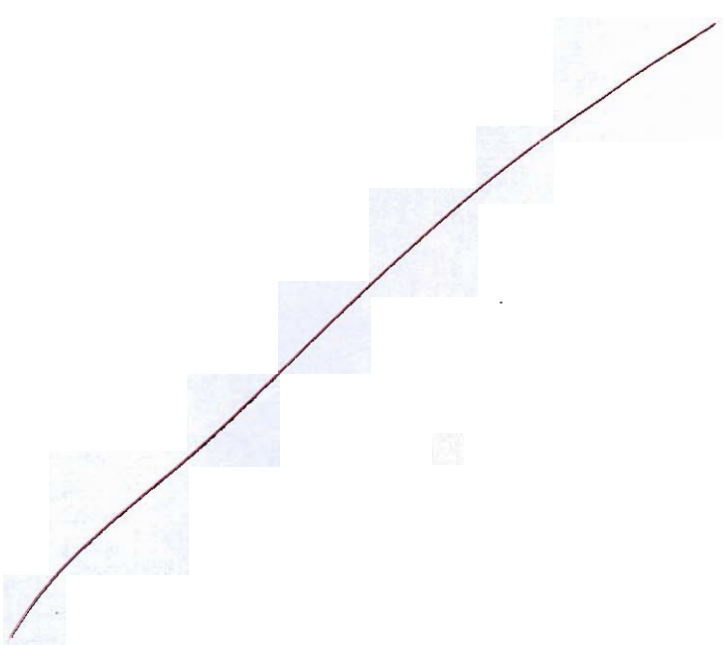

Space for Rough Work

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