MADE EASY
Leading Institute for ESE, GATE & PSUs

ESE 2026 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Mechanical Engineering

Test-2 : Strength of Materials & Mechanics

Thermodynamics-1 + IC Engine-1 + Refrigeration & Air-conditioning-1

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	23
Q.2	17
Q.3	—
Q.4	43
Section-B	
Q.5	48
Q.6	—
Q.7	57
Q.8	—
Total Marks Obtained	188

Signature of Evaluator ....

Cross Checked by ....

Corp. office : 44 - A/1, Kalu Sarai, New Delhi-110016 | **Ph:** 9021300500 | **Web:** www.madeeasy.in

Keep up this Consitent effort

IMPORTANT INSTRUCTIONS

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

DONT'S

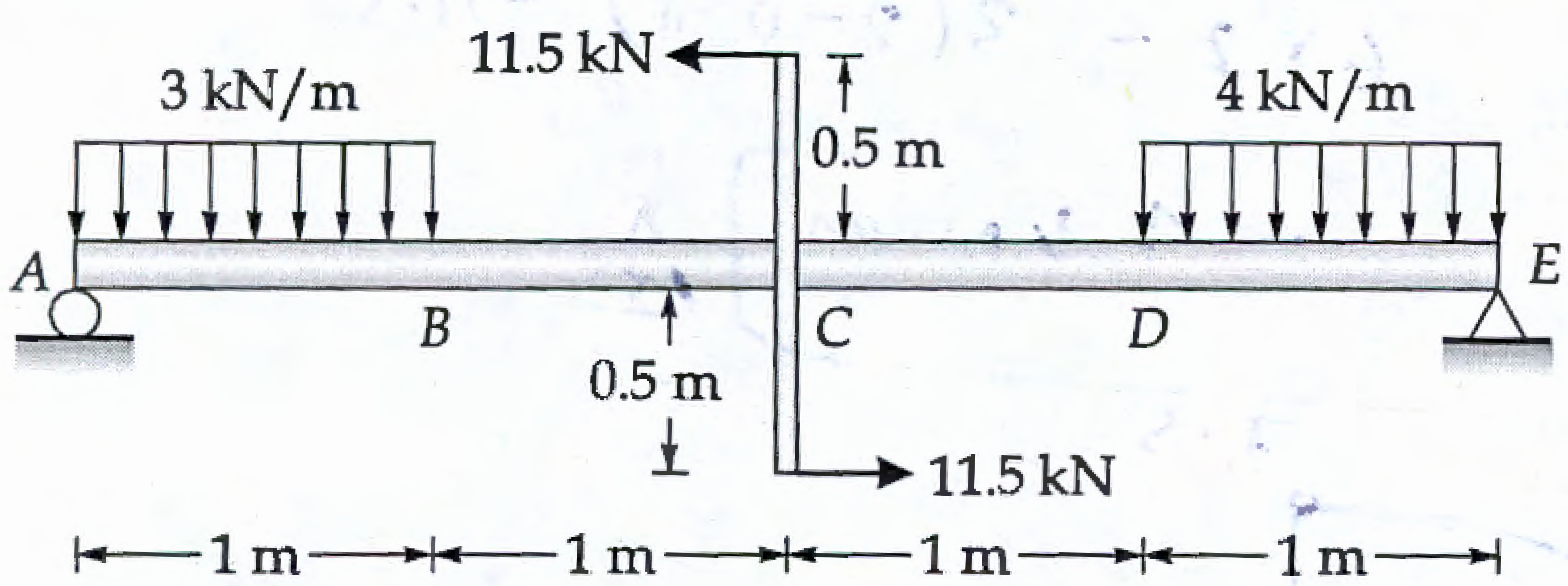
1. Do not write your name or registration number anywhere inside this Question-cum-Answer Booklet (QCAB).
2. Do not write anything other than the actual answers to the questions anywhere inside your QCAB.
3. Do not tear off any leaves from your QCAB, if you find any page missing do not fail to notify 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

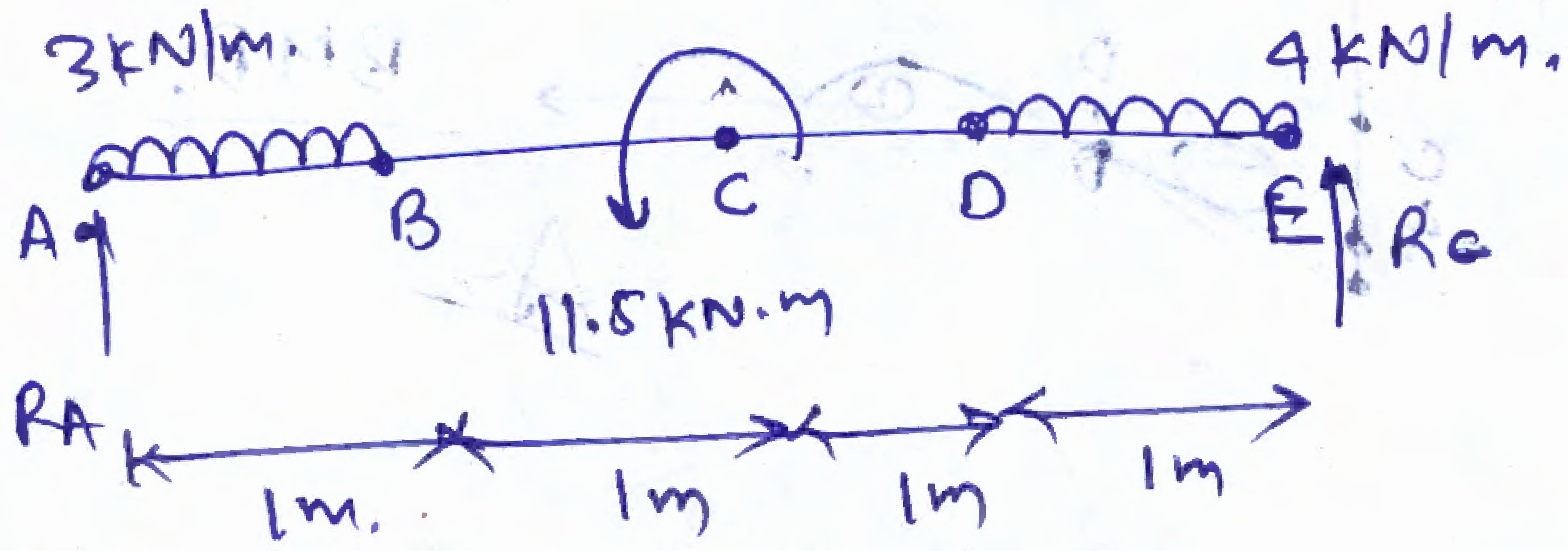
1. Read the Instructions on the cover page and strictly follow them.
2. Write your registration number and other particulars, in the space provided on the cover of QCAB.
3. Write legibly and neatly.
4. For rough notes or calculation, the last two blank pages of this booklet should be used. The rough 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 : Strength of Materials & Mechanics

Q.1 (a) A beam *ABCDE* is simply supported at *A* and *E*. The segments *AB* and *DE* are subjected to uniformly distributed loads of 3 kN/m and 4 kN/m respectively as shown in figure. At the mid point *C*, two horizontal forces of 11.5 kN each are acting at the ends of a vertical arm attached to the beam. Sketch the shear force and bending moment diagrams for the beam. Also, find the maximum bending moment acting on the beam.



[12 marks]

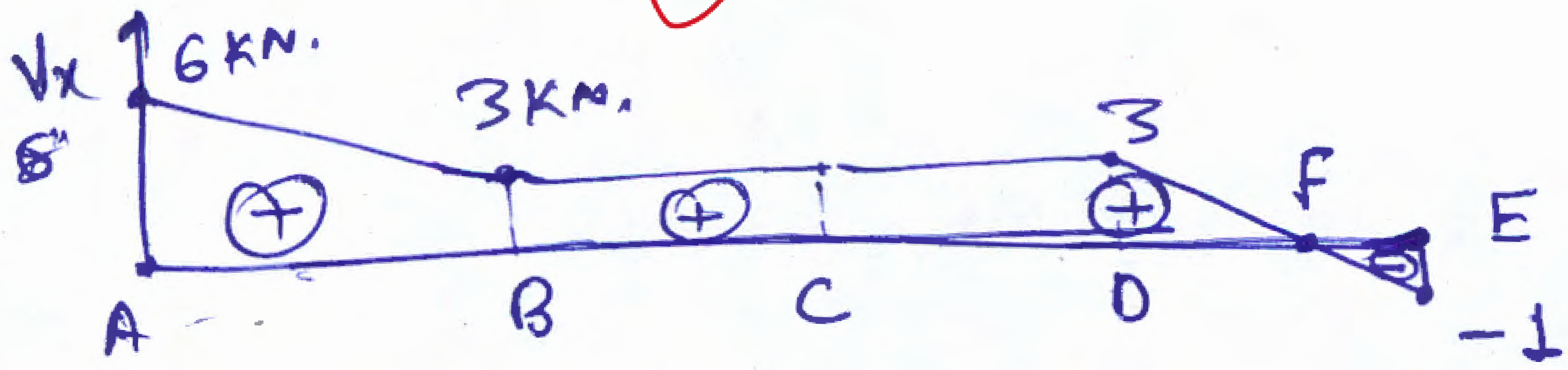


$$\uparrow RA = \frac{11.5}{4} + \frac{3\times 3.5}{4} + \frac{4\times 0.5}{4}$$

$$RA = 6\ kN. \uparrow$$

$$RE = \frac{-11.5}{4} + \frac{3\times 1\times 0.5}{4} + \frac{4\times 3.5}{4}$$

$$Re = 1\ kN \uparrow$$



$$Vx = 6 - 3x\ ,\ \text{for}\ 0 \leq x < 1$$

$$Vx = 6 - 3 - 4(x-3)\ \text{for}\ 3 \leq x \leq 4$$

$$= 3 - 4(x-3)$$

$$Mx = 6x - \frac{3x^2}{2},\ \text{for}\ 0 \leq x \leq 1$$

$$Mx = 6x - 3(x-0.5)\ ,\ \text{for}\ 1 \leq x < 2$$

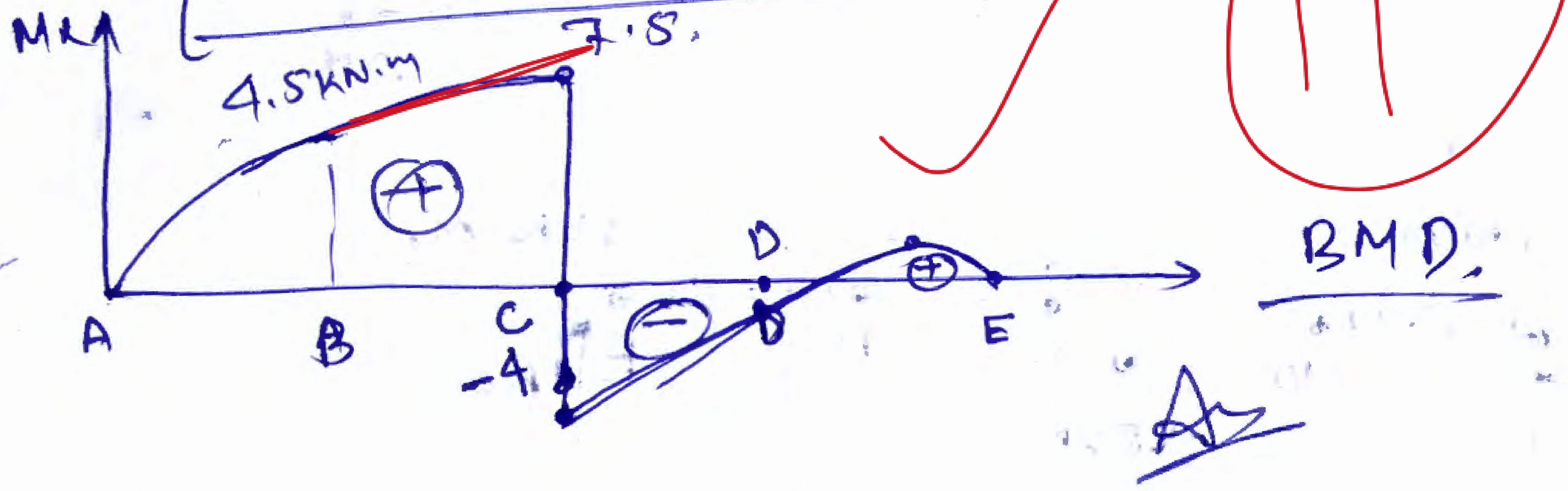
$M_x = 6x - 3(x-0.5) - 11.5$ for $2 \leq x < 3$

$M_x = 1.x - \frac{4x^2}{2}$ (RHS) for $0 \leq x \leq 1$

$M_{x \, (x=0.25 \text{ for RHS})} = 0.25 - \frac{4 \times 0.25^2}{2} = 0.125$ KN.m.

$M_{x \, (x=2)} = 6 \times 2 - 3(2-0.5) - 11.5$

LHS) $\boxed{M_{x \, (x=2)} = -4 \text{ kN.m}}$



BMD.

11

Q.1 (b) Due to differential settlement of the foundation, a circular tower becomes inclined at an angle α to the vertical. The structural core of the tower is idealized as a hollow circular cylinder of height (h) 50 m, outer diameter (d_2) 15 m, and inner diameter (d_1) 12 m. Assuming that the self weight of the tower is uniformly distributed along its height, derive an expression for the maximum permissible inclination angle α such that no tensile stress develops anywhere in the tower. Hence, determine its numerical value for the given data. Assume the base of the tower behaves like cantilever.

[12 marks]

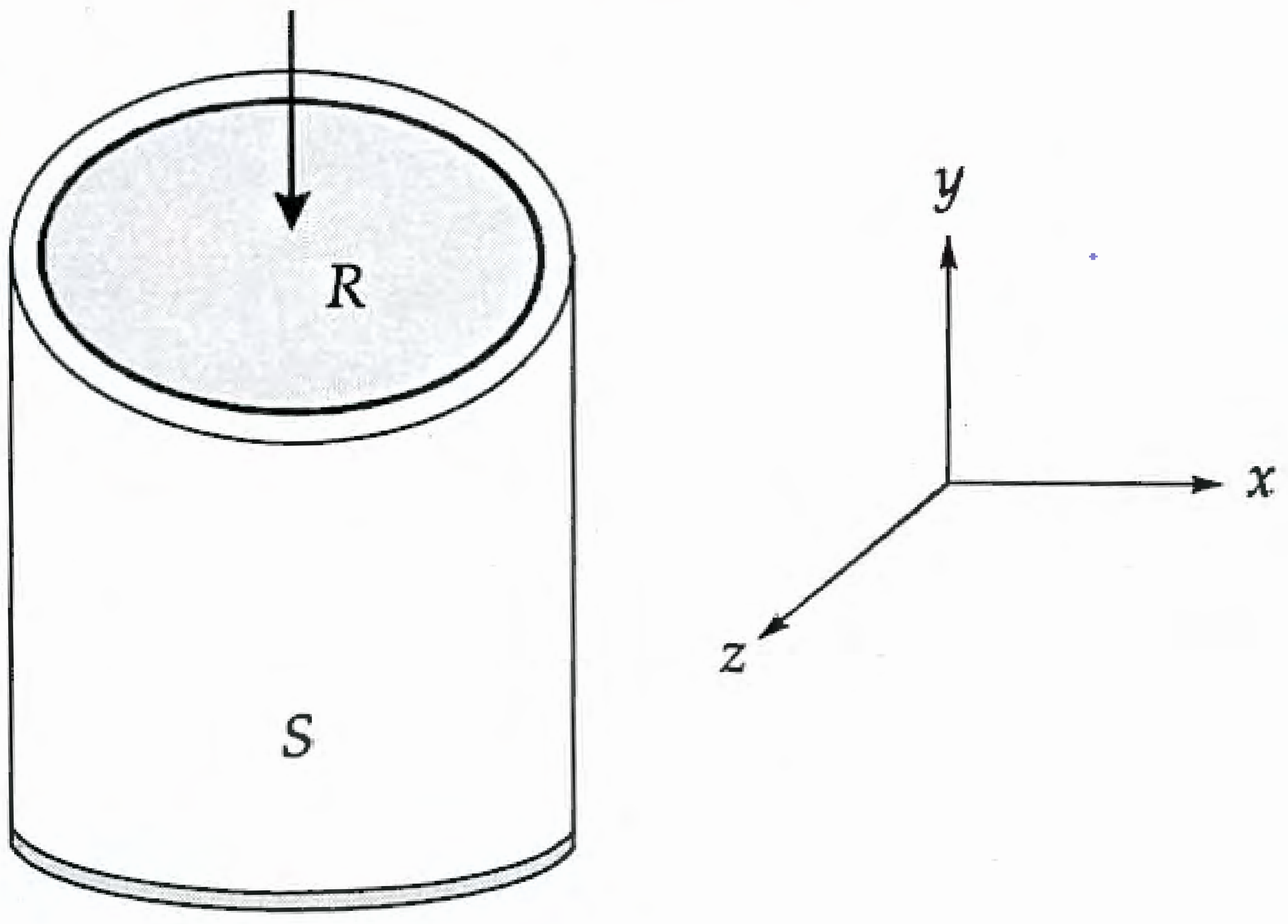
Q.1 (c) A cylindrical block of compressible material, R is tightly confined inside a rigid steel container S. An external force causes a uniformly distributed pressure of p_0 applied to the top surface of the material. Assume that the friction between the material and the container is negligible and that the steel container is rigid compared to the compressible material. The material of the block is homogeneous, and linearly elastic with Young's modulus E and Poisson's ratio μ.

Derive expressions in terms of p_0, E and μ for

(i) The lateral pressure exerted by the block on the rigid sleeve.

(ii) The dilation of the block.

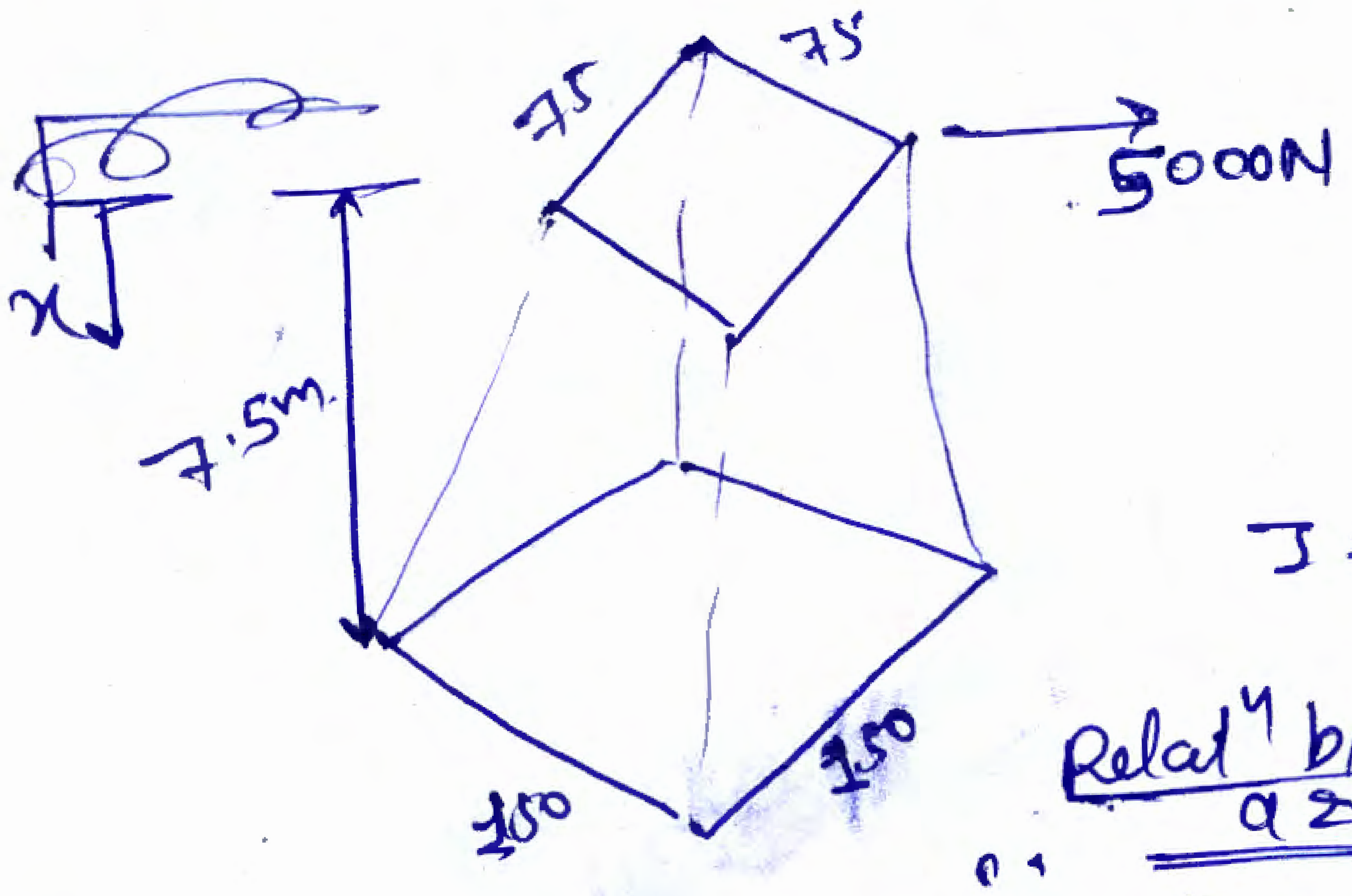
(iii) The strain energy density stored in the block.



[12 marks]

Q.1 (d) A vertical flat staff standing 7.5 m above the ground is of square section throughout, the dimensions being 75 mm × 75 mm at the top, tapering uniformly to 150 mm × 150 mm at the ground. A horizontal pull of 5000 N is applied at the top along a diagonal of the section. Calculate the maximum stress due to bending and the position where it acts.

[12 marks]



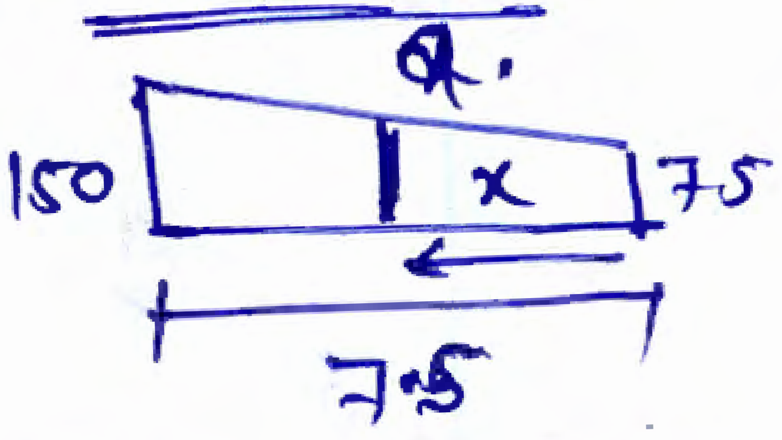
$\sigma_b = \frac{My}{I}$

$I = \frac{a^4}{12}$

$Z = \frac{I}{y}$

Relat^n b/w a & x

$M = 5000x.$



$Z = \frac{a^4}{\cancel{12}6 \times \frac{a\sqrt{2}}{\cancel{2}}}$

$Z = \frac{a^3}{6\sqrt{2}}$

$\frac{150-75}{\cancel{1500}\,a-75} = \frac{7500}{x-0}.$

$\frac{\cancel{75}}{a-75} = \frac{\cancel{7500}\,100}{x.}$

$x = 100a - 7500$

$\sigma_b = \frac{5000x \times 6\sqrt{2}}{a^3}$

$\sigma_b = \frac{5000(100a - 7500) \times 6\sqrt{2}}{a^3}$

$\frac{d\sigma_b}{da} = 5000 \cdot 6\sqrt{2}\left[\frac{100(-2)}{a^3} + \frac{(3)7500}{a^4}\right] = 0$

$\frac{-200}{a^3} + \frac{3 \times 7500}{a^4}$

$a\, 20\cancel{0} = 3 \times 75\cancel{0}\cancel{0}$

$\boxed{a = 112.5 \text{ mm}}$

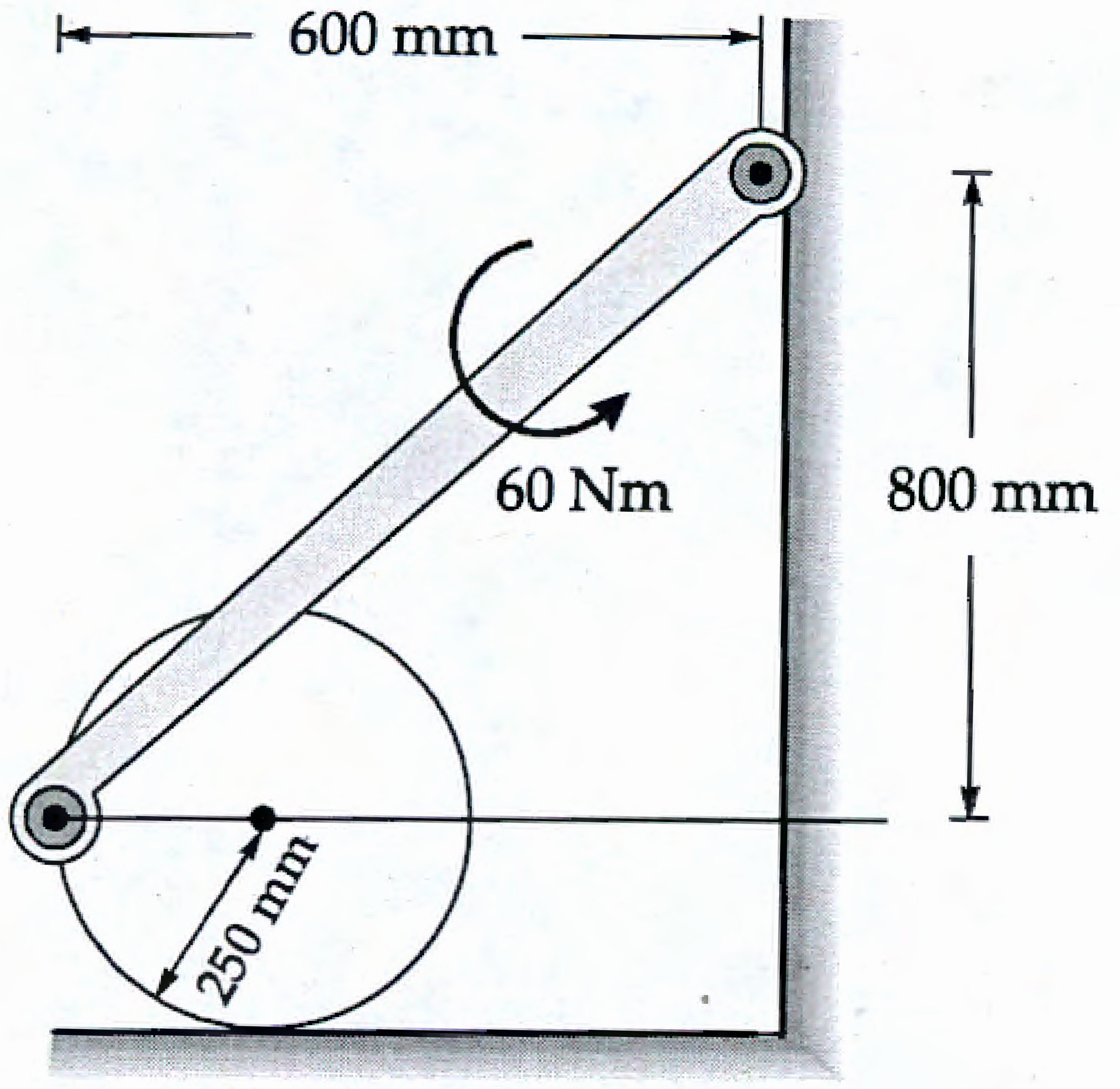
$\boxed{x = 3750 \text{ mm}}$

$$(\sigma_b)_{m} = \frac{5000 \times 3750 \times 6\sqrt{2}}{112.5^3}$$

$$\boxed{(\sigma_b)_{max} = 111.74 \text{ MPa}}$$

12

Q.1 (e) A 50 kg disk rests on a horizontal surface as shown in the figure. A couple moment of 60 N-m is applied to the attached bar. Determine the minimum coefficient of static friction between the disk and surface so that the disk does not slip.

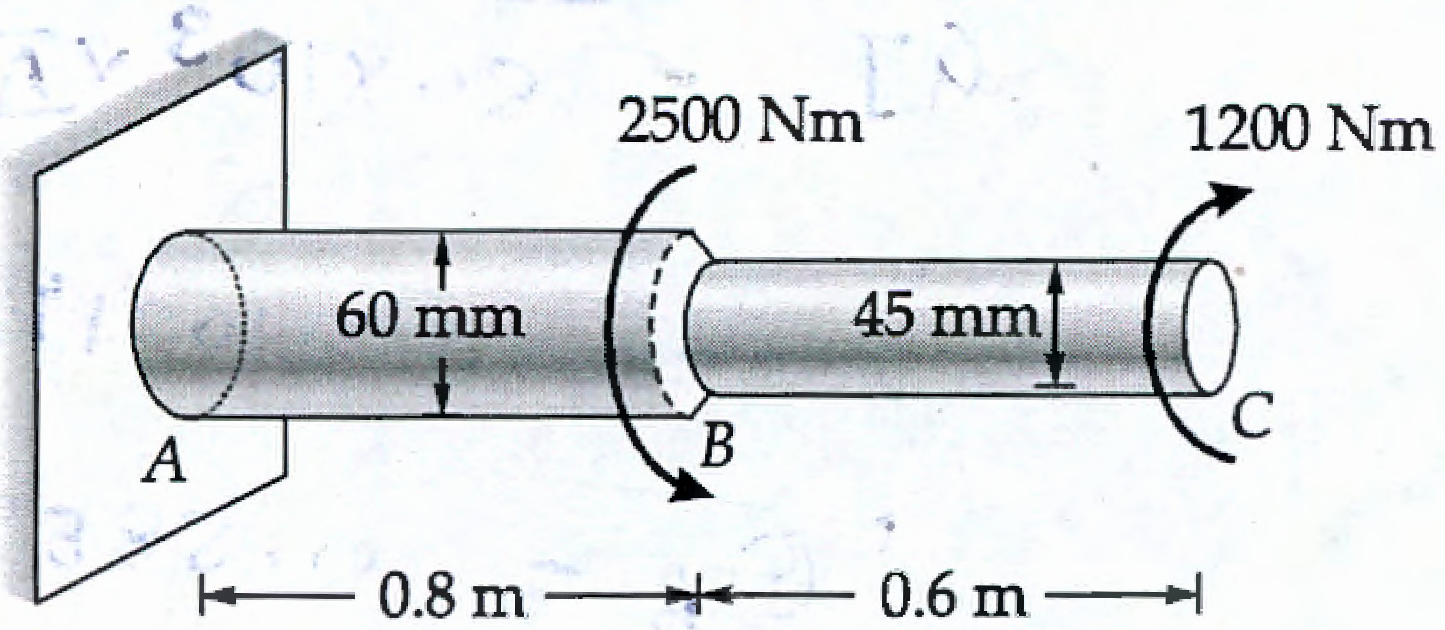


[12 marks]

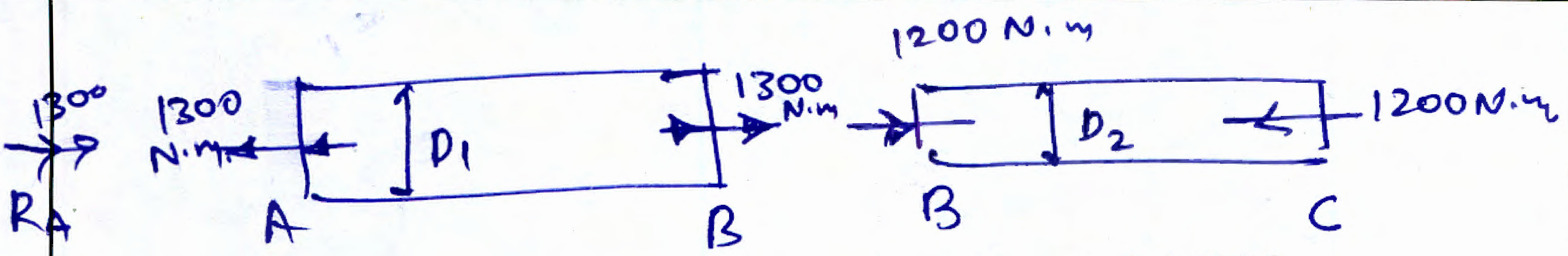
Q.2 (a) A stepped shaft *ABC* consisting of two solid circular segments, is subjected to torques of 2500 Nm and 1200 Nm acting in opposite directions, as shown in the figure. The larger segment of the shaft has a diameter of 60 mm and a length of 0.8 m while the smaller segment has a diameter 45 mm and a length 0.6 m. Determine the reaction torque at support A. Then

(i) Find the internal torsional moments in segments *AB* and *BC* with properly drawn free- body diagrams.

(ii) Determine the maximum shear stress developed in the shaft and the angles of twist at sections *B* and C. Assume the shear modulus of the material, $G = 80$ GPa.



[20 marks]



$D_1 = 60mm$ | $D_2 = 45mm$

$L_1 = 0.8 m.$ | $L_2 = 0.6m.$

React^n Torque at A

= 1300 N-m { A.C. }

Torsional moment of AB = 1300 N.m

Torsional moment of BC = 1200 N.m.

$$\tau_{AB} = \frac{16 T_{AB}}{\pi D_1^3} = \frac{16 \times 1300}{\pi \times 0.06^3}$$

$$\boxed{\tau_{AB} = 30.652 \text{ MPa}}$$ Answer

$$\tau_{BC} = \frac{16 T_{BC}}{\pi D_2^3} = \frac{16 \times 1200 \times 10^3}{\pi \times 45^3}$$

$$\boxed{\tau_{BC} = 67.0677 \text{ MPa}}$$ Answer

$$\frac{\tau}{R} = \frac{T}{J} = \frac{G\theta}{l}$$

angle of Twist at B

$$\theta_B = \frac{TL}{GJ} = \frac{1300 \times 0.8}{86 \times 10^9 \times \frac{\pi}{32} \times 0.06^4}$$

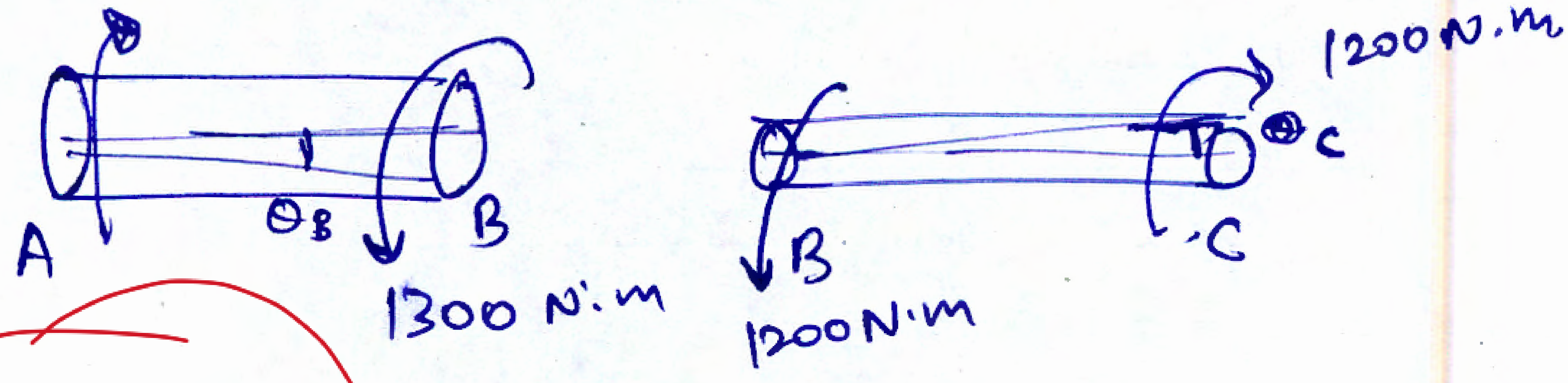
$$= 0.01021 \text{ Rad}$$

$$\boxed{\theta_B = 0.585°}$$ Ans

$$-\theta_c = \frac{TL}{GJ} = \frac{1200 \times 0.6}{80\times10^9 \times \frac{\pi}{32} \times 0.045^4}$$

$$= 0.02235 \text{ Rad}$$

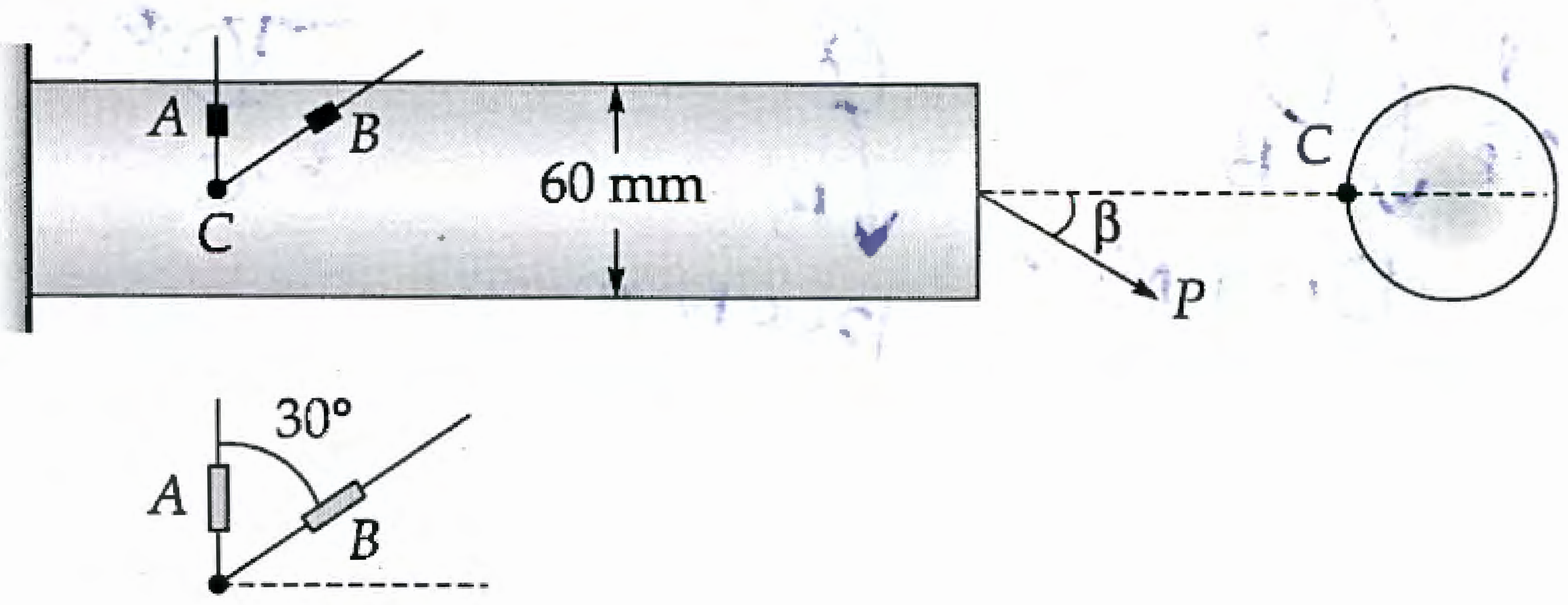
$$\boxed{\theta_c = 1.28 \text{ deg}}$$



17

Q.2 (b) A cantilever beam with a circular cross-section of diameter 60 mm is subjected to a force P inclined to the axis and passing through the centroid of cross-section at the free end as shown in the figure. Two strain gauges are placed at point C, located on the surface of the beam at the end of the horizontal centroidal axis of the cross-section. Gauge A measures strain in the vertical direction while gauge B measures strain at an angle 30° to the vertical. The measured strains are $\varepsilon_A = -50 \times 10^{-6}$ and $\varepsilon_B = -160 \times 10^{-6}$.

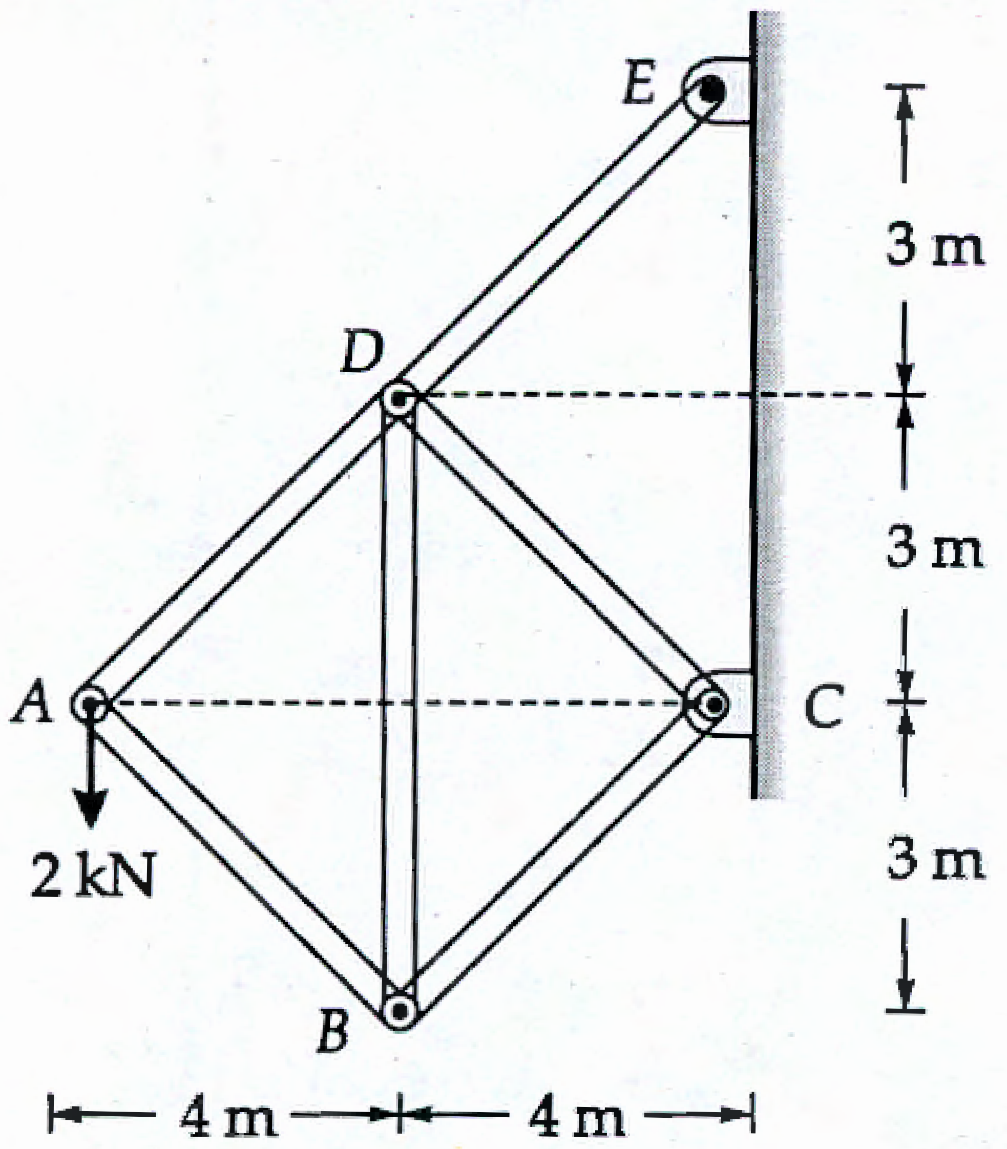
Determine the magnitude of force P and its angle of inclination. Assume the material is steel with $E = 200$ GPa and $v = 0.3$.



[20 marks]

Do not write in this margin

Q.2 (c) Using the method of joints, determine the force in each member of the truss shown in the figure below. Also, indicate whether each member is in tension or compression.

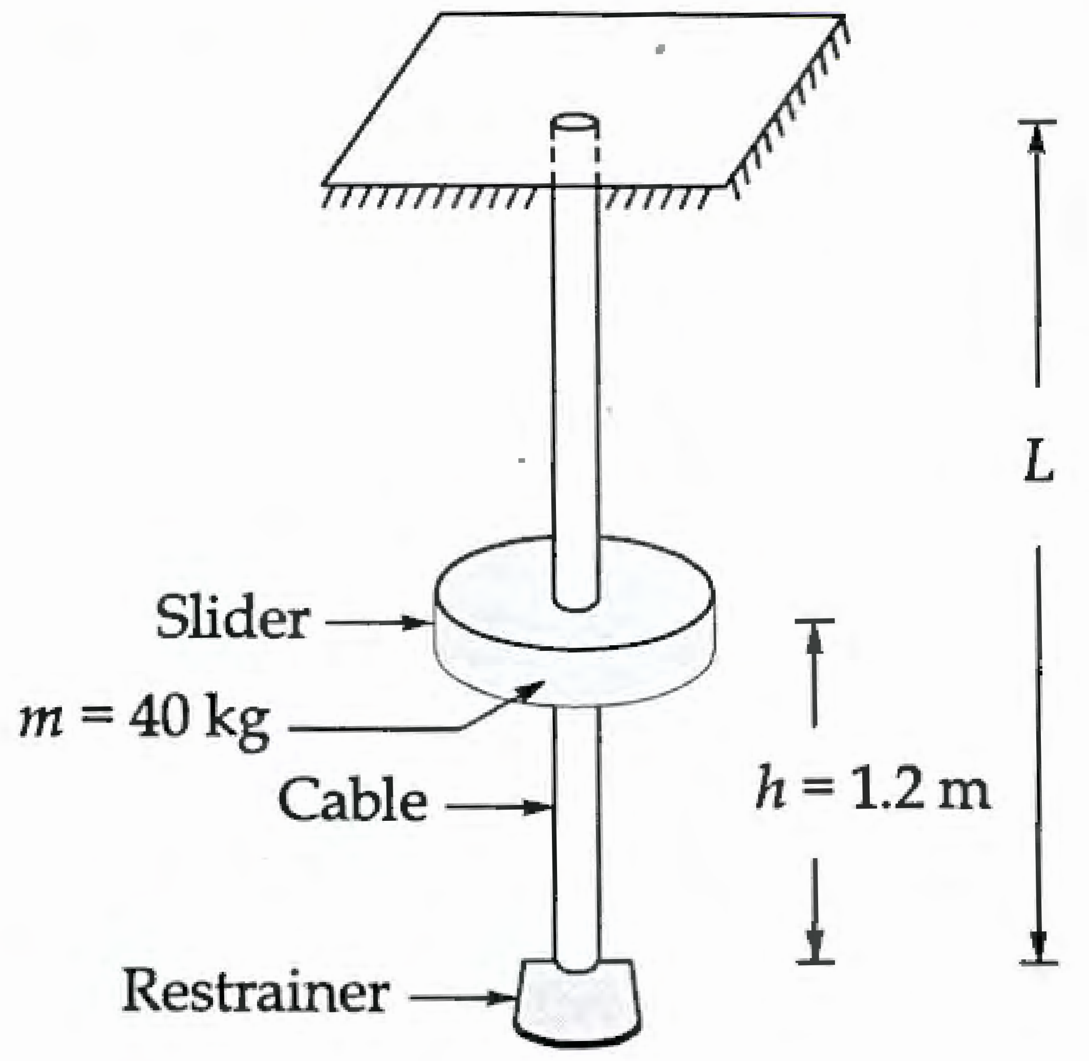


[20 marks]

Q.3 (a) A cable with constant cross-sectional area is suspended vertically from a rigid support at its upper end. The lower end of the cable is provided with a rigid restrainer, which arrests the motion of a falling load. The cable has an effective cross-sectional area of 45 mm^2 and a modulus of elasticity of 150 GPa. The self weight of cable may be neglected. A rigid slider of mass 40 kg falls freely from rest through a vertical height of 1.2 m and strikes the restrainer as shown in the figure. The material of the cable is assumed to remain linear elastic.

(i) Derive an expression for the maximum tensile stress developed in the cable due to the impact loading.

(ii) If the maximum permissible tensile stress in the cable under impact loading is 450 MPa, determine the minimum required length of the cable.



[20 marks]

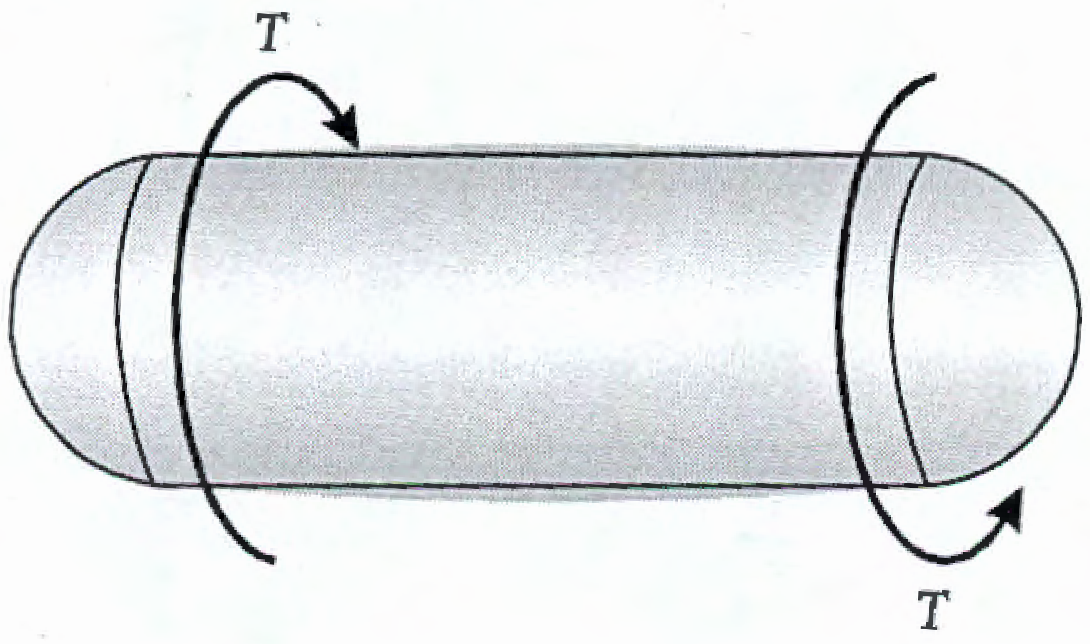
Q.3 (b) A uniform straight bar PQR of total length L and circular cross-section of diameter d rotates with a constant angular speed ω in a horizontal plane about a vertical axis passing through its midpoint Q. The bar is made of a linearly elastic material with modulus of elasticity E and total mass M. Point masses, each of magnitude $\frac{M}{3}$ are rigidly attached at each ends P and R of the bar. As a result of rotation, the bar undergoes axial deformation. Obtain an expression for the total elongation of the bar.

[20 marks]

Q.3 (c) A cylindrical pressure vessel is subjected to an internal pressure P of 3 MPa and an additional torque T of 100 kN-m as shown in figure. The vessel has a radius of 250 mm and a wall thickness of 20 mm.

(i) Determine the maximum tensile stress, maximum compressive stress and the minimum in-plane shear stress in the wall of the cylinder.

(ii) If the torque is increased to T = 150 kNm and the allowable in-plane shear and allowable normal stress are 20 MPa and 50 MPa, respectively, then what will be the minimum required wall thickness?



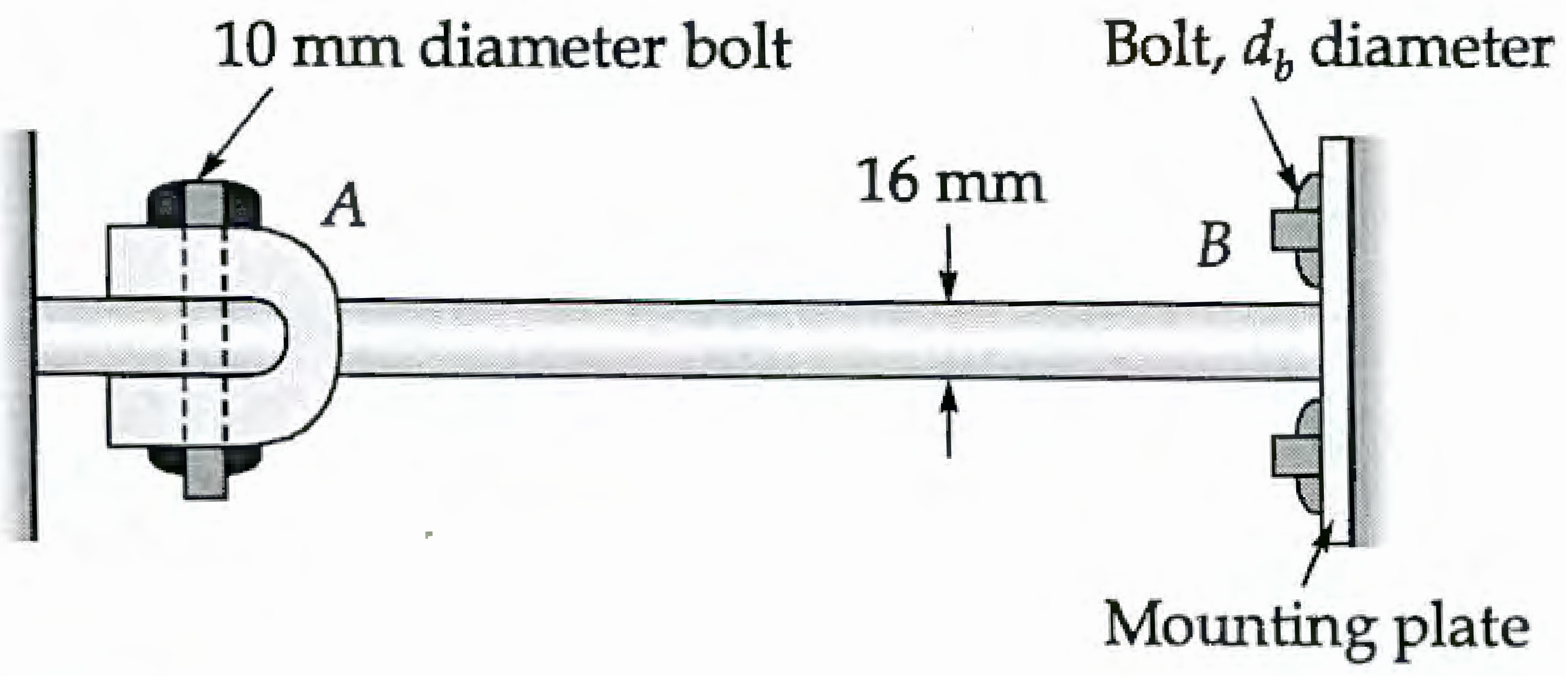
[20 marks]

Do not write in this margin

Q.4 (a) A steel rod of 16 mm diameter is mounted between rigid walls with no initial stress present, as shown in the figure. (For the steel rod, Take $\alpha = 11 \times 10^{-6}/°C$ and $E = 200$ GPa).

(i) Determine the temperature decrease (in °C) at which the average shear stress developed in the 10 mm-diameter bolt reaches 50MPa, and also compute the associated normal stress in the rod.

(ii) For the connection at B as shown in figure; determine the required diameter of each bolt connecting the end plate to the wall, if the temperature drop is 40°C and the allowable bolt stress is 80MPa.



[20 marks]

$D_s = 16mm.$

$\alpha_s = 11 \times 10^{-6}/°C.$, $E_s = 200GPa.$

① Temp^r decrease = ? (in °c)

$50 \times 2 \times \frac{\pi}{4} \times 10^2 =$ Load P

↳ Required to generate 50 MPa shear stress

$P = 2500\pi$ N.

∵ $\underset{\text{(steel stress)}}{\sigma_s} = E\alpha\Delta T$

$$\frac{P}{area} = 200 \times 10^3 \times [11 \times 10^{-6}] \times \Delta T \rightarrow ?$$

$$\frac{2500\pi}{\frac{\pi}{4} \times 16^2} = 200 \times 10^3 \times 11 \times 10^{-6} \times \Delta T$$

$$\boxed{\Delta T = 17.75°C}$$ Ans:

17.75°C Temp^r decrease required to generate 50 MPa shear stress.

Normal stress on Rod

$$\boxed{\sigma = \frac{2500\pi}{\pi/4 \times 16^2} = 39.0625 \text{ MPa}}$$

②

$$\left(\frac{P}{area}\right)_{steel} = (E\alpha\Delta T)_{steel} \rightarrow 40^\circ c$$

$$\frac{P_{steel}}{\pi/4 \times 16^2} = 200\times10^3 \times 11\times10^{-6} \times 40$$

$$\boxed{P_{steel} = 5632\pi \ N.}$$

Then

$$\frac{P_{steel}}{2\times \text{area of Bolt}} = 80.$$

$$\frac{5632\pi}{2\times\frac{\pi}{4}d_b^2} = 80$$

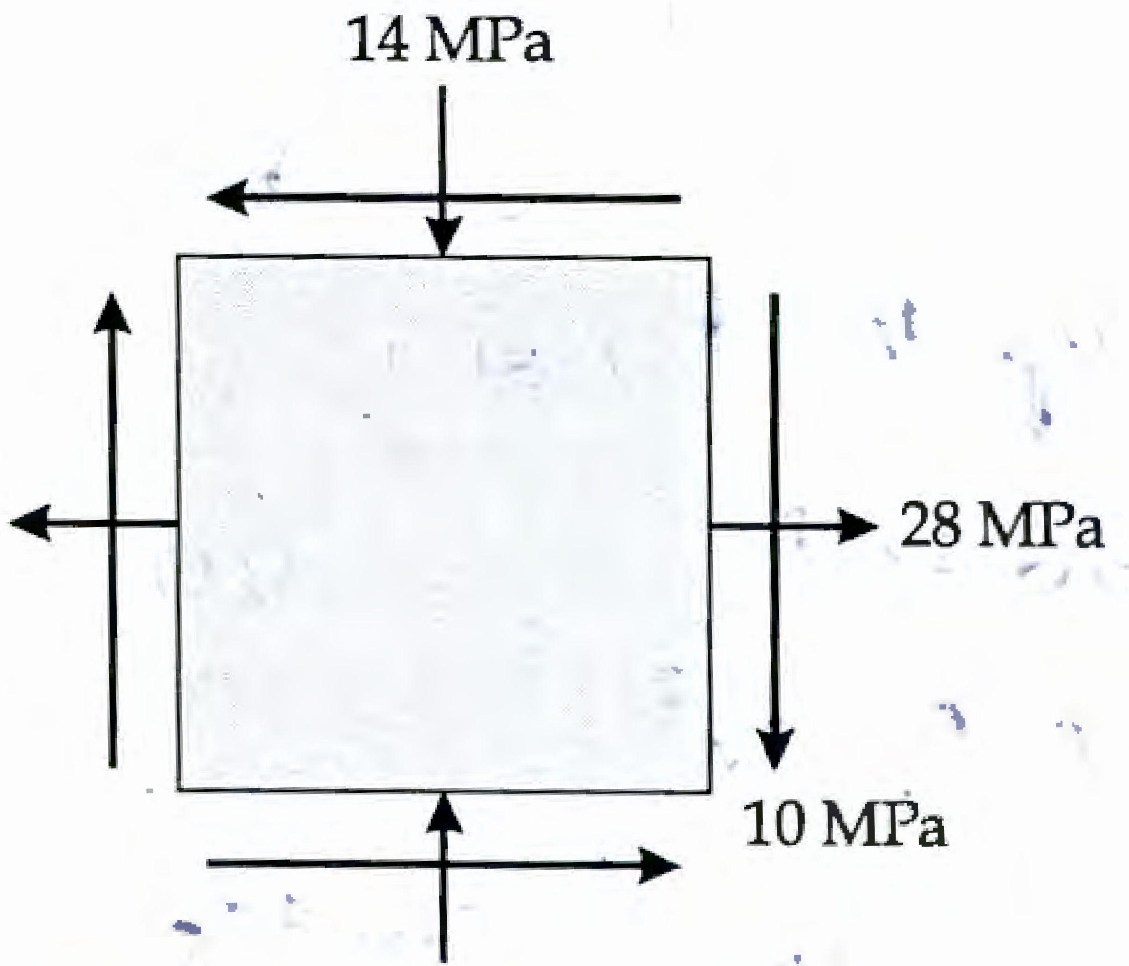
$$d_b = \sqrt{704/5}$$

Answer $\boxed{d_b = 11.8659 \text{ mm}}$ ✓

20

Q.4 (b) An element of a thin rectangular plate used in a mechanical structure is subjected to a state of plane stress. The normal stress acting in the horizontal direction is tensile with a magnitude of 28 MPa, while the normal stress acting in the vertical direction is compressive with a magnitude of 14MPa. In addition, in-plane shear stresses of magnitude 10 MPa act in the direction as shown in figure.

Determine the maximum shear stress and the corresponding normal stresses. Also, indicate the stresses on a sketch of the element in the orientation at which the maximum shear stress occurs.



[20 marks]

$\sigma_x = +28\,MPa$

$\sigma_y = -14\,MPa$

$\tau_{xy} = -10\,MPa.$

$$\sigma_{1,2} = \frac{\sigma_x+\sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x-\sigma_y}{2}\right)^2 + \tau_{xy}^2}$$

$$= \frac{28-14}{2} \pm \sqrt{\left(\frac{28+14}{2}\right)^2 + (-10)^2}$$

$$\sigma_{1,2} = 7 \pm 23.259$$

$\sigma_1 = 30.259\,MPa$, $\sigma_2 = -16.259\,MPa$

$\sigma_3 = 0.$

$$\tau_{max}' = \text{max of} \left\{ \left|\left(\frac{\sigma_1-\sigma_2}{2}\right)\right|, \left|\left(\frac{\sigma_2-\sigma_3}{2}\right)\right|, \left|\left(\frac{\sigma_2-\sigma_1}{2}\right)\right| \right\}$$

$$= \frac{30+16.259}{2}$$

$$\boxed{\tau_{max} = 23.1295\,MPa \quad Ans}$$

✓

$$\because \quad \tau = -\left(\frac{\sigma_x-\sigma_y}{2}\right)\sin 2\theta + \tau_{xy}\cos 2\theta$$

when $\tau \rightarrow \tau_{max}$; $\theta \rightarrow \theta_1$

$$\tau_{max} = -\left(\frac{28+14}{2}\right)\sin 2\theta_1 + (-10)\cos 2\theta_1$$

$$23.1295 = -21\sin 2\theta_1 - 10\cos 2\theta_1$$

$$\theta_1 = -1.0604 \text{ rad.}$$

$$\theta_1 = -60.76^\circ$$

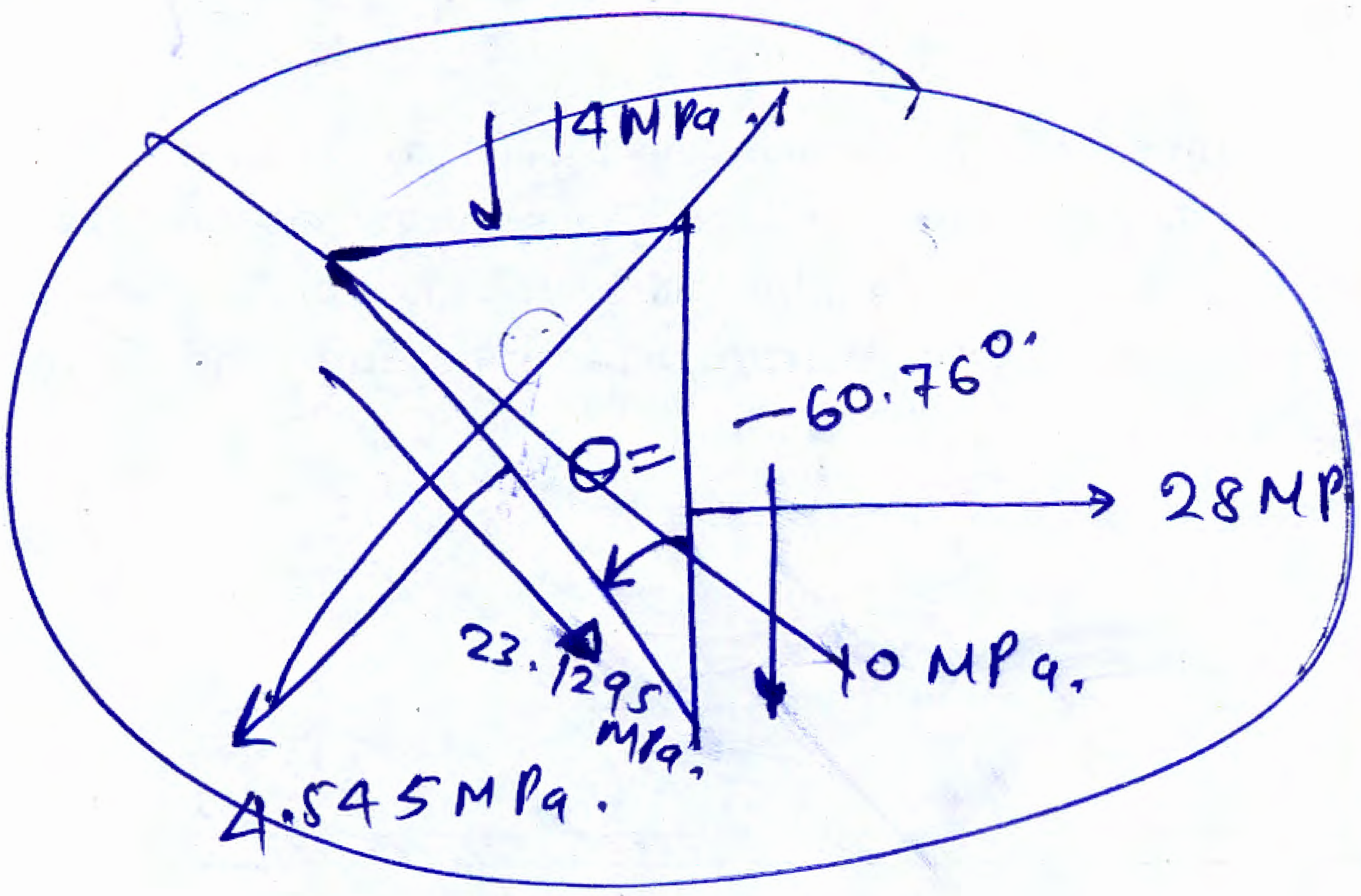
Normal stress corresponding to,

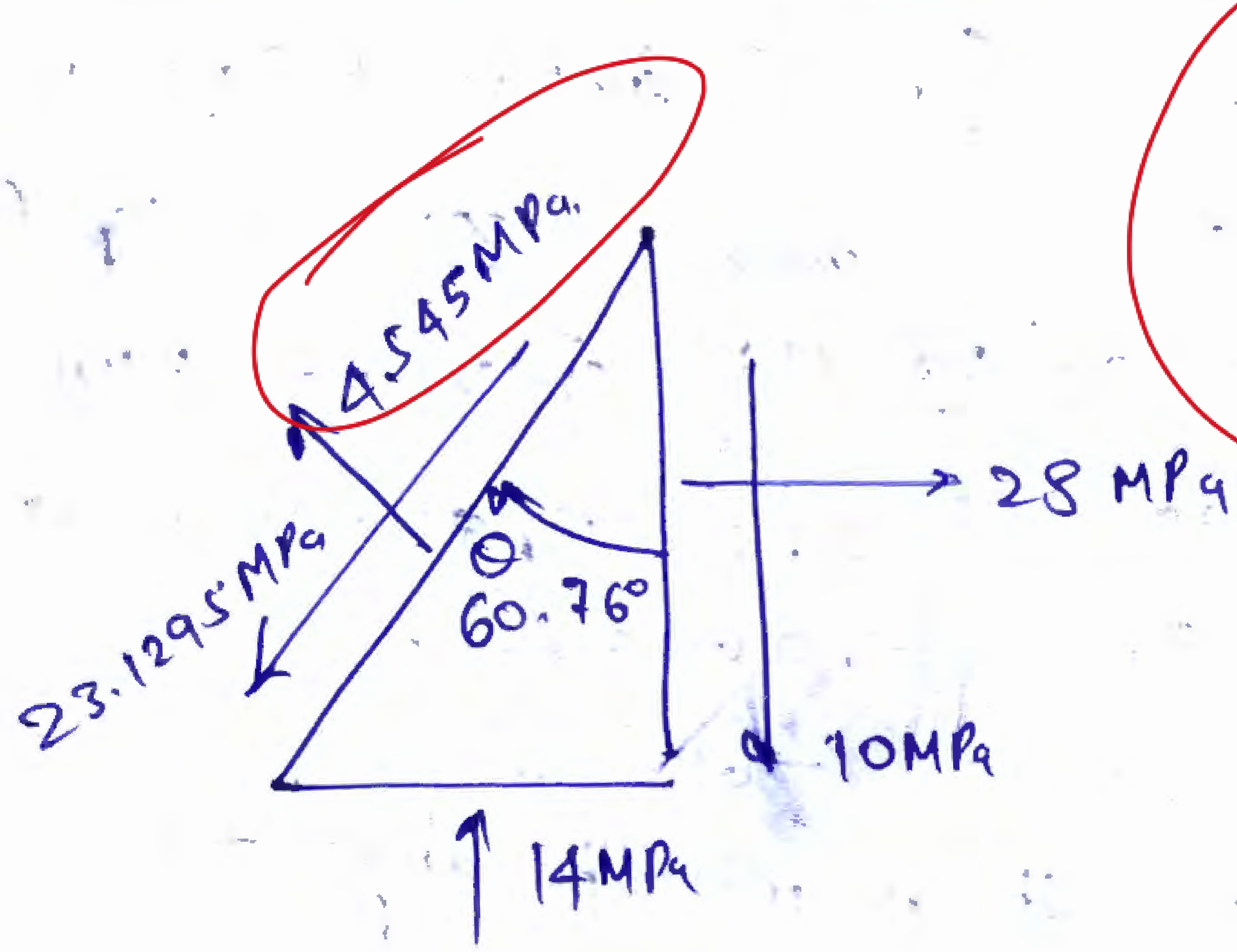
$$\theta_1 = -60.76^\circ$$

$$\left(\sigma_n\right)_{\theta=-60.76^\circ} = \left(\frac{\sigma_x+\sigma_y}{2}\right) + \left(\frac{\sigma_x-\sigma_y}{2}\right)\cos 2\theta + \tau_{xy}\sin 2\theta$$

$$= \left(\frac{28-14}{2}\right) + \left(\frac{28+14}{2}\right)\cos(-2\times 60.76^\circ) + (-10)\sin(-2\times 60.76^\circ)$$

$$\left(\sigma_n\right)_{\theta=-60.76^\circ} = 4.545 \text{ MPa}$$



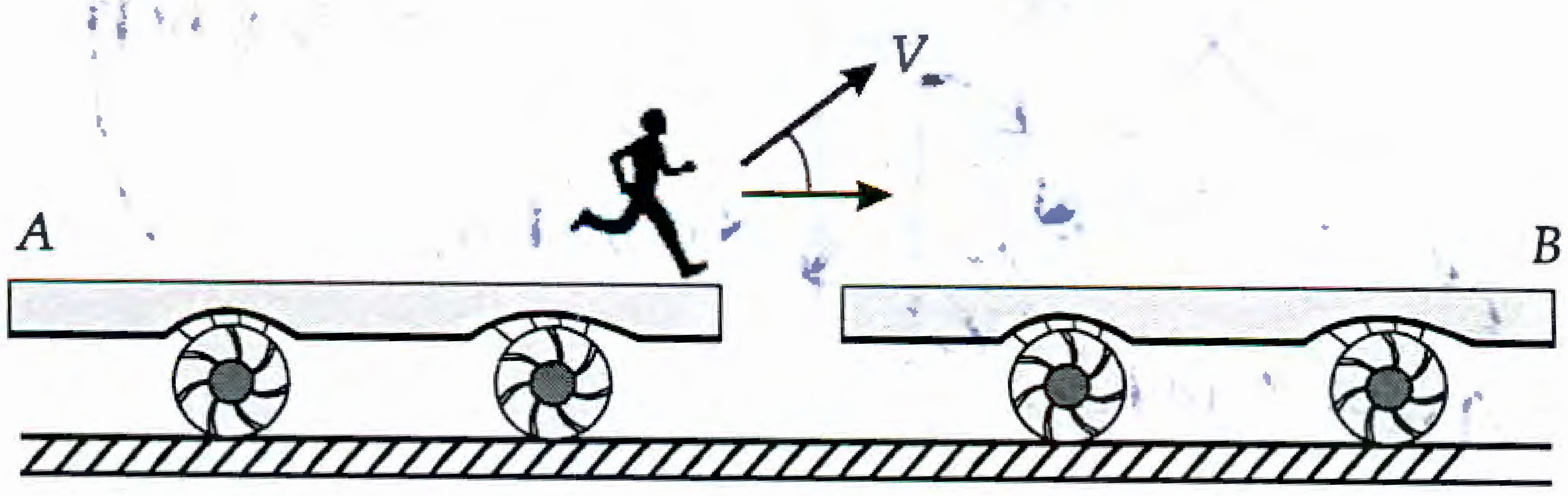


8

Q.4 (c) **(i)** Discuss the followings:

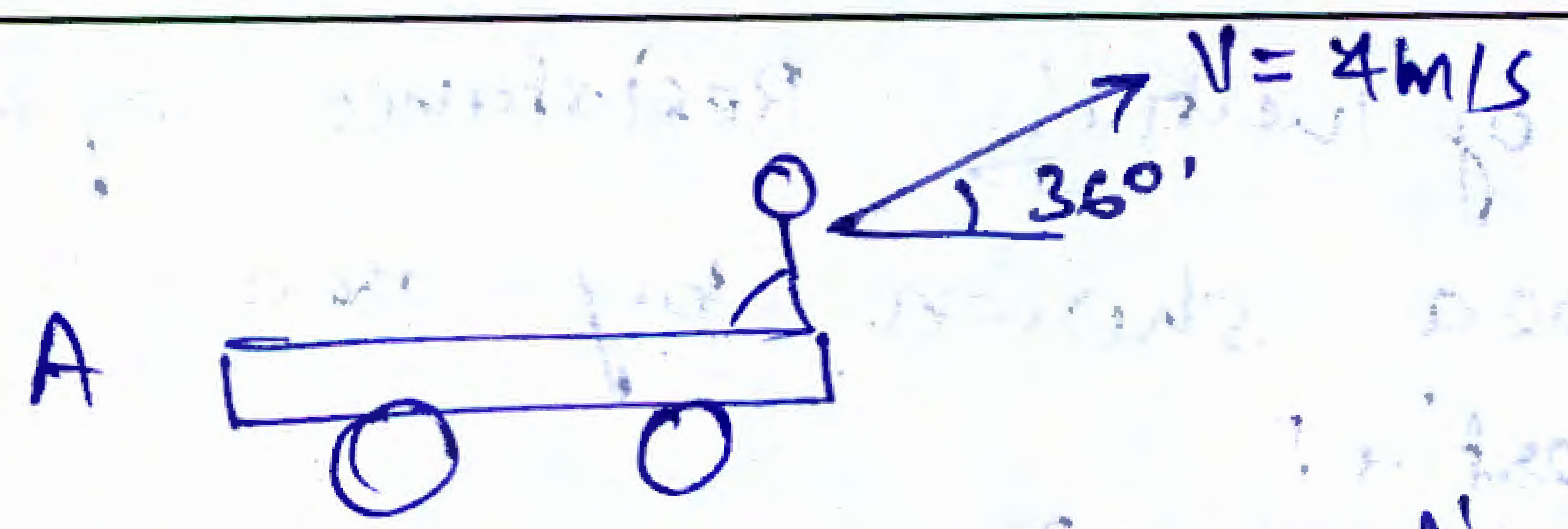
1. The centre of gravity, centre of mass and the centroid of a body.
2. The area moment of inertia and mass moment of inertia.
3. The radius of gyration of an area.

(ii) A 80 kg boy jumps off cart A with a velocity of 4 m/s at an angle of 36° from the horizontal. He, then lands on cart B with the same velocity and at the same angle at which he left cart *A*. Cart *A* and *B* each have a mass of 40 kg and are initially at rest. Determine the velocity of cart *A* just after he jumps and the velocity of cart *B* just after he lands on it.



[12 + 8 = 20 marks]

(iv)



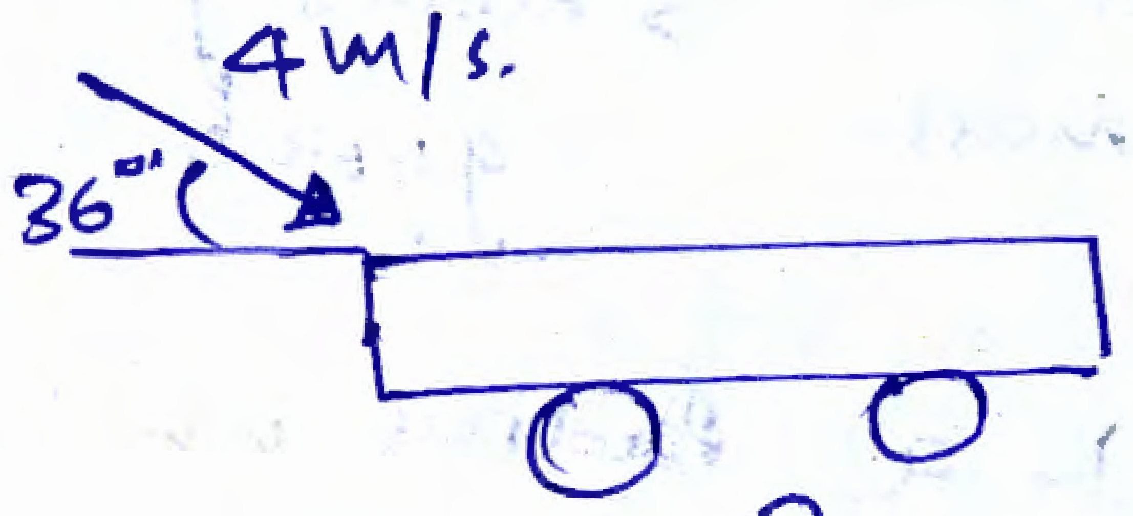
momentum conservation in x direct^n.

$$80 \times 4\cos 36^\circ = m_{A_{cart}} \times V_A$$

$$8\cancel{0} \times \cancel{4}\cos 36^\circ = \overset{10}{\cancel{40}} V_A$$

$$\boxed{V_A = 6.4721\ m/s} \leftarrow \text{direct}^n$$

8



momentum conservation in x direct^n.
B

$$m_{bog} \times 4\cos 36^\circ = (m_{bog} + m_{B_{cart}}) V$$

$$80 \times 4\cos 36^\circ = (80+40) V.$$

$$\boxed{V_B = 2.1573\ m/s}$$

① Centre of Gravity: COG is a point at which all the weight of a body can be considered as a centered.

② Centre of Mass: COM is a point on a body at which all the mass of a body can be considered at located

③ Centroid: P

?

② Area Moment of Inertia! Resistance of a moment of area shown by area moment of Inertia.

$$I = \underset{\hookrightarrow \text{area}}{A}K^2 \longleftarrow \text{Radius of Gyratia}$$

③ Mass moment of Inertia! Resistance of a moment of mass shown by the mass moment of Inertia

$$I = \underset{\hookrightarrow \text{mass}}{m}k^2 \longrightarrow \text{Radius of gyrati-}$$

③ Radius of gyration! Is a Radius which is used to calculate the moment of Inertia.

7

Section B : Thermodynamics-1 + IC Engine-1 + Refrigeration & Air-conditioning-1

Q.5 (a) For a vapor compression refrigeration using R-22 as refrigerant, condenser outlet temperature is 42°C and evaporator inlet is –18°C. In order to avoid flashing of refrigerant, a liquid-suction vapor heat exchanger is provided where liquid is subcooled to 28°C. The refrigerant leaves the evaporator as saturated vapor. The compression is isentropic. Find the power requirement and coefficient of performance if capacity of the system is 10 kW at –18°C. Show the cycle on temperature entropy and pressure enthalpy diagrams. The specific heat of vapor refrigerant is 1.03 kJ/kgK.

Temp. (°C)	p_{sat} (bar)	Sp. liquid $v_f \times 10^3$ (m^3/kg)	Volume Vapour, v_g (m^3/kg)	Enthalpy			Entropy		
				h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
				(kJ/kg)			(kJ/kgK)		
–18	2.643	0.744	0.0864	179.44	218.93	398.37	0.9226	0.8580	1.7806
28	11.309	0.846	0.0208	233.81	179.93	413.74	1.1770	0.5975	1.7145
42	16.096	0.891	0.0144	251.68	164.53	416.21	1.1749	0.5220	1.6969

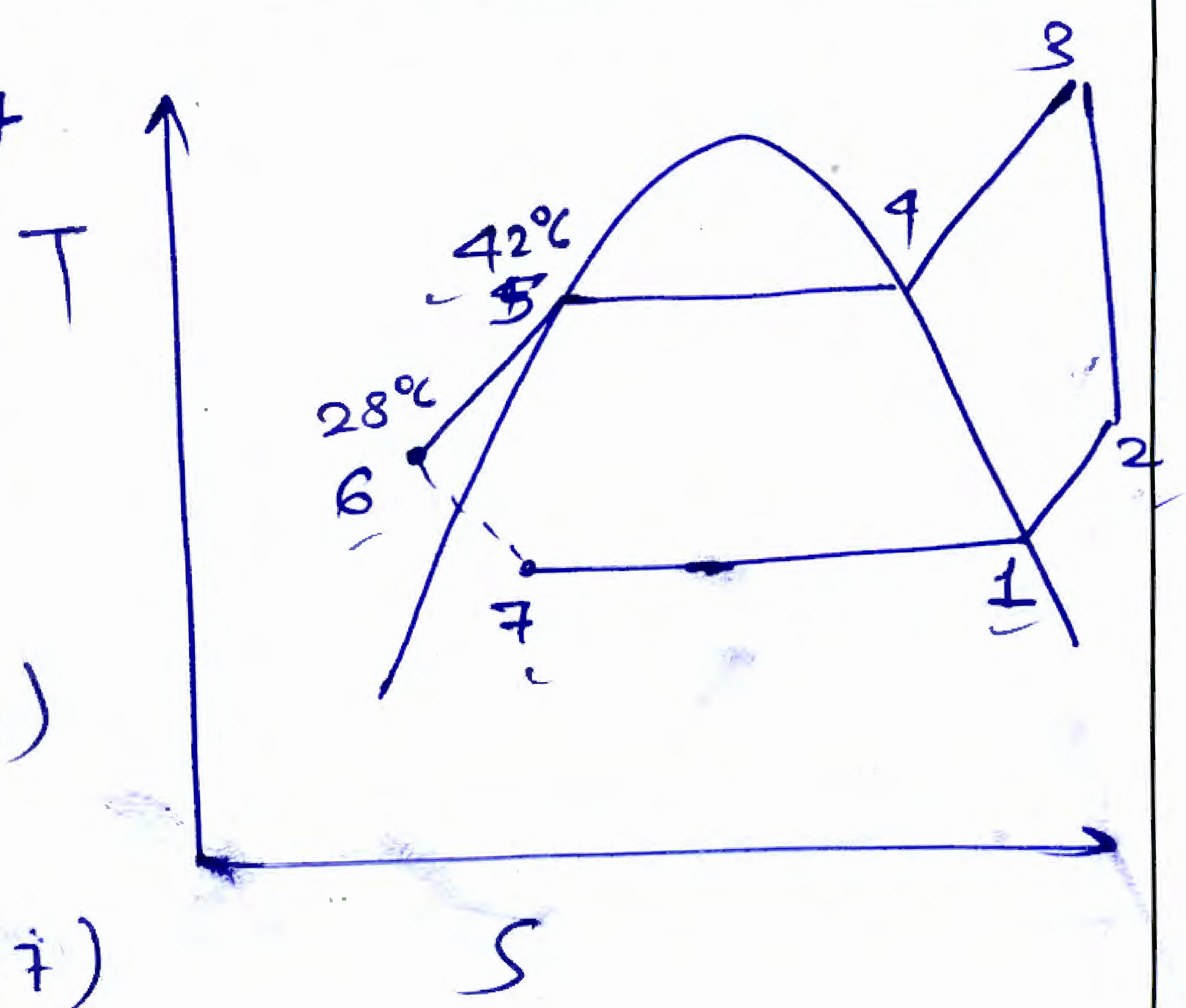
[12 marks]

$h_1 = 398.37$ kJ/kg

$h_5 = 251.68$ kJ/kg

$h_6 = 233.81$ kJ/kg

$h_7 = 233.81$ kJ/kg



∵ HE involves

$(h_5 - h_6) = (h_2 - h_1)$

$(251.68 - 233.81) = (h_2 - 398.37)$

$\boxed{h_2 = 416.24 \text{ kJ/kg}}$

$h_4 = 416.21$ kJ/kg.

$s_1 = 1.7806$ kJ/kgK.

$(h_2 - h_1) = C_p(T_2 - T_1)$

$416.24 - 398.37 = 1.03 \times (T_2 - 255)$

$\boxed{T_2 = 272.3495°K}$

$S_2 = S_1 + C_{pv} \ln(T_2/T_1)$

$= 1.7806 + 1.03 \ln\left(\frac{272.3495}{255}\right)$

$S_2 = 1.84839$ kJ/kgK

$S_2 = S_3$

$S_3 = 1.84839$

$S_4 + C_{pv} \ln\left(\frac{T_3}{T_4}\right) = 1.84839$

$1.6969 + 1.03 \ln\left(\frac{T_3}{315}\right) = 1.84839$

$T_3 = 364.9^\circ K$

$h_3 = h_4 + C_{pv}(T_3 - T_4)$

$h_3 = 467.6$ kJ/kg

RC = 10 kW

$\dot{m} \times (h_1 - h_7) = 10$

$$\dot{m}_{Ref} = \frac{10}{398.37 - 233.81}$$

$\dot{m}_{Ref} = 0.06076$ kg/s

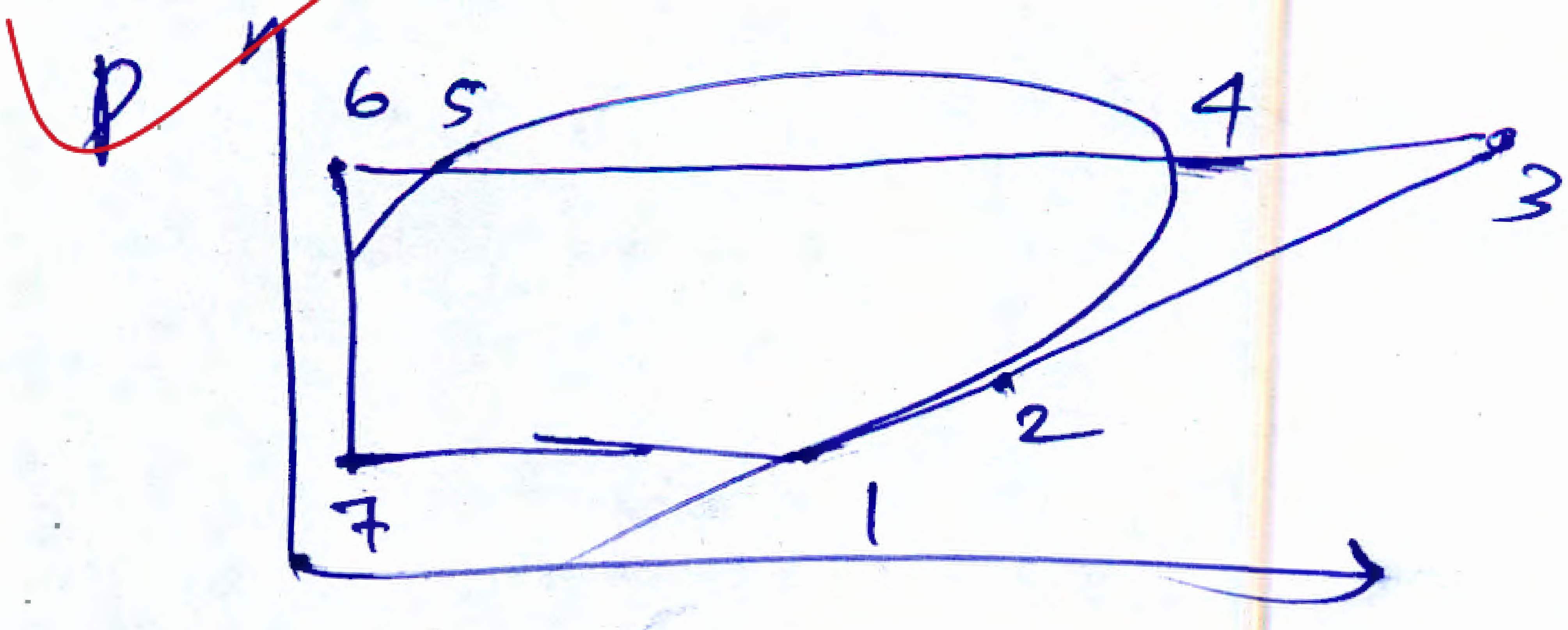
$$COP = \frac{RE}{w_{in}} = \frac{h_1 - h_7}{h_3 - h_2} = \frac{398.37 - 233.81}{467.6 - 416.24}$$

$$\boxed{COP = 3.204}$$

Power $= \dot{m}_{Ref}(h_3 - h_2)$

$= 0.06076 \times (\quad)$

Power = 3.12 kW

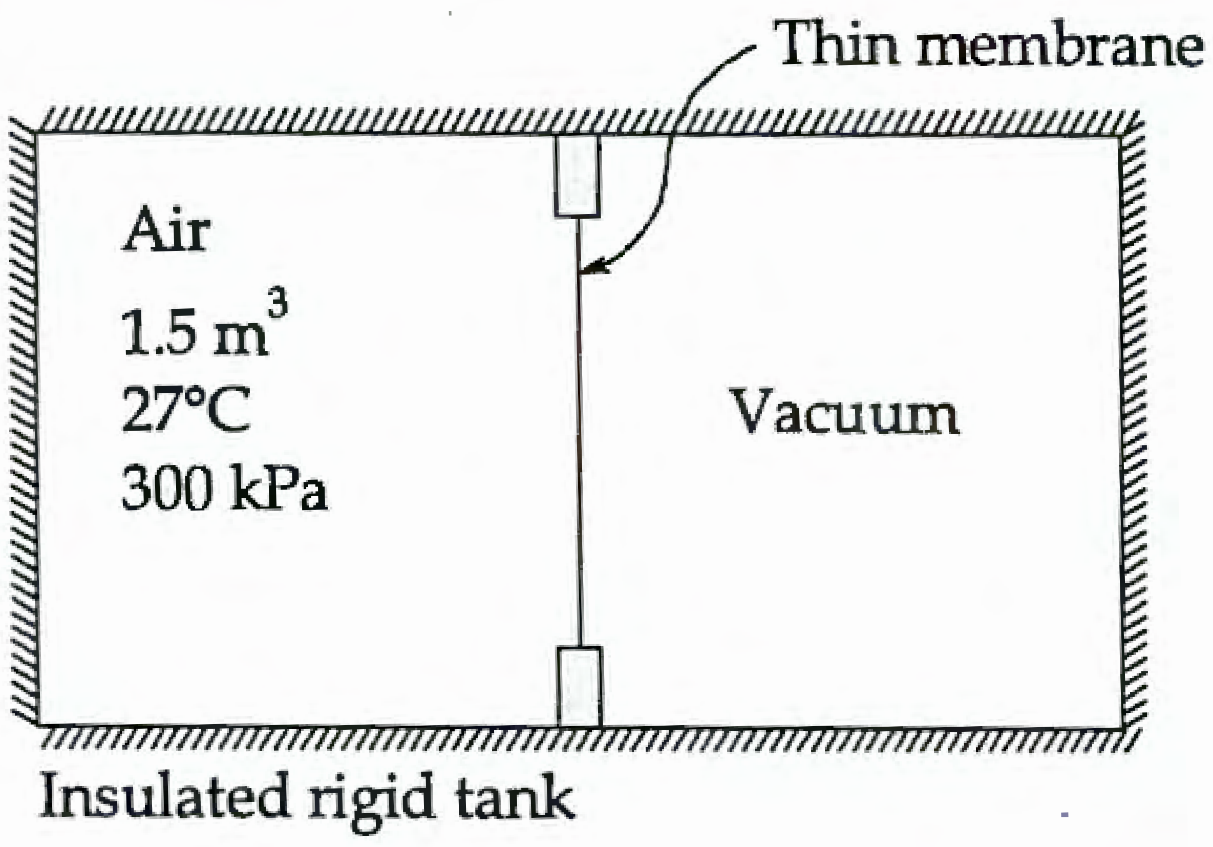


12

Q.5 (b) What is scavenging in two-stroke engines and how is it carried out? Also explain the various methods of scavenging in two-stroke engines with neat sketches.

[12 marks]

Q.5 (c) What is a "Free- expansion" process? Comment on the work done by the gas during a free- expansion process. As shown in the figure, one side of a rigid insulated container initially contains 1.5 m^3 of air at 27°C and 300 kPa. The air is separated by a thin membrane from an evacuated volume of 1.5 m^3. Determine the Irreversibility during this process.



[12 marks]

free expansion

$P_iV_i = P_f V_f$

* free expansion is a process inwhich gas gets expand in the initially evacuated portion without any disturbance.

(*) In free expansion gas temp^r initially gets decrease due to expansion then increases due to irreversibility.

$P_1 = 300\,kPa$, $T_1 = 300°K$

$V_1 = 1.5\,m^3$

then $V_2 = 3m^3$

$P_1V_1 = P_2V_2$

$300 \times \cancel{1.5} = P_2 \times \cancel{3}\ 2$

$P_2 = 150\,kPa$

~~(A) Rgas=~~ $m_{gas\ air} = \frac{P_1V_1}{RT_1} = \frac{300 \times 1.5}{0.287 \times 300}$

$= 5.2264$ kg.

$$(\Delta S)_{air} = C_p \ln\left(\cancel{\frac{T_2}{T_1}}\right) - R\ln(P_2/P_1)$$

$\swarrow 0$

$$(\Delta S)_{air} = -0.287 \ln\left(\frac{150}{300}\right) = 0.19893 \text{ kJ/kg K}$$

$$(\Delta S)_{sur} = 0.$$

$$(\Delta S)_{un} = (\Delta S)_{air} + (\Delta S)_{sur}$$

$$= 0.19893 \text{ kJ/kg K}$$

$$(\Delta S)_{uni} = \dot{m} \times (\Delta S)_{un} = 5.2264 \times 0.19893$$

$$= 1.0397 \text{ kJ/K}.$$

$$\overset{a}{I} = \cancel{T_0}\ (\Delta S)_{un} \times T_0$$

$$= 1.0397 \times 300$$

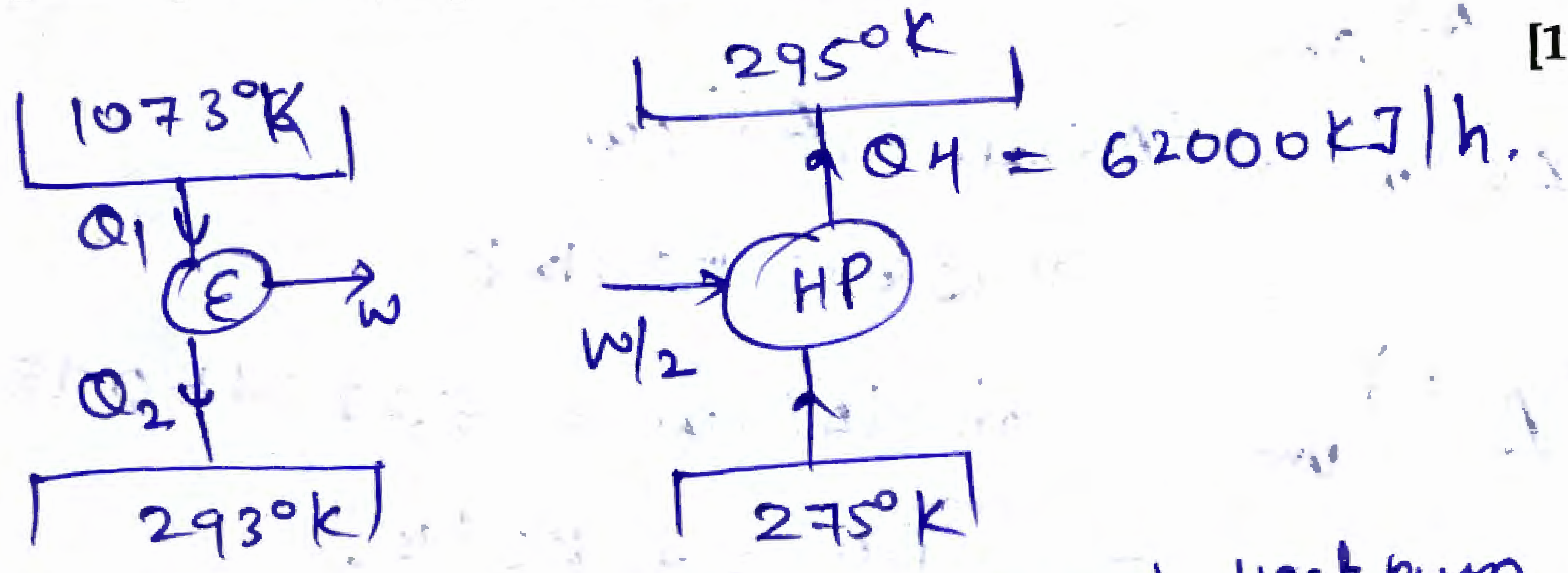
$$\boxed{\overset{o}{I} = 311.911 \text{ kJ}}$$ Answer

Irreversibility

12

Q.5 (d) A heat engine operates between two reservoirs at 800°C and 20°C. One-half of the work output of the heat engine is used to drive a Carnot heat pump that removes heat from cold surroundings at 2°C and transfer it to a house maintained at 22°C. If the house is losing heat at a rate of 62000 kJ/h, determine the minimum rate of heat supply to the heat engine required to keep the house at 22°C.

[12 marks]



∵ HP → carnot Heat pump

$$(COP)_{carnot\ HP} = \frac{295}{295-275} = \frac{DL}{win}$$

$$\frac{295}{20} = \frac{62000}{3600 \times win}$$

$$win = \frac{W}{2} = 1.1672\ kW$$

$$\boxed{W = 2.3352\ kW}$$

∵ min. Rate of H.S. will come for carnot engine.

$$\eta = \frac{W}{Q_1} = 1 - \frac{293}{1073}$$

$$\frac{2.3352}{Q_1} = 1 - \frac{293}{1073}$$

Answer $\boxed{Q_1 = 3.2123\ kW}$

Answer $\boxed{Q_1 = 11564\ kJ/hr.}$ ✓

12

Q.5 (e) A cylinder contains 1 kg of certain fluid at an initial pressure of 20 bar. The fluid is allowed to expand reversibly behind a piston according to a law PV^2 = Constant until the volume is doubled. The fluid is then cooled reversibly at constant pressure until the piston regains its original position; heat is then supplied reversibly with the piston firmly locked in position until the pressure rises to the original value of 20 bar. Calculate the net work done by the fluid for an initial volume of 0.05 m^3.

[12 marks]

$P_1 = 20 \text{bar}$

$V_2 = 2V_1$

$V_3 = V_1$

$V_1 = 0.05 m^3 = V_3$

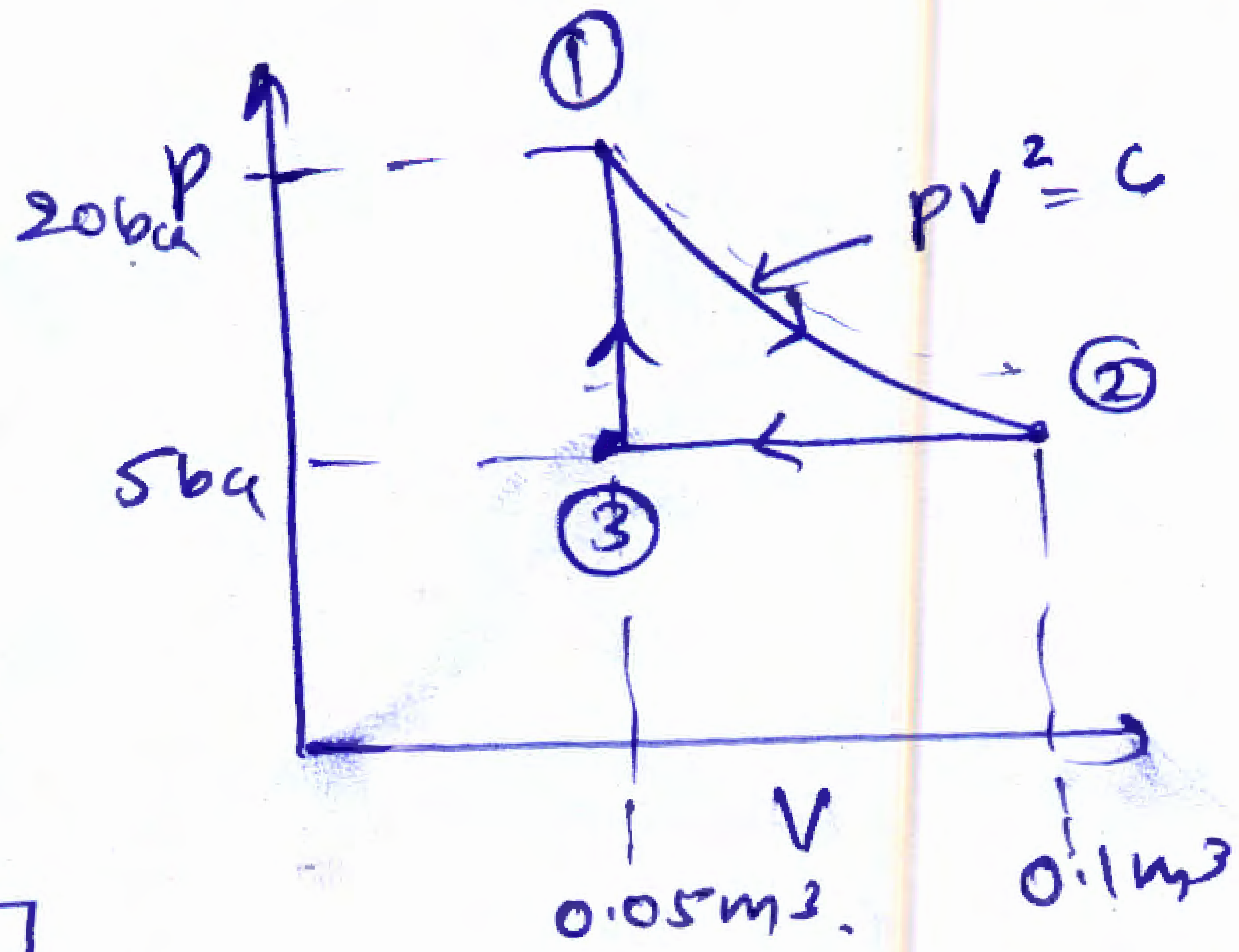
$V_2 = 0.1 m^3$

$P_1 V_1^2 = P_2 V_2^2$

$20 \times 0.05^2 = P_2 \times 0.1^2$

$\boxed{P_2 = 5 \text{bar}}$

$P_2 = P_3 = 5 b$



$$W_{net} = W_{1-2} - W_{2-3}$$

$$= \frac{(P_1V_1 - P_2V_2)}{n-1} - P_2(V_2 - V_3)$$

$$= \left\{\frac{(20 \times 0.05 - 5 \times 0.1)}{1} - 5 \times (0.1 - 0.05)\right\} \times 10^2$$

$$\boxed{W_{net} = 25\ kJ/kg}$$ Ans

12

Q.6 (a) A gasoline engine having a stroke volume 'V_s' and a compression ratio 'r'. At the beginning of compression stroke the state of working fluid is (P, V, T). Take working fluid as an ideal gas with characteristic gas constant 'R'. Ignition is set so that the pressure rises along a straight line during combustion and attains its highest value of 'K' times the pressure before compression and during combustion-process piston has travelled 'α' fraction of stroke-volume. The charge consists of a gasoline-air mixture in proportion by mass M : 1. Take calorific value of fuel as 'CV' and specific heat ratio of working fluid as 'γ'. Find the expression of heat lost per kg of charge during combustion.

[All the given parameters are to be considered in respective SI units without any scaling].

[20 marks]

Do not write in this margin

Q.6 (b) **(i)** Classify refrigerants based on their origin and chemical composition. Explain the standard refrigerant nomenclature system with suitable examples.

(ii) Explain harmful effects of R-12 and R-22 refrigerant. Also suggest new eco-friendly substitutes of these two refrigerants.

[10 + 10 = 20 marks]

Q.6 (c) Two tanks are connected by a valve. One tank contains 2.5 kg of Carbon monoxide gas at 77°C and 0.5 bar. The other tank holds 10 kg of the same gas at 27°C and 1000 kPa. The valve is opened and the gases are allowed to mix while receiving energy by heat transfer from the surroundings. The final equilibrium temperature is 35°C. Using the ideal gas model with constant C_V. Determine:

(i) The final equilibrium pressure

(ii) Heat transferred during the process

(iii) Loss of available energy during the process.

[20 marks]

Do not write in this margin

Q.7 (a) A test on a single-cylinder, 4-stroke oil-engine having bore of 15 cm and stroke to bore ratio of 2 gave the following results:

Brake torque = 200 Nm; Speed = 300 rpm; P_{imep} = 8 bar;

Fuel consumption = 2.5 kg/hr; Cooling water flow = 5 kg/min;

Cooling water temperature rise = 35°C; Air-fuel ratio = 22;

Exhaust gas temperature = 450°C; Barometer pressure 1 bar;

Room temperature = 20°C; Calorific value of fuel= 45 MJ/kg and contains 15% by weight hydrogen; Take Latent heat of vapourisation of fuel as 2250 kJ/kg.

Determine :

(i) The indicated thermal efficiency.

(ii) The volumetric efficiency based on atmospheric conditions

Draw up a heat balance in terms of kJ/min.

Take, c_p = 1 kJ/kgK for dry exhaust gas; c_p = 2.1 kJ/kgK for superheated steam; and R = 0.287 kJ/kgK

[20 marks]

1 Cylinder , 4stroke.

$D = 0.15 m.$

$L/D = 2$, $L = 0.3 m.$

$T_b = 200 N\cdot m$, $N = 300 rpm$

$$BP = T \times \frac{2\pi N}{60} = 6283.185 W$$

$$\underline{BP = 6.283185 kW} = \underline{376.9911 kJ/min}$$

$P_{imp} = 8 bar.$

$$\dot{V}_s = \left(\frac{\pi}{4} D^2 L\right) \times \frac{N}{60 \times 2}$$

$$\dot{V}_s = 0.013253 m^3/s$$

$$IP = P_{imep} \times \dot{V}_s = 800 \times 0.013253$$

$$\underline{IP = 10.6028 kW} = \underline{636.168 kJ/min}$$

$$\dot{m}_f = 2.5 kg/hr = \frac{2.5}{60} kg/min.$$

$$AFR = \frac{\dot{m}_a}{\dot{m}_f} = 22$$

$$\dot{m}_a = 22 \times 2.5 = 55 kg/hr.$$

$$= \frac{55}{60} kg/min$$

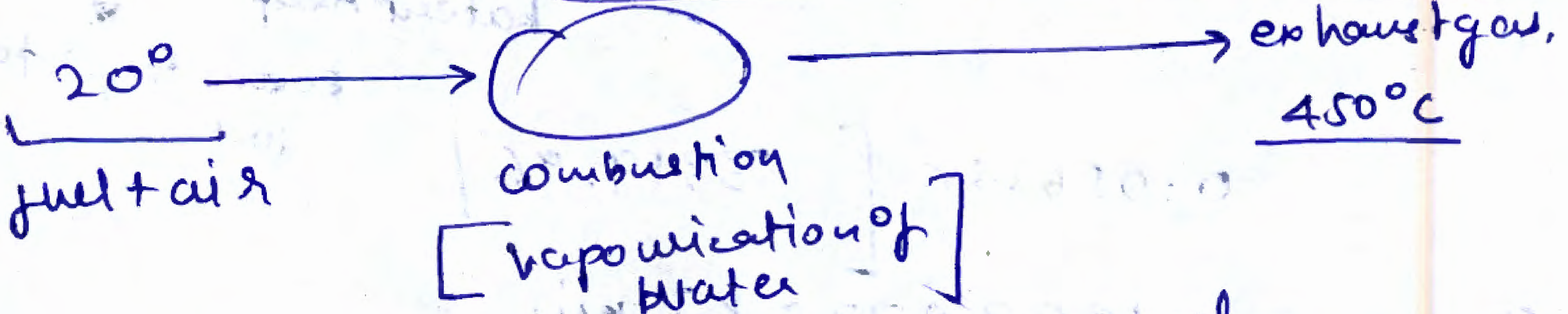
$\dot{m}_w = 5$ kg/min | $(\Delta T)_{cw} = 35°C$

$= \left(\frac{5}{60}\right)$ ~~kg/min~~ kg/s.

Heat Rejected through Cooling water

$= (5 \times 35 \times 4.187)$ kJ/min

$\boxed{Q_{water} = 732.725 \text{ kJ/min}}$



Heat addition by Burning of fuel

$HA/min = m_f \, cv_f = \frac{2.5}{60} \times 45000$ kJ/min

$HA/min = 1875$ kJ/min.

① $\eta_{ith} = \frac{IP}{HA/s} = \frac{636.168}{1875} \times 100\%$

3

∴ Answer $\boxed{\eta_{ith} = 33.92\%}$

② $PV = m_a RT$

$100 \times \dot{V}_{act} = \frac{55}{60 \times 60} \times 0.287 \times 293$

~~$\dot{V}_{act} = 0.77083$ m³/s.~~

$\dot{V}_{act} = 0.01284$ m³/s

$\eta_{vol} = \frac{\dot{V}_{act}}{\dot{V}_{swept}} = \frac{0.01284}{0.013253} = 0.9693$

$\boxed{\eta_{vol} = 96.93\%}$ Ans

fuel contain 15% weight of Hydrogen

$0.85C + 0.15H$ —

Then $\left(\frac{2.5}{60} \times 0.15\right)$ Hydrogen will produce

$\longrightarrow \left(9 \times \frac{2.5}{60} \times 0.15\right)$ ~~kg~~/min amount of water

$H + \frac{1}{2}O_2 \longrightarrow H_2O.$

$1 + 8 \longrightarrow 9$ kg of H_2O, superHeated steam ↓

Heat Through wet exhaust

$$= \left(\frac{2.5}{60} \times 9 \times 0.15\right) \times \left[\underbrace{2250}_{\text{latent Heat}} + (450-100) \times 2.1 + \underbrace{4.187 \times 80}_{\text{Room temp}^n \text{ to } 100^\circ c}\right]$$

$$= 0.05625 \times [3319.96]$$

$$Q_{\text{wet exhaust}} = 186.74775 \text{ kJ/mi.}$$

$$Q_{\text{dry exhaust}} = \left\{\left(\frac{2.5+55}{60}\right) - \left(\frac{2.5 \times 9 \times 0.15}{60}\right)\right\} \left[1 \times (450-20)\right]$$

$$Q_{\text{dry ex}} = 387.895 \text{ kJ/mi.}$$

Heat Balance

		%
①	HA/min = 1875 kJ/min	100 %
②	Qwater = 732.72 kJ/mi.	39 %
③	Qwet exhaust = 186.747 kJ/mi	9.95 %
④	Qdry exhaust = 387.895 kJ/mi	20.687 %
⑤	IP = 636.18 kJ/mi.	33.92 %

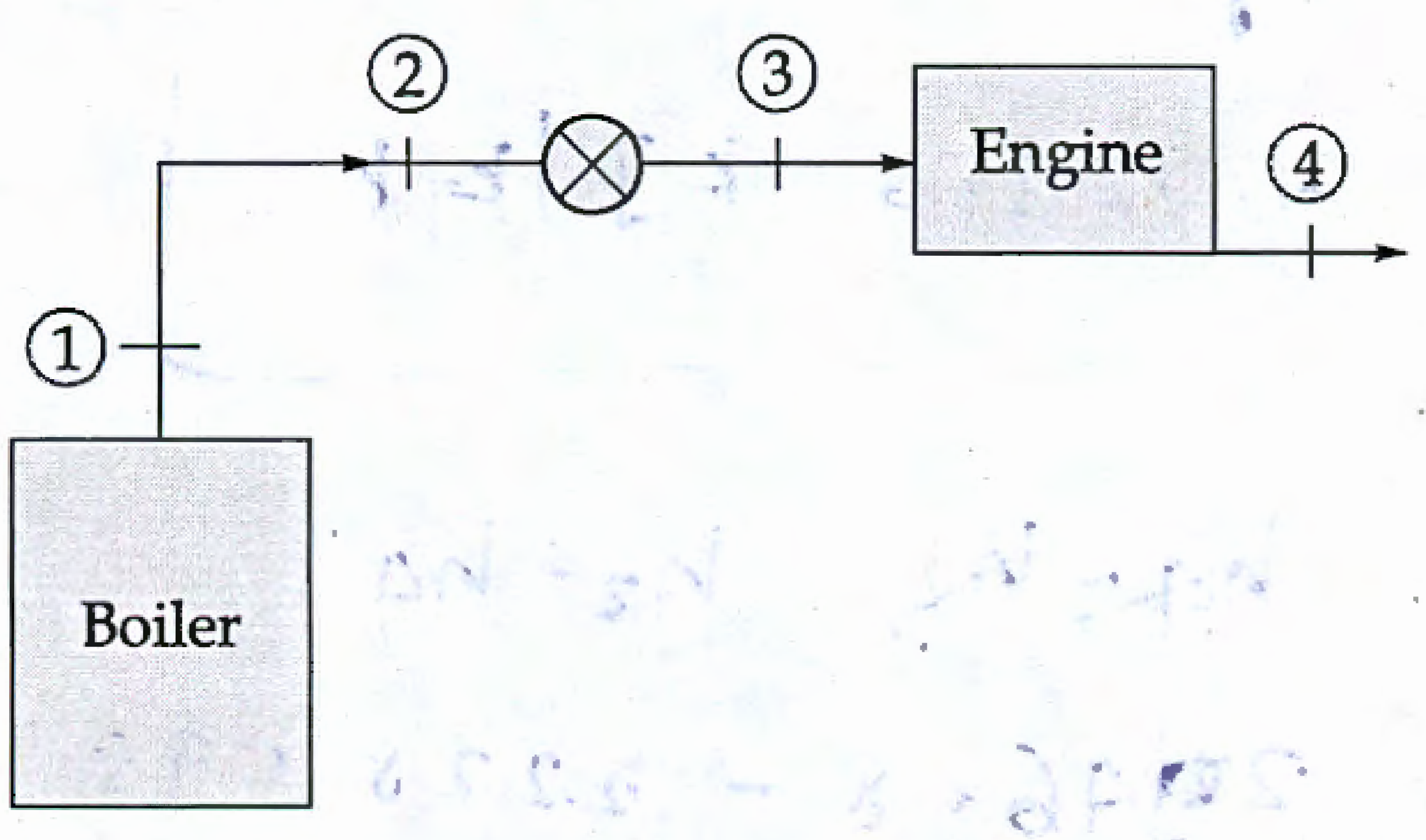
18

Q.7 (b) As shown in figure below, boiler steam at 10 bar, 300°C reaches the engine control valve through a pipeline at 9 bar, 250°C. It is throttled to 6 bar before expanding in the engine to 0.1 bar and 0.85 dry. Determine (per kg of steam)

(i) The temperature drop across throttle valve and work output of engine.

(ii) The entropy change due to throttling and entropy change in passing through the engine.

[Use steam table attached at the end]



[20 marks]

$P_1 = 10$ bar, $T_1 = 300^\circ C$

$= 1$ MPa,

$P_2 = 9$ bar, $T_2 = 250^\circ C$, $s_2 = 6.9805$ kJ/kgK

$P_3 = 6$ bar,

$P_4 = 0.1$ bar, $x = 0.85$

$h_2 = 2946.8$ kJ/kg, $u_2 = 2713.1$ kJ/kg

as throttling is isenthalpic process

Hence $h_2 = h_3$

$P_3 = 6$ bar, $h_3 = 2946.8$ kJ/kg

$T_3 = 245^\circ C$, $s_3 = 7.1629$ kJ/kgK.

Temp^r Drop a/c throttle value $= 250 - 245$

$= 5^\circ C$ Ans

$P_4 = 0.1$ bar, $x = 0.85$

$T_4 = 45.806^\circ C$.

@ 0.1 bar

$s_f = 0.64920$ kJ/kgK $s_{fg} = 7.4996$ kJ/kgK.

$h_f = 191.81$ kJ/kg, $h_{fg} = 2392.1$ kJ/kg

$h_4 = h_f + x h_{fg}$

$= 191.81 + 0.85 \times 2392.1$

$\boxed{h_4 = 2225.095 \text{ kJ/kg}}$

$s_4 = s_f + x s_{fg}$

$\boxed{s_4 = 7.02386 \text{ kJ/kgK}}$

$w_{o/p} = \cancel{h_4 - h_2}\ h_2 - h_4$

$= 2946.8 - 2225.095$

$\boxed{w_{/p} = 721.705 \text{ kJ/kg}}$ ✓ Ans

(2) (ΔS) during throttling $= S_1 - S_2$

$= 7.1629 - 6.9805$

$\boxed{(\Delta S)_{\text{throttling}} = 0.1824 \text{ kJ/kgK}}$ ✓ Ans

(ΔS) engine $= S_4 - S_3$

$= 7.02386 - 7.1629$

$\boxed{(\Delta S)_{\text{passing through engine}} = -0.13904 \text{ kJ/kgK}}$ ✓ Answer

20

Q.7 (c) **(i)** State disadvantages of wet compression over dry compression in vapour compression refrigeration system.

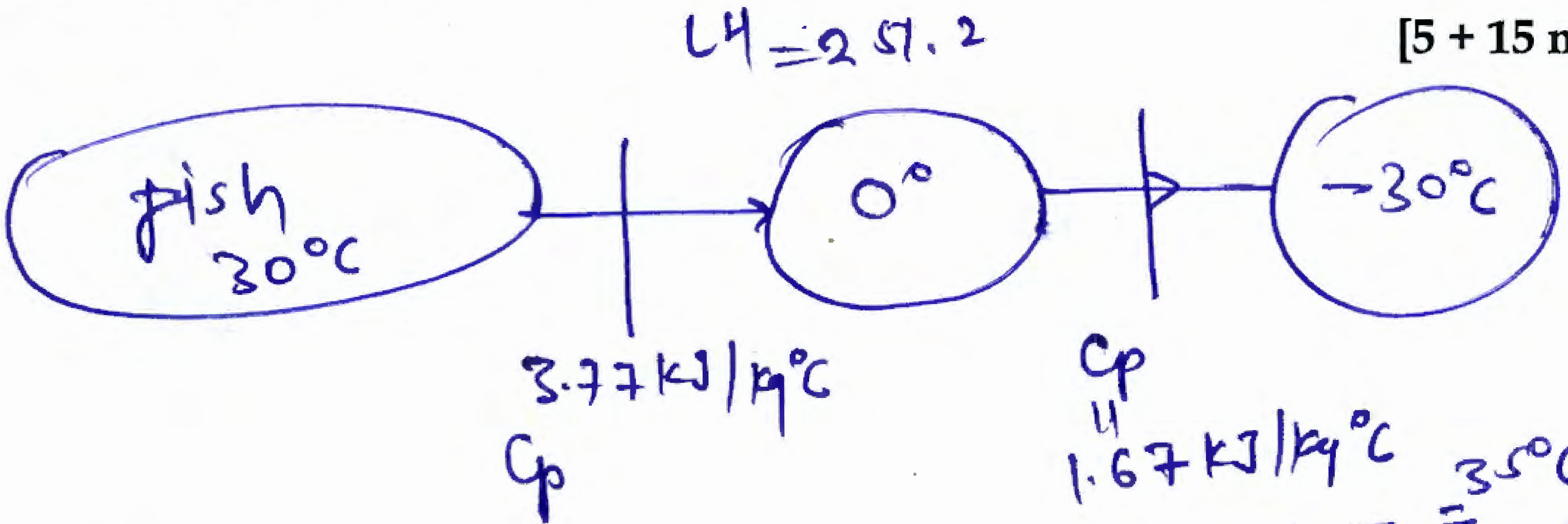
(ii) 32.4 tonnes of fish has to be frozen to –30°C per day when the fish enters at 30°C. The specific heat of thawed fish is 3.77 kJ/kg°C and for frozen fish is 1.67 kJ/kg°C. The latent heat of fusion of fish (at 0°C) is 251.2 kJ/kg. If actual COP of refrigeration system is 40% of ideal. Calculate:

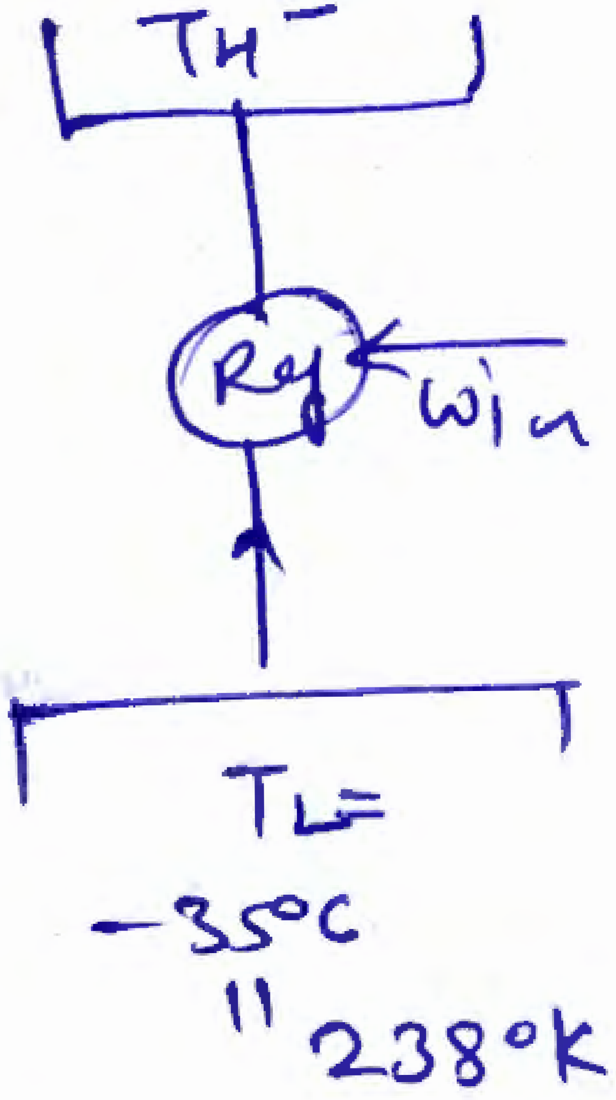
1. Refrigeration capacity of the refrigeration system in tons of refrigeration.
2. Electricity cost per year of the refrigeration system, if electricity cost is Rs. 0.5 per kW-hr.

Assume air as secondary refrigerant, for heat transfer in evaporator and condensor 5°C temperature difference is required.

[5 + 15 marks]

②.





$$(COP)_{carnot} = \frac{238}{70}$$

$$(COP)_{ideal} = 3.4$$

$$(COP)_{actual} = 0.4 \times (COP)_{ideal}$$

$$(COP)_{actual} = \underline{1.36}$$

$$RC = \underbrace{32.4 \times 10^3}_{\text{mass of fish}} \times \left[30 \times \overset{Cp}{1.67} + \underbrace{251.2}_{LH} + \underbrace{3.77 \times 30}_{Cp} \right] \text{ perday}$$

$$RC = \frac{32.4 \times 10^3 \times (414.4)}{24 \times 3600} \text{ kW}$$

$$\boxed{RC. = 155.4 \text{ kW}}$$

$\boxed{RC = 44.4 \text{ Tons}}$ Answer

⑥ Electricity cost = 0.5 Rs/ kWhr.

$$\because \quad COP_{act} = \frac{DE}{win}$$

$$1.36 = \frac{155.4}{win}$$

$$win = 114.264 \text{ kw.}$$

24 hours

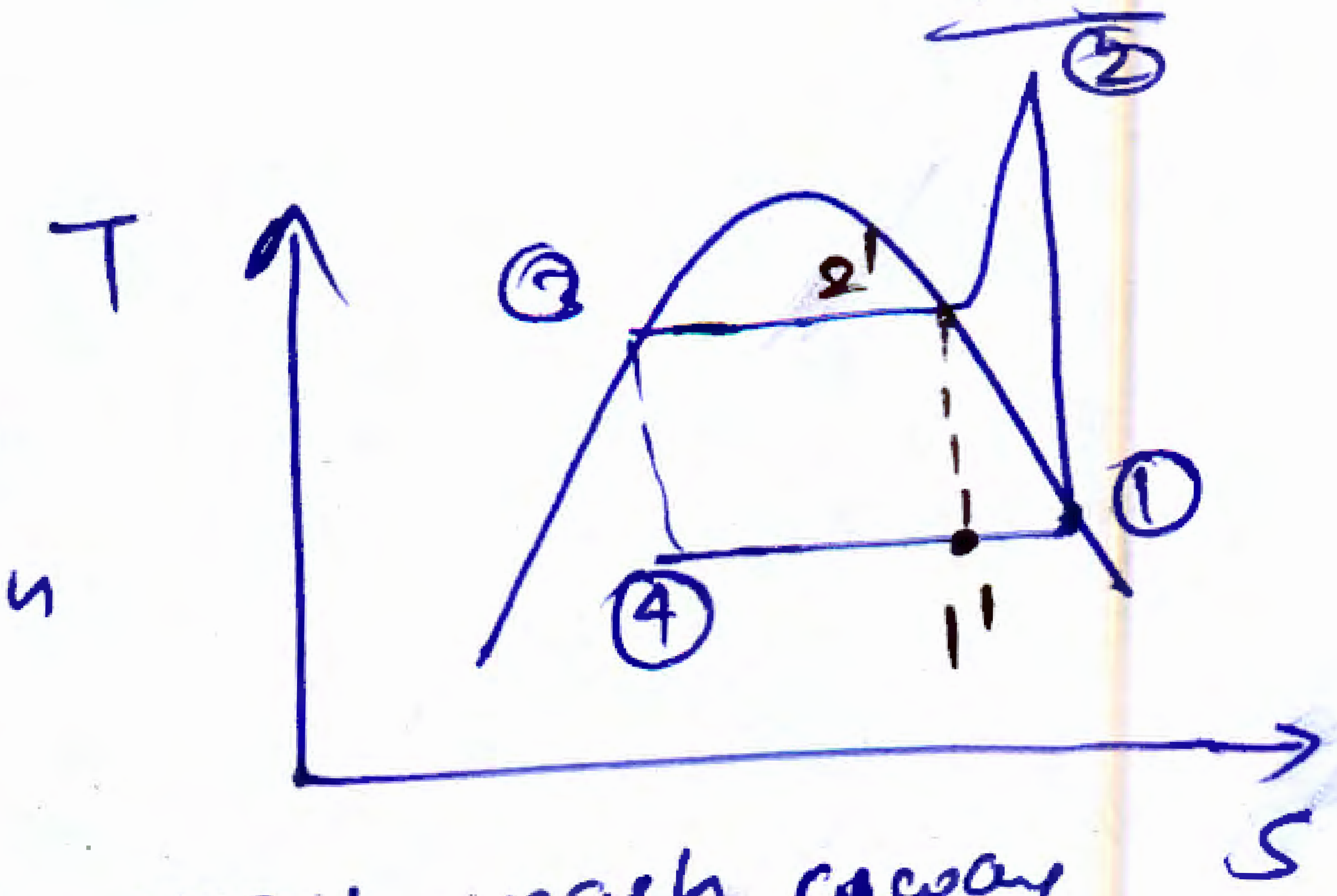
$$\text{Electricity cost per year} = \frac{114.264 \times 0.5 \times \cancel{3600} \times 24 \times 365}{\cancel{3600}}$$

365 days

$\boxed{\text{Cost of electricity} = 500479.4118 \text{ Rs.}}$ Ans

15

⑦



① . 1'–2' ⇒ wet compression

1–2 ⇒ Dry compression

~~①~~ ① wet compression may wash away the lubricant in compressor.

② wet compression will Reduce the Refrigeration effect.

③. It is difficult to stop the process at specific dryness fraction point

④ Bcz of liquid particals wear & tear

4

will increase in compressor.

Q.8 (a) An engine in outer space operates on the carnot-cycle. Heat is rejected by the engine to the surroundings is by radiation only and is proportional to the product of the fourth power of absolute temperature of radiating surface and its area. For a given power output of the engine hot reservoir temperature is 700°C. Determine the temperature of surrounding for minimum area of radiating surface.

[20 marks]

Do not write in this margin

Q.8 (b) A two stage cascade refrigeration system is used to provide cooling at –20°C. While operating the high temperature condenser at 1 MPa, each stage operates on the ideal vapour compression refrigeration cycle. The upper vapour compression refrigeration cycle uses water as its working fluid and operates its evaporator at 5°C. The lower cycle uses R-12 as working fluid and operates its condenser at 400 kPa. This system produces a cooling effect of 100 TR. Determine mass flow rate of R-12 and water and overall COP of cascade system. Use following table for water and R-12 :

for water :

t(°C)	P(kPa)	h_f(kJ/kg)	h_g(kJ/kg)	s_f(kJ/kgK)	s_g(kJ/kgK)
5	–	21.02	2510.1	0.0763	9.0249
143.61	400	604.66	2738.1	1.7765	6.8955
179.88	1000	762.51	2777.1	2.1381	6.5850

For steam, specific heat at constant pressure is 2.1 kJ/kgK.

For R-12

t(°C)	P (kPa)	h_f(kJ/kg)	h_g(kJ/kg)	s_f(kJ/kgK)	s_g(kJ/kgK)
–20	–	17.79	178.73	0.0730	0.7087
5	–	40.69	189.63	0.1585	0.6943
8.28	400	43.74	191.02	0.1694	0.6928

For R-12 vapour, specific heat at constant pressure is 0.95 kJ/kgK.

[20 marks]

Do not
write in
this margin

Q.8 (c) A three-litre four-stroke diesel engine develops 12 kW per m^3 of free air induced per minute. The volumetric efficiency is 82% at 3600 rpm referred to atmospheric condition of 1 bar and 27°C. A rotary compressor which is machanically coupled to the engine is used to supercharge the engine. The pressure ratio and the isentropic efficiency of the compressor are 1.6 and 70%, respectively. Calculate the percentage increase in brake power due to supercharging. Assume mechanical efficiency of the engine to be 75% and air intake to the cylinder to be at the pressure equal to delivery pressure from compressor and temperature equal to 5.7°C less than the delivery temperature of the compressor. Also, assume that cylinder contains volume of charge equal to swept volume and ratio of specific heats is 1.4.

[20 marks]

○○○○

Saturated Water and Steam (Pressure-based)

$p_{tp} = 611.657$ Pa $= 0.000611657$ MPa

p	T_{sat}	Volume, m^3/kg		Energy, kJ/kg		Enthalpy, kJ/kg			Entropy, kJ/(kg K)		
MPa	°C	v_f	v_g	u_f	u_g	h_f	h_g	h_{fg}	s_f	s_g	s_{fg}
p_{tp}	**0.01**	0.00100021	205.991	**0**	2374.9	0.00	2500.9	2500.9	**0**	9.1555	9.1555
0.0007	1.881	0.00100011	181.217	7.89	2377.4	7.89	2504.3	2496.5	0.02878	9.1058	9.0770
0.0008	3.761	0.00100008	159.640	15.81	2380.1	15.81	2507.8	2492.0	0.05748	9.0567	8.9992
0.0009	5.444	0.00100009	142.757	22.89	2382.4	22.89	2510.9	2488.0	0.08297	9.0135	8.9305
0.0010	6.970	0.00100014	129.178	29.30	2384.5	29.30	2513.7	2484.4	0.10591	8.9749	8.8690
0.0012	9.654	0.00100032	108.670	40.57	2388.2	40.57	2518.6	2478.0	0.14595	8.9082	8.7623
0.0014	11.969	0.00100054	93.899	50.28	2391.3	50.28	2522.8	2472.5	0.18015	8.8521	8.6719
0.0016	14.010	0.00100080	82.743	58.83	2394.1	58.83	2526.5	2467.7	0.21004	8.8035	8.5935
0.0018	15.837	0.00100108	74.011	66.49	2396.7	66.49	2529.9	2463.4	0.23662	8.7608	8.5241
0.0020	17.495	0.00100136	66.987	73.43	2398.9	73.43	2532.9	2459.4	0.26056	8.7226	8.4620
0.0024	20.414	0.00100193	56.375	85.65	2402.9	85.65	2538.2	2452.5	0.30239	8.6567	8.3544
0.0028	22.935	0.00100249	48.729	96.19	2406.4	96.19	2542.8	2446.6	0.33816	8.6012	8.2631
0.0032	25.158	0.00100305	42.952	105.49	2409.4	105.49	2546.8	2441.3	0.36945	8.5533	8.1838
0.0036	27.152	0.00100358	38.430	113.83	2412.1	113.83	2550.4	2436.6	0.39729	8.5110	8.1138
0.0040	28.960	0.00100410	34.791	121.39	2414.5	121.39	2553.7	2432.3	0.42239	8.4734	8.0510
0.0045	31.012	0.00100473	31.131	129.96	2417.3	129.96	2557.4	2427.4	0.45069	8.4313	7.9806
0.0050	32.874	0.00100533	28.185	137.74	2419.8	137.75	2560.7	2423.0	0.47620	8.3938	7.9176
0.0055	34.581	0.00100590	25.762	144.87	2422.1	144.88	2563.8	2418.9	0.49945	8.3599	7.8605
0.0060	36.159	0.00100645	23.733	151.47	2424.2	151.48	2566.6	2415.2	0.52082	8.3290	7.8082
0.0065	37.627	0.00100699	22.009	157.60	2426.2	157.61	2569.3	2411.6	0.54060	8.3007	7.7601
0.0070	39.000	0.00100750	20.524	163.34	2428.0	163.35	2571.7	2408.4	0.55903	8.2745	7.7154
0.0075	40.290	0.00100800	19.233	168.74	2429.8	168.75	2574.0	2405.3	0.57627	8.2501	7.6738
0.0080	41.509	0.00100848	18.099	173.83	2431.4	173.84	2576.2	2402.4	0.59249	8.2273	7.6348
0.0085	42.663	0.00100895	17.095	178.66	2433.0	178.67	2578.3	2399.6	0.60780	8.2060	7.5982
0.0090	43.761	0.00100940	16.199	183.24	2434.4	183.25	2580.2	2397.0	0.62230	8.1858	7.5635
0.0095	44.807	0.00100984	15.396	187.62	2435.8	187.63	2582.1	2394.5	0.63607	8.1668	7.5308
0.010	45.806	0.00101027	14.670	191.80	2437.2	191.81	2583.9	2392.1	0.64920	8.1488	7.4996
0.011	47.683	0.00101110	13.412	199.64	2439.7	199.65	2587.2	2387.5	0.67372	8.1154	7.4417
0.012	49.419	0.00101188	12.358	206.90	2442.0	206.91	2590.3	2383.4	0.69628	8.0849	7.3887
0.013	51.034	0.00101263	11.462	213.66	2444.1	213.67	2593.1	2379.4	0.71717	8.0570	7.3398
0.014	52.547	0.00101335	10.691	219.98	2446.1	219.99	2595.8	2375.8	0.73664	8.0311	7.2945
0.016	55.313	0.00101471	9.4306	231.55	2449.7	231.57	2600.6	2369.1	0.77201	7.9846	7.2126
0.018	57.798	0.00101597	8.4431	241.94	2453.0	241.96	2605.0	2363.0	0.80355	7.9437	7.1402
0.020	60.058	0.00101716	7.6480	251.40	2455.9	251.42	2608.9	2357.5	0.83202	7.9072	7.0752
0.024	64.053	0.00101934	6.4453	268.13	2461.2	268.15	2615.9	2347.7	0.88191	7.8442	6.9623
0.028	67.518	0.00102131	5.5778	282.63	2465.6	282.66	2621.8	2339.2	0.92472	7.7912	6.8664
0.032	70.586	0.00102312	4.9215	295.49	2469.6	295.52	2627.1	2331.6	0.96228	7.7453	6.7830
0.036	73.345	0.00102480	4.4072	307.05	2473.1	307.09	2631.8	2324.7	0.99579	7.7050	6.7092
0.040	75.857	0.00102638	3.9930	317.58	2476.4	317.62	2636.1	2318.4	1.0261	7.6690	6.6429
0.045	78.715	0.00102821	3.5759	329.57	2480.0	329.62	2640.9	2311.2	1.0603	7.6288	6.5686
0.050	81.317	0.00102993	3.2400	340.49	2483.2	340.54	2645.2	2304.7	1.0912	7.5930	6.5018

Continued ...

Water/Steam at $p = 0.60$ MPa ($T_{\text{sat}} = 158.826$°C)

T	v	u	h	s
°C	m^3/kg	kJ/kg	kJ/kg	kJ/kg K
0	0.00099990	-0.03	0.57	-0.00011
5	0.00099979	21.02	21.62	0.07624
10	0.00100006	42.01	42.61	0.15103
15	0.00100067	62.95	63.55	0.22437
20	0.00100157	83.88	84.48	0.29636
25	0.00100273	104.78	105.38	0.36707
30	0.00100415	125.68	126.28	0.43657
35	0.00100578	146.57	147.17	0.50492
40	0.00100762	167.46	168.06	0.57217
45	0.00100966	188.34	188.95	0.63836
50	0.00101189	209.24	209.85	0.70354
55	0.00101429	230.14	230.75	0.76773
60	0.00101687	251.06	251.67	0.83098
65	0.00101961	271.98	272.59	0.89333
70	0.00102251	292.92	293.53	0.95479
75	0.00102557	313.86	314.48	1.0154
80	0.00102879	334.83	335.45	1.0752
85	0.00103217	355.82	356.44	1.1342
90	0.00103569	376.83	377.45	1.1925
95	0.00103937	397.86	398.48	1.2500
100	0.00104321	418.91	419.54	1.3068
105	0.00104719	440.00	440.63	1.3630
110	0.00105134	461.12	461.75	1.4184
115	0.00105564	482.27	482.90	1.4733
120	0.00106010	503.45	504.09	1.5275
125	0.00106472	524.69	525.33	1.5812
130	0.00106951	545.97	546.61	1.6343
135	0.00107447	567.29	567.93	1.6869
140	0.00107961	588.67	589.32	1.7390
145	0.00108492	610.11	610.76	1.7905
150	0.00109042	631.61	632.26	1.8417
155	0.00109611	653.16	653.82	1.8923
158.826	0.00110060	669.72	670.38	1.9308
158.826	0.31558	2566.8	2756.1	6.7592
160	0.31668	2569.0	2759.0	6.7659
165	0.32129	2578.3	2771.1	6.7937
170	0.32583	2587.5	2783.0	6.8206
175	0.33032	2596.4	2794.6	6.8466
180	0.33475	2605.1	2806.0	6.8720
185	0.33915	2613.8	2817.3	6.8968
190	0.34350	2622.4	2828.5	6.9211
195	0.34783	2630.9	2839.6	6.9449
200	0.35212	2639.3	2850.6	6.9683
210	0.36063	2656.0	2872.4	7.0139
220	0.36905	2672.5	2893.9	7.0580
230	0.37740	2688.9	2915.3	7.1008
240	0.38568	2705.1	2936.5	7.1426
250	0.39390	2721.3	2957.6	7.1832
260	0.40208	2737.3	2978.5	7.2230
270	0.41021	2753.4	2999.5	7.2619
270	0.41021	2753.4	2999.5	7.2619
280	0.41831	2769.3	3020.3	7.3000
290	0.42638	2785.4	3041.2	7.3373
300	0.43442	2801.3	3062.0	7.3740
310	0.44243	2817.3	3082.8	7.4100
320	0.45042	2833.3	3103.6	7.4453
330	0.45839	2849.4	3124.4	7.4801
340	0.46634	2865.5	3145.3	7.5144
350	0.47427	2881.5	3166.1	7.5481
360	0.48219	2897.7	3187.0	7.5813
370	0.49010	2913.8	3207.9	7.6141
380	0.49799	2930.0	3228.8	7.6464
390	0.50587	2946.3	3249.8	7.6782
400	0.51374	2962.6	3270.8	7.7097
410	0.52160	2978.8	3291.8	7.7407
420	0.52945	2995.2	3312.9	7.7713
430	0.53729	3011.6	3334.0	7.8016
440	0.54513	3028.1	3355.2	7.8315
450	0.55296	3044.7	3376.5	7.8611
460	0.56078	3061.2	3397.7	7.8903
470	0.56859	3077.9	3419.1	7.9192
480	0.57640	3094.7	3440.5	7.9478
490	0.58420	3111.4	3461.9	7.9761
500	0.59200	3128.2	3483.4	8.0041
520	0.60758	3162.1	3526.6	8.0592
540	0.62315	3196.1	3570.0	8.1132
560	0.63870	3230.4	3613.6	8.1663
580	0.65424	3265.0	3657.5	8.2183
600	0.66976	3299.8	3701.7	8.2695
620	0.68528	3334.9	3746.1	8.3198
640	0.70078	3370.3	3790.8	8.3693
660	0.71628	3405.9	3835.7	8.4180
680	0.73176	3441.8	3880.9	8.4659
700	0.74725	3478.0	3926.4	8.5131
720	0.76272	3514.6	3972.2	8.5597
740	0.77819	3551.3	4018.2	8.6056
760	0.79365	3588.3	4064.5	8.6508
780	0.80911	3625.6	4111.1	8.6954
800	0.82457	3663.2	4157.9	8.7395
820	0.84002	3701.0	4205.0	8.7830
840	0.85547	3739.1	4252.4	8.8260
860	0.87091	3777.6	4300.1	8.8684
880	0.88635	3816.2	4348.0	8.9103
900	0.90178	3855.1	4396.2	8.9518
920	0.91722	3894.4	4444.7	8.9927
940	0.93265	3933.8	4493.4	9.0332
960	0.94808	3973.6	4542.4	9.0733
980	0.96351	4013.5	4591.6	9.1129
1000	0.97893	4053.7	4641.1	9.1521

Water/Steam at $p = 0.9$ MPa ($T_{\text{sat}} = 175.350$°C)

T °C	v m^3/kg	u kJ/kg	h kJ/kg	s kJ/kg K
0	0.00099975	-0.03	0.87	-0.00009
5	0.00099964	21.01	21.91	0.07624
10	0.00099992	42.00	42.90	0.15101
15	0.00100053	62.94	63.84	0.22433
20	0.00100143	83.86	84.76	0.29630
25	0.00100260	104.76	105.66	0.36699
30	0.00100401	125.65	126.55	0.43648
35	0.00100565	146.53	147.44	0.50482
40	0.00100749	167.41	168.32	0.57205
45	0.00100953	188.30	189.21	0.63823
50	0.00101175	209.20	210.11	0.70340
55	0.00101416	230.10	231.01	0.76758
60	0.00101673	251.00	251.92	0.83082
65	0.00101947	271.92	272.84	0.89316
70	0.00102237	292.86	293.78	0.95461
75	0.00102543	313.80	314.72	1.0152
80	0.00102865	334.76	335.69	1.0750
85	0.00103202	355.75	356.68	1.1340
90	0.00103555	376.75	377.68	1.1923
95	0.00103922	397.77	398.71	1.2498
100	0.00104305	418.83	419.77	1.3066
105	0.00104704	439.91	440.85	1.3627
110	0.00105118	461.02	461.97	1.4182
115	0.00105547	482.17	483.12	1.4730
120	0.00105993	503.35	504.30	1.5273
125	0.00106455	524.57	525.53	1.5809
130	0.00106933	545.85	546.81	1.6340
135	0.00107429	567.16	568.13	1.6866
140	0.00107942	588.54	589.51	1.7387
145	0.00108472	609.96	610.94	1.7902
150	0.00109022	631.46	632.44	1.8413
155	0.00109590	653.01	654.00	1.8920
160	0.00110179	674.65	675.64	1.9422
165	0.00110788	696.35	697.35	1.9921
170	0.00111418	718.14	719.14	2.0415
175	0.00112072	740.01	741.02	2.0906
175.350	0.00112118	741.55	742.56	2.0940
175.350	0.21489	2579.6	2773.0	6.6213
180	0.21792	2589.1	2785.2	6.6482
185	0.22112	2598.8	2797.8	6.6759
190	0.22426	2608.3	2810.1	6.7027
195	0.22736	2617.6	2822.2	6.7286
200	0.23042	2626.7	2834.1	6.7539
210	0.23644	2644.6	2857.4	6.8027
220	0.24236	2662.2	2880.3	6.8495
230	0.24818	2679.3	2902.7	6.8946
240	0.25393	2696.4	2924.9	6.9382
250	0.25962	2713.1	2946.8	6.9805
260	0.26526	2729.8	2968.5	7.0216
270	0.27085	2746.3	2990.1	7.0618
270	0.27085	2746.3	2990.1	7.0618
280	0.27640	2762.8	3011.6	7.1009
290	0.28192	2779.3	3033.0	7.1392
300	0.28740	2795.6	3054.3	7.1767
310	0.29286	2811.9	3075.5	7.2134
320	0.29829	2828.2	3096.7	7.2495
330	0.30370	2844.6	3117.9	7.2849
340	0.30909	2860.8	3139.0	7.3197
350	0.31447	2877.2	3160.2	7.3539
360	0.31983	2893.5	3181.3	7.3876
370	0.32517	2909.8	3202.5	7.4207
380	0.33050	2926.3	3223.7	7.4534
390	0.33582	2942.6	3244.8	7.4856
400	0.34113	2959.1	3266.1	7.5173
410	0.34643	2975.5	3287.3	7.5486
420	0.35172	2992.1	3308.6	7.5795
430	0.35700	3008.6	3329.9	7.6101
440	0.36227	3025.2	3351.2	7.6402
450	0.36753	3041.8	3372.6	7.6700
460	0.37279	3058.5	3394.0	7.6994
470	0.37804	3075.3	3415.5	7.7285
480	0.38329	3092.0	3437.0	7.7572
490	0.38853	3108.9	3458.6	7.7857
500	0.39376	3125.8	3480.2	7.8138
520	0.40422	3159.8	3523.6	7.8692
540	0.41465	3194.0	3567.2	7.9235
560	0.42508	3228.4	3611.0	7.9768
580	0.43549	3263.2	3655.1	8.0290
600	0.44588	3298.1	3699.4	8.0803
620	0.45627	3333.3	3743.9	8.1308
640	0.46665	3368.7	3788.7	8.1804
660	0.47702	3404.5	3833.8	8.2292
680	0.48738	3440.5	3879.1	8.2773
700	0.49773	3476.7	3924.7	8.3246
720	0.50808	3513.2	3970.5	8.3712
740	0.51842	3550.0	4016.6	8.4172
760	0.52876	3587.1	4063.0	8.4625
780	0.53909	3624.4	4109.6	8.5072
800	0.54941	3662.1	4156.6	8.5514
820	0.55974	3699.9	4203.7	8.5949
840	0.57005	3738.2	4251.2	8.6379
860	0.58037	3776.6	4298.9	8.6804
880	0.59068	3815.3	4346.9	8.7224
900	0.60099	3854.2	4395.1	8.7639
920	0.61130	3893.4	4443.6	8.8049
940	0.62160	3933.0	4492.4	8.8454
960	0.63190	3972.7	4541.4	8.8855
980	0.64220	4012.7	4590.7	8.9251
1000	0.65250	4053.0	4640.2	8.9643

Water/Steam at $p = 1.0$ MPa ($T_{\text{sat}} = 179.878$°C)

T	v	u	h	s
°C	m^3/kg	kJ/kg	kJ/kg	kJ/kg K
0	0.00099970	-0.02	0.98	-0.00009
5	0.00099959	21.01	22.01	0.07624
10	0.00099987	41.99	42.99	0.15100
15	0.00100048	62.94	63.94	0.22431
20	0.00100138	83.85	84.85	0.29628
25	0.00100255	104.75	105.75	0.36697
30	0.00100397	125.64	126.64	0.43645
35	0.00100560	146.52	147.53	0.50478
40	0.00100744	167.40	168.41	0.57202
45	0.00100948	188.29	189.30	0.63819
50	0.00101171	209.18	210.19	0.70335
55	0.00101411	230.08	231.09	0.76753
60	0.00101669	250.98	252.00	0.83077
65	0.00101943	271.90	272.92	0.89310
70	0.00102233	292.84	293.86	0.95455
75	0.00102539	313.78	314.81	1.0152
80	0.00102860	334.74	335.77	1.0750
85	0.00103197	355.72	356.75	1.1340
90	0.00103550	376.72	377.76	1.1922
95	0.00103917	397.75	398.79	1.2497
100	0.00104300	418.80	419.84	1.3065
105	0.00104699	439.87	440.92	1.3626
110	0.00105112	460.99	462.04	1.4181
115	0.00105542	482.13	483.19	1.4729
120	0.00105987	503.32	504.38	1.5272
125	0.00106449	524.54	525.60	1.5808
130	0.00106927	545.81	546.88	1.6339
135	0.00107423	567.13	568.20	1.6865
140	0.00107935	588.50	589.58	1.7386
145	0.00108466	609.93	611.01	1.7901
150	0.00109015	631.41	632.50	1.8412
155	0.00109583	652.96	654.06	1.8919
160	0.00110171	674.60	675.70	1.9421
165	0.00110780	696.30	697.41	1.9919
170	0.00111410	718.09	719.20	2.0414
175	0.00112063	739.96	741.08	2.0905
179.878	0.00112723	761.39	762.52	2.1381
179.878	0.19436	2582.7	2777.1	6.5850
180	0.19444	2583.0	2777.4	6.5857
185	0.19742	2593.3	2790.7	6.6148
190	0.20034	2603.2	2803.5	6.6427
195	0.20320	2612.8	2816.0	6.6695
200	0.20602	2622.3	2828.3	6.6955
210	0.21156	2640.6	2852.2	6.7456
220	0.21698	2658.5	2875.5	6.7934
230	0.22231	2676.1	2898.4	6.8393
240	0.22756	2693.3	2920.9	6.8836
250	0.23275	2710.4	2943.1	6.9265
260	0.23788	2727.2	2965.1	6.9681
270	0.24296	2743.9	2986.9	7.0087
270	0.24296	2743.9	2986.9	7.0087
280	0.24801	2760.6	3008.6	7.0482
290	0.25301	2777.2	3030.2	7.0868
300	0.25799	2793.6	3051.6	7.1246
310	0.26294	2810.1	3073.0	7.1616
320	0.26786	2826.5	3094.4	7.1979
330	0.27276	2842.9	3115.7	7.2335
340	0.27764	2859.3	3136.9	7.2685
350	0.28250	2875.7	3158.2	7.3029
360	0.28735	2892.0	3179.4	7.3367
370	0.29218	2908.5	3200.7	7.3700
380	0.29700	2924.9	3221.9	7.4028
390	0.30181	2941.4	3243.2	7.4351
400	0.30661	2957.9	3264.5	7.4669
410	0.31139	2974.4	3285.8	7.4984
420	0.31617	2990.9	3307.1	7.5294
430	0.32094	3007.6	3328.5	7.5600
440	0.32569	3024.2	3349.9	7.5902
450	0.33045	3040.9	3371.3	7.6200
460	0.33519	3057.6	3392.8	7.6495
470	0.33993	3074.4	3414.3	7.6786
480	0.34466	3091.1	3435.8	7.7075
490	0.34939	3108.0	3457.4	7.7360
500	0.35411	3125.0	3479.1	7.7641
520	0.36354	3159.1	3522.6	7.8196
540	0.37295	3193.3	3566.2	7.8740
560	0.38235	3227.8	3610.1	7.9273
580	0.39174	3262.5	3654.2	7.9796
600	0.40111	3297.5	3698.6	8.0310
620	0.41047	3332.7	3743.2	8.0815
640	0.41982	3368.2	3788.0	8.1312
660	0.42916	3403.9	3833.1	8.1800
680	0.43850	3440.0	3878.5	8.2281
700	0.44783	3476.3	3924.1	8.2755
720	0.45715	3512.9	3970.0	8.3221
740	0.46647	3549.6	4016.1	8.3681
760	0.47578	3586.7	4062.5	8.4135
780	0.48508	3624.1	4109.2	8.4582
800	0.49438	3661.7	4156.1	8.5024
820	0.50368	3699.6	4203.3	8.5460
840	0.51297	3737.8	4250.8	8.5890
860	0.52226	3776.2	4298.5	8.6315
880	0.53155	3814.9	4346.5	8.6735
900	0.54083	3854.0	4394.8	8.7150
920	0.55011	3893.2	4443.3	8.7560
940	0.55939	3932.7	4492.1	8.7965
960	0.56867	3972.4	4541.1	8.8366
980	0.57794	4012.5	4590.4	8.8763
1000	0.58721	4052.7	4639.9	8.9155

Space for Rough Work

Space for Rough Work