GATE & Other States PGECET Examinations

MECHANICAL ENGINEERING

Previous Years

Chapterwise Objective Solved Papers

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In the event of any dispute, the Judicial area will be Prayagraj.

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GATE Volume-I

ENGINEERING MECHANICS

THEORY OF MACHINES

MACHINE DESIGN

MATERIAL SCIENCE

PRODUCTION TECHNOLOGY

Industrial and Maintenance Engineering

SYLLABUS

GATE MECHANICAL ENGINEERING

Section 1: Engineering Mathematics

Linear Algebra: Matrix algebra, systems of linear equations, eigen values and eigenvectors.

Calculus: Functions of single variable, limit, continuity and differentiability, mean value theorems, indeterminate forms; evaluation of definite and improper integrals; double and triple integrals; partial derivatives, total derivative, Taylor series (in one and two variables), maxima and minima, Fourier series; gradient, divergence and curl, vector identities, directional derivatives, line, surface and volume integrals, applications of Gauss, Stokes and Green's theorems.

Differential equations: First order equations (linear and nonlinear); higher order linear differential equations with constant coefficients; Euler-Cauchy equation; initial and boundary value problems; Laplace transforms; solutions of heat, wave and Laplace's equations.

Complex variables: Analytic functions; Cauchy-Riemann equations; Cauchy's integral theorem and integral formula; Taylor and Laurent series.

Probability and Statistics: Definitions of probability, sampling theorems, conditional probability; mean, median, mode and standard deviation; random variables, binomial, Poisson and normal distributions.

Numerical Methods: Numerical solutions of linear and non-linear algebraic equations; integration by trapezoidal and Simpson's rules; single and multi-step methods for differential equations.

Section 2: Applied Mechanics and Design

Engineering Mechanics: Free-body diagrams and equilibrium; friction and its applications including rolling friction, belt-pulley, brakes, clutches, screw jack, wedge, vehicles, etc.; trusses and frames; virtual work; kinematics and dynamics of rigid bodies in plane motion; impulse and momentum (linear and angular) and energy formulations; Lagrange's equation.

Mechanics of Materials: Stress and strain, elastic constants, Poisson's ratio; Mohr's circle for plane stress and plane strain; thin cylinders; shear force and bending moment diagrams; bending and shear stresses; concept of shear centre; deflection of beams; torsion of circular shafts; Euler's theory of columns; energy methods; thermal stresses; strain gauges and rosettes; testing of materials with universal testing machine; testing of hardness and impact strength.

Theory of Machines: Displacement, velocity and acceleration analysis of plane mechanisms; dynamic analysis of linkages; cams; gears and gear trains; flywheels and governors; balancing of reciprocating and rotating masses; gyroscope.

Vibrations: Free and forced vibration of single degree of freedom systems, effect of damping; vibration isolation; resonance; critical speeds of shafts.

Machine Design: Design for static and dynamic loading; failure theories; fatigue strength and the SN diagram; principles of the design of machine elements such as bolted, riveted and welded joints; shafts, gears, rolling and sliding contact bearings, brakes and clutches, springs.

Section 3: Fluid Mechanics and Thermal Sciences

Fluid Mechanics: Fluid properties; fluid statics, forces on submerged bodies, stability of floating bodies; control-volume analysis of mass, momentum and energy; fluid acceleration; differential equations of continuity and momentum; Bernoulli's equation; dimensional analysis; viscous flow of incompressible fluids, boundary layer, elementary turbulent flow, flow through pipes, head losses in pipes, bends and fittings; basics of compressible fluid flow.

Heat-Transfer: Modes of heat transfer; one dimensional heat conduction, resistance concept and electrical analogy, heat transfer through fins; unsteady heat conduction, lumped parameter system, Heisler's charts; thermal boundary layer, dimensionless parameters in free and forced convective heat transfer, heat transfer correlations for flow over flat plates and through pipes, effect of turbulence; heat exchanger performance, LMTD and NTU methods; radiative heat transfer, Stefan- Boltzmann law, Wien's displacement law, black and grey surfaces, view factors, radiation network analysis

Thermodynamics: Thermodynamic systems and processes; properties of pure substances, behavior of ideal and real gases; zeroth and first laws of thermodynamics, calculation of work and heat in various processes; second law of thermodynamics; thermodynamic property charts and tables, availability and irreversibility; thermodynamic relations.

Applications: Power Engineering: Air and gas compressors; vapour and gas power cycles, concepts of regeneration and reheat. I.C. Engines: Air-standard Otto, Diesel and dual cycles. Refrigeration and air-conditioning: Vapour and gas refrigeration and heat pump cycles; properties of moist air, psychrometric chart, basic psychrometric processes. Turbomachinery: Impulse and reaction principles, velocity diagrams, Pelton-wheel, Francis and Kaplan turbines; steam and gas turbines.

Section 4: Materials, Manufacturing and Industrial Engineering

Engineering Materials: Structure and properties of engineering materials, phase diagrams, heat treatment, stress-strain diagrams for engineering materials.

Casting, Forming and Joining Processes: Different types of castings, design of patterns, moulds and cores; solidification and cooling; riser and gating design. Plastic deformation and yield criteria; fundamentals of hot and cold working processes; load estimation for bulk (forging, rolling, extrusion, drawing) and sheet (shearing, deep drawing, bending) metal forming processes; principles of powder metallurgy. Principles of welding, brazing, soldering and adhesive bonding.

Machining and Machine Tool Operations: Mechanics of machining; basic machine tools; single and multi-point cutting tools, tool geometry and materials, tool life and wear; economics of machining; principles of non-traditional machining processes; principles of work holding, jigs and fixtures; abrasive machining processes; NC/CNC machines and CNC programming.

Metrology and Inspection: Limits, fits and tolerances; linear and angular measurements; comparators; interferometry; form and finish measurement; alignment and testing methods; tolerance analysis in manufacturing and assembly; concepts of coordinate-measuring machine (CMM).

Computer Integrated Manufacturing: Basic concepts of CAD/CAM and their integration tools; additive manufacturing.

Production Planning and Control: Forecasting models, aggregate production planning, scheduling, materials requirement planning; lean manufacturing.

Inventory Control: Deterministic models; safety stock inventory control systems.

Operations Research: Linear programming, simplex method, transportation, assignment, network
flow models, simple queuing models, PERT and CPM.

GATE and Other State
Previous Years Papers Analysis Chart

Sl No	Exam	Proposed Year		Total Question
GATE Mechanical				
1.	**GATE**	2025	Set-I	55
2.	**GATE**	2024	Set-I	55
3.	**GATE**	2023	Set-I	55
4.	**GATE**	2022	Set-I	55
5.	**GATE**	2022	Set-II	55
6.	**GATE**	2021	Set-I	55
7.	**GATE**	2021	Set-II	55
8.	**GATE**	2020	Set-I	55
9.	**GATE**	2020	Set-II	55
10.	**GATE**	2019	Set-I	55
11.	**GATE**	2019	Set-II	55
12.	**GATE**	2018	Set-I	55
13.	**GATE**	2018	Set-II	55
14.	**GATE**	2017	Set-I	55
15.	**GATE**	2017	Set-II	55
16.	**GATE**	2016	Set-I	55
17.	**GATE**	2016	Set-II	55
18.	**GATE**	2016	Set-III	55
19.	**GATE**	2015	Set-I	55
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21.	**GATE**	2015	Set-III	55
22.	**GATE**	2014	Set-I	55
23.	**GATE**	2014	Set-II	55
24.	**GATE**	2014	Set-III	55
25.	**GATE**	2014	Set-IV	55
26.	**GATE**	2013		55
27.	**GATE**	2012		55
28.	**GATE**	2011		55
29.	**GATE**	2010		55
30.	**GATE**	2009		60
31.	**GATE**	2008		85
32.	**GATE**	2007		85
33.	**GATE**	2006		85
34.	**GATE**	2005		85
35.	**GATE**	2004		90
36.	**GATE**	2003		90
37.	**GATE**	2002		70
38.	**GATE**	2001		70
39.	**GATE**	2000		70
40.	**GATE**	1999		70
41.	**GATE**	1998		75
42.	**GATE**	1997		75
43.	**GATE**	1996		75
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45.	**GATE**	1994		71
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47.	**GATE**	1992		40
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GATE-XE				
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54.	GATE-XE	2023		66
55.	GATE-XE	2022		66
56.	GATE-XE	2021		66
57.	GATE-XE	2020		66
58.	GATE-XE	2018		66
59.	GATE-XE	2017		66
60.	GATE-XE	2016		66
61.	GATE-XE	2015		66
62.	GATE-XE	2014		66
63.	GATE-XE	2013		66
64.	GATE-XE	2012		66
65.	GATE-XE	2011		66
66.	GATE-XE	2010		66
67.	GATE-XE	2009		66
68.	GATE-XE	2008		66
69.	GATE-XE	2007		66
GATE-P.I.				
70.	GATE-P.I.	2024		55
71.	GATE-P.I.	2023		55
72.	GATE-P.I.	2022		55
73.	GATE-P.I.	2021		55
74.	GATE-P.I.	2020		55
75.	GATE-P.I.	2018		55
76.	GATE-P.I.	2017		55
77.	GATE-P.I.	2016		55
78.	GATE-P.I.	2015		55
79.	GATE-P.I.	2014		55
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81.	GATE-P.I.	2012		55
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90.	GATE-P.I.	2003		55
91.	GATE-P.I.	2002		55
92.	GATE-P.I.	2001		55
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98.	GATE-P.I.	1994		55
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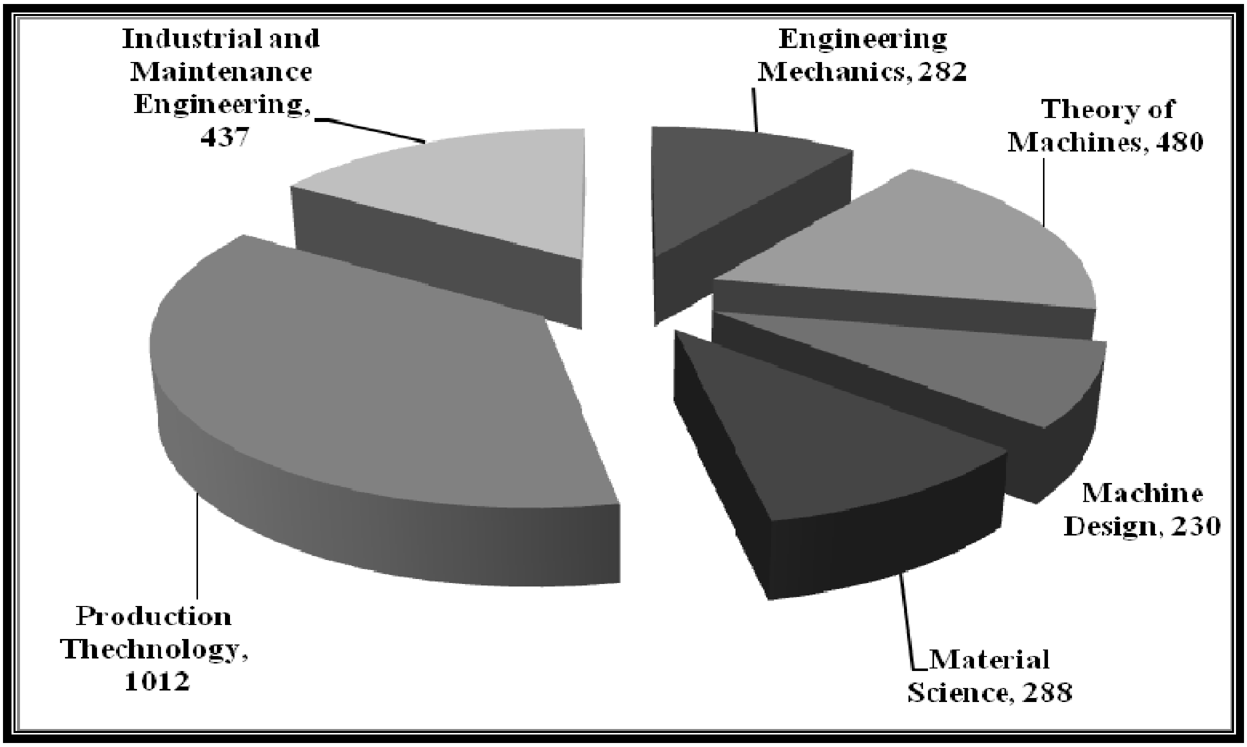
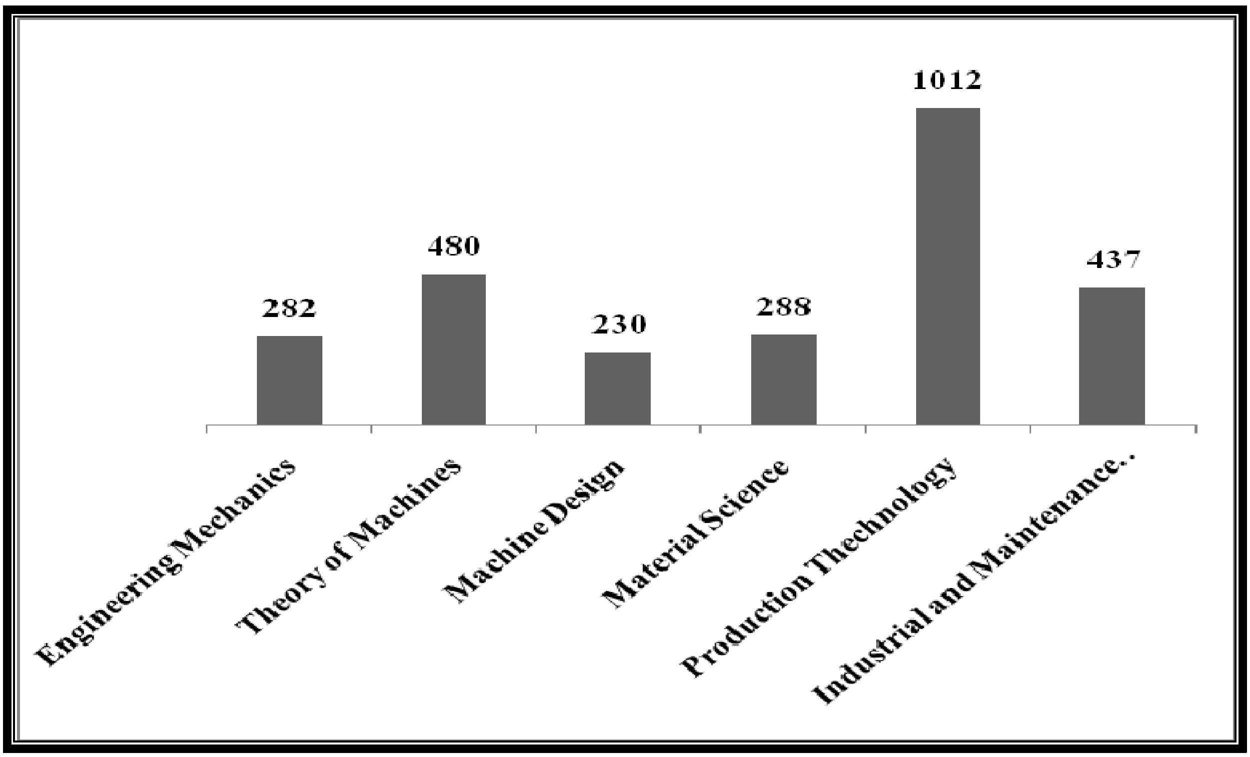
105.	GATE-P.I.	1987		55
TS-PGECET				
106.	TS-PGECET	2024		120
107.	TS-PGECET	2023		120
108.	TS-PGECET	2022		120
109.	TS-PGECET	2021		120
110.	TS-PGECET	2020		120
111.	TS-PGECET	2018		120
112.	TS-PGECET	2017		120
113.	TS-PGECET	2016		120
114.	TS-PGECET	2015		120
AP-PGECET				
115.	AP-PGECET	2024		120
116.	AP-PGECET	2023		120
117.	AP-PGECET	2022		120
118.	AP-PGECET	2021		120
119.	AP-PGECET	2020		120
120.	AP-PGECET	2018		120
121.	AP-PGECET	2017		120
122.	AP-PGECET	2016		120
123.	AP-PGECET	2015		120
Karnataka PGECET				
124.	Karnataka PGECET	2020		100
125.	Karnataka PGECET	2019		100
126.	Karnataka PGECET	2018		100
127.	Karnataka PGECET	2017		100
128.	Karnataka PGECET	2016		100
129.	Karnataka PGECET	2015		100
130.	Karnataka PGECET	2014		100
131.	Karnataka PGECET	2013		100
132.	Karnataka PGECET	2012		100
133.	Karnataka PGECET	2010		100
134.	**TANCET**			
135.	TANCET	2016		120
136.	TANCET	2017		120
137.	TANCET	2022		120
NTA CUET-PG				
138.	NTA CUET-PG	2024		80
139.	NTA CUET-PG	2023		80
140.	NTA CUET-PG	2022		80
141.	NTA CUET-PG	2021		80
142.			**Total**	**9959**

Trend Analysis of Mechanical Engineering Through Pie Chart and Bar Graph





01 ENGINEERING MECHANICS

INDEX

01 EQUILIBRIUM

A. Free Body Diagrams

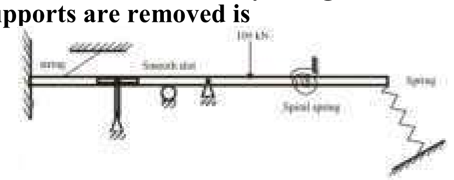
1. **Free-body diagram of a body isolated from a system involves the following**
   (a) Only external forces acting on the body
   (b) Both external and reactive forces acting on the body
   (c) External forces acting on the body and its deflection caused by them
   (d) The body free from all forces, deflections and deformations

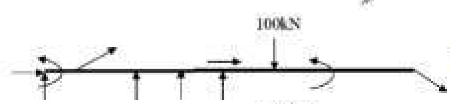
NTA CUET PG 07.09.2022

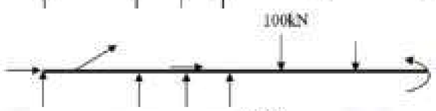
Ans. (b) : A free body diagram isolates a body from its surroundings. It shows all the forces acting on that body. These forces can be categorized into.
- External forces- Forces applied to the body from outside the system.
- Reactive forces- Forces exerted by the body's surroundings in the response to the external forces.

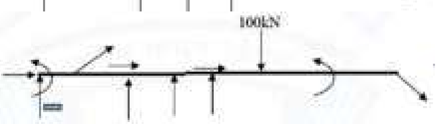
By including both type of forces acting on the body.

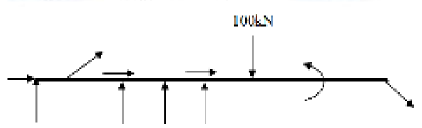
2. **The figure shows a structure with supports. The correct free body diagram when the supports are removed is**



(a) 

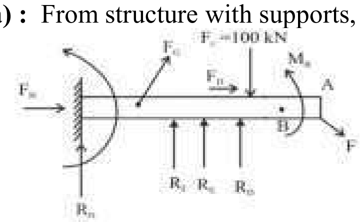
(b) 

(c) 

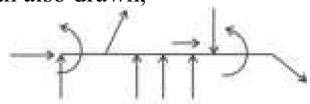
(d) 

[GATE-XE-2021: 2M]

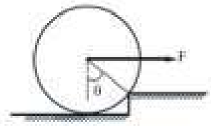
Ans. (a) : From structure with supports,



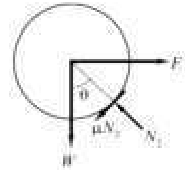
So, it can also drawn,

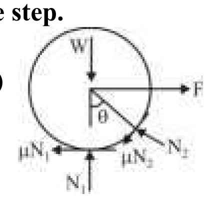


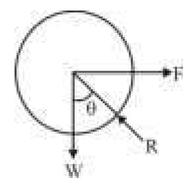
3. **An attempt is made to pull a roller of weight W over a curb (step) by applying a horizontal force F as shown in the figure,**

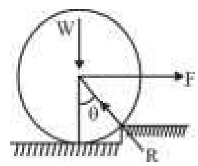


The coefficient of static friction between the roller and the ground (including the edge of the step) is μ. Identify the correct free body diagram (FBD) of the roller when the roller is just about to climb over the step.

(a) 

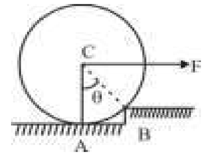
(b) 

(c) 

(d) 

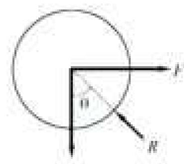
[GATE-2020 : Set-II: 1M]

Ans. (c) :

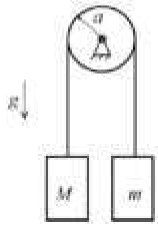


Weigh = W

Note:
(i) When the cylinder is about to make out of the curb, it will lose its contact at point A, only contact will be at it B.
(ii) At verge of moving out of curb, roller will be in equilibrium under W, F and contact force from B and these three forces has to be concurrent so contact force from B will pass through C
(iii) Even the surfaces are rough but there will be no friction at B for the said condition FBD

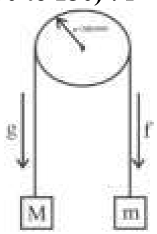


4. **Consider two point masses m = 10 kg and M = 30 kg connected by a massless inextensible string passing over a massless and frictionless pulley with radius a = 100 mm as shown. The masses are released from rest and move vertically under the action of gravity. Let acceleration due to gravity, g = 10 m/s^2. The tension (in N) in the string is _____.**

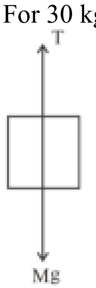


[GATE-XE 2020:1M]

Ans. (150 to 150) : F→ acceleration of the system

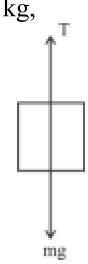


For 30 kg,



$$Mg - T = Mf \quad \ldots(i)$$

For 10 kg,



$$T - mg = mf \quad \ldots(ii)$$

By equation (i) and (ii), we get –

$$(M + m)f = Mg - mg = g(M - m)$$

$$f = \left(\frac{M-m}{M+m}\right)g$$

$$f = \left(\frac{30-10}{30+10}\right)\times 10$$

$$F = 5 m/s^2$$

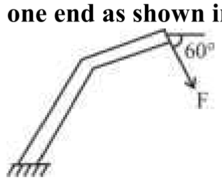
From equation (ii),

$$T - mg = mf$$

$$T = mf + mg = 10 \times 5 + 10 \times 10 = 150 \text{ N}$$

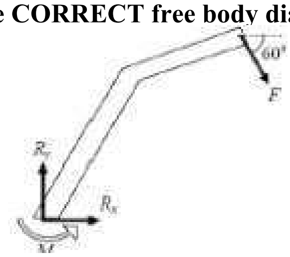
$$T = 150 \text{ N}$$

5. A force F is acting on a bent bar which is clamped at one end as shown in the figure.

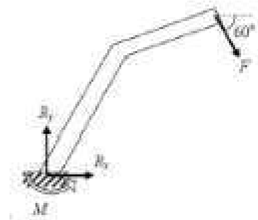


The CORRECT free body diagram is

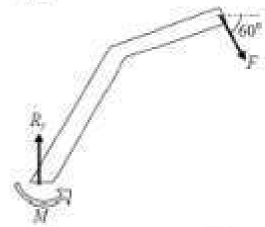
(a)



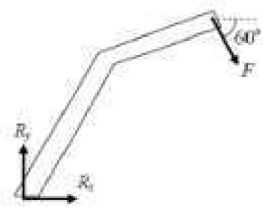
(b)



(c)

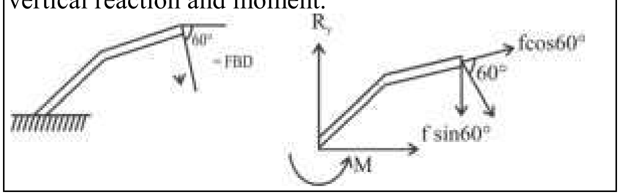


(d)

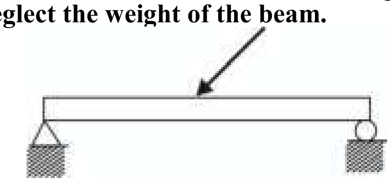


[GATE-2016; Set-III: 1M]

Ans. (a) : Free Body diagram (F B D) –
Fixed support should be replaced by horizontal reaction, vertical reaction and moment.

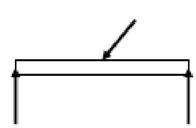


6. A beam is subjected to an inclined concentrated load as shown in the figure below. Neglect the weight of the beam.

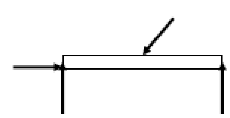


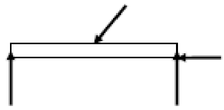
The correct Free Body Diagram of the beam is

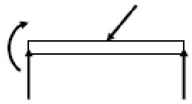
(a)



(b)

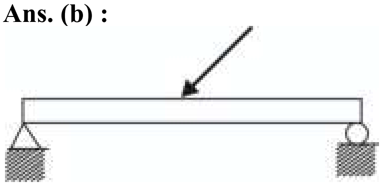


(c) 

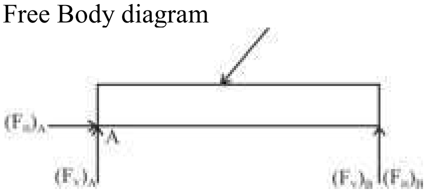
(d) 

[GATE-PI 2016: 1M]

Ans. (b) :

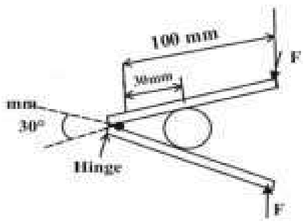


Free Body diagram



- At simple hinged support, no translation motion is possible but beam is free to rotate about hinge.
- And at roller support translation motion only in the plane of rolling is possible and motion beam is free to rotate.

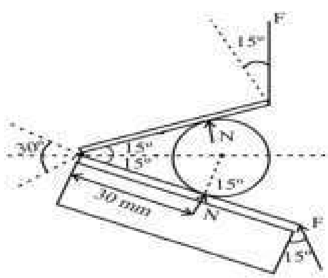
7. **A small spherical ball fails at a normal load of 10 kN under the arrangement as shown below. The vertical force F required to crush the ball is**



(a) 11.6 kN (b) 6.0 kN
(c) 3.5 kN (d) 3.1 kN

[GATE-XE 2009: 1M]

Ans. (d) :



Given,
A small spherical ball falls at a normal load of (N) = 10 kN
Taking moment at point 'O',

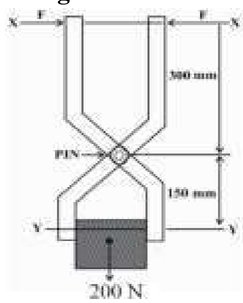
$\Sigma M_0 = 0$

$N \times 30 = F \cos 15^\circ \times 100$

$$F = \frac{10 \times 30}{100 \times \cos 15^\circ}$$

$F = 3.1$ kN

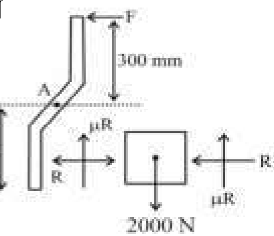
8. **The figure shows a pair of pin jointed gripper tongs holding an object weighing 2000 N. The co-efficient of friction (μ) at the griping surface is 0.1XX is the line of action of the input force and YY is the line of application of gripping force. If the pin-joint is assumed to be frictionless, the magnitude of force F required to hold the weight is**



(a) 1000 N (b) 2000 N
(c) 2500 N (d) 5000 N

[GATE-2004: 2M]

Ans. (d) : Given that,
Weight of object (W) = 2000 N
Coefficient of friction (μ) = 0.1
Taking moment about point A,



$\Sigma M_A = 0$

$R \times 150 - F \times 300 = 0$

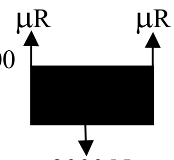
$R = 2F$

FBD of object

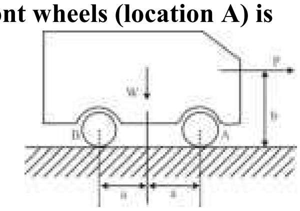
$2\mu R = 2000$

$2\mu \times 2F = 2000$

$F = 5000 N$



9. **An automobile of weight W is shown in Figure. A pull 'P' is applied as shown. The reaction at the front wheels (location A) is**



(a) $\frac{W}{2} - \frac{Pb}{2a}$ (b) $\frac{W}{2} + \frac{Pb}{2a}$

(c) $\frac{W}{2} - \frac{Pa}{2b}$ (d) $\frac{W}{2}$

[GATE-2000, 2M]

Ans. (b):

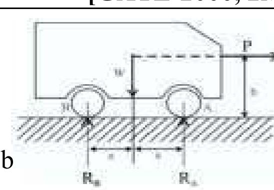
$R_A + R_B = W$

Taking moment about B,

$\Sigma M_B = 0$

$R_A \times 2a = W \times a + P \times b$

$$R_A = \frac{W}{2} + \frac{Pb}{2a}$$



B. Coplanar Equilibrium Analysis

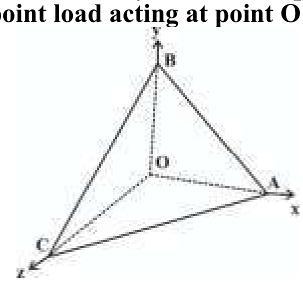
10. The moment of the resultant of two concurrent forces with respect to a center in their plane is equal to the algebraic sum of the moments of the components with respect to the same center". This statement is known as ________.

(a) Newton's Theorem
(b) D'Alembert's Theorem
(c) Lame's Theorem
(d) Varignon's Theorem

AP PGECET 30.05.2024, Shift –II
NTA CUET-PG 07.09.2022
AP PGECET 11.05.2018, Shift-II

Ans. (d) : "Varignon's theorem" states that the sum of the moments of several concurrent forces about a point is equal to the moment of the resultant of those forces. Or alternately, the moment of a force about a point equals the sum of the moments of its components.

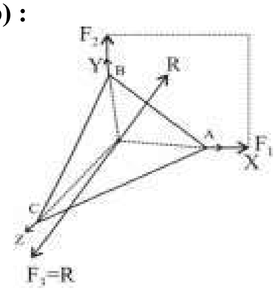
11. A rigid massless tetrahedron is place such that vertex O is at the origin and the other three vertices A, B, and C lie on the coordinate axes as shown in the figure. The body is acted on by three point loads, of which one is acting at A along x-axis and another at point B along y-axis. For the body to be in equilibrium, the third point load acting at point O must be



(a) Along z-axis
(b) In x – y plane but not along x or y axis
(c) In y – z plane but not along y or z axis
(d) In z – x plane but not along z or x axis

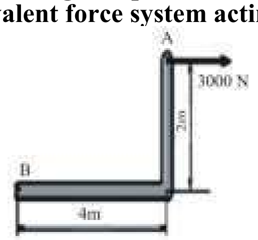
[GATE-2024: 1M]

Ans. (b) :



For the body to be in equilibrium, the three forces can be coplanar, parallel or concurrent.

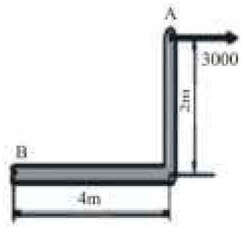
12. The force acting at a point A is shown in figure. The equivalent force system acting at point B is



(a) Force 3000 N in same direction and 6000 Nm clock wise moment
(b) Force 3000 in opposite direction and 6000 Nm clock wise moment
(c) Force 3000 N in opposite direction and 6000 Nm counter clock wise moment
(d) Force 3000 N in same direction and 12000 Nm counter clock wise moment

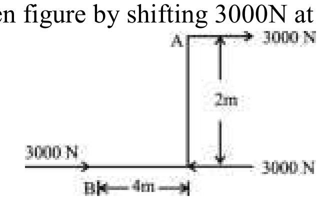
AP-PGECET 30.05.2024, Shift-II

Ans. (a) :



Taking moment at point B, M_B = 3000 × 2 Nm clock wise M_B = 6000 Nm clock wise

FBD of given figure by shifting 3000N at point B,



From above figure net force at point B,

F_B = 3000N (Towards right)

13. Match List I with List II:

List-I		List-II	
(A)	**Line of action lying on the same line**	**(I)**	**Parallel forces**
(B)	**Lines of action parallel to each other**	**(II)**	**Concurrent forces**
(C)	**Lines of action intersecting at a point**	**(III)**	**Non-Coplanar forces**
(D)	**Lines of action lying on different planes or in space**	**(IV)**	**Collinear forces**

Choose the correct answer from the options given below:

(a) (A)-(IV), (B)-(I), (C)-(II), (D)-(III)
(b) (A)-(I), (B)-(II), (C)-(IV), (D)-(III)
(c) (A)-(III), (B)-(IV), (C)-(II), (D)-(I)
(d) (A)-(II), (B)-(III), (C)-(I), (D)-(IV)

NTA CUET PG 14.06.2023

Ans. (a) : Collinear forces - The force whose line of action lying on the same line.

Parallel forces - The force whose line of action parallel to each other.

Concurrent forces - The force whose line of action intersecting at a point.

Non coplanar forces - The force whose line of action lying on different planes or in space.

14. If three forces acting on a rigid body are in equilibrium, then they must:

(a) be all parallel
(b) meet at a point
(c) meet at a different point
(d) never meet

NTA CUET PG 14.06.2023

Ans. (b) : If three forces acting in a one plane upon a rigid body, keep it in equilibrium, they must be meet in a point.

15. Force are called concurrent when their lines of action meet in

(a) One point (b) Two points
(c) Plane (d) Perpendicular planes

TS-PGECET 30.05.2023, Shift-I

Ans. (a) : Concurrent force- The forces which meet at one point are known as concurrent forces. The concurrent forces may or move be collinear.

OR

The sun of mass moment of inertia of the mass about their centre of gravity is equal to the mass moment of inertia of the body

$k = \sqrt{h_1 h_2}$

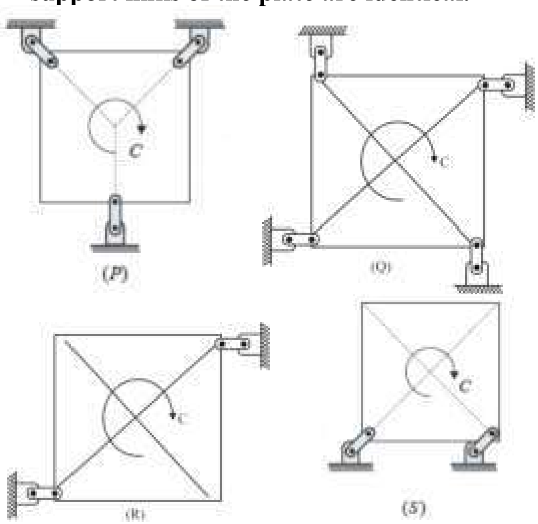
16. A concurrent force system means that

(a) All the forces pass through a single line
(b) All the forces are parallel to each other
(c) At least two forces intersect at a point
(d) All the forces pass through a single point

NTA CUET PG 07.09.2022

Ans. (d) : A concurrent force system means that all the forces acting on a body intersect at a single point.

17. A square plate is supported in four different ways (configurations (P) to (S) as shown in the figure). A couple moment C is applied on the plate. Assume all the members to be rigid and mass-less, and all joints to be frictionless. All support links of the plate are identical.

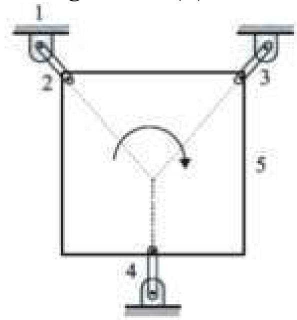


The square plate can remain in equilibrium in its initial state for which one or more of the following support configurations?

(a) Configuration (P) (b) Configuration (Q)
(c) Configuration (R) (d) Configuration (S)

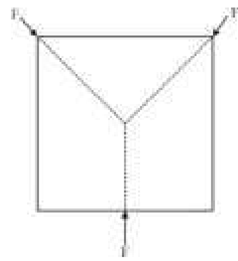
[GATE-2022 Set-I: 1M]

Ans. (b,c,d) : Configuration (P) :



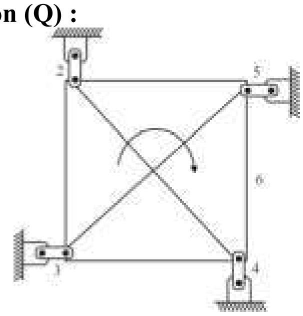
Therefore, it is structure and stable system will be in equilibrium. But, we know equilibrium is a state of the body where all the forces are of the same magnitude making the net resultant zero. This is called static concurrent equilibrium.

i.e.,



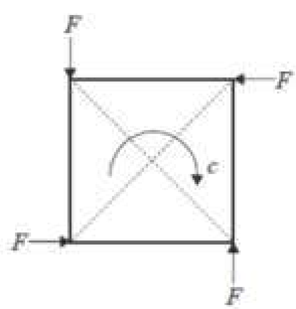
But the given square plate has couple moment C which will be the disturbing action for the concurrent forces and the square plate (configurations P) due to this action cannot be remain in equilibrium. Hence, cannot be remain in equilibrium.

Configuration (Q) :



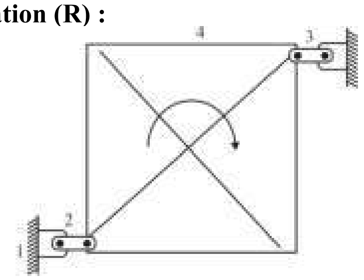
Here, the forces acting on the square plate is countering the action of couple moment C. Due to this counter action of forces (F) to resist the couple moment C, the square plate will remain in equilibrium.

i.e.

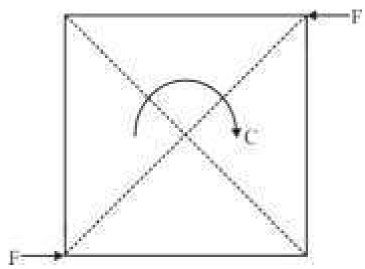


Forces (F) giving counter clockwise moment and couple moment C giving clockwise moment. Hence, will remain in equilibrium.

Configuration (R) :

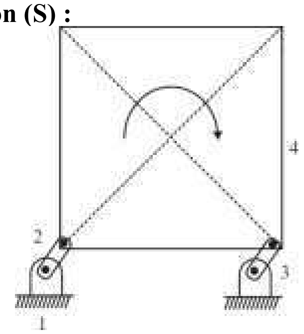


Similarly as we discussed above, here also the forces (F) resisting the couple moment C which is in clockwise direction by providing the anticlockwise moment.
i.e.

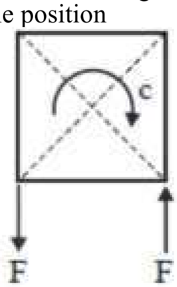


Hence, will remain in equilibrium.

Configuration (S) :



In the above arrangement, due to couple moment C, the reactions forces will try to counter the clockwise rotation which in result bring the arrangement in equilibrium or stable position



Hence will remain in equilibrium.

18. If an elevator of gross weight of 1000 N starts to move upward with a constant acceleration and acquires a velocity of 6 m/s after traveling a distance of 6 m, what approximate tension the cable of the elevator needs to support?

(a) 1000 N (b) 1300 N
(c) 1500 N (d) 2000 N

NTA CUET PG 07.09.2022

Ans. (b) : Given,
Weight (w) = 1000 N
g = 10 m/s22
The mass of the elevator

$$w = mg$$

$$m = \frac{w}{g} = \frac{1000}{10} = 100\text{kg}$$

Acceleration of the elevator,
The equation of motion,

$$v^2 = u^2 + 2as$$

Given,
v = 6 m/s, u = 0 (starts from rest)
s = 6 m
Substitute the values, we get

$$(6)^2 = 0 + 2 \times a \times 6$$
$$36 = 12a$$
$$a = 3 \text{ m/s}^2$$

Now,
The tension in the cable,
Net force = Tension (T) – Weight (W)

$$ma = T - W$$
$$T = W + ma$$
$$= 1000 + 100 \times 3$$
$$T = 1300 \text{ N}$$

19. Consider the following statements:

A. Two couples in the same plane can be added algebraically
B. Coplanar and concurrent forces are the ones which do neither lie in one plane nor meet at a point
C. Non-concurrent forces are the ones which do not meet at a point
D. A single force may be replaced by a force and couple.

Which of the following statement are correct?

(a) A, B and D (b) B, C and D
(c) A, B and C (d) A, C and D

AP PGECET 19.07.2022, Shift-II

Ans. (d) : Statement (A) – Couple can be represented by vectors, and these vectors can be added algebraically to find the resultant couple.
(This statement is true)
Statement (B) – Coplanar forces lie in the same plane and concurrent forces meet at point.
(This statement is false)
Statement (C) – Non-current forces are the ones which do not meet at point.
(This statement is true)
Statement (D) – This is a fundamental principle in mechanics, known as the principle of transmissibility.
(This statement is true)

20. What will be the minimum number of unequal forces required for maintaining a body in static equilibrium?

(a) 2
(b) 3
(c) 4
(d) Depends upon the magnitudes and inclinations of the forces

NTA CUET PG 07.09.2022

Ans. (b) : For a body to be in static equilibrium, the net force acting on it must be zero. This means that the vector sum of all forces acting on the body should be equal to zero.

- **Two forces:-** It's impossible for two unequal forces to balance each other and result in a net force of zero.
- **Three forces:-** If three forces are acting on a body, it is possible to arrange them in a way that their vector sum is zero.

21. In accordance to Varignon's theorem, the algebraic sum of moment of the two force about any point in their plane is equal to

(a) Zero
(b) The moments of the minimum force about the same point
(c) The moments of the maximum force about the same point
(d) The moments of their resultant about the same point

TS PGECET 2021

Ans. (d) : Varignon's theorem states that the algebraic sum of the moments of a system of coplanar forces about any point is equal to the moment of the resultant force about the same point.

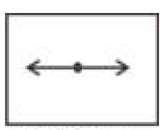
22. A two force member in equilibrium is one in which

(a) Forces act at two points and forces are collinear
(b) Forces act at two points and member is always straight
(c) Forces act at two points but the member is free to carry moment at any point
(d) Forces acts at one point and moment acts at second point

[GATE-XE 2021: 1M]

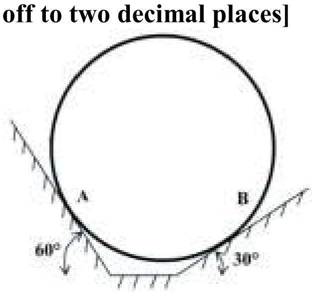
Ans. (a) :

Forces are in equilibrium. Both the side force is P. Line of action of all the forces act along the same line are collinear forces.



collinear

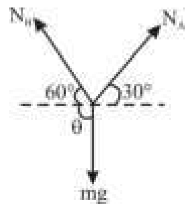
23. A 30 kg smooth, solid sphere rests on two frictionless inclines as shown in the figure. The magnitude of contact force in N acting at the point A is (take acceleration due to gravity g = 9.81 m/s^2 and consider both sphere and inclines to be rigid)________.
[round off to two decimal places]



[GATE PI-2021: 1 M]

Ans. (147 to 147.30) : Given,

m = 30 kg
g = 9.81 m/s^2

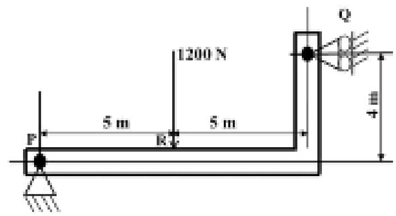


Using Lami's theorem,

$$\frac{N_A}{\sin(90°+60°)} = \frac{(30\times 9.81)}{\sin 90°}$$

$\therefore$ $N_A = 147.15$ N

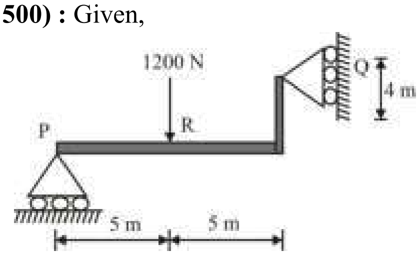
24. A beam of negligible mass is hinged at support P and has a roller support Q as shown in the figure.



A point load of 1200 N is applied at point R, the magnitude of reaction force at support Q is __ N.

[GATE-2020; Set-II: 1M]

Ans. (1500) : Given,



R_Q = ?
$\sum M_p$ = ?
$1200\times 5 - R_Q \times 4 = 0$
$R_Q = 1500$ N

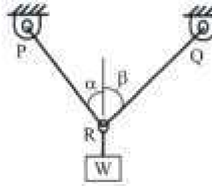
25. For a system of co-planar parallel forces to be in equilibrium

(a) The resultant force must vanish alone is sufficient
(b) The resultant couple must vanish alone is sufficient
(c) Both resultant force & resultant couple must vanish
(d) Both resultant force & resultant couple must non zero value

AP PGECET 29.09.2020, Shift-II

Ans. (c) : A system in which all the forces acts in the same plane is termed as coplanar force system. For any system of coplanar forces to be in equilibrium both resultant force and resultant couple must vanish i.e. zero.

26. A truss with two bars PR and QR, making angles α and β, respectively, with the vertical, is shown in the figure below. The connections at P, Q and R are hinged connections. The truss supports a body of weight W (in N) at R as shown. The tension in the bar QR (in N) is

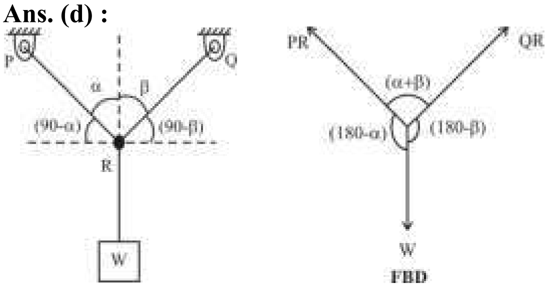


(a) $\frac{W\sin\beta}{\cos(\alpha+\beta)}$ (b) $\frac{W\cos\beta}{\cos(\alpha+\beta)}$

(c) $\frac{W\cos\alpha}{\cos(\alpha+\beta)}$ (d) $\frac{W\sin\alpha}{\sin(\alpha+\beta)}$

[GATE-2020;Set-II:2M]
[GATE PI-2020: 2M]

Ans. (d) :



Applying Lami's theorem,

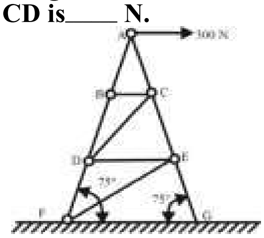
$$\frac{PR}{\sin(180-\beta)} = \frac{QR}{\sin(180-\alpha)} = \frac{W}{\sin(\alpha+\beta)}$$

$$QR = \frac{W\sin(180-\alpha)}{\sin(\alpha+\beta)}$$

$$QR = \frac{W\sin\alpha}{\sin(\alpha+\beta)}$$

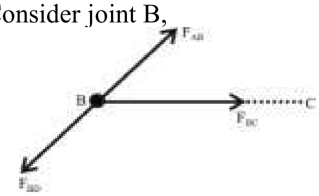
Hence, the tension in the bar QR = $\frac{W\sin\alpha}{\sin(\alpha+\beta)}$

27. The figure shown an idealized plane truss. If a horizontal force of 300N is applied at point A, then the magnitude of the force produced in member CD is____ N.



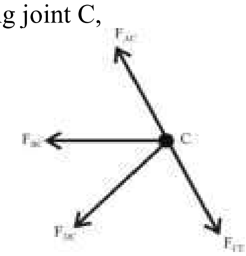
[GATE-2019, Set-II: 1M]

Ans. (0) : Consider joint B,



$\Rightarrow F_{BC} = 0$

Now considering joint C,



$\Rightarrow F_{DC} = 0$

Form the figure AB and BD are collinear. So, $R_{BC} = 0$ and AC and CE are collinear then $R_{CD} = 0$

28. A force which combines with two or more forces to produce equilibrium is called

(a) resultant (b) equilibrium
(c) couple (d) moment

Karnataka PGCET 2019

Ans. (b) : • Equilibrium is the state of a system where the net force and net torque are zero.

• Resultant is a single force that replace multiple forces and has the same effect.

• Couple is a pair of equal and opposite parallel forces.

• Moment is the turning effect of a force.

29. A body is acted upon by a concurrent force system. It can be brought to equilibrium by the application of

(a) a collinear force equal in magnitude and opposite to the direction of the resultant force
(b) a force acting on suitable line and a moment along the direction of the force
(c) a force acting on anywhere along a suitable line
(d) a force acting anywhere on the body

AP PGECET 03.05.2019, Shift-II

Ans. (a) : To bring a body acted upon by a concurrent force system to equilibrium if the collinear force equal in magnitude and opposite to the direction of the resultant force.

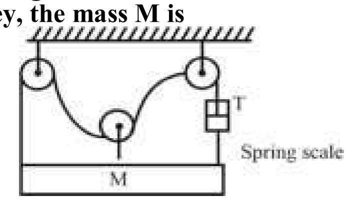
30. Resultant of two equal forces is equal to either of them. The angel between the force is

(a) 0° (b) 60°
(c) 90° (d) 120°

Karnataka PGCET 2019

Ans. (d) : For the resultant of two equal forces to be equal to either force, the force must be acting at an angle such that they partially cancel each other out. This occur when the angle between then is 120 degrees.

31. A spring scale indicates a tension T in the right hand cable of the pulley system shown in the figure, Neglecting the masses of the pulleys and ignoring the friction between the cable and pulley, the mass M is



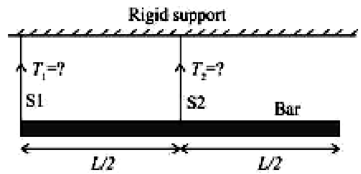
(a) $\frac{2T}{g}$ (b) $\frac{T(1+e^{4\pi})}{g}$

(c) $\frac{4T}{g}$ (d) $\frac{T}{g}$

TS PGECET 30.05.2018, Shift-I

Ans. (c) : The pulley system has 4 segments of rope supporting the mass (M).
Each segment carries a tension (T).
Since there are 4 segments.
The total force supporting M is 4 Tμ.
$Mg = 4T\mu$
$$M = \frac{4T}{g}\mu$$
Where, μ = friction coefficient that is negligible.

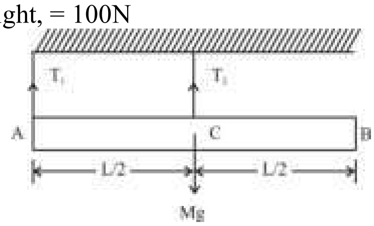
32. A bar of uniform cross section and weighing 100 N is held horizontally using two mass less and inextensible strings S1 and S2 as shown in the figure.



The tensions in the strings are
(a) $T_1 = 100$ N and $T_2 = 0$ N
(b) $T_1 = 0$ N and $T_2 = 100$ N
(c) $T_1 = 75$ N and $T_2 = 25$ N
(d) $T_1 = 25$ N and $T_2 = 75$ N

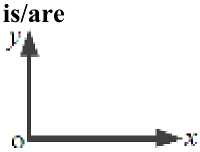
[GATE-2018; Set-I: 1M]

Ans. (b) : FBD of given bar-string system,
Given,
Bar weight, = 100N



From FBD,
$T_1 + T_2 = 100$ ……(i)
Taking moment about point A,
$$T_1 \times 0 + T_2 \times \frac{L}{2} = Mg \times \frac{L}{2}$$
$T_2 = Mg$
$T_2 = 100$ N
From equation (i),
$T_1 + T_2 = 100$
$T_1 + 100 = 100$
$T_1 = 0$ N
Hence, the tension in the strings are $T_2 = 100$ N & $T_1 = 0$ N

33. Considering the coordinate system shown in the figure, a force of magnitude 10 kN has x-component of – 6 kN. Possible y-component (s) of the force is/are



(a) + 8 kN only (b) + 5 kN only
(c) + 8 kN and – 8 kN (d) + 5 kN and – 5 kN

[GATE PI-2018: 1M]

Ans. (c) : Given that,
Magnitude of force, F = 10 kN
x-component of force, $F_x = -6$ kN
y-component of force, F_y = ?
We know that,
Resultant force,
$$F = \pm\sqrt{F_x^2 + F_y^2}$$
$$10 = \pm\sqrt{6^2 + F_y^2}$$
$$100 = 36 + F_y^2$$
$$F_y = \pm\sqrt{64}$$
$$F_y = \pm 8\,kN$$
Hence, possible y-component of the force, + 8kN and – 8kN.

34. A couple produces
(a) Translatory motion
(b) Rotational motion
(c) Translatory and rotational motion
(d) Linear motion

AP PGECET 11.05.2017, Shift-II

Ans. (b) : Couple :- A pair of equal and opposite forces acting on a rigid body, tending to produce rotation.

35. The forces, which meet at one point and their lines of action also lie on the same plane, are known as
(a) Coplanar concurrent forces
(b) Coplanar non-concurrent forces
(c) Non-coplanar concurrent forces
(d) Non-coplanar non-concurrent forces

TS PGECET 2017

Ans. (a) : The forces, which meet at one point and their lines of action also lies on the same plane is known as coplanar concurrent forces.

36. Geometrical method of addition of two vector is called
(a) triangular method
(b) parallelogram method
(c) both
(d) none of the above

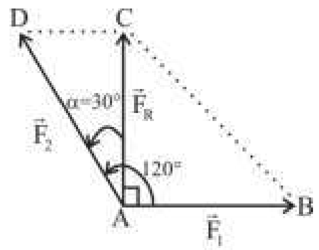
TANCET 2017

Ans. (c) : Geometrical method of addition of two vector is called triangular and parallelogram method.

37. Two forces are acting at an angle of 120° the bigger force is 40 N, and the resultant force is perpendicular to the smaller one. The smaller force is
(a) 20 N (b) 30 N
(c) 40 N (d) 35 N

AP PGECET 11.05.2017, Shift-II

Ans. (a) : According to question,
If smaller force is $\vec{F}_1$ and bigger force is $\vec{F}_2$ and resultant force is $\vec{F}_R$.



Then,
$\alpha = 120° - 90° = 30°$
It mean resultant makes an angle of 30° with the bigger force $\vec{F}_2$
Now, ΔACD

$$\sin\alpha = \frac{DC}{AD}$$

AD = Length of $\vec{F}_2 = 40N$ (given)

DC = Length of $\vec{F}_1$

$$\vec{F}_1 = \vec{F}_2 \sin 30°$$

$$= 40 \times \frac{1}{2}$$

$\vec{F}_1 = 20N$

38. For two non-zero vectors $\overline{A}$ and $\overline{B}$, if $\overline{A}+\overline{B}$ is perpendicular to $\overline{A}-\overline{B}$, then

(a) The magnitude of $\overline{A}$ is twice the magnitude of $\overline{B}$
(b) The magnitude of $\overline{A}$ is half the magnitude of $\overline{B}$
(c) $\overline{A}$ and $\overline{B}$ cannot be orthogonal
(d) The magnitudes of $\overline{A}$ and $\overline{B}$ are equal

[GATE PI-2017: 1M]

Ans. (d) : We know that,
For an two vectors which are perpendicular to each other than their dot product is equal to zero.

$\therefore \quad (\overline{A}+\overline{B})\cdot(\overline{A}-\overline{B}) = 0$

$(\overline{A}\cdot\overline{A}) - (\overline{A}\cdot\overline{B}) + (\overline{B}\cdot\overline{A}) - (\overline{B}\cdot\overline{B}) = 0$

$\because \quad \overline{A}\cdot\overline{B} = \overline{B}\cdot\overline{A}$

$|\overline{A}|^2 - |\overline{B}|^2 = 0$

$\therefore \quad |\overline{A}| = |\overline{B}|$

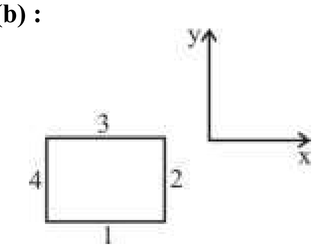
Hence, the magnitudes of $\overline{A}$ and $\overline{B}$ are equal.

39. Four forces, P, 2P, 3P and 4P act along the sides taken in order of a square. The resultant force is

(a) Zero (b) $2\sqrt{2}P$
(c) 2P (d) $\sqrt{5}P$

Karnataka PGCET 2016

Ans. (b) :

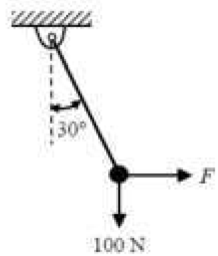


Now, along side (1), it is $P\hat{i}$
along side (2), it is $2P\hat{j}$
along side (3), it is $-3P\hat{i}$
along side (4), it is $-4P\hat{j}$

There force, the net force vector is $= -2P\hat{i} + -2P\hat{j}$
It's magnitude is,

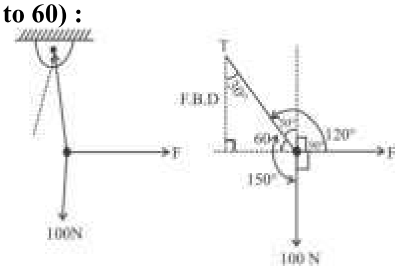
$$= \sqrt{(-2P)^2 + (-2P)^2} = \sqrt{8P^2} \quad = 2\sqrt{2}.P$$

40. A rigid ball of weight 100 N is suspended with the help of a string. The ball is pulled by a horizontal force F such that the string makes an angle of 30° with the vertical. The magnitude of force F (in N) is ________.



[GATE-2016; Set-1: 1M]

Ans. (55 to 60) :



Applying Lami's theory,

$$\frac{F}{\sin 150°} = \frac{T}{\sin 90°} = \frac{100}{\sin 120°}$$

$$F = \frac{100\sin 150°}{\sin 120°} = \frac{100\sin(90°+60°)}{\sin(90°+30°)} = \frac{100\cos 60°}{\cos 30}$$

F = 57.74 N

41. Figure 9 shows the two equal forces at right angles acting at a point. The value of force R acting along their bisector and in opposite direction is

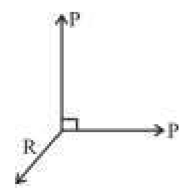


Figure - 9

(a) P/2 (b) 2P

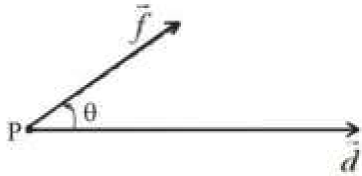
(c) $\sqrt{2}$P (d) $\frac{P}{\sqrt{2}}$

Karnataka PGCET 2015

Ans. (c) : If two forces acting at a right angle and their effect are neutralized by the third force which bisect them, then the magnitude of the resultant force.

$$R = \sqrt{P^2 + Q^2 + 2PQ\cos\theta}$$
$$= \sqrt{P^2 + P^2 + 2P\,P\cos 90^o}$$
$$= \sqrt{2P^2 + 0}$$
$$= \sqrt{2}\,P$$

42. If a constant force $\vec{f}$ applied on an object P, displaces it by a distance $\vec{d}$, inclined at an angle θ to the direction of force $\vec{f}$, then the work done by the force $\vec{f}$ is



(1) $\text{div}(\vec{f} \times \vec{d})$

(2) $\left|\vec{f} \times \left(\text{curl}\,\vec{d}\right)\right|$

(3) $\left|\vec{f} \times \vec{d}\right|$

(4) $\vec{f}.\vec{d}$

(a) 1 (b) 2
(c) 3 (d) 4

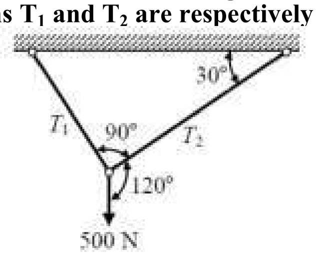
[GATE PI-2015: 1M]

Ans. (d) : According to the given question,
The work done by the force $\vec{f}$ applied on object P,

$$W = \vec{f} \cdot \vec{d}\cos\theta$$

Where, W = work done
$\vec{f}$ = force
$\vec{d}$ = displacement
θ = angle between force and direction of motion.
If, θ = 0°
$W = \vec{f} \cdot \vec{d}$

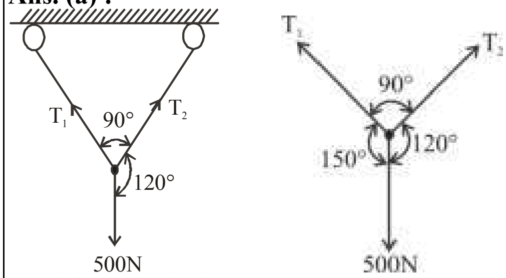
43. A weight of 500 N is supported by two metallic ropes as shown in the figure. The values of tensions T_1 and T_2 are respectively



(a) 433 N and 250 N (b) 250 N and 433 N
(c) 353.5 N and 250 N (d) 250 N and 353.5 N

AP PGECET 03.05.2019, Shift-II
[GATE-2015; Set-III, 1M]

Ans. (a) :



Applying Lami's theorem,

$$\frac{T_1}{\sin 120°} = \frac{T_2}{\sin 150°} = \frac{500}{\sin 90°}$$

$$T_1 = \frac{500 \times \sin 120°}{\sin 90°} = \frac{500\sin(90° + 30°)}{\sin 90°}$$

$$= \frac{500\cos 30°}{\sin 90°} = 500 \times \frac{\sqrt{3}}{2}$$

T_1 = 433 N

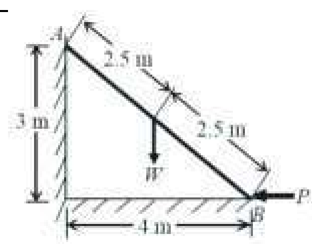
$$T_2 = \frac{500\sin 150°}{\sin 90°} = \frac{500\sin(90° + 60°)}{\sin 90°}$$

= 500 cos60°

$$= 500 \times \frac{1}{2}$$

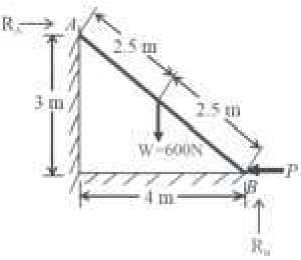
T_2 = 250 N

44. A ladder AB of length 5 m and weight (W) 600 N is resting against a wall. Assuming frictionless contact at the floor (B) and the wall (A), the magnitude of the force P (in newton) required to maintain equilibrium of the ladder is ____



[GATE-2014; Set-IV: 2M]

Ans. (399 to 401) :



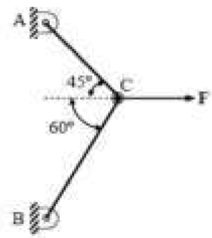
Taking moment about B.

$$R_A \times 3 = W \times 2.5\cos\theta$$

$$R_A = \frac{600 \times 2.5 \times \frac{4}{5}}{3} = \frac{6000}{15} = 400 \text{ N}$$

$\sum F_H = 0$
$R_A - P = 0$
$P = R_A$
P = 400 N

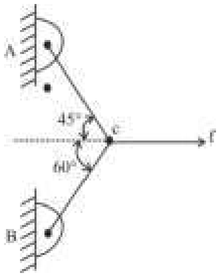
Common Data for Questions 45 and 46:
Two steel truss members, AC and BC, each having cross sectional area of 100 mm^2, are subjected to a horizontal force F as shown in figure. All the joints are hinged.



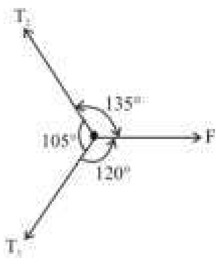
45. If F = 1 kN, the magnitude of the vertical reaction force developed at the point B in kN is
(a) 0.63 (b) 0.32
(c) 1.26 (d) 1.46

[GATE-PI 2012: 2M]
[GATE-2012: 2M]

Ans. (a) :



FBD,



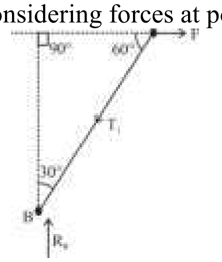
Using Lami's theorem,

$$\frac{T_1}{\sin(135°)} = \frac{F}{\sin 105°} = \frac{T_2}{\sin 120°} \qquad [\because F = 1\text{kN}$$

$$T_1 = \frac{\sin 135°}{\sin 105°}$$

$T_1 = 0.732$ kN

Now considering forces at point B



By resolving vertical forces $\left(\sum f_v = 0\right)$

$R_B - T_1 \cos 30° = 0$
$R_B = T_1 \cos 30°$
$R_B = 0.732 \cos 30°$
$R_B = 0.63$ kN

46. The maximum force F in kN that can be applied at C such that the axial stress in any of the truss members DOES NOT exceed 100 MPa is
(a) 8.17 (b) 11.15
(c) 14.14 (d) 22.30

[GATE-PI 2012: 2M]
[GATE-2012: 2M]

Ans. (b) : Given that,
Cross-sectional area of member = 100 mm^2
Maximum stress = 100 MPa
Using lami's theorem,

$$\frac{T_1}{\sin 135°} = \frac{T_2}{\sin 120°} = \frac{F}{\sin 105°}$$

$T_1 = 0.7320F$ and $T_2 = 0.8965$ F
As the value of T_2 is greater than T_1
The maximum stress will occur at truss AC.
So, maximum load
$\sigma_{max} = 100$ MPa
$T_2 = \sigma_{max} \times A$
0.8965 F = 100 × 100
F = 11.154 kN

47. An irregular planar body in space is acted upon by a force $\vec{F} = (2\vec{i} + \vec{j})$N at position $\vec{r}_1 = (\vec{i} + 2\vec{j})$m and a moment $\vec{M} = 3\vec{k}$Nm at position $\vec{r}_2 = (-2\vec{i})$m. The corresponding equivalent force $\vec{F}_0$ and moment $\vec{M}_0$ at the origin are
(a) $\vec{F}_0 = (2\vec{i} + \vec{j})\text{N}; \vec{M}_0 = (3\vec{k})\text{Nm}$
(b) $\vec{F}_0 = (2\vec{i} + \vec{j})\text{N}; \vec{M}_0 = 0\text{Nm}$
(c) $\vec{F}_0 = (2\vec{i} - \vec{j})\text{N}; \vec{M}_0 = (-6\vec{k})\text{Nm}$
(d) $\vec{F}_0 = (2\vec{i} + \vec{j})\text{N}; \vec{M}_0 = (6\vec{k})\text{Nm}$

[GATE-XE 2012: 1M]

Ans. (b) : Corresponding equivalent force is always equal to the acting force.

$$\vec{F}_0 = \left(2\vec{i} + \vec{j}\right)\text{N}$$

Moment $\vec{M}_0$ = r × F
Moment in the k direction whereas point in $\vec{i}$ and $\vec{j}$ direction so moment at the origin = 0.

48. Three forces acting on a particle are given as F_1 = (5i + 6j) N, F_2 = (–i + 4k) N and F_3 = (i + 6j + 16k) N,
Where i, j, k are the unit vectors along Cartesian coordinate axes. Which one of the following statements is true?
(a) Forces are coplanar and the particle is in equilibrium
(b) Forces are coplanar but the particle is not in equilibrium
(c) Forces are not coplanar but the particle is in equilibrium
(d) Forces are not coplanar and the particle is not in equilibrium

[GATE-XE 2010: 1M]

Ans. (b) : Case-I :
Coplanarity check,
The forces are coplanar if the scalar triple product is zero.

$$\det\begin{vmatrix}5 & 6 & 0\\ -1 & 0 & 4\\ 1 & 6 & 16\end{vmatrix} = 5(0-24)-6(-16-4)$$

$$= -120 + 120 = 0$$

Since the determinant is zero, the forces are coplanar.

Case-II :
Equilibrium check,
For equilibrium, the cross product must be equal,

1. $\vec{F}_1 \times \vec{F}_2 = 24i - 20j + 6k$
2. $\vec{F}_2 \times \vec{F}_3 = -24i + 20j - 6k$

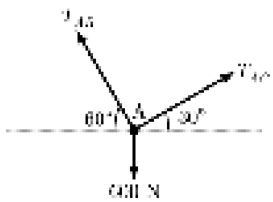
Since these are not equal, the forces are not in equilibrium.
Conclusion:
Forces are coplanar but not in equilibrium.

49. If three nonparallel forces are in equilibrium they
(a) must be concurrent but need not be coplanar
(b) must be coplanar but need not be concurrent
(c) must be both concurrent and coplanar
(d) need not have zero as the geometric sum of the force vectors

[GATE-XE 2008: 1M]

Ans. (a) : If three nonparallel forces are in equilibrium they must be concurrent. If the forces are not concurrent, they will create a net torque, and the rigid body will not be in equilibrium.

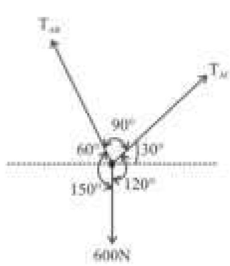
50. If point A is in equilibrium under the action of the applied forces, the values of tensions T_{AB} and T_{AC} are respectively



(a) 520 N and 300 N (b) 300 N and 520 N
(c) 450 N and 150 N (d) 150 N and 450 N

Karnataka PGECET 30.05.2018, Shift-I
Karnataka PGECET 2020
[GATE-2006: 2M]

Ans. (a) :



Applying Lami's theorem,

$$\frac{T_{AB}}{\sin 120°} = \frac{T_{AC}}{\sin 150°} = \frac{600}{\sin 90°}$$

$$\frac{T_{AB}}{\sin 120°} = \frac{600}{\sin 90°}$$

$$T_{AB} = \frac{600\sin 120°}{\sin 90°} = \frac{600\sin(90°+30°)}{\sin 90°} = \frac{600\cos 30°}{\sin 90°}$$

$$= 600 \times \frac{\sqrt{3}}{2} = 300\sqrt{3}$$

$$= 519.6 \approx 520 \text{ N}$$

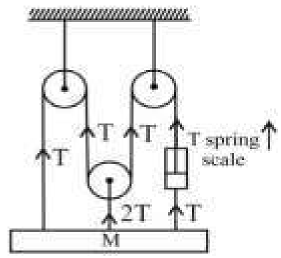
$T_{AB} = 520$ N

$$T_{AC} = \frac{600\sin 150°}{\sin 90°}$$

$$= \frac{600\sin(90°+60°)}{\sin 90°} = \frac{600\cos 60°}{\sin 90°} = 600 \times \frac{1}{2} = 300$$

$T_{AC} = 300$ N

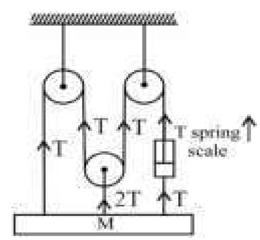
51. A spring scale indicates a tension T is the right hand cable of the pulley system shown in figure below. Neglecting the mass of the pulleys and ignoring friction between the cable and pulley the mass m is:



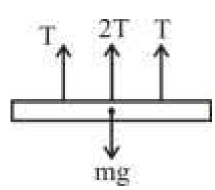
(a) $\frac{2T}{g}$ (b) $\frac{T(1+e^{4\pi})}{g}$
(c) $\frac{4T}{g}$ (d) None of the above

[GATE- 1995: 2M]

Ans. (c) :



FBD,



In equilibrium $\sum fy = 0$ $[\uparrow + \downarrow -]$

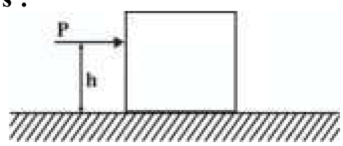
$T + 2T + T - mg = 0$
$4T = mg$

$$m = \frac{4T}{g}$$

02 FRICTION

A. Problems Involving Dry Friction

52. A square block of side 1 m and mass 10 kg is resting on a horizontal surface. The coefficient of static friction between the block and the surface is 0.75. A horizontal force P acts on the block as shown in the figure. The force P is gradually increased from zero until the block either slides or topples. The maximum value of *h* (in m, rounded off to two decimal places) for which the block slides without toppling is _____. Take the acceleration due to gravity *g*= 10 m/s^2.



[GATE-XE 2024: 2M]

Ans. (0.66 to 0.68) : The maximum Force P that can be applied without sliding,

$P_{max} = \mu N$
$= 0.75 \times 10 \times 10$
$= 75$ N

The maximum moment that can be applied without toppling.

$$M_{max} = mg\frac{L}{2} \qquad (L = 1m)$$
$$= \frac{10 \times 10}{2}$$
$= 50$ Nm

Therefore,
Equating the moment of force P to the maximum moment

$75\,h = 50$

$$h = \frac{50}{75}$$

$h \approx 0.67$m

Hence, the maximum value of h for which the block slides without toppling is 0.67 m.

53. Dry friction between a pair of bodies does not depend upon
(a) Surface roughness of the bodies
(b) Types of the materials of the bodies
(c) Contact area of the bodies
(d) Type of the material of the smaller body

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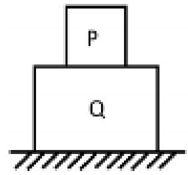
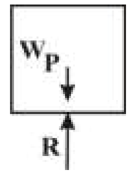
Ans. (c) : The main source of friction is the irregularity of the surface in contact. The co-efficient of friction between a given pair of substances is largely independent of the area of contact between them.

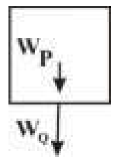
54. The figure shows two bodies P and Q. The body Q is placed on the ground and the body P is placed on top of it. The weights of P and Q are W_P and W_Q, respectively. The bodies are at rest and all the surfaces are assumed to be frictionless. R represents reactions force, if any, between the bodies.

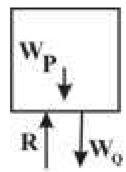


The correct free body diagram of the body P is

(a)

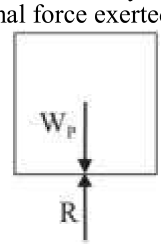

(b)


(c)


(d)


[GATE-2020; Set-II: 1M]
[GATE PI-2020: 1M]

Ans. (b) : As the body Q is placed on the ground and the body P is placed on the top of it.
Since, bodies are at rest and frictionless.
Therefore, no frictional forces to be considered and body P has only one interface in contact with body Q.
The force associated with body P are the weight the body P and the normal force exerted by body Q.



Where,
R = Normal force exerted by body Q on body P.
W_P = Weight of body P

55. Frictional force encountered after commencement of motion is
(a) Limiting friction (b) Kinematic friction
(c) Frictional resistance (d) Dynamic friction

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Ans. (d) : Dynamic friction is the frictional force encountered after the commencement of motion.

56. The maximum frictional force which comes in to play when a body just begins to slide over the surface of the other body, is known as:
(a) Static friction
(b) dynamic friction
(c) Limiting friction
(d) coefficient of friction

AP PGECET 11.05.2018, Shift-II

Ans. (c) : The frictional force is independent of the area of contact of the surfaces. When one body is just on the point of sliding over the other body, the maximum force of friction is being exerted, this is called the limiting friction.

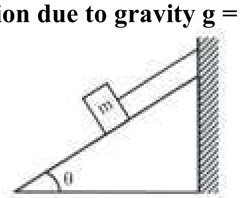
57. The friction experienced by a body, when in motion is known as
(a) Rolling friction (b) Limiting friction
(c) Dynamic friction (d) Static friction
AP PGECET 11.05.2017, Shift-II

Ans. (c) : When a body is moving relative to another body, the friction experienced by the body is dynamic friction.

58. Pick up wrong statement about friction force for dry surfaces. Friction force is
(a) Proportional to normal load between the surfaces
(b) Dependent on the materials of contact surface
(c) Proportional to velocity of sliding
(d) Independent of the area of contact surfaces
TS PGECET 2017

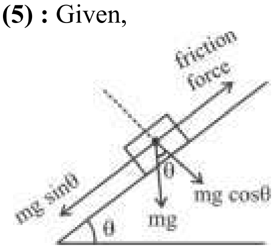
Ans. (c) : Friction force between solids, such as a mass on a spring, or a block on a table, is generally proportional to the normal force, not velocity.

59. A block of mass m rests on an inclined plane and is attached by a string to the wall as shown in the figure. The coefficient of static friction between the plane and the block is 0.25. The string can withstand a maximum force of 20 N. The maximum value of the mass (m) for which the string will not break and the block will be in static equilibrium is ____________ kg.
Take cosθ = 0.8 and sinθ = 0.6.
Acceleration due to gravity $g = 10\ m/s^2$



[GATE-2016; Set-1: 2M]

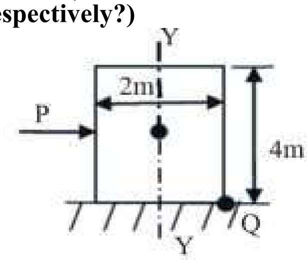
Ans. (5) : Given,



Coefficient of static friction (μ) = 0.25
$\cos\theta = 0.8$ and $\sin\theta = 0.6$
$T_{max} = 20\ N$
$g = 10\ m/s^2$
We know that,
Friction force (F) = μ × N
[N = Normal reaction mg cosθ]
$= 0.25 \times mg\cos\theta = 0.25 \times 10m \times 0.8$
$= 2\ m$

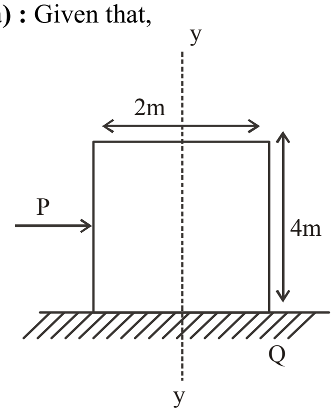
As per condition of equilibrium,
$mg\sin\theta = 20 + \text{friction force}$
$m \times 10 \times 0.6 = 20 + 2m$
$6m = 20 + 2m$
$4m = 20$
$m = 5\ kg$

60. A wardrobe (mass 100 kg, height 4 m, width 2 m, depth 1 m), symmetric about the Y-Y axis, stands on a rough level floor as shown in the figure. A force P is applied at mid-height on the wardrobe so as to tip it about point Q without slipping. What are the minimum values of the force (in newton) and the static coefficient of friction μ between the floor and the wardrobe, respectively?)

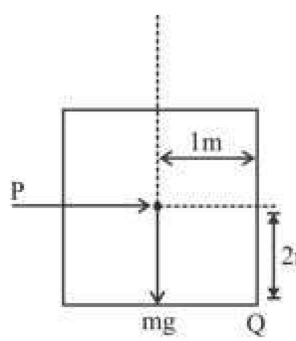


(a) 490.5 and 0.5 (b) 981 and 0.5
(c) 1000.5 and 0.15 (d) 1000.5 and 0.25
[GATE-2014; Set-IV: 2M]

Ans. (a) : Given that,



FBD,



Mass of wardrobe (m) = 100 kg
Height (h) = 4 m
Width (b) = 2 m
Depth (d) = 1 m
Taking moment about point Q
$\sum M_Q = 0$
$P \times 2 - mg \times 1 = 0$

$$P = \frac{mg}{2} = \frac{100 \times 9.81}{2} = 490.5\,\text{N}$$

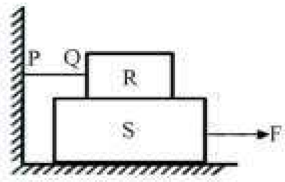
When the wardrobe is just to slide,

$P = \mu mg$

$490.5 = \mu \times 100 \times 9.81$

$\mu = 0.5$

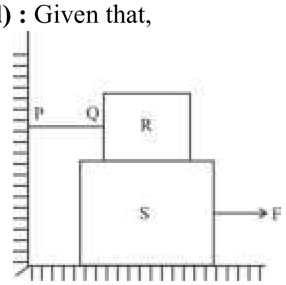
61. A block R of mass 100 kg is placed on a block S of mass 150 kg as shown in the figure. Block R is tied to the wall by a massless and inextensible string PQ. If the coefficient of static friction for all surfaces is 0.4, the minimum force F (in kN) needed to move the block S is



(a) 0.69 (b) 0.88
(c) 0.98 (d) 1.37

[GATE-2014; Set-I: 2M]

Ans. (d) : Given that,

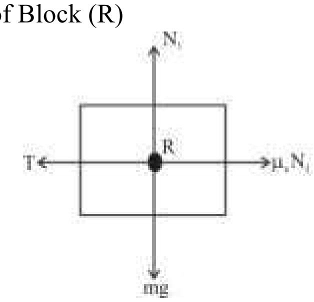


Mass of block R : $(m_1) = 100$ kg

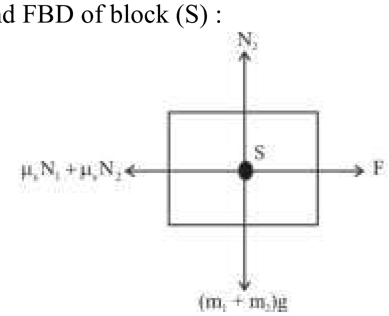
Mass of block S : $(m_2) = 150$ kg

Coefficient of friction $(\mu) = 0.4$

FBD of Block (R)



And FBD of block (S) :



In equilibrium condition,

$N_1 = m_1g$ …..(i)

And, $N_2 = (m_1 + m_2)g$ …..(ii)

$T = \mu N_1$ …..(iii)

$F = \mu N_1 + \mu N_2$ …..(iv)

$F = \mu(m_1g) + \mu(m_1 + m_2)g$

$= \mu(2m_1 + m_2)g$

$= 0.4(2\times 100 + 150) \times 9.81$

$= 1373.4$ N

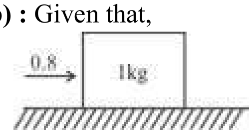
$F = 1.37$ kN

62. A 1 kg block is resting on a surface with coefficient of friction μ = 0.1. A force of 0.8 N is applied to the block as shown in the figure. The friction force is

(a) 0 (b) 0.8 N
(c) 0.98 N (d) 1.2 N

[GATE-2011: 2M]

Ans. (b) : Given that,



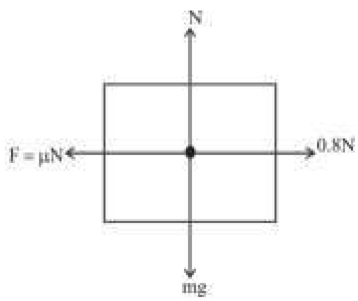
Mass of block (m) = 1 kg

Coefficient of friction $(\mu) = 0.1$

Applied force (P) = 0.8 N

We consider F is friction force

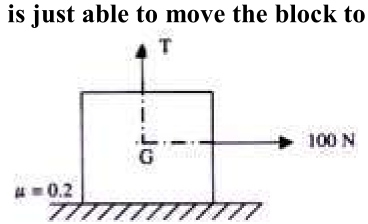
FBD,



In equilibrium condition,

$F = 0.8$ N

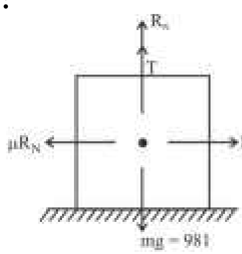
63. A block weighing 981 N is resting on a horizontal surface. The coefficient of friction between the block and the horizontal surface is μ = 0.2. A vertical cable attached to the block provides partial support as shown. A man can pull horizontally with a force of 100 N. What will be the tension, T (in N) in the cable if the man is just able to move the block to the right?



(a) 176.2 (b) 196.0
(c) 481.0 (d) 981.0

[GATE-2009: 1M]

Ans. (c) :



Given,

$W = 981$ N

$\mu = 0.2$

$F_S = 100$ N

Number of vertical forces-

$\sum F_y = 0$

$T + R_N - W = 0$

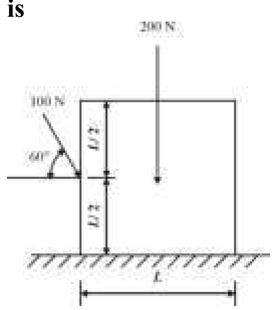
Normal reaction,

$$R_N = \frac{100}{0.2} = 500\,\text{N} \qquad \{\because F_S = \mu R_N\}$$

Tension $T = 981 - 500$ $\qquad [T = W - R_N]$

$T = 481$ N

64. A homogeneous cubic block of side L and weight 200 N resting on a horizontal floor is acted upon by a force of 100 N at an angle of 60° to the horizontal as shown in the figure. If the coefficient of friction is 0.3, the magnitude of the frictional force between the block and the floor is



(a) 0 N (b) 50 N

(c) 86 N (d) 100 N

[GATE-XE 2008: 2M]

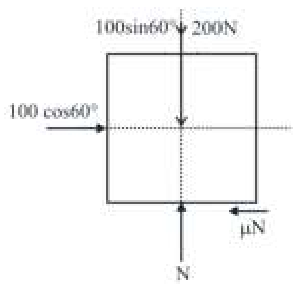
Ans. (b) : Given,

Weight of block = 200 N

Force = 100 N at an angle of 60° to horizontal coefficient of friction (μ) = 0.3

Frictional force between the block and the floor = ?

Now,



Where, N is the normal reaction between block and horizontal plane.

$\because \sum F_y = 0$

$\therefore N = 200 + 100 \sin 60°$

Maximum value of static frictional force

$F_S = \mu N$

$= 0.3\,(200 + 100\sin60°) = 86$ N

We know that,

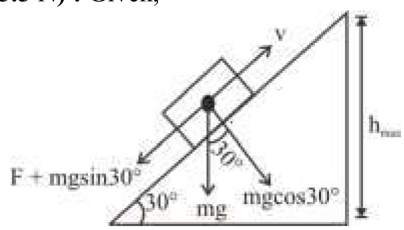
When applied force in tangential direction is less than the maximum force then the frictional force is equal to applied force.

$\therefore F = 100 \cos 60° = 50$ N

65. A block of mass 5 kg is thrust up a 30° inclined plane with an initial velocity of 4m/sec. it travels a distance of 1.0 m before it comes to rest. The force of friction acting on it would be …….

[GATE-1994: 1M]

Ans. (15.5 N) : Given,



Mass of the block (m) = 5 kg

Inclination angle (θ) = 30°

Initial velocity (v) = 4 m/s

Distance travelled (d) = 1.0 m

Let the force of friction be F and height be h the maximum height raised by the block is

$h_{max} = d \sin\theta = d\sin30°$

$h_{max} = \frac{d}{2} = 0.5\text{m}$

Form energy conservation,

$$\frac{1}{2}mv^2 = f \times d + mgd\sin 30°$$

$$f = \frac{1}{2}5(4^2 - 9.81)$$

$f = 15.5$ N

B. Application of Friction

66. A car travelling at a speed of 60 kmph came to rest in 6s after the brakes are applied. The minimum coefficient of friction between the wheels and the road would be

(a) 0.107 (b) 0.227

(c) 0.3 (d) 0.417

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Ans. (c) : Given data,

Final speed (v) = 0 m/s

Initial speed (u) = 60 km/hr.

$$= 60 \times \frac{5}{18}\,\text{m/s}$$

$$= \frac{50}{3}\,\text{m/s}$$

Time (t) = 6 second
Minimum coefficient of friction, μ_s = ?
We know that,
v = u – at

$$0 = \frac{50}{3} - a \times 6$$

$$a = \frac{25}{9} m/s^2 \text{ (De-accelerating/breaking condition)}$$

$$F_s = F$$

$$\mu_s mg = ma$$

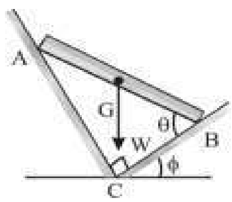
$$\mu_s = \frac{a}{g}$$

$$\mu_s = \frac{25}{9} \times \frac{1}{9.8} = 2.777 \times 0.101$$

$\mu_s = 0.28 \approx 0.3$

Hence, minimum coefficient of friction between the wheels & the road is 0.3

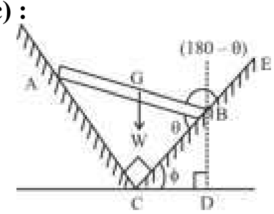
67. A uniform rod AB is in equilibrium when resting on a smooth groove, the walls of which are at right angles to each other as shown in figure. What is the relation between θ and ϕ in degrees?



(a) θ = 45° + ϕ (b) θ = 45° – ϕ
(c) θ = 90° – ϕ (d) θ = 90° + ϕ

AP-PGECET 30.05.2024, Shift-II

Ans. (c) :



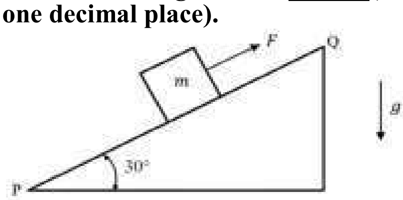
In ΔBCD, using property of triangle

$$\angle BCD + \angle BDC = \angle GBE$$

$$\phi + 90° = 180° - \theta$$

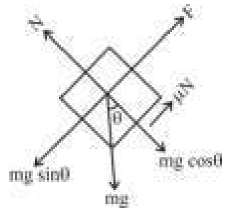
$$\theta = 90° - \phi$$

68. A block of mass m = 10 kg is lying on an inclined plane PQ. The mass is restrained from sliding down the inclined plane by a force F. The coefficient of friction between the block and the inclined plane is 0.3. Take the acceleration due to gravity as 10 m/s^2. The smallest force F (in N) required to prevent the block from sliding down is______(rounded off to one decimal place).



[GATE-XE 2023: 2M]

Ans. (23.0 to 25.0) : Given,
Mass (m) = 10 kg
μ = 0.3



$$N = mg\cos\theta$$

$$N = 10 \times 10 \times \cos 30°$$

$$N = 100 \times 0.866 = 86.6N$$

Maximum frictional force $F_{friction}$

$$F_{friction} = \mu N$$

$$F_{friction} = 0.3 \times 86.6 = 25.98N$$

Now,
Component of the gravitational force

$$mg\sin\theta = 10 \times 10 \times \sin 30°$$

$$mg\sin\theta = 100 \times 0.5 = 50 \text{ N}$$

Smallest force F required to prevent sliding

$$F + F_{friction} = mg\sin\theta$$

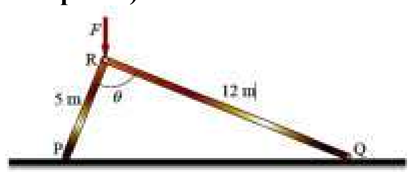
$$F = (mg\sin\theta) - (F_{friction})$$

$$= 50 - 25.98$$

$$= 24.02 \text{ N}$$

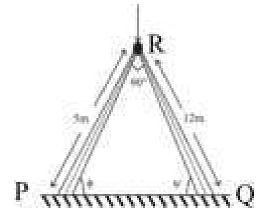
The smallest force F required to prevent the block from sliding down approx 24 N.

69. Two rigid massless rods PR and RQ are joined at frictionless pin-joint R and are resting on ground at P and Q, respectively, as shown in the figure. A vertical force F acts on the pin R as shown. When the included angle < 90°, the rods remain in static equilibrium due to Coulomb friction between the rods and ground at locations P and Q. At = 90°, impending slip occurs simultaneously at points P and Q. Then the ratio of the coefficient of friction at Q to that at P (μ_Q/μ_P) is _________ (round off to two decimal places).



[GATE-2022; Set-I: 2M]

Ans. (5.70 to 5.80) : Given that,

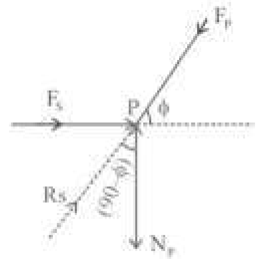


At θ = 90°, slip occurs simultaneously at point P and Q.

$$\tan\phi = \frac{12}{5}$$

And, $\tan\psi = \frac{5}{12}$

FBD at point (P),



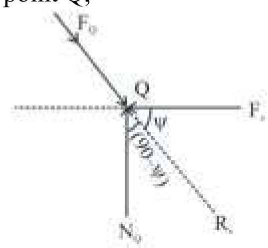
Angle of static friction is the angle between resultant and normal reaction so,

$$\tan(90° - \phi) = \mu_p$$

$$\cot\phi = \mu_p$$

$$\mu_p = \frac{1}{\tan(\phi)} = \frac{5}{12}$$

FBD at point Q,



$$\tan(90 - \psi) = \mu_Q$$

$$\cot\psi = \mu_Q$$

$$\mu_Q = \frac{1}{\tan(\psi)} = \frac{12}{5}$$

$$\frac{\mu_Q}{\mu_P} = \frac{\frac{12}{5}}{\frac{5}{12}} = \frac{12\times12}{5\times5} = \frac{144}{25}$$

$$\frac{\mu_Q}{\mu_P} = 5.76$$

70. If the maximum angle at which an object can rest on a inclined plane without sliding down is 30 degree, then the coefficient of static friction between the two bodies will be

(a) Greater than 0.5 (b) Less than 0.5

(c) 0.5 (d) 0.3

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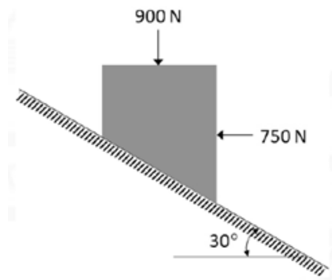
Ans. (a) : Coefficient of static friction,

$$\mu_S = \tan\theta$$

$$\mu_S = \tan 30°$$

$$\mu_s = \frac{1}{\sqrt{3}} = 0.577$$

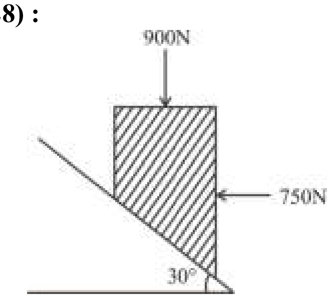
71. A block of negligible mass rests on a surface that is inclined at 30° to the horizontal plane as shown in the figure. When a vertical force of 900 N and a horizontal force of 750 N are applied, the block is just about to slide.



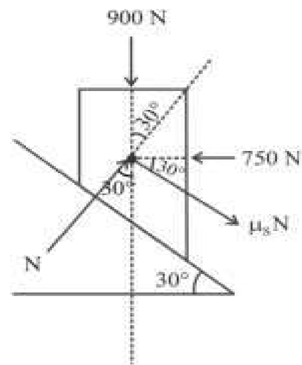
The coefficient of static friction between the block and surface is _(round off to two decimal places).

[GATE-2021; Set-II: 2M]

Ans. (0.1728) :



FBD,



In equation condition

$$\sum f_x = 0$$

$$\mu_s N\cos 30° + N\sin 30° = 750 \quad \text{....(i)}$$

$$\sum f_v = 0$$

$$-\mu_s \sin 30° + N\cos 30° = 900 \quad \text{....(ii)}$$

Divide equation (i) and (ii),

$$= \frac{\mu_s N\cos 30° + N\sin 30°}{-\mu_s \sin 30° + N\cos 30°} = \frac{750}{900}$$

$$= \frac{\mu_s\sqrt{3}+1}{-\mu_s+\sqrt{3}} = \frac{5}{6}$$

$$\mu_s = 0.1728$$

72. Which among the following statements is true for a body moving on a dry surface under the action of applied forces ?

(a) Kinetic-friction force is zero.

(b) Kinetic-friction force is equal to the static-friction force

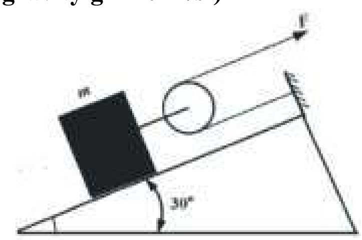
(c) Kinetic-friction force is greater than the static-friction force

(d) Kinetic-friction force is lower than the static-friction force.

[GATE-XE 2020:1M]

Ans. (d) : Kinetic friction acts when surfaces are sliding over each other and is generally lower than static friction, which resists the start of sliding. Static friction can adjust up to a maximum value, when kinetic friction is constant once motion begins.

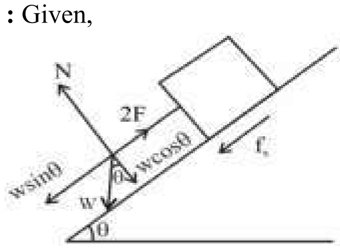
73. The block of mass m = 10 kg is held in place along the incline by the force F applied via a pulley arrangement as shown. The coefficient of static friction between the block and incline is 0.65. The range of F (in N) for which the block will remain at rest is (use acceleration due to gravity g = 10 m/s^2)



(a) 6.3 to 106.30 (b) 0 to 106.30
(c) 0 to 53.15 (d) 53.15 to 106.30

[GATE-XE 2019-2M]

Ans. (c) : Given,



m = 10 kg, w = 100 N

$\mu_s = 0.65$

g = 10 m/s^2

$\theta = 30°$

$2F = w\sin\theta + f_s$

$2F = w\sin\theta + \mu N$ …(i)

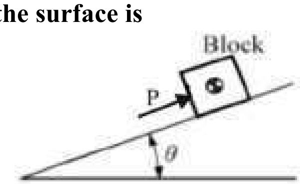
$N = w\cos\theta$ ….(ii)

Solving equation (i) and (ii), we get–

$F \approx 53.15$ N

So, the range of force f is $0 \le F \le 53.15$

74. A horizontal effort P is applied to raise a block of weight W on a rough surface inclined at an angle θ with the horizontal. If μ_s is the coefficient of static friction between the block and the surface, the minimum effort P required to impend the upward motion of the block along the surface is

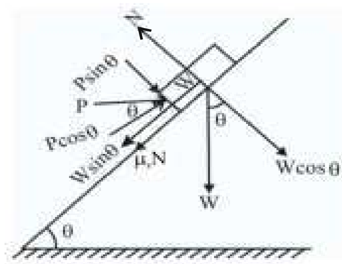


(a) $W\left(\frac{\mu_s - \tan\theta}{1+\mu_s\tan\theta}\right)$ (b) $W\left(\frac{\mu_s + \tan\theta}{1-\mu_s\tan\theta}\right)$

(c) $W\left(\frac{\mu_s - \tan\theta}{1-\mu_s\tan\theta}\right)$ (d) $W\left(\frac{\mu_s + \tan\theta}{1+\mu_s\tan\theta}\right)$

[GATE-XE 2018: 2M]

Ans. (b) :



Where,

P = Horizontal effort

N = Normal Reaction

μ_s = Coefficient of friction

Now,

$P\cos\theta = W\sin\theta + \mu_s N$ (Parallel to the incline) ...(i)

And,

$N = P\sin\theta + W\cos\theta$ (Perpendicular to the incline)

Put the value of N in equation (i),

$P\cos\theta = W\sin\theta + \mu_s(P\sin\theta + W\cos\theta)$

$P\cos\theta = W\sin\theta + \mu_s P\sin\theta + \mu_s W\cos\theta$

Or, $P\cos\theta - \mu_s P\sin\theta = W\sin\theta + \mu_s W\cos\theta$

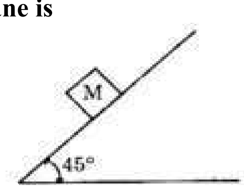
$P(\cos\theta - \mu_s\sin\theta) = W(\sin\theta + \mu_s\cos\theta)$

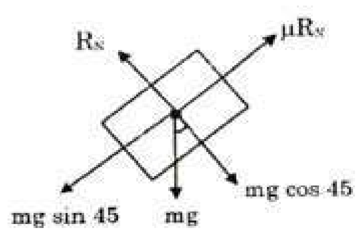
$$P = W\left[\frac{(\sin\theta + \mu_s\cos\theta)}{(\cos\theta - \mu_s\sin\theta)}\right]$$

$$P = W\left[\frac{\cos\theta(\tan\theta + \mu_s)}{\cos\theta(1-\mu_s\tan\theta)}\right]$$

$$P = W\left[\frac{\mu_s + \tan\theta}{1-\mu_s\tan\theta}\right]$$

75. A body of mass (M) 10 kg is initially stationary on a 45° inclined plane as shown in figure. The coefficient of dynamic friction between the body and the plane 0.5. The body slides down the plane and attains a velocity of 20 m/s. The distance travelled (in meter) by the body along the plane is

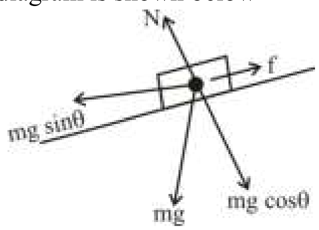




(a) 56 to 59 (b) 66 to 69
(c) 76 to 79 (d) 86 to 89

TANCET 2017

Ans. (a) : Given,
Mass of body (M) = 10 kg
Velocity (v) = 20 m/s
Inclined (θ) = 45°
Friction (μ) = 0.5
We know that,
The FBD of diagram is shown below



Now applying force balance,

$mg\sin\theta - \mu mg\cos\theta = ma$

$a = g(\sin\theta - \mu\cos\theta)$

$= 9.81 \times (\sin 45° - 0.5\cos 45°)$

$a = 9.81 \times (0.7071 - 0.3535)$

$a = 3.4688 \text{ m/s}^2$

The elistance covered by body

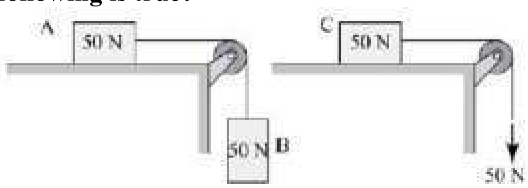
$V^2 = u^2 + 2as$

$(20)^2 = 0 + 2 \times 3{\cdot}4688 \times S$

$S = \frac{400}{2 \times 3 \cdot 4688}$

$S = 57{\cdot}69$ m

76. Two systems shown below start from rest. For the system shown on the left, two 50N blocks are connected by a cord. For the system shown on the right, the 50N block is pulled by a 50N downward force. Neglect friction. Which of the following is true?



(a) Block A and C have the same acceleration.
(b) Block C will have a larger acceleration than block A.
(c) Block A will have a larger acceleration than block C.
(d) Block A will not move.

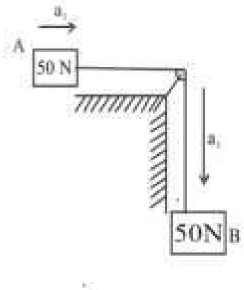
[GATE-XE 2015]

Ans. (b) : Let, a_1 = acceleration of block A,
a_2 = acceleration of block C.

For Left side figure:

50 N block $m = \frac{50}{9.81} \approx 5.1\text{kg}$

Net force on each block: F = mg – T
Both blocks have the same acceleration a_1

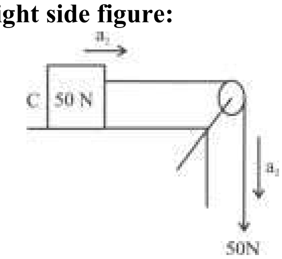


Net force per block

$F_{net} = \frac{50}{2} = 25\text{N}$

Acceleration, $a_1 = \frac{F_{net}}{m} = \frac{25}{5.1} \approx 4.9\text{m/s}^2$

For right side figure:



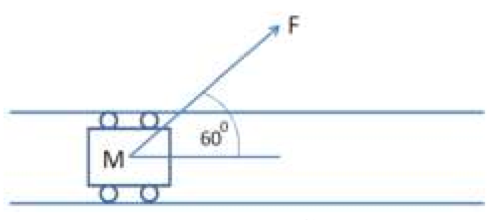
Block, $m = \frac{50}{9.81} = 5.1\text{kg}$

Net force, $F_{net} = 50\text{N}$

Acceleration $a_2 = \frac{F_{net}}{m} = \frac{50}{5.1} \approx 9.8\text{m/s}^2$

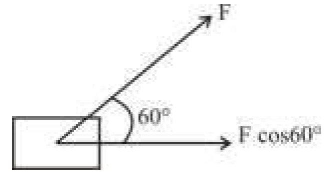
Contusion Block C (a_2 = 9.81 m/s^2) has greater acceleration than block A (a_1 = 4.9 m/s^2)

77. A force F = 2 N is applied on a block of mass M = 0.5 kg as shown in the figure. The block is constrained to move along the horizontal direction in a guideway. Find out the distance (in meters) travelled by the block in 2 s starting from rest. Neglect any friction between the block and the guideway. _______.



[GATE-XE 2013: 1M]

Ans. (3.9 to 4.1) : Given,



Applying Newton's second law,

$F = M.a$

$$a = \frac{F}{M} = \frac{2\cos 60°}{0.5\text{kg}} = \frac{2\left(\frac{1}{2}\right)}{0.5}$$

$a = 2$ m/s^2

Now, the distance travelled, the block start from rest.
So, the initial velocity u = 0
The distance traveled after time t = 2 s can be,

$$S = ut + \frac{1}{2}at^2$$

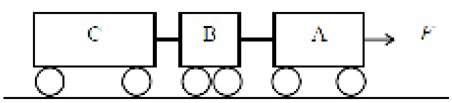
$$S = 0 \times 2 + \frac{1}{2} \times 2 \times 2^2$$

$$S = \frac{1}{2} \times 2 \times 4 = 4 \text{ meters}$$

S = 4 meters

The block travels 4 meters in 2 seconds.

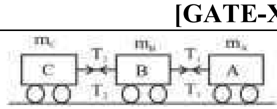
78. Three connected railway coaches A, B and C of masses m_A, m_B and m_c, respectively are being pulled by a locomotive with force F over a horizontal track. The coaches may be assumed to move on frictionless wheels with negligible air resistance. The tension in the connector between coaches A and B is



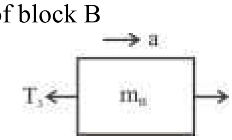
(a) F
(b) $Fm_A/(m_A + m_B + m_C)$
(c) $Fm_B/(m_A + m_B + m_C)$
(d) $F(m_B + m_C)/(m_A + m_B + m_C)$

[GATE-XE 2012: 1M]

Ans. (d)



FBD of block B



$m_{total} = m_A + m_B + m_C$

Acceleration of the entire system

$$a = \frac{F}{m_{total}} = \frac{F}{m_A + m_B + m_C}$$

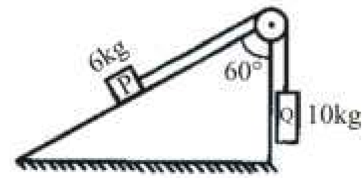
Tension between A and B

$T_{AB} = (m_B + m_C) \times a$

$$T_{AB} = (m_B + m_C) \times \frac{F}{m_A + m_B + m_C}$$

$$T_{AB} = \frac{F(m_B + m_C)}{(m_A + m_B + m_C)}$$

79. Two blocks P and Q are connected by a string, which passes over a pulley as shown in the figure. The block P is sliding on an inclined surface. Ignoring the masses of the string and the pulley, the tension in the string is (use gravitational acceleration g = 9.81 m/s^2 and neglect all friction)

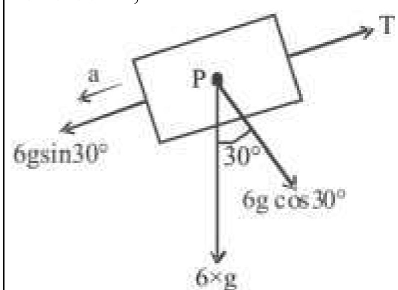


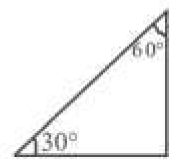
(a) 55.2 N
(b) 62.5 N
(c) 74.3 N
(d) 86.2 N

[GATE-XE 2010: 2M]

Ans. (a) : Given,
Mass of block P = 6 kg
Mass of block Q = 10 kg
Angle of incline = 60°
g = 9.8 m/s^2

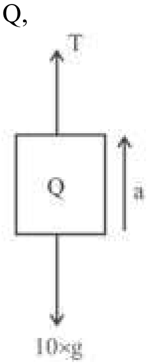
For block P,





$6 g \sin 30° - T = 6 \times a$ …(i)

For block Q,



$T - 10g = 10a$ …(ii)

Value of a from equation (ii),

$$a = \frac{T}{10} - g$$

Putting in equation (i),

$$6g \sin 30° - T = 6 \times \left(\frac{T}{10} - g\right)$$

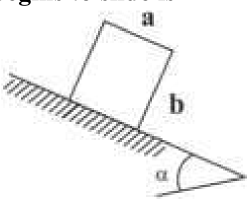
Simplifying,

$$\frac{6T}{10} + T = 6g + 6g\sin 30°$$

$$\frac{16T}{10} = 58.86 + 29.43$$

16T = 88.29 × 10
16T = 882.9
T = 55.181 ≈ 55.2 N

80. A block of length a and height b rests on a rough inclined plane (coefficient of friction μ) as shown below. The angle α, of the inclined planed is slowly increased. The condition that the block will topple due to its own weight before it begins to slide is

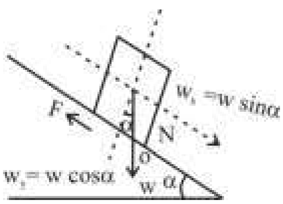


(a) $\frac{a}{b} < \mu$ (b) $\frac{a}{b} > \mu$

(c) $\frac{a}{b} > \sqrt{1-\mu}$ (d) $\frac{a}{b} < \sqrt{1-\mu}$

[GATE-XE 2009: 2M]

Ans. (a) :



For a block not to slide when toppling occurs –

$F_{max} = \mu N = \mu w \cos\alpha$

$\mu\, w\cos\alpha > w \sin\alpha$

$\mu > \tan\alpha$ …(i)

When the block topless then taken a moment of about point O.

$$w\sin\alpha \times \frac{b}{2} - w\cos\alpha \times \frac{a}{2} = 0$$

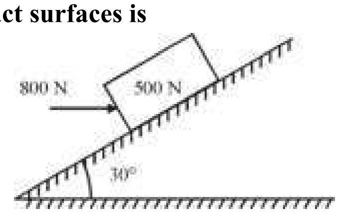
$$\Rightarrow \sin\alpha \times \frac{b}{2} = \cos\alpha \times \frac{a}{2}$$

$$\Rightarrow \tan\alpha = \frac{a}{b} \quad \text{….(ii)}$$

From equation (i) and equation (ii),

$$\Rightarrow \mu > \frac{a}{b}$$

81. A block of weight 500 N is about to move up the plane due to a horizontal force of 800 N. The coefficient of static friction between the contact surfaces is

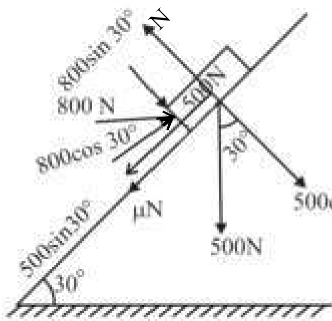


(a) 0.15 (b) 0.25

(c) 0.33 (d) 0.53

[GATE-XE 2008: 2M]

Ans. (d) : Given,



From above diagram–

$800 \cos30° = \mu N + 500 \sin30°$ …..(i)

(Where, N = Normal Reaction)

$N = 800 \sin30° + 500 \cos30°$

$= 800 \times \frac{1}{2} + 500 \times \frac{\sqrt{3}}{2}$

$N = 400 + 250\sqrt{3}$

$N = 833$ N

Value of, (N) = 833 N

By putting the value of 'N' in equation (i), we get–

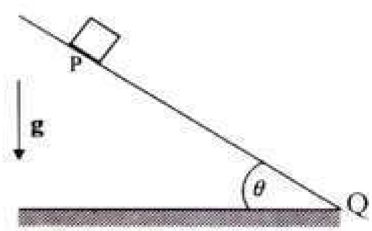
$$800 \times \frac{\sqrt{3}}{2} = \mu \times 833 + 500 \times \frac{1}{2}$$

$400\sqrt{3} = \mu \times 833 + 250$

On solving,

$\mu = 0.53$

82. A block of mass M is released from point P on a rough inclined plane with inclination angle θ, shown in the figure below. The coefficient of friction is μ. If μ < tan θ, then the time taken by the block to reach another point Q on the inclined plane, where PQ = S, is



(a) $\sqrt{\frac{2s}{g\cos\theta(\tan\theta - \mu)}}$

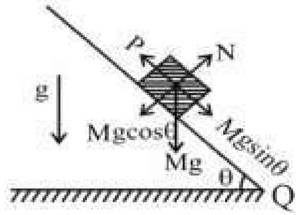
(b) $\sqrt{\frac{2s}{g\cos\theta(\tan\theta + \mu)}}$

(c) $\sqrt{\frac{2s}{g\sin\theta(\tan\theta - \mu)}}$

(d) $\sqrt{\frac{2s}{g\sin\theta(\tan\theta + \mu)}}$

[GATE-2007: 2M]

Ans. (a) : Resolving force along the inclined plane and normal to the plane.



Normal angle ⇒ $Mg\cos\theta = N$

Inclined plane angle ⇒ $Mg\sin\theta - f = Ma$

So ∵ $f = \mu N$

$Mg\sin\theta - \mu Mg\cos\theta = Ma$

$a = g\sin\theta - \mu g\cos\theta$

$a = g\cos\theta(\tan\theta - \mu)$

∵ Velocity equation in this surface of sliding

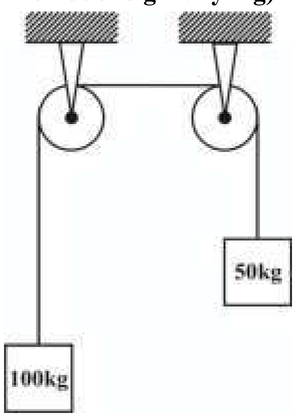
$$s = ut + \frac{1}{2}at^2$$

But, $u = 0,\ s = \frac{1}{2}at^2$

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

$$t = \sqrt{\frac{2s}{g\cos\theta(\tan\theta - \mu)}}$$

83. Two masses are attached to the two ends of a cable which passes over two frictionless pulleys as shown in the figure.
(acceleration due to gravity = g)



The acceleration of the 100 kg mass is

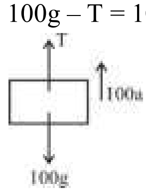
(a) g (b) g/2

(c) g/3 (d) g/4

[GATE-XE 2007: 1M]

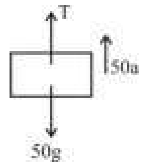
Ans. (c) : For the 100 kg mass,

$100g - T = 100a$ …… (i)



For the other mass 50kg:

$T - 50g = 50a$ ……. (ii)



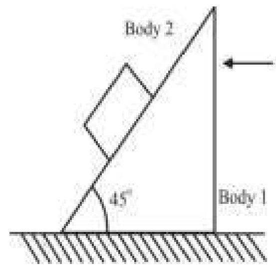
From equation (i) & (ii), we get –

$100g - 50g = 100a + 50a$

$50g = 150a$

$a = g/3$

84. Bodies 1 and 2 shown in the figure have equal mass m. All surfaces are smooth. The value of force P required to prevent sliding of body 2 on body 1 is



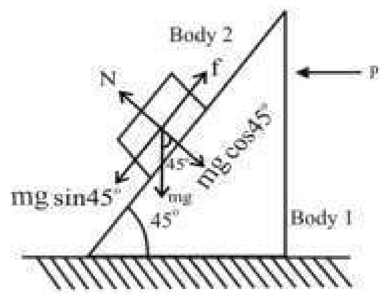
(a) $P = 2$ mg (b) $P = \sqrt{2}$ mg

(c) $P = 2\sqrt{2}$ mg (d) $P = $ mg

[GATE-2001: 2M]

Ans. (a) : Let,

The acceleration for both bodies be a L equal relative acceleration and normal force be NC (common for both bodies).



Body considering body (2),

$mg\cos45° = mg\sin45°$

And, $N = mg\cos45° + ma\sin45°$ ….(i)

$N = \sqrt{2}$ mg ….(ii)

For Body (i),

$P - N\sin45° = mg$

$$P = mg + \frac{N}{\sqrt{2}}$$

$$P = mg + \frac{\sqrt{2}\,mg}{\sqrt{2}}$$

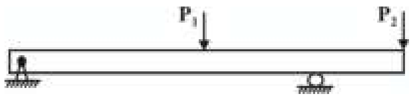
From equation (i) and (ii), we get –

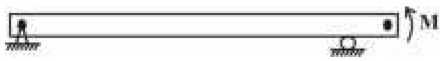
$P = 2$ mg

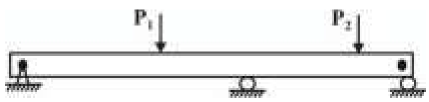
03 TRUSS AND FRAMES

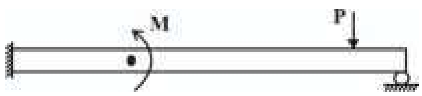
A. Basics of Truss

85. Which of the following beam (s) is/are statically indeterminate?

(a) 

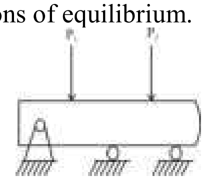
(b) 

(c) 

(d) 

[GATE-2024: 2M]

Ans. (c, d) : Statically indeterminate structures are those structures that cannot be analyzed using statics or equations of equilibrium.



Number of unknown = 3
Number of equilibrium equation = 2

86. A plane truss has four members and four joints. The truss is

(a) Perfect (b) Deficient
(c) Redundant (d) Rigid

AP-PGECET 30.05.2024, Shift-II

Ans. (b) : Given,
Number of member (n) = 4
Number of joints (j) = 4
We know that,

$$n = 2j - 3$$
$$n = 2 \times 4 - 3$$
$$n = 5$$
$$n_{given} < n_{obtained}$$

Hence, the truss is deficient.

87. For a statically determinate plane truss, the relation between the number of members (n) and number of joints (j) is expressed by

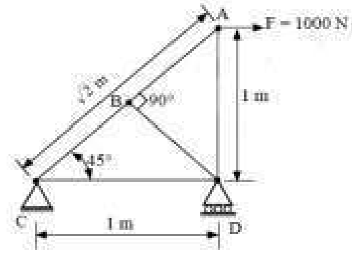
(a) $n = 2j + 1$ (b) $n = 2j + 3$
(c) $n = 2j - 3$ (d) $n = 2j - 1$

TS PGECET 2021

Ans. (c) : The equation $n = 2j - 3$ applies to statically determinate plane trusses,
Where,
- 2j represents the total number of members connected to all joints and
- 3 represent the three reaction forces (two horizontal and one vertical)

B. Method of Joints

88. A truss structure is loaded as shown in the figure below. Among the options given, which member in the truss is a zero-force member?

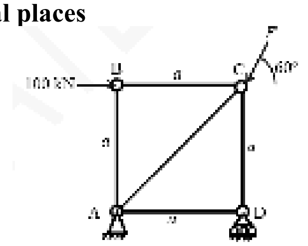


(a) BD (b) BC
(c) BA (d) AD

[GATE-2025: 1M]

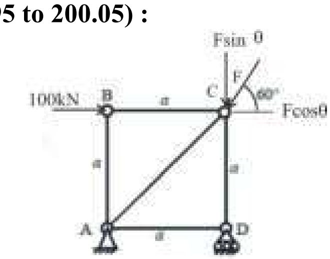
Ans. (a) : At joint B, AB & BC are collinear, BD is non-collinear
⇒ BD is a zero force member.

89. In the truss shown in the figure, member AC is an inextensible string, other members are rigid, and ABCD is a square with each side of length a. The maximum value of force F (in kN) for which the truss will remain in static equilibrium is _________. (Rounded off to 2 decimal places



[GATE PI-2024: 1M]

Ans. (199.95 to 200.05) :



Condition of equilibrium,

$$\Sigma Fx = 0$$

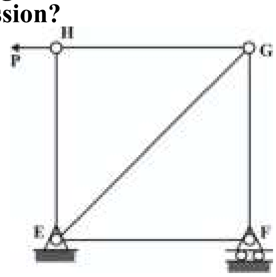
$F\cos 60° - 100\text{ kN} = 0$ …..(i)
$F\sin 60° = 0$ …..(ii)

According to equation (i),

$F\cos 60° = 100$ $\left(\because \cos 60° = \frac{1}{2}\right)$

$$\frac{F}{2} = 100$$
$$F = 200\text{ kN}$$

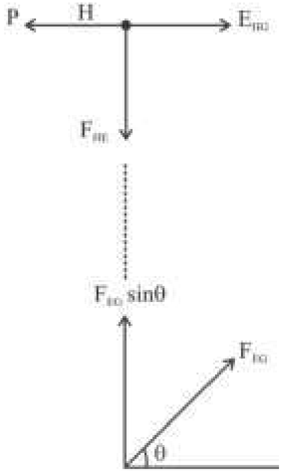
90. A pin-jointed truss has a pin support at the point E and a roller support at the point F. A horizontal force P is applied at pin H as shown in the figure. Which one of the members is in compression?



(a) EF (b) FG
(c) EG (d) EH

[GATE-XE 2024: 2M]

Ans. (c) : Given,
The truss with members EF, FG, GH, HE, and diagonal EG
Joint H:
Horizontal force P is applied at H Let the force in member HE be F_{HE}, in HG be F_{HG} and in EG be F_{EG}.
Horizontal force Balance:

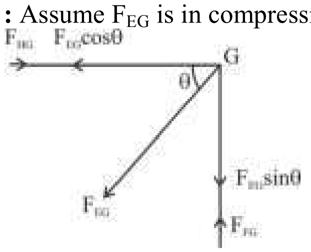


$$\sum F_x = 0 \ , \ \ F_{HG} = P \qquad \ldots(i)$$

Vertical force balance:

$$\sum F_y = 0 \ , \ \ F_{HE} = F_{EG}.\sin\theta$$

Joint G : Assume F_{EG} is in compression,



$$\sum F_x = 0 \ , \ \ F_{HG} - F_{EG}.\cos\theta = 0$$

$F_{HG} = F_{EG}\cos\theta$

From equation (i),

$P = F_{EG}\cos\theta$

$$\sum F_y = 0$$

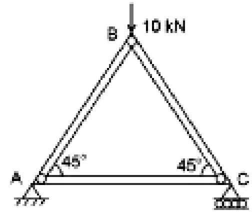
$F_{FG} - F_{EG} . \sin\theta = 0$

$F_{FG} = F_{EG}\sin\theta$

Determine compression or tension,

If F_{EG} is positive and the force acts to resist the horizontal force P, then F_{EG} is in compression,
Thus, member EG is in compression.

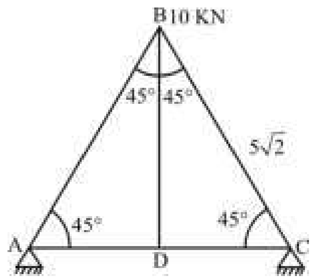
91. A truss ABC loaded at B with a force of 10 kN as shown in the figure. The force in the member AC is:



(a) 5 kN (b) 10 kN
(c) 7.5 kN (d) 2.5 kN

NTA CUET PG 14.06.2023

Ans. (a) :



By symmetry-
Force in member AB and CB will be same.

∴ $R_A = R_C = 5$ KN

At Joint C,

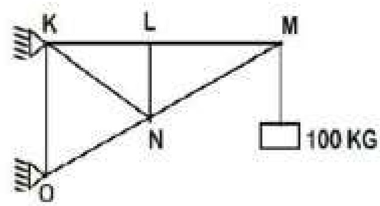
$F_{DC} = 5\sqrt{2}\cos 45°$

$F_{DC} = 5\sqrt{2} \times \frac{1}{\sqrt{2}} \qquad \left(\because \cos 45° = \frac{1}{\sqrt{2}}\right)$

$F_{DC} = 5$ kN

∴ The force in the member AC is 5 kN.

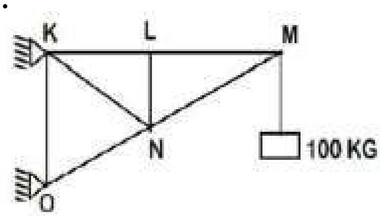
92. A figure shows a pin-joined plane truss loaded at the point 'M' by hanging a mass of 100 kg. The member LN of the truss is subjected to a load of



(a) zero
(b) 490 N in compression
(c) 981 N in compression
(d) 981 N tension

AP PGECET 29.05.2023, Shift-II

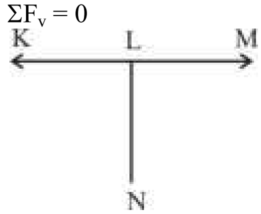
Ans. (a) :



Take points in condition of equilibrium

$\Sigma F_h = 0$

$\Sigma F_v = 0$



$\Sigma F_v = 0$

$F_{KL} - F_{ML} = 0$

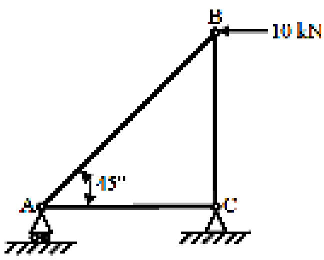
$F_{KL} = F_{ML}$

$\Sigma F_v = 0$

$F_{LN} = 0$

$\therefore$ The member LN of the truss is subjected to zero load.

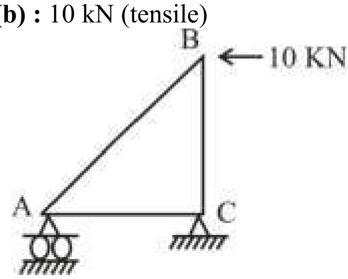
93. In the three-member truss shown in the figure, AC = BC. An external force of 10 kN is applied at B, parallel to AC. The force in the member BC is



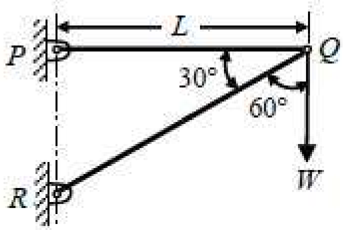
(a) zero (b) 10 kN (tensile)
(c) 10 kN (compressive) (d) 7.07 kN (tensile)

[GATE-2022; Set-II: 2M]

Ans. (b) : 10 kN (tensile)



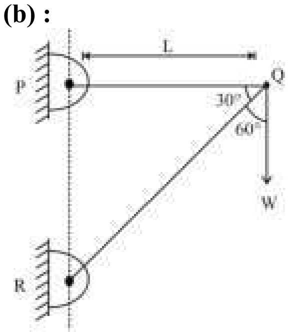
94. A two-member truss PQR is supporting a load W. The axial forces in members PQ and QR are respectively



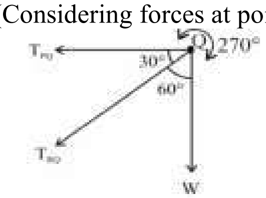
(a) 2W tensile and $\sqrt{3}$W compressive
(b) $\sqrt{3}$W tensile and 2W compressive
(c) $\sqrt{3}$W compressive and 2W tensile
(d) 2W compressive and $\sqrt{3}$W tensile

[GATE-2016; Set-1: 2M]

Ans. (b) :



FBD (Considering forces at point Q),



By resolving vertical forces $\left(\sum f_v = 0\right)$

$T_{RQ}\cos 60° + W = 0$

$T_{RQ} = -2W$

$T_{RQ} = 2W$ compressive

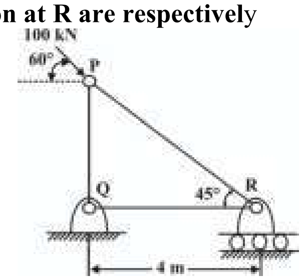
By resolving Horizontal forces, $\left[\sum f_x = 0\right]$

$T_{PQ} + T_{RQ}\sin 60° = 0$

$T_{PQ} = -(-2W)\sin 60°$

$T_{PQ} = \sqrt{3}\,W$ (Tensile)

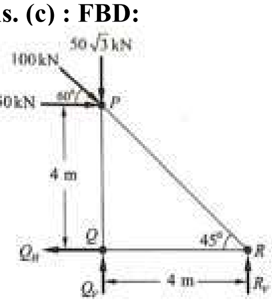
95. For the truss shown in figure, the magnitude of the force in member PR and the support reaction at R are respectively



(a) 122.47 kN and 50 kN
(b) 70.71 kN and 100 kN
(c) 70.71 kN and 50 kN
(d) 81.65 kN and 100 kN

[GATE-2015; Set-I: 2M]

Ans. (c) : FBD:



$PQ = QR \times \tan 45 = 4m$

Considering moment at Q,

$\sum M_Q = 0$

$100\cos 60° \times 4 = R_v \times 4$

$R_v = 50kN$

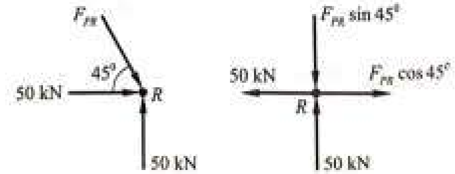
Again, $\sum M_Q = 0$

$Q_H = 50kN$

Method-1 :

Hence, force in member QR = 50kN

Drawing free body diagram of R, we have



By resolving horizontal forces ($\sum F_H = 0,$),

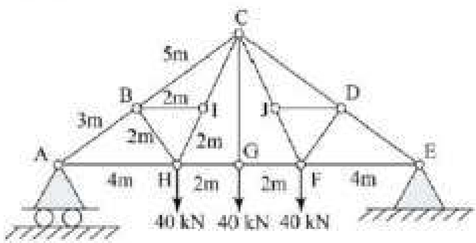
$F_{PR}\cos 45 - 50 = 0$

$P_{PR} = \dfrac{50}{\cos 45°}$

$F_{PR} = 70.71kN$

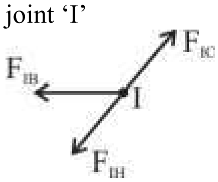
Hence, the correct option is (c).

96. Find the force (in kN) in the member BH of the truss shown.



[GATE-XE 2015]

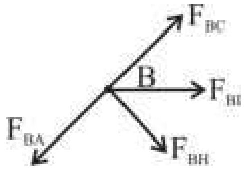
Ans. (Zero) : For joint 'I'



Since, three members (or forces) meet at joint I, force F_{IC} and F_{IH} are collinear,

• The force F_{IB} will be zero.

For joint B,



Now, consider the forces F_{BA} and F_{BH}, similarly for joint B, since the force F_{BC} and F_{AB} are collinear, F_{BH} will also be zero. Thus, the force in member BH is zero.

97. In a statically determinate place truss, the number of joints (j) and the number of members (m) are related by

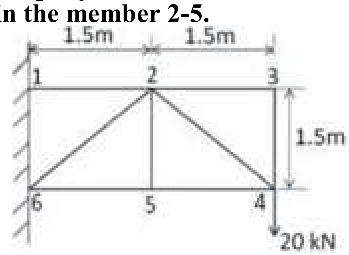
(a) j = 2m – 3
(b) m = 2j + 1
(c) m = 2j – 3
(d) m = 2j – 1

[GATE-2014; Set-IV: 1M]

Ans. (c) : For a statically determinate plane truss, the relationship between the number of joints (J) and number of member (m) is given by

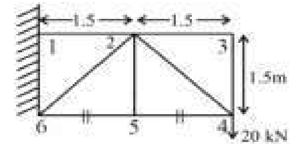
m = 2j – 3.

98. For the pin jointed truss, find the axial force (in kN) in the member 2-5.



[GATE-XE 2014: 1M]

Ans. (0 to 0) :

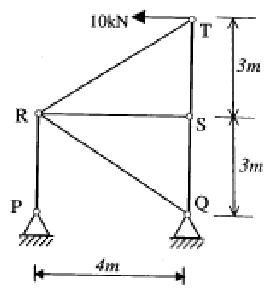


Member 2-5,

Axial force in the member 2-5 = 0

It does not contribute to the structural load, since two forces at joint are collinear then third will have zero force.

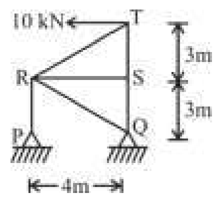
99. The force in the member PR for the truss shown is



(a) 12 kN Tensile
(b) 12 kN Compressive
(c) 15 kN Tensile
(d) 15 kN Compressive

[GATE-XE 2011: 2M]

Ans. (d) :



At T,

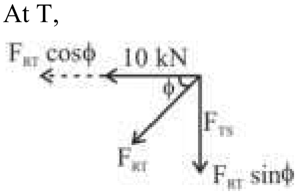


fig. (1)

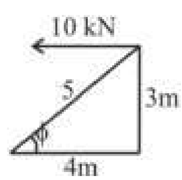


fig. (2)

From above fig (1) $\qquad \tan\phi = \dfrac{3}{4}$

$F_{RT}\cos\phi + 10\text{ kN} = 0 \qquad \sin\phi = 3/5$

$F_{RT} = \dfrac{-10}{4/5} = -\dfrac{50}{4} \qquad \cos\phi = 4/5$

From fig. (1),

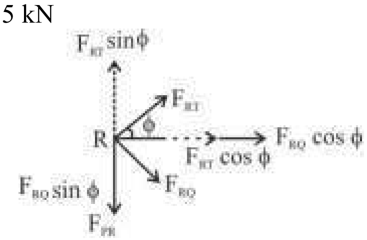
$F_{RT}\sin\phi + F_{TS} = 0$

$F_{TS} = -F_{RT}\sin\phi$

$F_{TS} = -\left(\frac{50}{4}\right)\cdot\frac{3}{5}$

$F_{TS} = \frac{10}{4}\times 3 = 30/4$, $F_{TS} = 7{\cdot}5$ kN

$F_{RT} = -12{\cdot}5$ kN



From fig. (2)

$F_{RT}\sin\phi = F_{RQ}\sin\phi + F_{PR}$ ….(ii)

From fig. (2)

$F_{RT}\cos\phi + F_{RQ}\cos\phi = 0$

$F_{RQ} = -F_{RT}$

$F_{RQ} = -(-12{\cdot}5)$

$F_{RQ} = 12{\cdot}5$ kN

We have,

$F_{RT} = -12{\cdot}5$,

$F_{RQ} = 12{\cdot}5$

So, from equation (ii)

$$-12\cdot5\times\frac{3}{5} = 12\cdot5\times\frac{3}{5} + F_{PR}$$

$$-12\cdot5\times\frac{3}{5} - 12\cdot5\frac{3}{5} = F_{PR}$$

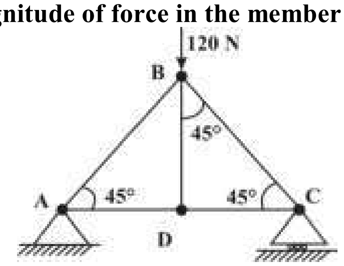
$$\frac{-3}{5}(12\cdot5+12\cdot5) = F_{PR}$$

$$F_{PR} = \frac{-3}{5}(25)$$

$F_{PR} = -3 \times 5 = -15$ kN

$F_{PR} = -15$ kN. Or 15 kN compressive

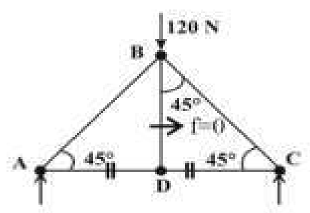
100. A truss consisting of members AD, DC, AB, BD and BC is subjected to a vertical force of 120 N at joint B as shown in the figure. The member AD, DC and are each of 1 length. The magnitude of force in the member BD is



(a) 0 (b) $20\sqrt{2}$N
(c) 40 N (d) 120 N

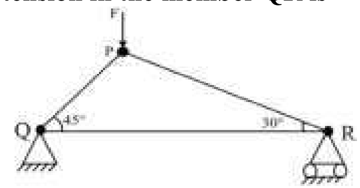
[GATE-XE 2010: 1M]

Ans. (a) :



In the truss, member AD and DC are collinear.
As a result, the force in member BD will be zero.
This is because, at any joint where three member or forces meet, if two of them are collinear, the third member must have zero force.
Thus, for joint D, where members AD and DC are collinear, the force member BD is determined by the vertical load applied at joint B, while the force in member BD is zero.

101. Consider a truss PQR loaded at P with a force F as shown in the figure.
The tension in the member QR is

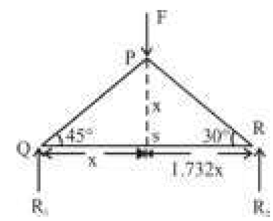


(a) 0.5 F (b) 0.63 F
(c) 0.73 F (d) 0.87 F

[GATE-2008: 2M]

Ans. (b) :

From figure,



$$\tan 45° = \frac{PS}{QS} = \frac{PS}{x}$$

PS = x

$$\tan 30° = \frac{PS}{RS}$$

$RS = \sqrt{3}\,PS = 1.732x$

$R_1 + R_2 = F$ ….. (i)

Taking moment about point Q,

$R_1 \times 0 + F \times x = R_2 \times 1.732x$

$R_2 = 0.366F$

From equation (i), $R_1 = F - R_2$

$R_1 = F - 0.366F$

$R_1 = 0.633F$

From figure,

$PR\sin30° = R_2$ ..…(ii)

$PR\cos30°$ = Tension in QR

From equation (ii),

$$PR = \frac{R_2}{\sin 30°} = \frac{0.366\,F}{\sin 30°}$$

Hence the tension in the number QR is,

$T_{QR} = PR\cos30°$

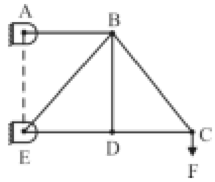
$$T_{QR} = \frac{0.366\,F}{\sin 30°}\times\cos 30°$$

$$T_{QR} = \frac{0.366\,F}{\tan 30°}$$

$T_{QR} = 0.63$ F

C. Zero force Members

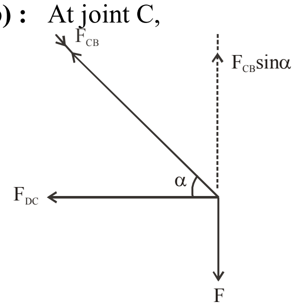
102. In the truss shown in the figure, all the members are pin jointed to each other. The members AB, BD, DE and DC have the same length. For the given loading, which of the following is the correct statement?



(a) BD is a zero-force member, and AB and ED are in compression
(b) AB is in tension, ED is in compression, and BD is a zero-force member
(c) AB and DC are in tension, and BC is in compression
(d) ED is in tension, and DC and BC are in compression

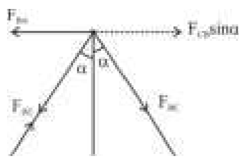
[GATE-XE 2022: 1M]

Ans. (b) : At joint C,



$F = F_{CB}\sin\alpha$

At joint B,



$F_{BE}\cos\alpha = F_{BC}\cos\alpha$

$F_{BE} = F_{BC}$

ED and DC are collinear,

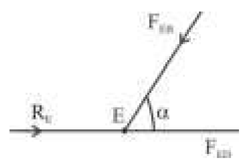
Hence, $F_{BD} = 0$

$F_{BA} = F_{BC}\sin\alpha + F_{BE}\sin\alpha$

$F_{BA} = F + F_{BE}\sin\alpha$

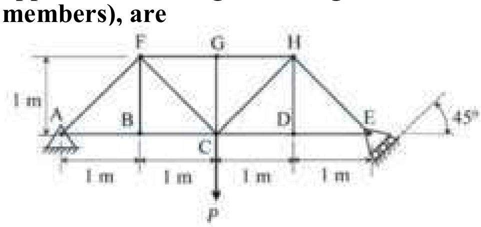
Hence, it will cause tensile stress in AB,

Joint E,



Hence, the reaction force R_E and the force F_{ED} will induce compression in the member ED.

103. The members carrying zero force (i.e. zero-force members) in the truss shown in the figure, for any load p > 0 with no appreciable deformation of the truss (i.e. with no appreciable change in angles between the members), are

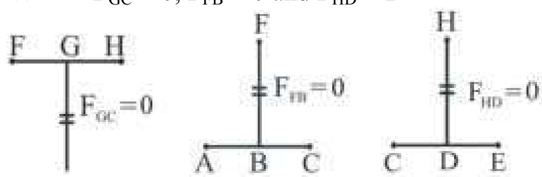


(a) BF and DH only
(b) BF, DH and GC only
(c) BF, DH, GC, CD and DE only
(d) BF, DH, GC, FG and GH only

[GATE-2020; Set-I: 1M]

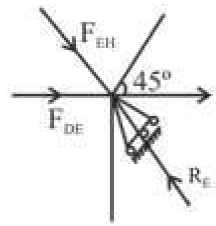
Ans. (c) : According to above diagram,
Consider at a joint 3 members are meet out of them 2 are collinear therefore force in 3rd member will be zero. Consider no load reaction at that joint.

∴ $F_{GC} = 0$, $F_{FB} = 0$ and $F_{HD} = D$



i.e., forces in the member GC, FB, HD is equal to zero

Now, considering joint E.

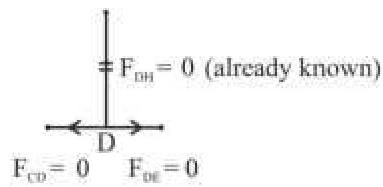


∴ $F_{EH} = R_E$

There is no horizontal force,

∴ $F_{DE} = 0$

Also considering joint D, we can say that force in member CD = 0



D. Method of Section

104. Which method would be most appropriate for determining the force transmitted by a given intermediate member of a truss?

(a) Method of joint
(b) Graphical method
(c) Method of section
(d) Member-force method

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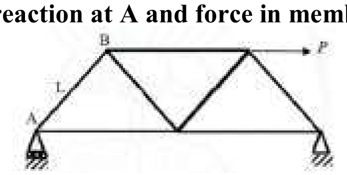
Ans. (c) : The method of sections involves dividing the truss in two sections and analyzing the forces acting on each section, using the conditions of equilibrium to determine the forces in the members.

105. The truss shown is subjected to a force P. All member of the truss have the same length L. The reaction at A and force in member AB are

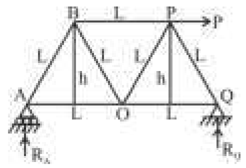


(a) $\frac{P\sqrt{3}}{4}$ and $\frac{P}{2}$ (b) $\frac{P\sqrt{3}}{8}$ and $\frac{P\sqrt{3}}{4}$

(c) $\frac{P\sqrt{3}}{4}$ and $\frac{P}{4}$ (d) P and $\frac{P}{4}$

[GATE-XE-2021: 2M]

Ans. (a) :



For equilateral triangle,

$$h = \frac{\sqrt{3}}{2}a \qquad \text{(Where, a = L)}$$

$$h = \frac{\sqrt{3}}{2}L$$

Taking moment at A,

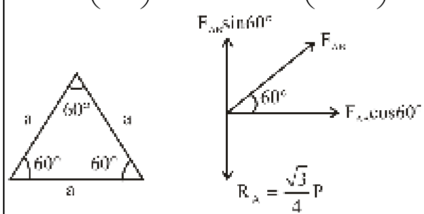
$$R_Q \times 2\,L = P \times \frac{\sqrt{3}}{2}L$$

$$R_Q = \frac{\sqrt{3}}{4}\,P \qquad \ldots(i)$$

Now vertical forces,

$$R_A + R_Q = 0$$

$$R_A = -\left(\frac{\sqrt{3}}{4}\right)P \quad \Rightarrow R_A = \left(\frac{\sqrt{3}}{4}.P\right) \text{ downward}$$



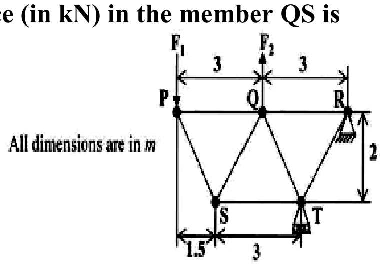
$R_A = F_{AB}$ sin60°

$$\frac{\sqrt{3}}{4}P \;=\; F_{AB} \times \frac{\sqrt{3}}{2}$$

$$P = 2\,F_{AB}$$

$$F_{AB} = \frac{P}{2}$$

106. For the truss shown in the figure, the forces F_1 and F_2 are 9 kN and 3 kN, respectively. The force (in kN) in the member QS is

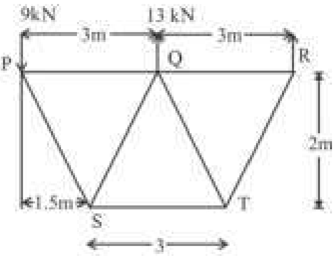


(a) 11.25 tension (b) 11.25 compression

(c) 13.5 tension (d) 13.5 compression

AP PGECET 29.09.2020, Shift-II

Ans. (a) :



Section through PQ, QS & ST

$$\tan\theta = \frac{2}{1.5}$$

$$= 53.13°$$

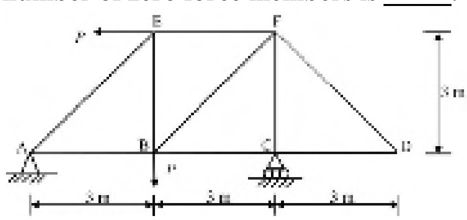
Considering L.H.S of section (1),

$$\sum F_V = 0$$

$$-9 + T_{SQ} + \sin\theta = 0$$

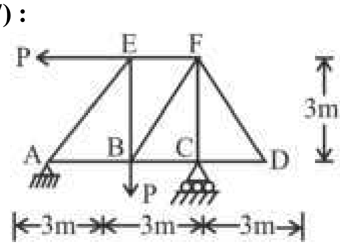
$$T_{SQ} = \frac{9}{\sin 53.13°} = 11.25 \text{ kN (Tension)}$$

107. A pin-joined truss has a pin support at A and a roller support at C. All the members are made of same material and have the same cross-section. Neglect the self-weight of the members. Due to the applied loading shown, the total number of zero force members is _____.



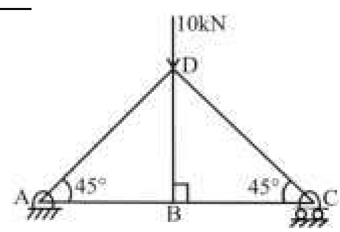
[GATE-XE 2020:2M]

Ans. (7 to 7) :



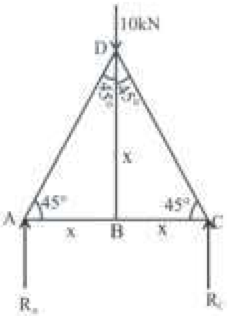
Member AE, AB, EF, EB, BC, FD and CD are zero force member.

108. A truss is composed of members AB, BC, CD, AD and BD, as shown in the figure. A vertical load of 10 kN is applied at point D. The magnitude of force (in kN) in the member BC is _____



[GATE-2019; Set-II: 2M]

Ans. (5 kN) : According to question,
FBD,



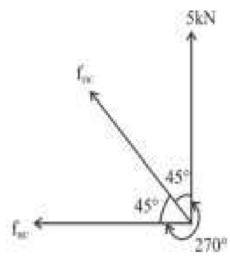
In equilibrium,
Resolving vertical forces $\left(\sum f_y = 0\right)$

$R_A + R_C = 10$

Taking moment about point A,

$\sum M_A = 0$ [↗+ −↖]

$R_c \times 2x - 10x = 0$
$R_c = 5kN$

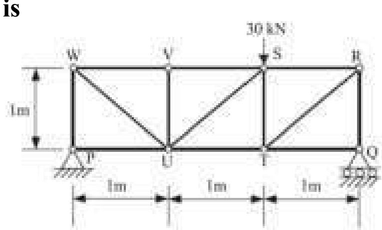


Using sine rule,

$$\frac{f_{BC}}{\sin 45°} = \frac{5}{\sin 45°}$$

$F_{BC} = 5$ kN

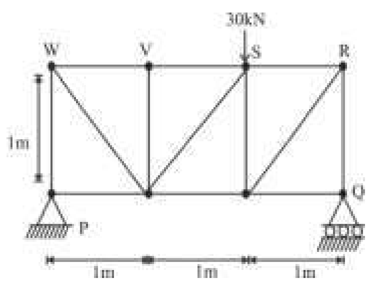
109. For the truss shown in the figure, the magnitude of the force (in kN) in the member SR is



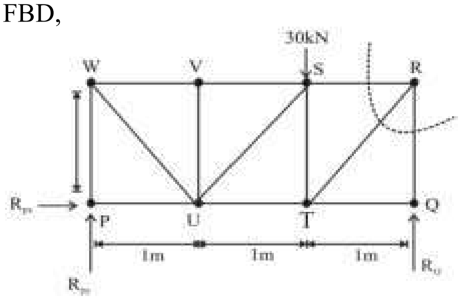
(a) 10 (b) 14.14
(c) 20 (d) 28.28

[GATE-2015; Set-II: 2M]

Ans. (c) :



FBD,



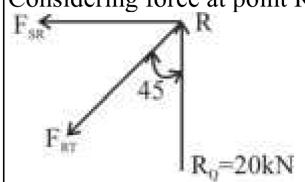
Taking moment about point P

$\sum M_P = 0$ [↗+ −↖]

$30 \times 2 - R_Q \times 3 = 0$

$R_Q = 20kN$

Considering force at point R



By Resolving vertical forces $[\sum F_V = 0]$

$F_{RT} \cos 45 - R_Q = 0$

$$F_{RT} = \frac{R_Q}{\cos 45} = \frac{20}{\frac{1}{\sqrt{2}}} = 20\sqrt{2}$$

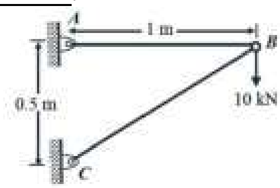
By resolving horizontal forces $(\sum F_H = 0)$

$F_{SR} + F_{RT} \sin 45 = 0$

$F_{SR} = -20\sqrt{2} \sin 45 = -20N$

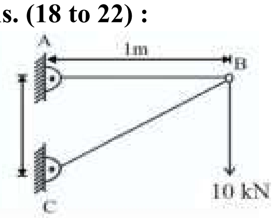
$F_{SR} = 20$ kN compressive

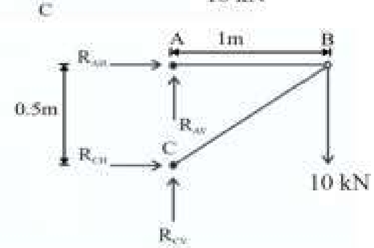
110. A two member truss ABC is shown in the figure. The force (in kN) transmitted in member AB is _______.



[GATE-2014; Set-II: 1M]

Ans. (18 to 22) :





From equilibrium condition of forces,

$\sum F_x = 0$

$R_{AH} + R_{CH} = 0$ ….(i)

$\sum F_y = 0$

$R_{AV} + R_{CV} = 10$ kN

Taking moment about point C,

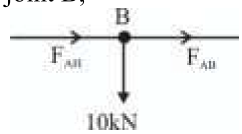
$\sum M_C = 0$

$10 \times 1 + R_{AH} \times 0.5 = 0$

$R_{AH} = -20$ kN

$R_{CH} = 20$ kN [From eq^n. (i)]

FBD of joint B,



From equilibrium condition of forces,

$$\sum F_x = 0$$

$F_{AB} + R_{AH} = 0$

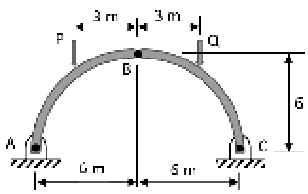
$F_{AB} = -R_{AH}$

$= -(-20)$

$F_{AB} = 20\text{kN}$

E. Analysis of Frame

111. A three-hinge arch ABC in the form of a semi-circle is shown in the figure. The arch is in static equilibrium under vertical loads of P = 100 kN and Q = 50 kN. Neglect friction at all the hinges. The magnitude of the horizontal reaction at B is _____ kN (rounded off to 1 decimal place).



[GATE-2024: 2M]

Ans. (37.0 to 38.0) : Initially, taking moment about hinged point C,

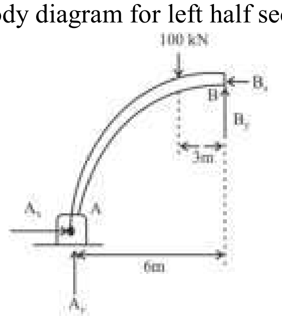
$$\sum M_C = 0$$

$A_y \times 12 - 100 \times 9 - 50 \times 3 = 0$

$12A_y = 1050$

$A_y = 87.5 \text{ kN}$

Free Body diagram for left half section,



Now, taking moment about point B

$$\sum M_B = 0$$

$A_x \times 6 - 87.5 \times 6 + 100 \times 3 = 0$

$A_x \times 6 = 225$

$A_x = 37.5 \text{ kN}$

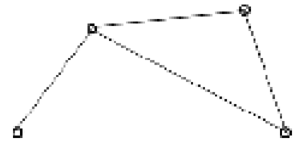
$$\sum F_x = 0$$

$A_x - B_x = 0$

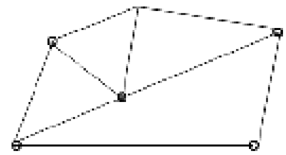
$B_x = A_x = 37.5 \text{ kN}$

112. The options show frames consisting of rigid bars connected by pin joints. Which one of the frames is non-rigid?

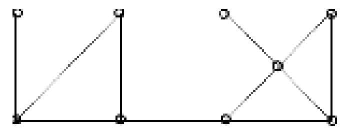
(a)



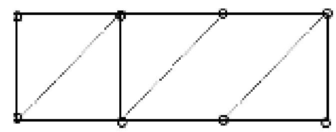
(b)



(c)

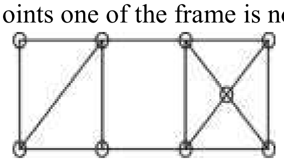


(d)

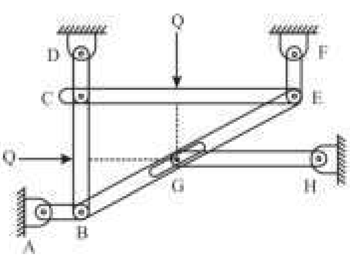


[GATE-2023:1M]

Ans. (c) : Given option analysis and option (c) is follow parameters of frames consisting of rigid bars connected by pin joints one of the frame is non-rigid.



113. The lengths of members BC and CE in the frame shown in the figure are equal. All the members are rigid and lightweight, and the friction at the joints is negligible. Two forces of magnitude $Q > 0$ are applied as shown, each at the mid-length of the respective member on which it acts.



Which one or more of the following members do not carry any load(force)?

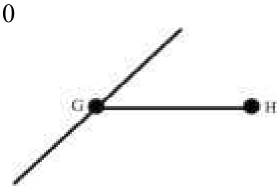
(a) AB (b) CD

(c) EF (d) GH

[GATE-2022 Set-I: 2M]

Ans. (b, d) : If at a joint 3 members are meeting and two are collinear then in 3rd member force will be zero.

$F_{GH} = 0$



114. A frame differs from a truss on the following point, when

(a) Members of the frame are pin-connected
(b) A force can be applied at any point of a member of the frame
(c) Members of the frame are known as two-force members
(d) Members of the frame cannot transmit moments

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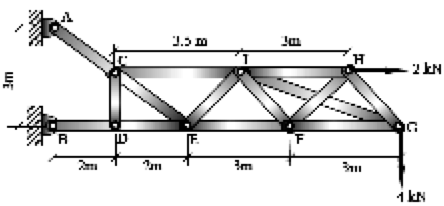
Ans. (d) : Member of the frame can transmit moments. In frame, members can transmit moments in addition to axial forces, where as in a truss member can only transmit axial force, which is a key difference from trusses.

115. A structure, along with the loads applied on it, is shown in the figure. Self-weight of all the members is negligible and all the pin joints are friction-less. AE is a single member that contains pin C. Likewise, BE is a single member that contains pin D. Members GI and FH are overlapping rigid members. The magnitude of the force carried by member CI is ________ kN (in integer).

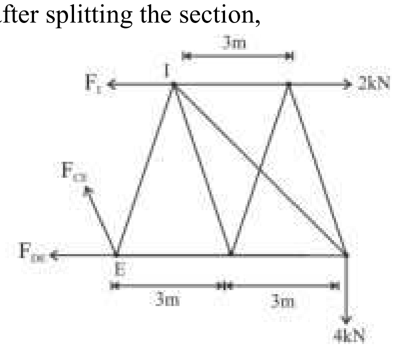


[GATE-2022; Set-I: 2M]

Ans. (18 to 18) : Given that,
From figure,

AB = 3 m
BE = 4 m
DE = 2E
GE = 6m

In order to find force in member CI split the truss from member CI.
Forces after splitting the section,



Applying equilibrium condition at point E, taking moment about point E

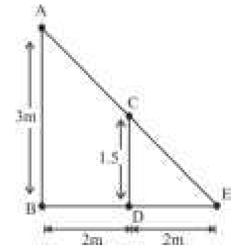
$$\sum M_E = 0 \; [\curvearrowright + \; \curvearrowleft -]$$

$$4 \times GE + 2CD - F_1 \times CD = 0 \qquad \ldots(i)$$

According to similarity triangle,

$$\frac{CD}{DE} = \frac{AB}{BE}$$

$$CD = \frac{3}{4} \times 2 = 1.5\text{m}$$



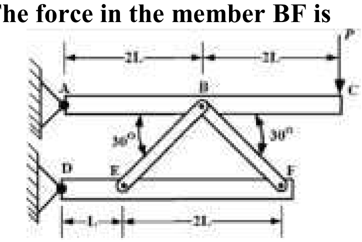
From equation (i), we get–

$4 \times 6 + 2 \times 1.5 - F_1 \times 1.5 = 0$

$F_1 = 27/1.5$

$F_1 = 18$ kN

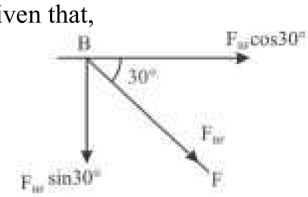
116. The frame shown comprises members ABC, BE, BF, and DEF. It is pin supported at A and D. Members BE and BF are pin connected to ABC and DEF. The vertical load P is applied at C. The force in the member BF is



(a) Compressive P
(b) Tensile P
(c) Compressive 2P
(d) Tensile 2P

[GATE-XE 2019-2M]

Ans. (d) : Given that,



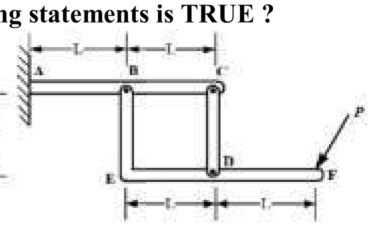
Considering point B,

$F_{BF} \sin 30° = P$

$$P = F_{BF} \frac{1}{2}$$

$F_{BF} = 2P$ (Tensile)

117. The frame comprises members ABC, CD and BEDF. This frame is fixed at A, and the connections between the three members are pins. Load P is applied at F. Which of the following statements is TRUE ?



(a) ABC and CD are two-force members
(b) CD is the only two-force member
(c) BEDF and CD are two-force members
(d) ABC is the only two-force member

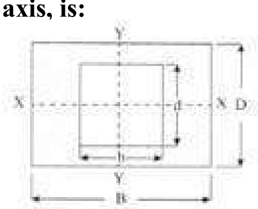
[GATE-XE 2019-1M]

Ans. (b) : A two force member in equilibrium is one in which forces act of two points and forces are collinear. The two forces acting on it must be equal in magnitude, opposite in direction and collinear meaning they must lie along the same straight line.

04 CENTROID AND MOMENT OF INERTIA

A. Moment of Inertia

118. Moment of inertia of a hollow rectangular section as shown in the below figure about x-x axis, is:



(a) $(BD^2/12 - (bd^3/12)$ (b) $(BD^3/12 - (bd^3/12)$
(c) $(BD^3/36) - (bd^3/36)$ (d) $(BD^3/36) - (bd^3/36)$

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Ans. (b) : We know that,
MOI is the second moment of area or mass.

$$I_y = \int x^2 dA$$

MOI indicates the distribution of particles about the reference axis:
Now according to the figure,

$I_{C.G} = (I_{x-x})_{BD} - (I_{x-x})_{bd}$

$$I_{C\cdot G} = \int_{-D/2}^{+D/2} y^2 \cdot Bdy - \int_{-d/2}^{+d/2} y^2 \cdot bdy$$

$$I_{C\cdot G} = \frac{BD^3}{12} - \frac{bd^3}{12}$$

119. The length to radius ratio $\frac{l}{r}$ of a solid cylinder such that the moments of inertia about the longitudinal and transverse axis are equal is

(a) 1 (b) $\sqrt{3}$ (c) $\sqrt{5}$ (d) 2

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Ans. (b) : Let's denote the length of the cylinder as l and the radius as r
1. Moment of inertia about the longitudinal axis

$$I_{long} = \frac{1}{2}mr^2$$

2. Moment of Inertia about the Transverse Axis

$$I_{trans} = \frac{1}{12}m\left(3r^2 + l^2\right)$$

$$\frac{1}{2}mr^2 = \frac{1}{12}m\left(3r^2 + l^2\right)$$

$$\frac{2mr^2 - mr^2}{4} = \frac{ml^2}{12} \Rightarrow \frac{mr^2}{4} = \frac{ml^2}{12}$$

$$r^2 = \frac{l^2}{3}$$

$$l = \sqrt{3}r$$

$$\frac{l}{r} = \sqrt{3}$$

120. The moment of inertia of a thin disc of mass m and radius r, about an axis through its centre of gravity and perpendicular to the plane of the disc is

(a) $\frac{mr^2}{2}$ (b) $\frac{mr^2}{4}$
(c) $\frac{mr^2}{6}$ (d) $\frac{mr^2}{8}$

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Ans. (a) : The moment of inertia I of a thin disc of mass m and radius r, about an axis perpendicular to the plane of the disc and passing through its centre is given by.

$$I = \frac{1}{2}mr^2$$

This formula is derived from the integral of mass distribution over the disc area

121. The polar moment of inertia is:

(a) the M.I. of an area about an axis parallel to centroidal axis
(b) equal to M.I. of an area squared
(c) equal to M.I. of an area doubled
(d) the M.I. of an area about a line or axis perpendicular to plane of the area

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Ans. (d) : The polar moment of inertia is the moment of inertia of an area about a line as axis perpendicular to the plane of the area. If measure the resistance of a shape to twisting about that axis.

122. Ratio of moment of inertia of a rectangle and that of a triangle, having same base and height with respect to their bases will be

(a) 2 : 1 (b) 3 : 1
(c) 4 : 1 (d) 5 : 1

TS PGECET 30.05.2018, Shift-I

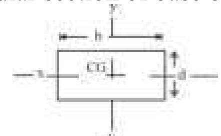
Ans. (c) : Using the parallel axis theorem $I_{S-S} = I_{CG} + Ar^2$

$$= I_{XX} + Ar^2$$

$$I_{S-S} = \frac{bd^3}{12} + \left(b \times d \times \left(\frac{d}{2}\right)^2\right)$$

$$I_{S-S} = \frac{bd^3}{3}$$

Consider rectangular section of base b and height d



Moment of inertia of the rectangular section about x –x axis passing through the C.G of the section

$$I_{xx} = \frac{b.d^3}{12}$$

∴ The ratio of moment of inertia of a triangle and that of rectangle same base and height about their bases will be

$$\text{Ratio} = \frac{\frac{bd^3}{3}}{\frac{bd^3}{12}} = 4:1$$

123. The moment of inertia of a thin rod of mass 'm' and length 'l' about an axis through its centre of gravity and perpendicular to its length is

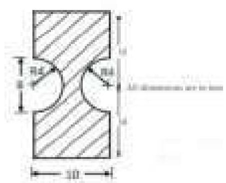
(a) $ml^2/4$ (b) $ml^2/6$
(c) $ml^2/8$ (d) $ml^2/12$

TS PGECET 2017

Ans. (d) : The correct formula for theorem of inertia I of a thin rod of mass m and length l about an axis through its centre of gravity and perpendicular to its length is:

$$I = \frac{ml^2}{12}$$

125. The figure shows cross-section of a beam subjected to bending. The area moment of inertia (in mm^4) of this cross-section about its base is



[GATE-2016; Set-1: 2M]

Ans. (21439) : We know that,
Moment of inertia of rectangle about x–x axis is

$$I = \frac{bd^3}{12}$$

Using parallel axis theorem,

$$I_{xx} = I_{cg} + Ay^2$$

Net moment of inertia

$$I = (I_{xx})_{\text{rectangle}} - (I_{xx})_{\text{circle}} \quad [\because I_{xx} = I_{cg} + Ay^2]$$

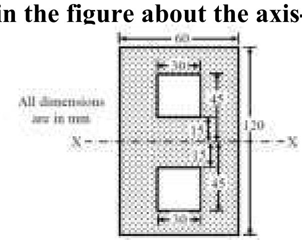
$$= \left[\frac{bd^3}{12} + bd(10)^2\right] - \left[\frac{\pi}{64}(d)^4 + \frac{\pi}{4}d^2 \times 10^2\right]$$

$$= \left[\frac{10\times20^3}{12} + 10\times20\times(10)^2\right] - \left[\frac{\pi}{64}\times8^4 + \frac{\pi}{4}\times8^2\times10^2\right]$$

$$= 26666.6 - 5227.61$$

$$I_{xy} = 21438.99$$

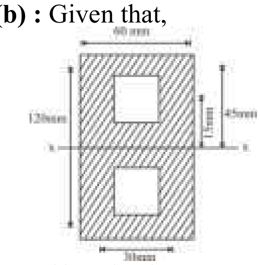
126. The value of moment of inertia of the section shown in the figure about the axis-XX is



(a) 8.5050×10^6 mm^4 (b) 6.8850×10^6 mm^4
(c) 7.7625×10^6 mm^4 (d) 8.5725×10^6 mm^4

[GATE-2015; Set-III: 2M]

Ans. (b) : Given that,



Moment of inertia about x-x axis

$$I_{xx} = (I\text{ Rectangle})_{xx} - 2(I_{\text{square}} + Ah^2)$$

$$I_{xx} = \frac{bd^3}{12} - 2\left[\frac{a^4}{12} + Ah^2\right]$$

$$\frac{1}{12}\times60\times(120)^3 - 2\left[\frac{1}{12}\times(30)^4 + 30\times30\times30^2\right]$$

$$I_{xx} = 6.8850\times10^6 \text{ mm}^4$$

127. Centre of gravity of a circular segment with a height of r units and base of 2r units is

(a) $\frac{2r}{3\pi}$ (b) $\frac{4r}{2\pi}$ (c) $\frac{4r}{3\pi}$ (d) $\frac{2r}{4\pi}$

Karnataka PGCET 2011

Ans. (c) : For a circular segment with a height h and base b, where h = r and b = 2r the center of segment is given by

$$\therefore \quad \text{Centre of gravity} = \frac{4r}{3\pi}$$

So, the correct answer from the provided options is

$$= \frac{4r}{3\pi}$$

128. Moment of inertia of rectangular section of width b and depth d is

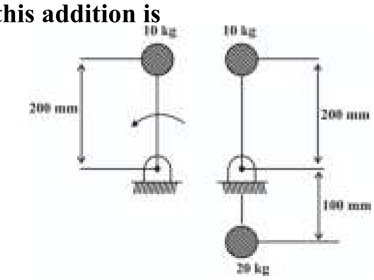
(a) $\frac{bd^2}{6}$ (b) $\frac{b^3d}{12}$ (c) $\frac{db^2}{6}$ (d) $\frac{bd^3}{12}$

Karnataka PGCET 2011

Ans. (d) : To find the moment of inertia of a rectangular section with width b and depth d about its centroidal axis, is $\frac{b.d^3}{12}$.

So, the correct answer $\frac{b.d^3}{12}$

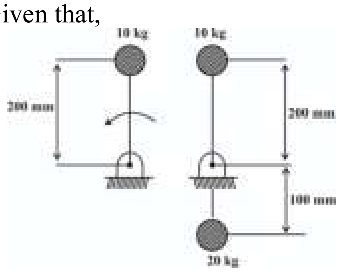
129. A rigid body shown in the fig. (a) has a mass of 10 kg. It rotates with a uniform angular velocity 'ω'. A balancing mass of 20 kg is attached as shown in Fig. (b) the percentage increase in mass moment of inertia as a result of this addition is



(a) 25% (b) 50%
(c) 100% (d) 200%

[GATE-2004: 2M]

Ans. (b) : Given that,



Mass of the body (m_1) = 10 kg
Mass of the blancing body (m_2) = 20 kg
Radius of rotation (r_1) = 200 mm = 0.2 m
And, (r_2) = 100mm = 0.1 m
We know that, mass moment of inertia

$I = mr^2$

Case-I: when balancing mass is not attached.

$I_1 = m_1 r_1^2 = 10 \times (0.2)^2 = 0.4 \text{ kgm}^2$

Case-II: When balancing mass is attached

$I_2 = m_1 r_1^2 + m_2 . r_2^2$
$= 10 \times (0.2)^2 + 20 \times (0.1)^2$
$= 0.4 + 0.2 = 0.6 \text{ kgm}^2$

Presentence increase in mass moment of inertia

$$= \frac{I_2 - I_1}{I_1} \times 100 \quad = \frac{0.6 - 0.4}{0.4} \times 100$$

$$= \frac{0.2}{0.4} \times 100 = \frac{2}{4} \times 100 = 50\%$$

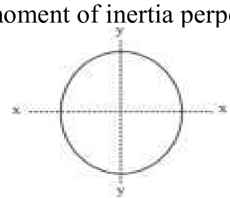
130. The second moment of a circular area about the diameter is given by (D is the diameter).

(a) $\frac{\pi D^4}{4}$ (b) $\frac{\pi D^4}{16}$

(c) $\frac{\pi D^4}{32}$ (d) $\frac{\pi D^4}{64}$

[GATE-2003: 1M]

Ans. (d) : We know that,
Polar moment of inertia perpendicular to the plane.



By perpendicular axis theorem,

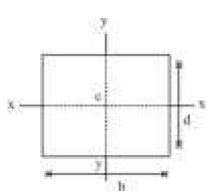
$I_p = I_{xx} + I_{yy}$ (∵ It is a symmetrical
$I_p = 2I_{xx}$ So, $I_{xx} = I_{yy}$)

$$2I_{xx} = \frac{\pi d^4}{32} \qquad \left[I_p = \frac{\pi d^4}{32} \right]$$

$$I_{xx} = \frac{\pi d^4}{64}$$

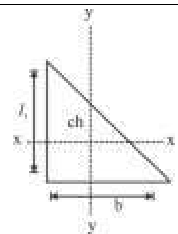
Shape Figure Moment of inertia,

Rectangle



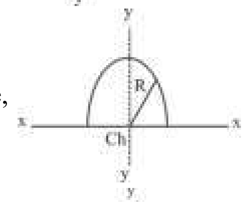
$$I_{xx} = \frac{bd^3}{12}$$
$$I_{yy} = \frac{db^3}{12}$$

Triangle,



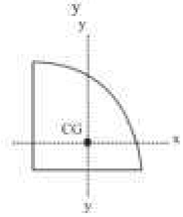
$$I_{xx} = \frac{bh^3}{36}$$
$$I_{yy} = \frac{hb^3}{36}$$

Semicircle,



$$I_{xx} = 0.11R^4$$
$$I_{yy} = \frac{\pi}{8} R^4$$

Quarter circle,



$$I_{xx} = 0.055R^4$$
$$I_{yy} = 0.055R^4$$

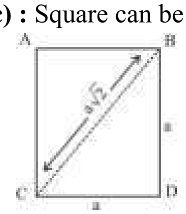
131. The area moment of inertia of a square of size 1 unit about its diagonal is

(a) $\frac{1}{3}$ (b) $\frac{1}{4}$

(c) $\frac{1}{12}$ (d) $\frac{1}{6}$

[GATE 2001: 1M]

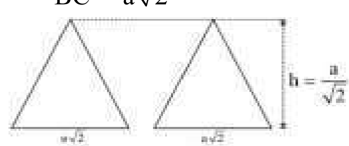
Ans. (c) : Square can be divided into two triangles,



ΔBDC,

$BC^2 = BD^2 + CD^2 = a^2 + a^2 = 2a^2$

$BC = a\sqrt{2}$



Mass moment of inertia of the square about the diagonal

$I_{square} = 2 \times \left(I_{triangle} \right)_{base}$

$$= 2 \times \frac{bh^3}{12} \qquad \left[\because \text{MOI of triangle, } (I_{triangle})_{base} = \frac{bh^3}{12} \right]$$

$$= \frac{2(a\sqrt{2})\left(\frac{a}{\sqrt{2}}\right)^3}{12}$$

$$I_{square} = \frac{a^4}{12} \qquad [\because a = 1]$$

$$I_{square} = \frac{1}{12}$$

05 KINEMATICS OF PARTICLES

A. Dimensional Translational Motion

132. A thin disc and a thin ring, both have mass M and radius R. Both rotate about axes through their centre of mass and are perpendicular to their surfaces at the same angular velocity, then which of the following is true ?

(a) The ring has higher kinetic energy
(b) The disc has higher kinetic energy
(c) The ring and the disc have the same kinetic energy
(d) Kinetic energies of both the bodies are zero

TS-PGECET 30.05.2023, Shift-I

Ans. (a) : We know that,
Moment of inertia of the ring about an axis passing through centre and perpendicular to the plane

$$I_{ring} = mR^2$$

$$I_{disc} = \frac{1}{2}mR^2$$

Kinetic energy (k.E) = $\frac{1}{2}I\omega^2$

I = Moment of inertia
ω = Angular velocity

So, that angular velocity of thin disc and a thin ring is same and kinetic energy is depends on moment of inertia.
If moment of inertia is more than the kinetic energy is also more

$$I_{ring} > I_{disc}$$

$$(K.E)_{ring} > (K.E)_{disc}$$

133. A circular disc rolls without any slip on an inclined plane. The ratio of rotational kinetic energy to the total energy is

(a) 1/3 (b) 2/3
(c) 1/4 (d) 1/2

TS PGECET 03.08.2022, Shift-I

Ans. (a) : The moment of inertia circular disc about its central axis.

$I = \frac{1}{2}mR^2$, where R = Radius of the disc.

For rolling without slipping the,
v = Rω (where ω angular velocity)
The translational kinetic energy is

$$(K.E)_{trans} = \frac{1}{2}mv^2$$

The rotational kinetic energy $K_{rot} = \frac{1}{2}I\omega^2$

$$(K.E)_{rot} = \frac{1}{2}\left(\frac{1}{2}mR^2\right)\omega^2$$

$$(K.E)_{rot} = \frac{1}{4}mR^2\omega^2$$

$$(K.E)_{rot} = \frac{1}{4}mv^2$$

The total kinetic energy

$$(K.E)_{Total} = (K.E)_{trans} + (K.E)_{rot}$$

$$= \frac{1}{2}mv^2 + \frac{1}{4}mv^2$$

$$(K.E)_{Total} = \frac{3}{4}mv^2$$

The ratio of rotational kinetic energy to the total energy

$$\frac{(K.E)_{rot}}{(K.E)_{total}} = \frac{\frac{1}{4}mv^2}{\frac{3}{4}mv^2} = \frac{1}{3}$$

134. A point mass is shot vertically up from ground level with a velocity of 4 m/s at time, t = 0. It loses 20% of its impact velocity after each collision with the ground. Assuming that the acceleration due to gravity is 10 m/s² and that air resistance is negligible, the mass stops bouncing and comes to complete rest on the ground after a total time (in seconds) of

(a) 1 (b) 2
(c) 4 (d) ∞

[GATE-2018; Set-I: 2M]

Ans. (c) : For first rebounding,

v = u + at
0 = 4 – 10t
t = 0.4 s

From, $v^2 = u^2 - 2gs$

$$s = \frac{u^2}{2g} = \frac{4^2}{2\times10} = 0.8\,m$$

After 20% loss of initial velocity,

u ' = 80% of u = 0.8u = 0.8 × 4
u ' = 3.2 m/s
∴ v ' = u' + at '

$0 = 3.2 - 10t'$

$t' = \frac{3.2}{10} = 0.32s$

$u'' = 0.8u' = 0.8 \times 3.2 = 2.56 m/s$

$v'' = u'' + at''$

$0 = 2.56 - 10t''$

$t'' = 0.256$ s

So, t, t', t'' are forming a GP series,

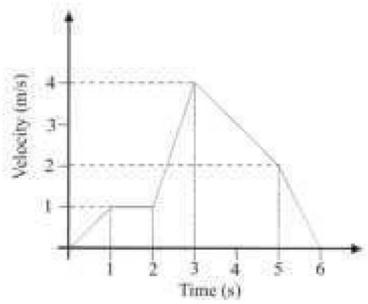
total = $2(t + t' + t'' + ...0)$

time= $2[0.4 + 0.32 + 0.256 + \quad .... + 0]$

$= 2 \times \frac{0.4}{1 - 0.8} = 2 \times 2$

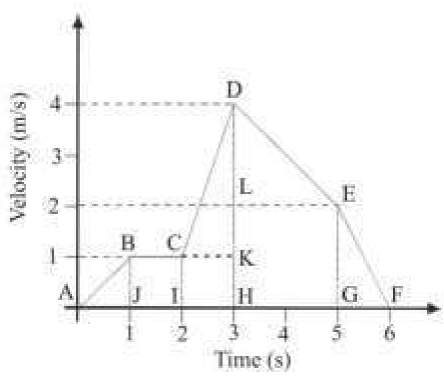
Total time = 4 s

135. The following figure shows the velocity-time plot for a particle traveling along a straight line. The distance covered by the particle from t = 0 to t = 5 s is ________ m.



[GATE-2017 Set-I : 1M]

Ans. (10) :



In the velocity time graph, plot the distance covered by the particle traveling along a straight line is the sum of area covered from t = 0 to t = 5sec.

So distance covered by the particle is area of region.

Area of ΔABJ + Area of rectangle BCIJ +Area of ΔCDK + Area of rectangle CKHI + Area of ΔLDE + Area of rectangle LEGH

$= \frac{1}{2} \times 1 \times 1 + 1 \times 1 + \frac{1}{2} \times 3 \times 1 + 1 \times 1 + \frac{1}{2} \times 2 \times 2 + 2 \times 2$

= 0.5 + 1 + 1.5 + 1 + 2 + 4 = 10 m

Distance covered by the particle from t = 0 to t = 5sec is 10m.

136. A ball of mass 0.1 kg, initially at rest, is dropped from height of 1 m. Ball hits the ground and bounces off the ground. Upon impact with the ground, the velocity reduces by 20%. The height (in m) to which the ball will rise is____.

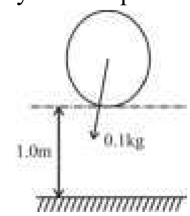
[GATE-2015; Set-I: 2M]

Ans. (0.64) : Given,

Mass of ball (m) = 0.1 kg

Height (h) = 1 m

Reduction in velocity after impact = 20%



If, v_1 = Velocity before just impact

v_2 = Velocity just after impact

Than velocity just before impact

$v_1 = \sqrt{2gh} = \sqrt{2 \times 9.8 \times 1}$

$v_1 = 4{\cdot}429$ m/s

∴ Reduced velocity after impact = 100-20 = 80%

$v_2 = 0{\cdot}8 \times 4{\cdot}429 = 3{\cdot}54$

We know that,

Kinetic energy remaining after the impact will be equal to the potential energy attained at a height

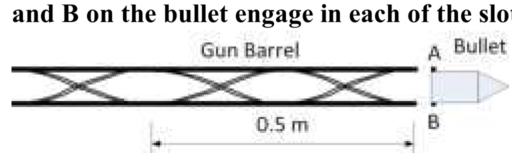
$\frac{1}{2} m v_2 = mgh$

$\frac{1}{2} \times 0.1 (3.54)^2 = 0.1 \times 9.81 \times h$

h = 0.639

h = 0.64

137. A bullet spins as the shot is fired from a gun. For this purpose, two helical slots as shown in the figure are cut in the barrel. Projections A and B on the bullet engage in each of the slots.



Helical slots are such that one turn of helix is completed over a distance of 0.5 m. If velocity of bullet when it exits the barrel is 20 m/s, its spinning speed in rad/s is ________.

[GATE-2015; Set-III: 2M]

Ans. (251 to 252) : Given that,

One turn helix length (l) = 0.5 m

The bullet rotation length is

s = 0.5 m

Bullet when it exits the barrel (v) = 20 m/s

We know that,

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SOM

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Sl No	Exam	Proposed Year		Total Question
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1.	**GATE**	2025	Set-I	55
2.	**GATE**	2024	Set-I	55
3.	**GATE**	2023	Set-I	55
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9.	**GATE**	2020	Set-II	55
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31.	**GATE**	2008		85
32.	**GATE**	2007		85
33.	**GATE**	2006		85
34.	**GATE**	2005		85
35.	**GATE**	2004		90
36.	**GATE**	2003		90
37.	**GATE**	2002		70
38.	**GATE**	2001		70
39.	**GATE**	2000		70
40.	**GATE**	1999		70
41.	**GATE**	1998		75
42.	**GATE**	1997		75
43.	**GATE**	1996		75
44.	**GATE**	1995		55
45.	**GATE**	1994		71
46.	**GATE**	1993		25

47.	**GATE**	1992		40
48.	**GATE**	1991		52
49.	**GATE**	1990		28
50.	**GATE**	1989		32
51.	**GATE**	1988		22
52.	**GATE**	1987		22
		GATE-XE		
53.	GATE-XE	2024		66
54.	GATE-XE	2023		66
55.	GATE-XE	2022		66
56.	GATE-XE	2021		66
57.	GATE-XE	2020		66
58.	GATE-XE	2018		66
59.	GATE-XE	2017		66
60.	GATE-XE	2016		66
61.	GATE-XE	2015		66
62.	GATE-XE	2014		66
63.	GATE-XE	2013		66
64.	GATE-XE	2012		66
65.	GATE-XE	2011		66
66.	GATE-XE	2010		66
67.	GATE-XE	2009		66
68.	GATE-XE	2008		66
69.	GATE-XE	2007		66
		GATE-P.I.		
70.	GATE-P.I.	2024		55
71.	GATE-P.I.	2023		55
72.	GATE-P.I.	2022		55
73.	GATE-P.I.	2021		55
74.	GATE-P.I.	2020		55
75.	GATE-P.I.	2018		55
76.	GATE-P.I.	2017		55
77.	GATE-P.I.	2016		55
78.	GATE-P.I.	2015		55
79.	GATE-P.I.	2014		55
80.	GATE-P.I.	2013		55
81.	GATE-P.I.	2012		55
82.	GATE-P.I.	2011		55
83.	GATE-P.I.	2010		55
84.	GATE-P.I.	2009		55
85.	GATE-P.I.	2008		55
86.	GATE-P.I.	2007		55
87.	GATE-P.I.	2006		55
88.	GATE-P.I.	2005		55
89.	GATE-P.I.	2004		55
90.	GATE-P.I.	2003		55
91.	GATE-P.I.	2002		55
92.	GATE-P.I.	2001		55
93.	GATE-P.I.	1999		55
94.	GATE-P.I.	1998		55
95.	GATE-P.I.	1997		55
96.	GATE-P.I.	1996		55
97.	GATE-P.I.	1995		55

98.	GATE-P.I.	1994		55
99.	GATE-P.I.	1993		55
100.	GATE-P.I.	1992		55
101.	GATE-P.I.	1991		55
102.	GATE-P.I.	1990		55
103.	GATE-P.I.	1989		55
104.	GATE-P.I.	1988		55
105.	GATE-P.I.	1987		55
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106.	TS-PGECET	2024		120
107.	TS-PGECET	2023		120
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110.	TS-PGECET	2020		120
111.	TS-PGECET	2018		120
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114.	TS-PGECET	2015		120
AP-PGECET				
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116.	AP-PGECET	2023		120
117.	AP-PGECET	2022		120
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119.	AP-PGECET	2020		120
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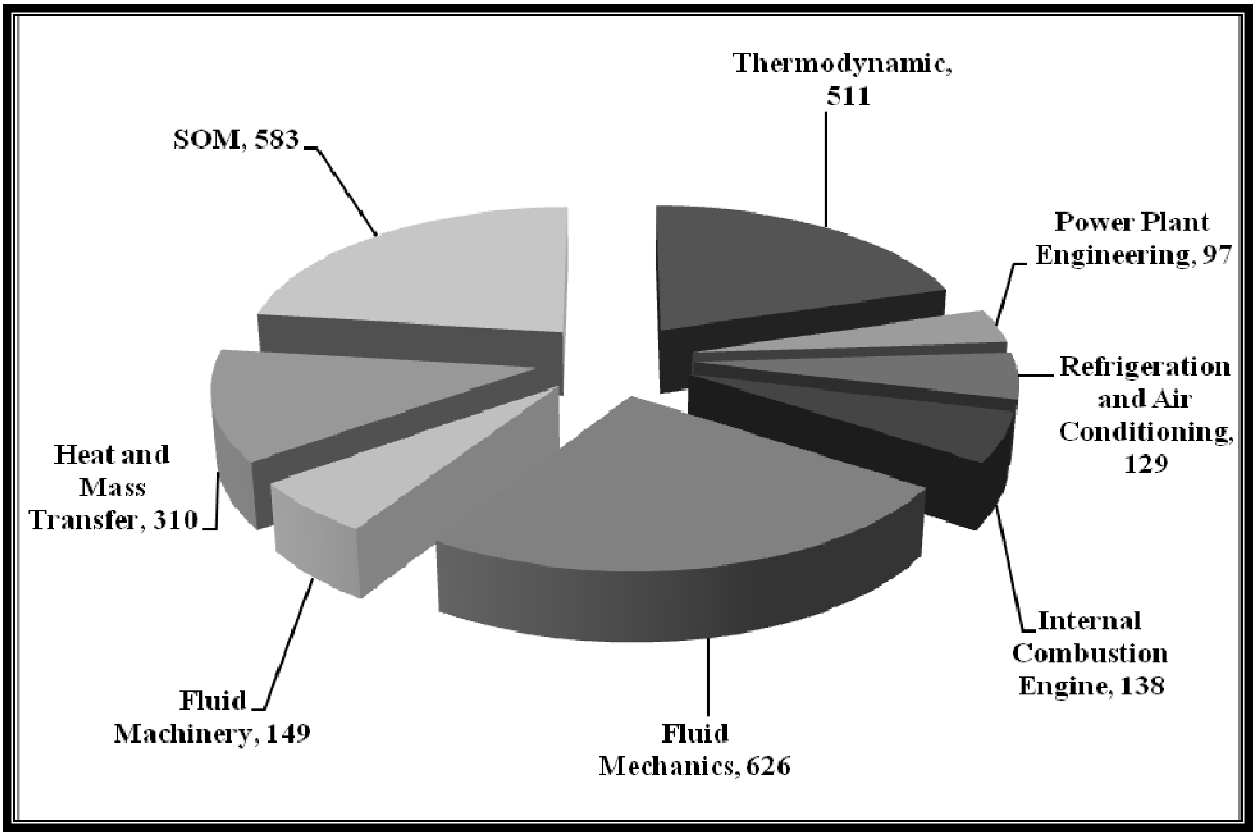
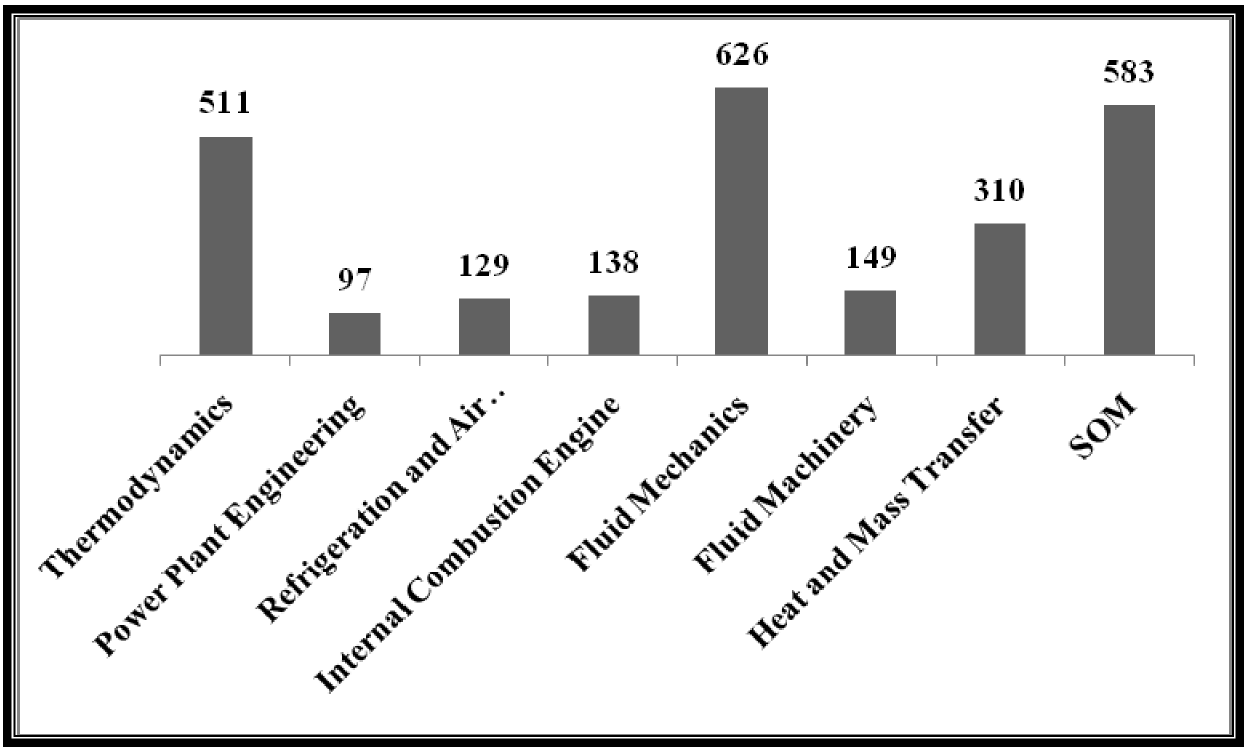
121.	AP-PGECET	2017		120
122.	AP-PGECET	2016		120
123.	AP-PGECET	2015		120
Karnataka PGECET				
124.	Karnataka PGECET	2020		100
125.	Karnataka PGECET	2019		100
126.	Karnataka PGECET	2018		100
127.	Karnataka PGECET	2017		100
128.	Karnataka PGECET	2016		100
129.	Karnataka PGECET	2015		100
130.	Karnataka PGECET	2014		100
131.	Karnataka PGECET	2013		100
132.	Karnataka PGECET	2012		100
133.	Karnataka PGECET	2010		100
134.	**TANCET**			
135.	TANCET	2016		120
136.	TANCET	2017		120
137.	TANCET	2022		120
NTA CUET-PG				
138.	NTA CUET-PG	2024		80
139.	NTA CUET-PG	2023		80
140.	NTA CUET-PG	2022		80
141.	NTA CUET-PG	2021		80
142.			**Total**	**9959**

Trend Analysis of Mechanical Engineering Through Pie Chart and Bar Graph





01 THERMODYNAMICS

INDEX

01 THERMODYNAMICS

A. Basic Concepts

1. Differential scanning calorimetry involves measurement of

(a) Weight change (b) entropy
(c) heat (d) vapour pressure

[GATE-XE 2024: 1M]

Ans. (c) : Differential scanning calorimetry is a technique used to measure the heat flow into or out of a sample as it is heated or cooled.
This is allow the determination of thermal transitions such as melting, crystallization and glass transitions, based on the amount of heat absorbed or released by the sample during these process.

2. According to the Joule's law of a perfect gas, the internal energy is a function of

(a) pressure only
(b) absolute temperature only
(c) specific volume only
(d) absolute entropy only

TS PGECET 06.11.2024

Ans. (b) According to Joule's law the internal energy of a perfect gas is a function of absolute temperature only, and is independent of pressure and volume change.
This is because in an ideal gas, there are no intermolecular forces of attraction and repulsion, and the collision are perfectly elastic.

3. In a polytropic process, heat rejected is given by

(a) $\frac{\gamma-n}{\gamma-1}\times$ Work done on the system

(b) $\frac{\gamma}{\gamma-1}\times$ Work done on the system

(c) $\frac{\gamma-n}{\gamma}\times$ Work done on the system

(d) $\frac{\gamma-n}{n}\times$ Work done on the system

TS PGECET 06.11.2024

Ans. (a) For the first law of thermodynamics

$$Q_{1-2} = \Delta U + W_{1-2}$$

Now, Polytropic process

$$PV^n = C$$

Work-done for a polytropic process,

$$W = \frac{P_2V_2 - P_1V_1}{1-n}$$

$$= mR\left(\frac{T_2-T_1}{1-n}\right) \quad \ldots.(i)$$

We know that

$$C_p - C_V = R \text{ and } \frac{C_P}{C_V} = \gamma$$

$$\therefore \quad C_V = \frac{R}{\gamma-1}$$

$$\Delta U = mC_v(T_2 - T_1)$$

From equation (i) -

$$\Delta U = m\frac{R}{\gamma-1}(T_2-T_1) = W\frac{(1-n)}{(\gamma-1)}$$

$$Q = \Delta U + W = W\left[1+\frac{(1-n)}{(\gamma-1)}\right] = W\frac{(\gamma-n)}{(\gamma-1)}$$

$$Q = \frac{(\gamma-n)}{(\gamma-1)}\times W$$

$$Q = \frac{\gamma-n}{\gamma-1}\times \text{work done on the system}$$

4. The slope of curve on p-V diagram for different processes

(a) decreases in negative direction with the increase of polytropic index
(b) increases in negative direction with the increases of polytropic index
(c) decreases in negative direction with the decreases of polytropic index
(d) does not change with the increase of polytropic index

TS PGECET 06.11.2024

Ans. (b) : According to given question. The Slope at curve on p-V diagram for different processes Increase in negative direction with increases of polytropic index.
Polytrophic Index,

$n = 0$
$PV^0 = C$
$P = C$, Isobaric
$n = 1$
$PV^1 = C$
$PV = C$, Isothermal
$1 < \gamma < \infty$
$PV^n = C$, Polytropic
$N = \gamma$
($PV^\gamma = C$) Adiabatic
($n = \infty$)
$PV^\infty = C$
$V = C$, Isochoric

(O – 10r 20r 30r 40r 5) = Expansion process.
(O – 1' or 2' or 3'or 4' or 5')= Compression process
Hence,
n↑ = Slope ↑ in (–ve) axis

5. An ideal gas at 27°C is heated at constant pressure till the volume becomes three times. The temperature of the gas will be

(a) 81ºC (b) 627ºC
(c) 900ºC (d) 1173ºC

AP-PGECET 30.05.2024, Shift-II

Ans. (b) : Given,

$V_1 = V, V_2 = 3V$
$T_1 = 27°C = 27 + 273 = 300$ K
$\because \quad PV = nRT$
When, $P = C$
Then, $V \propto T$

$$\therefore \quad \frac{V_1}{V_2} = \frac{T_1}{T_2}$$

$$T_2 = \frac{300 \times 3V}{V}$$

$T_2 = 900$ K

$T_2 = 900 - 273 = 627$ ºC

$T_2 = 627$ ºC

6. Which of the following is not an extensive property?

(a) Pressure (b) Volume
(c) Energy (d) Entropy

AP-PGECET 30.05.2024, Shift-II

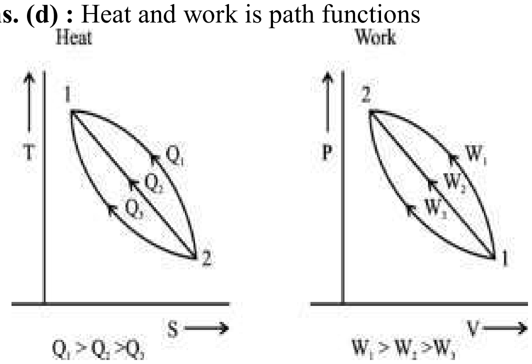
Ans. (a) : Extensive property:- Extensive properties are physical properties that depend on the amount of matter.
Some examples – Volume, mass energy,
Intensive properties:- Intensive properties are physical properties that do not depend on the amount of matter.
Same examples – Density, Temperature, Pressure.

7. Heat and work is

(a) intensive properties
(b) extensive properties
(c) point functions
(d) path functions

AP PGECET 29.05.2023, Shift-II

Ans. (d) : Heat and work is path functions



8. Adiabatic bulk modulus of a substance is defined as

(a) $-\frac{1}{v}\left(\frac{\partial v}{\partial P}\right)_T$ (b) $-v\left(\frac{\partial P}{\partial v}\right)_T$

(c) $-\frac{1}{v}\left(\frac{\partial v}{\partial P}\right)_S$ (d) $-v\left(\frac{\partial P}{\partial v}\right)_S$

[GATE-XE 2023: 1M]

Ans. (d) : Adiabatic bulk modulus is given by,

$$\beta_s = -v\left(\frac{\partial p}{\partial v}\right)_s$$

9. Read the following statements for some properties:

(A) Pressure is an extensive property.
(B) Specific internal energy is intensive property.
(C) Enthalpy is extensive property.
(D) Temperatures is intensive property.
(E) Specific heat is intensive property.

Choose the correct answer from the options given below:

(a) (A), (B), (C), (E) only
(b) (B), (C), (D), (E) only
(c) (A), (C), (D) only
(d) (A), (D), (E) only

NTA CUET-PG 14.06.2023

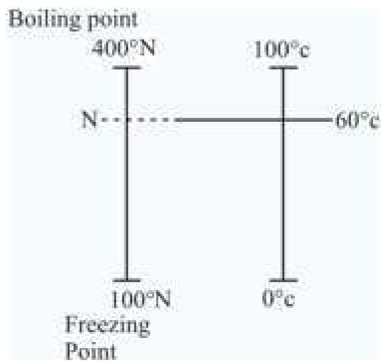
Ans. (b) : **Intensive properties:-** These properties are independent of mass.
Example:- pressure, density, specific internal energy, specific heat etc.
Extensive properties :- These properties are dependent of mass.
Example:- volume, enthalpy, energy etc.

10. A new temperature scale in degrees N is to be defined. The boiling and freezing on this scale are 400 °N and 100 °N respectively, then what will be the reading on new scale corresponding to 60 °C?

(a) 120 °N (b) 180 °N
(c) 220 °N (d) 280 °N

TS-PGECET 30.05.2023, Shift-I

Ans. (d) :



$$\frac{N - LFP}{UFP - LFP} = \frac{C - LFP}{UFP - LEP}$$

$$\frac{N - 100}{400 - 100} = \frac{C - 0}{100 - 0}$$

$$\frac{N - 100}{300} = \frac{60}{100}$$

$N - 100 = 300 \times 0.6$

$N = 180 + 100$

$= 280°$ N

11. Which of the following are extensive properties?

(1) Temperature **(2) Viscosity**
(3) Internal energy **(4) Entropy**

(a) 1, 2, 3 and 4 (b) 3 and 4 only
(c) 2 and 3 only (d) 2 and 4 only

TS-PGECET 30.05.2023, Shift-I

Ans. (b) : Intensive properties: Intensive properties are those that are independent of the size or mass of system such as temperature pressure density etc.
Extensive properties: Extensive properties are those whose values depend on the size or mass of the system such as mass (m), volume (v) and total energy (E) etc.

- Heat and work is not properties.
- Each specific properties are intensive property.
- The ratio of two extensive properties are intensive properties.

12. Which of the following is an extensive property of a system?

(a) Density (b) Pressure
(c) Temperature (d) Total mass

[GATE-XE 2023: 1M]

Ans. (d) : Pressure, temperature and density are intensive properties whereas total mass is an extensive property.

13. Which one of the following is an intensive property of a thermodynamic system?

(a) Mass (b) Density
(c) Energy (d) Volume

[GATE-2022 Set-I: 1M]

Ans. (b) : Intensive Properties – These are defined as the properties whose value is not dependent on the mass of system i.e. independent of mass of system.
Example : Density
Extensive Properties – These are defined as the properties whose value is not dependent on the mass of system i.e. independent of mass of system.
Example : Mass, Energy, Volume

14. Heat flow into a system is _______ and heat flow out of the system is

(a) positive, positive (b) negative, negative
(c) negative, positive (d) positive , negative

AP PGECET 19.07.2022, Shift-II

Ans. (d) : Heat flow out of a system is taken as negative while heat flow into a system is taken as positive.

15. The absolute zero pressure will be

(a) when the molecular momentum of the system becomes zero
(b) at sea level
(c) at the temperature of – 273 K
(d) at the centre of the earth

TS PGECET 03.08.2022, Shift-I

Ans. (a) : The absolute zero pressure will be when the molecular momentum of the system becomes zero.

16. What Changes the energy of dilation may causes to a body?

(a) Changes the shape
(b) Changes the size
(c) Changes both shape and size
(d) Does not affect shape and size

NTA CUET-PG 07.09.2022

Ans. (b) : Energy of dilation is related to a change in volume or size of a body while keeping the shape unchanged. Dilation involves uniform expansion or contraction in all direction which alters the size of the body but not its shape.
For example, when a material undergoes thermal expansion, its size changes due to dilation, but its overall shape remains the same.

17. Thermal efficiency of heat engine cycle is defined as

(a) Net Work input/Total Heat output
(b) Net Work output/Total Heat input
(c) Total Heat output/Net Work input
(d) Total Heat input/Net Work output

AP PGECET 19.07.2022, Shift-II

Ans. (b) :

$$\text{Thermal efficiency} = \frac{\text{Net work output}}{\text{Total heat input}}$$

The efficiency of a heat engine is defined as the ratio of the net work done by the engine in one cycle to the amount of heat absorbed by the working substance from the source.

18. Ice kept in a well-insulated thermos flask is an example of which system?

(a) Closed system
(b) Isolated system
(c) Open system
(d) Non - flow adiabatic system

AP PGECET 28.09.2021, Shift-II

Ans. (b) : Heat and work cannot be transferred into the ice kept in a well insulated thermos flask.
Hence, it is an isolated system.

19. When the heat transfer into a system is more than the work transfer out of the system, then.

(a) The internal energy of the system remains constant
(b) The internal energy of the system decreases
(c) The internal energy of the system increase
(d) Cannot be predicted

AP PGECET 28.09.2021, Shift-II

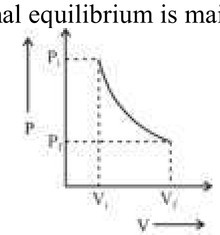
Ans. (c) : When heat is transferred in a system, it means that energy is being added to the system. On the other hand, when work is transferred out of the system, it means that energy is being taken away from the system. Therefore, if the heat transfer in to the system is more than the work transfer out of the system, the system is gaining more energy than it is losing.
Now, This result in an overall increase in the internal energy of the system.

20. Air is being forced by the bicycle pump into a tyre against a pressure of 4.5 bars. A slow downward movement of piston can be approximated as.

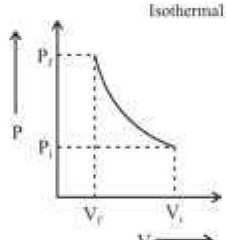
(a) Isobaric process (b) Adiabatic process
(c) Throttling process (d) Isothermal process

AP PGECET 28.09.2021, Shift-II

Ans. (d) : Isothermal process:- An Isothermal process in which the temperature of a system remains constant. The transfer of heat into or out of the system happens so slowly that thermal equilibrium is maintained.



Isothermal expansion



Isothermal Compression

21. Which of the following thermodynamic system is an example of Ice kept in a perfectly insulated container

(a) Non-flow adiabatic system
(b) Closed system
(c) Open system
(d) Isolated systems

TS PGECET 2021

Ans. (d) : Isolated system neither mass nor energy crosses the boundary of the system. When ice is kept in well insulated thermo flask it is considered an example of an isolated system

22. If the time taken by a system to execute a process through a finite gradient is infinitely large, the process,

(a) Becomes reversible
(b) Remains irreversible
(c) Becomes Isothermal
(d) Becomes adiabatic

AP PGECET 28.09.2021, Shift-II

Ans. (a) : The process has finite gradient i.e. a fixed temperature or pressure difference. The time available is infinitely large. This large time can be taken as the process is large enough. So due to finite temperature difference, the process will be irreversible because reversible processes have zero gradient.

23. The energy of an isolated system

(a) Is always decreasing (b) Is always constant
(c) Is always increasing (d) Cannot be predicted

AP PGECET 28.09.2021, Shift-II

Ans. (b) : In an isolated system, there is no mass and energy interaction across the system boundary.
Therefore, mass and the energy of the isolated system is constant.
For an isolated system, dQ = 0 and dW = 0
From the first law of thermodynamics,

$$dQ = \Delta E + dW$$
$$\Delta E = 0$$
$$E = \text{Constant}$$

Therefore, the energy of an isolated system is always constant.

24. The process where there is no work transfer is involved is

(a) Adiabatic expansion
(b) Isothermal expansion
(c) Polytropic expansion
(d) Free expansion

TS PGECET 24.09.2020, Shift-I

Ans. (d) : Free expansion is the process where there is no work transfer.

25. A new temperature scale (°N) has been proposed where the normal freezing and normal boiling points of water are marked as 500 °N and 100°N, respectively. If the temperature of a system is measured to be 0°N, its temperature according to the Celsius scale (in °C) is _______.

[GATE-XE 2020:1M]

Ans. (125 to 125) : From the new temperature scale,

$$N = aC + b \quad ....(i)$$

Where,
N = °N temperature scale
C = °C temperature scale
Now, at C = 0, N = 500 and C = 100, N = 100 put the value from equation (i)

$$500 = a \times 0 + b$$
$$b = 500 \quad ....(ii)$$

And,

$$a \times 100 + 500 = 100$$
$$100a = -400$$
$$a = \frac{-400}{100}$$
$$a = -4 \quad ....(iii)$$

From equation (i) we can write the new temperature scale as,

$$N = -4C + 500 \quad ....(iv)$$

At
N = 0, Put the value from equation (iv),

$$-4C + 500 = 0$$
$$-4C = -500$$
$$C = 125$$

26. Which of the following are intensive properties
I. Kinetic Energy
II. Specific Enthalpy
III. Pressure
IV. Entropy
Select the correct answer in the following for above options

(a) I and III (b) II and III
(c) I, III and IV (d) II and IV

TS PGECET 24.09.2020, Shift-I

Ans. (b) : Intensive properties:- The properties of matter that do not depends on the size or quantity of matter in any way are referred to as an intensive property of matter. Temperature, density coleus, melting and boiling point specific enthalpy, pressure.

27. In a polytropic process described by PV^n = constant, if n = 0, the process is called as

(a) isobaric (b) isochoric
(c) isothermal (d) isentropic

[GATE-XE 2020:1M]

Ans. (a) : For a polytropic process with n = 0,
The process is defined by,

$$PV^n = C$$
$$n = 0$$
$$P = C$$

This means constant pressure or isobaric process.

28. Hot coffee stored in a well-insulated thermos flask is an example of

(a) isolated system
(b) closed system
(c) open system
(d) non-flow adiabatic system

AP PGECET 03.05.2019, Shift-II

Ans. (a) : When hot coffee stored in thermos flask is an example of isolated system. Because when the flask is closed, the coffee as well as heat can not come out from flask body surface.

29. Which of the following is an intensive thermodynamic property ?

(a) Enthalpy (b) Internal energy
(c) Entropy (d) Pressure

[GATE-XE 2019-1M]

Ans. (d) : Intensive Property:-
An intensive property is one that does not depend on the mass of the substance or system.
Examples – Temperature (T), pressure (P) and density.
• Pressure is an intensive thermodynamic property.

30. The internal energy of an ideal gas is function of
(a) pressure only
(b) absolute temperature only
(c) pressure and volume
(d) pressure, volume and temperature
TS PGECET 30.05.2018, Shift-I

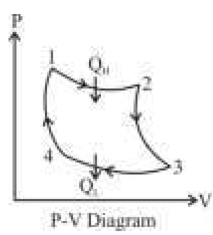
Ans. (b) : The internal energy of an ideal gas is function of absolute temperature only.
• The ideal gas is defined as a gas that obeys the following equation of state-
$PV = RT$
The internal energy of an ideal gas is a function of temperature only. That is u = u (T) using the definition of enthalpy and the equation of state of an ideal gas h = u + PV = u + RT.
Since R is a constant and u = u (T) it follows that, The enthalpy of an ideal gas is also a function of temperature only.

31. See beck effect is used in
(a) thermistors
(b) thermocouples
(c) RTD
(d) hot wire sensors
TS PGECET 30.05.2018, Shift-I

Ans. (b) : See beck effect is used in thermocouples. The see beck effects is used to measure temperature with great sensitivity and accuracy (see thermocouple) and to generate electric power of special application.

32. Area of p–v diagram for the Carnot cycle represents
(a) heat supplied
(b) heat rejected
(c) work done
(d) temperature drop
TS PGECET 30.05.2018, Shift-I

Ans. (c) :



P-V Diagram

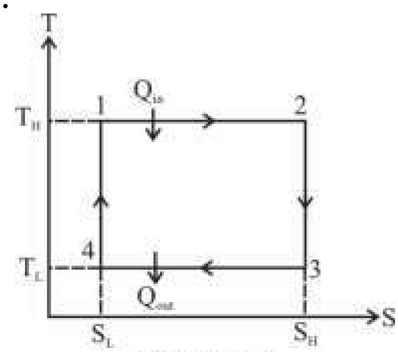
We know that,
Work done (W) = PΔV
The arc under the P-V diagram represents the work done.

33. Isentropic process is
(a) reversible adiabatic
(b) irreversible adiabatic
(c) frictionless fluid flow process
(d) quasi-static process
TS PGECET 30.05.2018, Shift-I

Ans. (a) : Isentropic process is a reversible adiabatic process.

34. In a Carnot cycle heat is rejected at constant
(a) volume (b) temperature
(c) pressure (d) entropy
TS PGECET 30.05.2018, Shift-I

Ans. (b) :



T-S diagram

A Carnot cycle consists of four process.
1⟶2 Reversible isothermal heat addition.
2⟶3 Reversible adiabatic expansion of gas.
3⟶4 Reversible isothermal heat rejection.
4⟶1 Reversible adiabatic compression of the gas.

35. Heat is closely related with
(a) Liquids (b) Entropy
(c) Temperature (d) Enthalpy
AP PGECET 11.05.2018, Shift-II

Ans. (c) : Heat is closely related to temperature as heat is a form of energy transfer between system or object due to a temperature difference when heat is added to or removed from a system. It offer causes a change in temperature. However, it can also influence other properties, such as entropy and enthalpy depending on the process.

36. A perfect gas 27°C is heated at constant pressure till its volume is doubled. The final temperature is
(a) 54°C (b) 654°C
(c) 108°C (d) 327°C
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Ans. (d) : Given,
$T_1 = 27°C = 300\text{ K}$
$V_1 = V$
$V_2 = 2V$
As the gas is heated at constant pressure
$P = C$
So, Applying Charles's law
$$\frac{V_2}{V_1} = \frac{T_2}{T_1}$$
$$\frac{2V}{V} = \frac{T_2}{300}$$
$T_2 = 600\text{ K} = 327°C$

37. Absolute zero temperature is taken as
(a) $-273^{o}C$ (b) $273^{o}C$
(c) $237^{o}C$ (d) $-373^{o}C$
AP PGECET 11.05.2017, Shift-II

Ans. (a) : Absolute zero is the low temperature possible in the universe, where there is no heat or motion. It's represented as 0 K, –273.15°C and –459.67°F.

38. Work done in an adiabatic process between a given pair of end states depends on

(a) The end states only
(b) Particular adiabatic process
(c) The value of index 'n'
(d) The value of heat transferred

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Ans. (a) : End states are determined by internal energy (U) levels at those states.

i.e. $dQ = dW + dU$

For an adiabatic process dQ = zero

Therefore, $|dW| = |dQ|$

In words, work done in an adiabatic process depends only on the end states.

39. Which of the following is an intensive property of a thermodynamic system ?

(a) Volume (b) Temperature
(c) Mass (d) Energy

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Ans. (b) : Intensive properties are independent of mass.
Example:- pressure, temperature, density etc.

40. Work done in a free expansion process is

(a) Zero (b) Minimum
(c) Maximum (d) Positive

TANCET (Auto) 2016

Ans. (a) : The work done in a free expansion process is zero. This is because there is no external pressure and no heat transfer during a free expansion. As we know that, free expansion into a vacuum or an insulated evacuated chambers.

41. In a reversible adiabatic process, the ratio of T_1/T_2 is equal to

(a) $(P_1/P_2)^{\gamma-1/\gamma}$ (b) $(P_2/P_1)^{\gamma-1/\gamma}$
(c) $(V_1/V_2)^{\gamma-1/\gamma}$ (d) $(V_2/V_1)^{\gamma-1/\gamma}$

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Ans. (a) : For adiabatic reversible process

$$PV^{\gamma} = c$$

$$P_1V_1^{\gamma} = P_2V_2^{\gamma} \quad .....(i)$$

And the ideal gas equation

$$PV = nRT \quad .....(ii)$$

$$V = \frac{nRT}{P}$$

Putting this in equation (i) we get,

$$P_1\left(\frac{nRT_1}{P_1}\right)^{\gamma} = P_2\left(\frac{nRT_2}{P_2}\right)^{\gamma}$$

$$P_1^{1-\gamma}T_1^{\gamma} = P_2^{1-\gamma}T_2^{\gamma}$$

$$\left(\frac{T_1}{T_2}\right)^{\gamma} = \left(\frac{P_2}{P_1}\right)^{1-\gamma}$$

$$\left(\frac{T_1}{T_2}\right)^{\gamma} = \left(\frac{P_1}{P_2}\right)^{\gamma-1}$$

$$\left(\frac{T_1}{T_2}\right) = \left(\frac{P_1}{P_2}\right)^{\frac{\gamma-1}{\gamma}}$$

42. Which of the following thermodynamic properties is NOT an intensive property of a thermodynamic system:

(a) Pressure (b) Temperature
(c) Density (d) Volume

[GATE-XE 2016: 1M]

Ans. (d) : Volume depends on the extent or mass of the system.

43. A heat exchange process in which product of pressure and volume remains constant is known as

(a) Adiabatic process (b) Throttling process
(c) Isentropic process (d) Hyperbolic process

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Ans. (d) : Hyperbollic Process:- A heat Exchange process in which product of pressure and volume remains constant is known as a hyperbolic process.

44. Which one of the following effects is the working principle of a thermocouple?

(a) Thomson (b) Seebeck
(c) Peltier (d) Meissner

[GATE-XE 2016: 1M]

Ans. (b) : Thermocouple :- The thermocouple is based on the principle of seebeck effect. A thermocouple is an electrical device which is used for measuring the variation in temperature. So it has to work on some kind of thermoelectric effect.

- A thermocouple is an electrical device containing junctions of two dissimilar metal joints. It is used as temperature sensors.
- Since the thermocouple wires consist of two dissimilar metals (with unique resistivities) each leg of the thermocouple has a unique resistance associated with it these resistances increase with longer or narrower gauge thermocouple wire.

45. Choose the wrong statement

(a) Energy is said to degraded each time it flows through a finite temperature difference.
(b) To increase work capacity of energy transferred by heat transfer from high temperature to low temperature, temperature difference should be increased.
(c) The actual work which a system is always less than the reversible work.
(d) None of the above.

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Ans. (b) : Heat is a form of energy that transfers from higher temperature to lower temperature. Heat transfer always occurs from hot to cold. Increasing the temperature difference will not increase the work capacity of energy transferred by heat transfer.

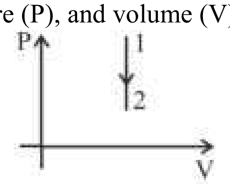
46. An ideal gas of mass m is contained in a rigid tank of volume V at a pressure P. During a reversible process its pressure reduces to P_1. Following statements are made regarding the process.
(P) Heat is transferred from the gas.
(Q) Work done by the gas is zero.
(R) Entropy of the gas remains constant.
(S) Entropy of the gas decreases.
Among the above statements, the correct ones are

(a) P and R only. (b) P, Q and R only.
(c) Q and R only. (d) P, Q and S only.

[GATE-PI 2016: 2M]

Ans. (d) : For constant volume process to decrease pressure, temperature has to be decreased. So heat has to be transferred from the gas.

mass (m), pressure (P), and volume (V) is fixed,



As change in volume is zero. Work done by the gas is also zero.
Entropy of the gas decreases as system is losing heat.
So, P, Q, S are correct.

47. The sum of internal energy (U) and the product of pressure and volume (p, v) is known as
(a) Work done (b) Entropy
(c) Enthalpy (d) None of these

Karnataka PGCET 2015

Ans. (c) : H = U + PV
Where, U = internal energy
PV = product of pressure and volume
H = Enthalpy.

48. If the value of n = 0 in the equation $PV^n = c$, then the process is called
(a) Isobaric process (b) Adiabitic process
(c) Isochoric process (d) Isothermal process

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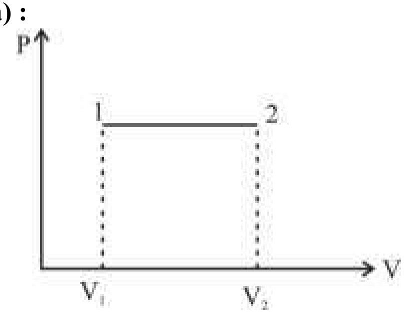
Ans. (a) :



Given

$PV^n = C$ and n = 0
$PV^0 = C$
P = C

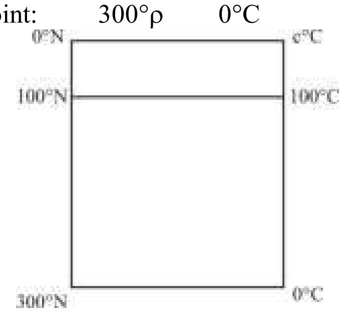
This process is constant pressure process (Isobaric process)

49. In a new temperature scale, the boiling point and freezing point of water are given as 100 units and 300 units respectively. The reading of 0 units on the new scale corresponds to
(a) 0°C (b) 50°C
(c) 100°C (d) 150°C

AP-PGECET 2015

Ans. (d) : Given data,

	°ρ scale	**°C scale**
Boiling point:	100°ρ	100°C
Freezing point:	300°ρ	0°C



$$\frac{°C - LFP}{UFP - LFP} = \frac{°\rho - LFP}{UFP - LFP}$$

Where, LFP = Lower Fixed Point
UFP = Upper Fixed Point

$$\frac{°C - 0°}{100° - 0°} = \frac{0° - 300°}{100° - 300°}$$

$$°C = 150°$$

50. A certain mass of gas at 0^oC is expanded to 81 times its original volume under adiabatic conditions. If ratio of specific heats of the gas, γ = 1.25 , the final temperature of the gas is
(a) –235 °C (b) – 182 °C
(c) –91 °C (d) 0 °C

[GATE-XE 2012: 2M]

Ans. (b) : Given,
$T_1 = 0^oC$
$V_2 = 81\ V_1$
$\gamma = 1.25$
$\Delta Q = 0$

$$\frac{C_p}{C_V} = \gamma = 1.25$$

For, Reversible Adiabatic expansion,

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

$$\frac{T_2}{T_1} = \left(\frac{1}{81}\right)^{1.25-1} = \left(\frac{1}{81}\right)^{0.25}$$

$T_2 = 91$ K
$T_2 = -182^oC$

51. A sample of gas with initial average kinetic energy, E is heated from 27 ^oC to 327 ^oC. The average kinetic energy after heating is
(a) E (b) 2E
(c) 27E (d) 327E

[GATE-XE 2012: 2M]

Ans. (b) : Given,
Temperature before heating, $T_1 = 27^oC = (27 + 273) = 300$ K
Temperature after heating, $T_2 = 327^oC = (327 + 273) = 600$ K
We know that,
Boltzman's constant, (k)
K.E before heating

$$K.E = \frac{3}{2} \times k \times T$$

$$E_1 = \frac{3}{2} \times k \times 300$$

$$E_1 = 450 \text{ k} \quad ...(i)$$

K.E after heating

$$E_2 = \frac{3}{2} \times k \times 600$$

$$E_2 = 900 \text{ K}$$

From equation (i)

$$K.E = 2 \times E_1$$

$$K.E = 2E$$

52. Identify the group containing the appropriate match of items in List-I and List-II.

	List-I		List-II
K	**A jet engine in flight**	**P**	**Closed system**
L	**Water being heated in a sealed container**	**Q**	**Control volume**
M	**Internal energy**	**R**	**Intensive property**
N	**Specific entropy**	**S**	**Extensive property**

(a) K-P,L-Q; M-R; N-S
(b) K-Q; L-P; M-R; N-S
(c) K-Q; L-P; M-S; N-R
(d) K-P; L-Q; M-S; N-R

[GATE-XE 2011:1M]

Ans. (c) :

K	A jet engine in flight	Q	Control volume
L	Water being heated in a sealed container	P	Closed system
M	Internal energy	S	Extensive property
N	Specific entropy	R	Intensive property

53. Match the items in Group I for their correctness with the corresponding appropriate terms given in Groups II and III.

GROUP I	GROUP II	GROUP III
P. Pressure	**1. Path dependent quantity**	**X. Intensive property**
Q. Heat	**2. Path independent quantity**	**Y. Extensive property**

(a) P,1,X
(b) P,2,X
(c) Q,1,X
(d) Q,2,Y

[GATE-XE 2010: 1M]

Ans. (b) : Pressure is a intensive property and a property is point function and not a path function.

54. For an ideal gas undergoing a throttling process 1-2 which of the following relationship holds?

(a) $T_1 = T_2$
(b) $\frac{P_1}{P_2} = \frac{T_1}{T_2}$
(c) $\frac{P_1}{P_2} = \left(\frac{T_1}{T_2}\right)^{\gamma(\lambda-1)}$
(d) $\frac{P_1}{P_2} = \frac{T_2}{T_1}$

[GATE-XE 2009: 1M]

Ans. (a) : In throttling process, enthalpy = constant

$\Delta h = 0$

For an ideal gas equation (i) reduces to

$$C_P \times (T_2 - T_1) = 0$$

$$T_1 = T_2$$

55. On a T-S diagram, the slope of the constant volume line for an ideal gas is

(a) less than that of constant pressure line
(b) more than that of constant pressure line
(c) less than that of constant enthalpy line
(d) equal to that of constant enthalpy line

[GATE-XE 2009: 1M]

Ans. (b) : T-S diagram the slope of the constant volume line for an ideal gas is more than that of constant pressure line.

For constant pressure line,

$$dS = \frac{C_p dT}{T}$$

$$\left(\frac{dS}{dT}\right)_P = \frac{C_p}{T}$$

And for constant volume line

$$\left(\frac{dS}{dT}\right)_V = \frac{C_V}{T}$$

Slope on T-S diagram

$$\left(\frac{dT}{dS}\right)_P = \frac{T}{C_P} \text{ and } \left(\frac{dT}{dS}\right)_V = \frac{T}{C_V}$$

Hence the slope of constant pressure line is more than constant volume line as.

$$C_p > C_v$$

56. Air (γ = 1.4) is compressed ideally form an initial state of 1 bar, 300 K to a final temperature of 600 K. The value of the pressure in bar is

(a) 2
(b) 3.7
(c) 7.2
(d) 11.3

[GATE-XE 2009: 1M]

Ans. (d) : $P_1 = 1$ bar

$T_1 = 300$ k

$T_2 = 600$ k

$\gamma = 1.4$

We know that,

$$\frac{P_2}{P_1} = \left(\frac{T_2}{T_1}\right)^{\frac{\gamma}{\gamma-1}}$$

$$P_2 = 1 \times \left(\frac{600}{300}\right)^{\frac{1.4}{1.4-1}} \text{ bar}$$

$$P_2 = 11.3 \text{ bar}$$

57. In a throttling process

(a) temperature always remains unchanged.
(b) temperature always increases.
(c) temperature always decreases.
(d) temperature may increase, decrease or remain unchanged.

[GATE-XE 2008: 1M]

Ans. (d) : In a throttling process the temperature change depends on the nature of the fluid and the conditions of the processes. Throttling refers to the expansion of fluid through a valve or orifice, where the pressure decrease without doing work and without heat exchange. For same fluid like ideal gas the temperature can remains constant, while for other, such as real gases (like refrigerants), the temperature can increase or decrease depending on the specific properties and the process conditions.

58. Match items from groups I, II, III, IV and V.

Group I	Group II	Group III	Group IV	Group V
	When added to the system is	Differential	Function	Phenomenon
E Heat	G Positive	I Exact	K Path	M Transient
F Work	H Negative	J Inexact	L Point	N Boundary

(a) F-G-J-K-M
E-G-I-K-N
(b) E-G-I-K-M
F-H-I-K-N
(c) F-H-J-L-N
E-H-I-L-M
(d) E-G-J-K-N
F-H-J-K-M

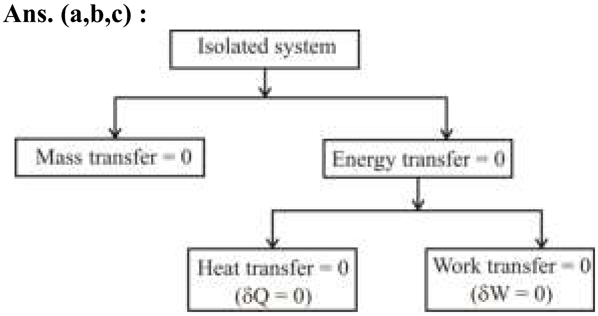
[GATE-2006: 2M]

Ans. (d) : Heat:-
1. When heat is added to the system, it is positive.
2. Heat transfer is path function.
3. Heat is not a property.
4. Heat is inexact differential
5. Heat is boundary phenomena.
6. Heat is energy in transit.
Works:-
1. Work transfer is path function.
2. It is not a property.
3. It is inexact differential.
4. It is boundary phenomena.
5. When work is added to the system, it is negative.
6. Work is energy in transit.

59. An isolated thermodynamic system executes a process. Choose the correct statement (s) from the following:
(a) No heat is transferred
(b) No work is done
(c) No mass flows across the boundary of the system
(d) No chemical reaction takes place within the system

[GATE-1997: 2M]

Ans. (a,b,c) :



So, for an isolated system,
- No heat transfer take place in or out from the system.
- No work is done.
- No mass flows across the boundary of the system.

60.

List I		List II	
(A)	**Heat to work**	**(1)**	**Nozzle**
(B)	**Heat to lift weight**	**(2)**	**Endothermic chemical reaction**
(C)	**Heat to strain energy**	**(3)**	**Heat engine**
(D)	**Heat to electromagnetic energy**	**(4)**	**Hot air balloon/evaporation**
		(5)	**Thermal radiation**
		(6)	**Bimetallic strips**

[GATE-1997: 2M]

Ans. (A - 3, B -4, C- 6, D - 5) :

(A)	Heat to work	(3)	Heat engine
(B)	Heat to lift weight	(4)	Hot air balloon/evaporation
(C)	Heat to strain energy	(6)	Bimetallic strips
(S)	Heat to electromagnetic energy	(5)	Thermal radiation

61. The definition of 1 K as per the internationally accepted temperature scale is
(a) $\frac{1}{100^{th}}$ the difference between normal boiling point and normal freezing point of water
(b) $\frac{1}{273.15^{th}}$ the normal freezing point of water
(c) 100 times the difference between the triple point of water and the normal freezing point of water
(d) $\frac{1}{273.16^{th}}$ of the triple point of water

[GATE-1994: 1M]

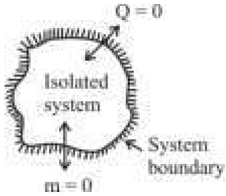
Ans. (d) : The definition of 1 k as per the internationally accepted temperature scale is one kelvin (1k) is formally defined as $\frac{1}{273.16^{th}}$ of triple point of water.

B. System, Property, Internally Reversible Process

62. A thermodynamic system is considered to be an isolated one if _______.
(a) mass transfer and entropy change are zero
(b) entropy change and energy transfer are zero
(c) energy transfer and mass transfer are zero
(d) mass transfer and volume change are zero

AP PGECET 03.05.2019, Shift-II

Ans. (c) : An isolated system is isolated from surrounding with respect to mass and energy i.e. mass and energy can nor cross the system boundary as show below.



But in isolated system is the entropy generation is possible and always positive.

63. Which of the following thermodynamic properties shows a discontinuity during a second-order phase transition?

(a) Volume (b) Enthalpy
(c) Entropy (d) Heat capacity

[GATE-XE 2016: 1M]

Ans. (d) : Heat capacity shows a discontinuity or singularity during a second - order phase transition, unlike other properties that remain continuous.

64. The thermodynamic property, x, of a thermometer varies with temperature, t, according to the relation $t = ax^2 + b$, where t is in °C, x is in cm, and a & b are constants. At ice point (0°C) and steam point (100°C), the values of x are 5 cm and 20 cm, respectively. When the thermometer is brought in contact with a heated body, the value of x is recorded as 15 cm. The temperature of the heated body in °C is

(a) 83.3 (b) 73.3
(c) 63.3 (d) 53.3

[GATE-XE 2011:2M]

Ans. (d) : Given,

$t = ax^2 + b$

Now, t = 0, x = 5 cm

$0 = a \times 5^2 + b$ ...(i)

Now, t = 100 & x = 20 cm

$100 = b \times 20^2 + b$ ...(ii)

Solving equation (i) and (ii)

$a = 0.267, b = –6.67$

Then,

$t = 0.267 \times x^2 – 6.67$

At, x = 15cm

$t = 0.267 \times 15^2 – 6.67$

$t = 53.405$

$t \approx 53.3°C$

65. The polytropic index n of an isochoric process is equal to

(a) zero (b) one
(c) minus one (d) infinity

[GATE-XE 2007: 2M]

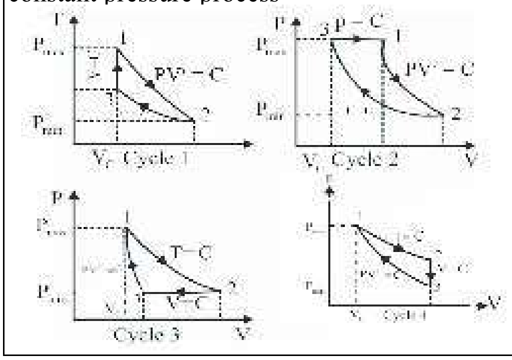
Ans. (d) : For a general polytropic process PV^n = constant.
In case of an isochoric process the value of this n is taken equal to infinity.

66. A reversible thermodynamic cycle containing only three processes and producing work is to be constructed. The constraints are:
(i) there must be one isothermal process
(ii) there must be one isentropic process
(iii) the maximum and minimum cycle pressures and the clearance volume are fixed
(iv) polytropic processes are not allowed. Then the number of possible cycles are

(a) 1 (b) 2
(c) 3 (d) 4

[GATE-2005: 1M]

Ans. (d) : Four clockwise cycles can be created including two constant volume processes and two at constant pressure process



C. Ideal and Real Gases

67. The equation for the state of real gas in terms of reduced form is

(a) $\left(P_r + \frac{3}{V_r^2}\right)(3V_r - 1) = 8T_r$

(b) $\left(P_r + \frac{3}{V_r}\right)(3V_r - 1) = 8T_r$

(c) $\left(P_r - \frac{3}{V_r^2}\right)(3V_r + 1) = 8T_r$

(d) $\left(P_r - \frac{3}{V_r}\right)(3V_r - 1) = 8T_r$

TS PGECET 06.11.2024

Ans. (a) For real gas used Vander Waals equation,

$$\left(P + \frac{a}{v^2}\right)(v - b) = RT \quad .....(i)$$

We know that,
Pressure, Temperature & volume in reduced from,

$$P_r = \frac{P}{P_c}, \quad T_r = \frac{T}{T_c}, \quad V_r = \frac{V}{V_c}$$

and, $a = 3P_cV_c^2$, $b = \frac{V_c}{3}$, $R = \frac{8P_cV_c}{3T_c}$

All values put in equation (i),

$$\left(P_r \cdot P_c + \frac{3P_cv_c^2}{V^2}\right)\left(V_r \cdot V_c \frac{V_c}{3}\right) = \frac{8P_cV_c}{3T_c} \times T_r \cdot T_c$$

$$\left[P_r + \frac{3}{\left(V/V_c\right)^2}\right](3V_r - 1)\frac{P_cV_c}{3} = \frac{8P_cV_c}{3} \times T_r$$

$$\boxed{\left(P_r + \frac{3}{V_r^2}\right)(3V_r - 1) = 8T_r}$$

68. Two rigid, impermeable containers A and B are filled with an ideal gas. They are allowed to exchange heat only with each other and not with the surroundings. P,V,N, and T represent the pressure, total volume, number of moles, and temperature, respectively. At equilibrium, which of the following conditions is/are necessarily satisfied?
(Subscripts A and B represent properties of the gas in the respective containers.)

(a) $P_A = P_B$ (b) $T_A = T_B$

(c) $\frac{P_A V_A}{N_A} = \frac{P_B V_B}{N_B}$ (d) $\frac{P_A}{V_A} = \frac{P_B}{V_B}$

[GATE-XE 2024: 1M]

Ans. (B;C) : As the system reaches to thermal equilibrium

So,

$$T_A = T_B$$

We know that,

$$P_A V_A = N_A \overline{R} T_A$$

$$T_A = \frac{P_A V_A}{N_A R}$$

And,

$$P_B V_B = N_B \overline{R} T_B$$

$$T_B = \frac{P_B V_B}{N_B R}$$

$$T_A = T_B$$

$$\frac{P_A V_A}{N_A} = \frac{P_B V_B}{N_B}$$

69. A rigid tank, initially at 1 bar and 300 K, contains 5 moles of O_2, 4 moles of N_2 , and 3 moles of H_2 . From this tank, 2 moles of O_2 are removed keeping the temperature constant. Assuming ideal gas behaviour, the final partial pressure of O_2 (in bar) inside the tank is _______ (rounded off to the three decimal places).
Use R = 8.314 J/mol.K Molecular weights of H_2, N_2 and O_2 are 2 g/mol, 28 g/mol, and 32 g/mol respectively.

[GATE-XE 2024: 1M]

Ans. (0.249 to 0.251) : Given data,

State I, P_1 = 1 bar and T_1 = 300 k

5 moles O_2 + 4 molesO_2 + 3 molesO_2

State II,

P_2 = ?

T_2 = 300 K

3 moles O_2 + 4 moles O_2 +3 moles O_2

$$P_1 V = \sum n\overline{R}T$$

$$100 \times V = \frac{(5+4+3)}{1000} \times 8.314 \times 300$$

V = 0.2993 MJ

$$P_2 V = \sum n\overline{R}T$$

$$P_2 \times 0.2993 = \frac{(3+4+3)}{1000} \times 8.314 \times 300$$

P_2 = 83.33 kPa

$$P_{O_2} = X_{O_2} P_2$$

$$P_{O_2} = \frac{3}{3+4+3} \times 83.33$$

$$P_{O_2} = 24.99 \text{ kPa} = 0.249 \text{ bar}$$

70. Pressure of an ideal gas is increased by keeping temperature constant. The kinetic energy of molecules

(a) Decreases
(b) Increases
(c) Remains same
(d) Increases or decreases depending on the nature of gas

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Ans. (c) : We know that,

The kinetic energy of molecules of an ideal gas is

$$E = \frac{3}{2} N K_B T$$

Where,

N = The number of molecules,

K_B = The Boltzmann constant

T = Temperature of gas

By the above expression it is clear that E depends on the temperature but not on the pressure, volume and nature of the gas.

Then, on increasing the pressure by keeping the temperature constant, the kinetic energy of molecules remains same.

71. On the basis of the ideal gas equation and van der Waals equation, the temperatures of a gas at pressure 10 MPa and specific volume 0.005 m^3/kg would be, respectively
(Assume gas constant R = 0.3 kJ/(kg K), a = 0.18 m^6 kPa/kg^2 and b = 0.0014 m^3/kg)

(a) 166.67 K and 235.89 K
(b) 166.67 K and 206.40 K
(c) 166.67 K and 267.21 K
(d) 166.67 K and 240.90 K

[GATE-XE 2022: 2M]

Ans. (b) : In ideal gas

PV = RT

$10 \times 10^6 \times 0.005 = 0.3 \times 1000 \times T$

T = 166.67 k

On the basis of Vander Waals equation

$$\left(p + \frac{a}{v^2}\right)(v-b) = RT$$

a = 0.18×1000 m^6 pa/kg^2

b = 0.0014 m^3/kg

$$\left[10 \times 10^6 \times \frac{0.18 \times 1000}{(0.005)^2}\right](0.005 - 0.0014) = 0.3 \times 1000 \times T$$

T = 206.40 K

72. A cylinder of volume 1 m^3 contains a mixture of CO_2 (20% by mol) and Q_2 (80% by mol) at 100 kPa and 300 K. This cylinder is connected to a 1 MPa pressure line carrying N_2 at 300 K. The cylinder is filled isothermally till the pressure of gas mixture inside it becomes 500 kPa, and then the filling is stopped. The

amount of N_2 gas that has entered the cylinder is ______ (in mole, 2 decimal places).
The universal gas constant is 8.3145 J/(mol K).
[GATE-XE-2021: 1M]

Ans. (159 to 162) : Given,
Initial pressure $P_1 = 100$ kPa $= 100\times10^3$ Pa
Final pressure $P_2 = 500$ kPa $= 500\times10^3$ Pa
Initial mole fraction of CO_2, $(X_1)_{CO_2} = 0.2$
Initial mole fraction of O_2, $(x_1)_{O_2} = 0.8$
Volume of the cylinder, $V = 1\ m^3$
The constant temperature maintained T = 300 K
Let the total number of moles of CO_2 and O_2 be n_1.
Then from the ideal gas equation of state we have

$$n_1 = \frac{P_1V}{R_0T}$$

$$n_1 = \frac{100\times10^3\times1}{8.3145\times300}$$

$n_1 = 40.09$
Let the total number of moles CO_2, O_2 and N_2 after filling of N_2 be n_2.
Then from the ideal gas equation of state, we get

$$n_2 = \frac{P_2V}{R_0T}$$

$$n_2 = \frac{500\times10^3\times1}{8.3145\times300}$$

$n_2 = 200.45$
Therefore, the number of moles of N_2 that has entered the cylinders.
$= 200.45 - 40.09 = 160.36$

73. For a real gas passing through an insulated throttling valve, the outlet temperature of the gas _____ with respect to the inlet temperature.
(a) is always higher
(b) is always lower
(c) may be higher, lower or same
(d) is always same
[GATE-XE-2021: 1M]

Ans. (c) : The Joule's Thomson coefficient for a substance is given by

$$\mu_J = \left(\frac{\partial T}{\partial P}\right)_h$$

It may be noted that a substance will produce cooling effect due to throttling if its $\mu_J > 0$ and vice-versa. For a real gas the value of μ_J can either be greater than or less than effect. Therefore, the throttling of a real gas may either produce a cooling effect or heating effect depending on weather the value of its Joule-Thomson coefficient is greater than or less than 0.

74. A cylinder of volume 0.1 m^3 is filled with 100 mol of propane (C_3H_8) at 2 MPa. If propane is assumed to obey the van der Waals equation of state, then its temperature is _____K(1 decimal place).
The van der Waals constants for propane are: a = 939.2 kPa $(m^3/kmol)^2$ and b = 0.0905 m^3/kmol. The universal gas constant is 8.3145 J/(mol K).
[GATE-XE-2021: 2M]

Ans. (320.0 to 323.0) : Given,
Volume, $V = 0.1\ m^3$
Number of moles, n = 100 mol = 0.1 k mol
Pressure, P = 2 MPa = 2000 kPa
Vander Waal's constants,
$a = 939.2$ kPa $(m^3/k\ mol)^2$
$b = 0.0905\ m^3/k$ mol
universal gas constant, R = 8.3145 J/mol.k
= 8.3145 kJ/mol k
The molar volume occupied by the gas,

$$v = \frac{V}{n} = \frac{0.1}{0.1}$$

$= 1\ m^3/k$ mol
Let the temperature of the gas be T.
The Vander waal's equation of state given,

$$T = \frac{\left(p + \frac{a}{v^2}\right)(v-b)}{R}$$

$$= \frac{\left(200 + \frac{939.2}{1^2}\right)(1-0.0905)}{8.3145}$$

= 321.51 K

75. Superheated steam at 1500 kPa, has a specific volume of 2.75 m^3/k-mol and compressibility factor (Z) of 0.95. The temperature of steam is____°C (round off to the nearest integer)
(a) 522 (b) 471
(c) 249 (d) 198
[GATE-2021;Set-I:1M]

Ans. (c) : Given,
Pressure (P) = 1500 kPa
Specific Volume $(\overline{V}) = 2.75\ m^3$/k-mol
Compressibility factor (Z) = 0.95
Temperature (T) of the steam = ?
We know that,

$$P\overline{V} = Z\times n\overline{R}T$$

$$P\frac{\overline{V}}{n} = Z\overline{R}T$$

$$P\overline{V} = Z\overline{R}T \qquad [\because n = 1]$$

$1500 \times 2.75 = 0.95 \times 8.314 \times T$
T = 522.26 K
= (522.26 – 273) °C
T = 249.26°C ≈ 249°C

76. In a mixture of gas there are 0.1 kmol of oxygen (O_2) , 0.1 kmol of nitrogen (N_2) and 0.8 kmol of methane (CH_4). If the molar mass of O_2, N_2 and CH_4 are 32 kg/kmol and 16 kg/kmol, respectively, then the mass fraction of N_2 in the gas mixture is
(a) 0.100 (b) 0.170
(c) 0.148 (d) 0.680
[GATE-XE 2020:2M]

Ans. (c) : Mass of O_2 present $(m)_{O_2} = (n)_{O_2}(M)_{O_2}$
$= 0.1\times32$
= 3.2 kg
Mass of N_2 present $(m)_{N_2} = (n)_{N_2}.(M)_{N_2}$

$= 0.1 \times 28$
$= 2.8$ kg

Mass of CH_4 present, $(m)_{CH_4} = (n)_{CH_4} . (m)_{CH_4}$
$= 0.8 \times 16$
$= 12.8$ kg

Therefore, the mass fraction of N_2 in the mixture

$$= \frac{(m)_{N_2}}{(m)_{O_2} + (m)_{N_2} + (m)_{CH_4}}$$

$$= \frac{2.8}{3.2 + 2.8 + 12.8}$$

$$= \frac{2.8}{18.8}$$

$= 0.148$

77. A 4-m^3 reservoir contains 10 kg of a real gas at 200 K. If this gas follows the van der Waal's equation of state with a = 0.0687 m^6. kPa/kg^2, b = 0.00657 m^3/kg and R = 0.187 kJkg.K, then the reservoir pressure (in kPa) is

(a) 93.5 (b) 94.6
(c) 95.7 (d) 101.3

[GATE-XE 2020:2M]

Ans. (b) : Vander waal's equation of state is

$$\left(p + \frac{a}{v^2}\right)(v - b) = RT \quad ...(i)$$

Now,

$$v = \frac{V}{m} = \frac{4}{10} m^3 / kg = 0.4 m^3 / kg$$

Therefore, from equation (i)

$$\left(p + \frac{0.0687}{(0.4)^2}\right)(0.4 - 0.00657) = 0.187 \times 200$$

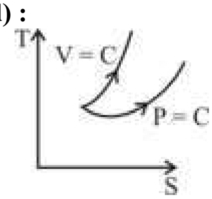
P = 94.6 kPa

78. For an ideal gas, a constant pressure line and a constant volume line intersect at a point, in the temperature (T) versus specific entropy (s) diagram. C_p is the specific heat at constant pressure and C_V is the specific heat at constant volume. The ratio of the slopes of the constant pressure and constant volume lines at the point of intersection is

(a) $\frac{C_p - C_V}{C_p}$ (b) $\frac{C_p}{C_V}$
(c) $\frac{C_p - C_V}{C_V}$ (d) $\frac{C_V}{C_p}$

[GATE-2020; Set-I:1M]

Ans. (d) :



If $V = C$
$Tds = du + Pdv$
$Tds = du$
$du = C_V dT$ $[\because V = C]$
$Tds = C_V dT$

$$\left[\frac{dT}{ds}\right]_V = \frac{T}{C_V}$$

If, $P = C$
$Tds = dh - Vdp$
$dh = C_p dT$ $[\because P = C]$
$Tds = C_p dT$

$$\left[\frac{dT}{ds}\right]_P = \frac{T}{C_P}$$

Ratio, $$\frac{(dT/ds)_P}{(dT/ds)_V} \Rightarrow \frac{(T/C_p)_P}{(T/C_v)_V} = \frac{C_v}{C_p}$$

79. One kg of an ideal gas (molecular weight = X) occupies a certain volume V at temperature T and pressure P_1. Four kgs of another ideal gas (molecular weight = 2X) is added to the first gas keeping the volume V and temperature T same as before. The final pressure is

(a) $2P_1$ (b) $3P_1$
(c) $4P_1$ (d) $5P_1$

[GATE-XE 2019-1M]

Ans. (b) : The number of moles of the gas with molecular weight X, $n_1 = \frac{1}{X}$

The number of moles of the gas with molecular weight 2X, $n_2 = \frac{4}{2X} = \frac{2}{X}$

Hence, the mole fraction of the gas with molecular weight X,

$$x_1 = \frac{n_1}{n_1 + n_2} = \frac{1/X}{\frac{1}{X} + \frac{2}{X}} = \frac{1}{3}$$

And the mole fraction of the gas with molecular weight 2X,

$$x_2 = \frac{n_2}{n_1 + n_2} = \frac{2/X}{\frac{1}{X} + \frac{2}{X}} = \frac{2}{3}$$

Now, the partial pressure of a gas is proportional to its mole fraction. Let the final pressure be P. Now, for the given volume and temperature the given mass of gas with molecular weight X exerts a partial pressure of P_1. Therefore,

$P_1 = x_1 P$

$$P = \frac{P_1}{x_1} = \frac{P_1}{1/3} = 3P_1$$

80. If one mole of H_2 gas occupies a rigid container with a capacity of 1000 litres and the temperature is raised from 27°C to 37°C, the change in pressure of the contained gas (round off to two decimal places), assuming ideal gas behaviour, is ______Pa. (R = 8.314 J/mol.K)

[GATE-2019; Set-II: 2M]

Ans. (83.14 Pa) : Given data,

$T_1 = 27°C$
$T_2 = 37°C$
$V = 1\ m^3$
$R = 8.134$ J/mol.K

For the ideal gas,

$$P_1V = n\bar{R}T_1$$
$$P_2V = n\bar{R}T_2$$
$$(P_2 - P_1)V = n\bar{R}(T_2 - T_1)$$
$$\Delta P \times 1 = 1 \times 8.314(37-27)$$
$$\Delta P = 83.14\,\text{Pa}$$

81. An ideal gas has a molar mass of 40 kg/kmol. Take R = 8.314 kJ/kmol.K. At a pressure of 2 bar and a temperature of 300 K, the volume (in m^3) of 1 kg of this gas (up to 2 decimal places) is _____.

[GATE-XE 2018: 1M]

Ans. (0.30 to 0.32) :
M = 40 kg/kmol
R = 8.314 kJ/kmol.K, p = 2 bar = 2 × 10^5 Pa
T = 300 K m = 1 kg
Hence, the number of moles,

$$n = \frac{m}{M} = \frac{1}{40}\text{kmol} = \frac{1}{40} \times 1000\,\text{mol}$$

Now, the equation of state is,

$$pV = nRT$$
$$V = \frac{nRT}{p}$$
$$= \frac{\frac{1}{40} \times 8.314 \times 300 \times 1000}{2 \times 10^3}$$
$$= 0.31\ m^3$$

82. According to kinetic theory of gases, the absolute zero temperature is attained when
(a) Volume of the gas is zero
(b) Pressure of the gas is zero
(c) Kinetic energy of the molecules is zero
(d) Specific heat of gas is zero

TS PGECET 2017

Ans. (c) : According to kinetic theory of gases kinetic energy of the molecules is zero at absolute zero temperature because molecules of gas directly proportional to temperatures.

83. The volume and temperature of air (assumed to be an ideal gas) in a closed vessel is 2.87 m^3 and 300 K, respectively. The gauge pressure indicated by a manometer fitted to the wall of the vessel is 0.5 bar. If the gas constant of air is R = 287 J/kg· K and the atmospheric pressure is 1 bar, the mass of air (in kg) in the vessel is
(a) 1.67 (b) 3.33
(c) 5.00 (d) 6.66

[GATE-2017;Set-II: 2M]

Ans. (c) : = 5 kg
Now, use the ideal gas law to find the mass is:

$$m = \frac{PV}{RT}$$

$$m = \frac{\left((P_{gauge} + P_{atm}) \times (V)\right)}{R \times T}$$

$$m = \frac{\left((0.5\,\text{bar} + 1\,\text{bar}) \times (2.87)\,m^3\right)}{287\,\text{J/kg} - \text{K} \times 300\text{K}}$$

$$m = \frac{(1.5 \times 10^5\,\text{Pa}) \times 2.87\,m^3}{86100\,\text{J/kg}}$$

$$m = \frac{4.305 \times 10^5}{86100} = 5.\text{kg}$$

84. The vander Waals equation of state is given as, $\left(p + \frac{a}{v^2}\right)(v - b) = R_uT$, where p in bar, v in m^3/kmol and T is in K.
for air, the constants, a and b, are 1.368 bar.$(m^3/kmol)^2$ and 0.0367 m^3/kmol. respectively. Air is contained in a system at 160 K and 0.08 m^3/kmol. If p_1 is the pressure calculated using ideal gas equation of state and p_2 is pressure calculated using vander Walls equation of state, then p_1/p_2 is equal to
(a) 1.78 (b) 1.52
(c) 1.28 (d) 1.0

[GATE-XE 2017]

Ans. (a) : We know,

$$p_{ideal} = \frac{R_uT}{V}$$

For ideal gas,

$$p_1 \text{ or } p_{ideal} = \frac{8.314 \times 160}{0.08}\text{kPa} = 16628\text{ kPa}$$

We know, 1 bar = 10^5 = 10^2 kPa
Now, Vander Waals equation

$$\left(p + \frac{a}{v^2}\right)(v - b) = R_uT$$

$$\therefore \left\{p_{vw} + \frac{1.368 \times 10^2}{(0.08)^2}\right\} \times (0.08 - 0.0367) = 8.314 \times 160$$

$\therefore$ p_2 or p_{vw} = 9346.47 kPa

$$\therefore \frac{p_1}{p_2} \text{ or } \frac{p_{ideal}}{p_{vw}} = \frac{16628}{9346.47} = 1.78$$

85. Air contains by volume 79% N_2 (molecular weight = 28 kg/kmol) and 21% O_2 (molecular weight = 32 kg/kmol). A stream of air flows at 32°C, 1 bar, at a rate of $2m^3$/s and is mixed with another stream of O_2 flowing at 0.4 kg/s. The molecular weight of the mixture (up to 2 decimal places) is ______.

[GATE-XE 2017]

Ans. (29.0 to 30.0) : We know that,
1 kmol = 22400 m^3
Hence, molecular weight of N_2 = 28/22400 kg/m^3 = 0.00125 kg/m^3
And molecular weight of O_2 = 32/22400 kg/m^3 = 0.00143 kg/m^3
Hence, the mass of N_2 present in 1 m^3 of air,
$(m)_{N_2}|_V$ = 0.79 × 0.00125 kg = 9.875 × 10^{-4} kg

And the mass of O_2 present in 1 m^3 of air,

$(m)_{O_2}|_V$ = 0.21 × 0.00143 kg = 3.003 × 10^{-4} kg

Therefore, the mass of N_2 present in 1 kg of air,

$$(m)_{N_2}|_m = \frac{9.875\times10^{-4}}{(9.875+3.003)\times10^{-4}} = 0.7668 \text{ kg}$$

And the mass of O_2 present in 1 kg of air,

$$(m)_{O_2}|_m = \frac{3.003\times10^{-4}}{(9.875+3.003)\times10^{-4}} = 0.2332 \text{ kg}$$

The number of moles of N_2 present in 1 kg of air,

$$(n)_{N_2} = \frac{0.7668}{28} \text{ kmol} = 0.0274 \text{ kmol}$$

The number of moles of O_2 present in 1 kg of air,

$$(n)_{O_2} = \frac{0.2332}{32} \text{ kmol} = 0.0073 \text{ kmol}$$

Therefore, the mole fraction of N_2,

$$(X)_{N_2} = \frac{0.0274}{0.0274+0.0073} = 0.7896$$

And mole fraction of O_2,

$$(X)_{O_2} = \frac{0.0073}{0.0274+0.0073} = 0.2104$$

Hence, the molecular weight of air is given by

$$M_{air} = (X)_{O_2}(M)_{O_2} + (X)_{N_2}(M)_{N_2}$$

$$= 0.2104 \times 32 + 0.7896 \times 28$$

$$= 28.84 \text{ kg/kmol}$$

Hence, the characteristic gas constant of air is

$$R_{air} = \frac{\bar{R}}{M_{air}} = \frac{8314}{28.84} \text{ J/kmol.K} = 288.28 \text{ J/kmol.K}$$

Now, let the mass flow rate of air at 32ºC or 305 K, 1 bar, at a flow rate of Q = 2 m^3/s be, $\dot{m}_{air}$.

Therefore,

$$pQ = \dot{m}_{air} \times R_{air} \times T$$

$$\dot{m}_{air} = \frac{pQ}{R_{air}T} = \frac{10^5\times2}{288.28\times305} = 2.275 \text{ kg/s}$$

This stream mixes with another stream of O_2 flowing at 0.4 kg/s.

The number of moles of air flowing per second in the mixture,

$$(n)_{air} = \frac{2.275}{28.84} = 0.0789 \text{ kmol}$$

The number of moles of O_2 flowing per second in the mixture,

$$(n)_{O_2} = \frac{0.4}{32} = 0.0125 \text{ kmol}$$

Therefore, the mole fraction of air in the mixture,

$$(X)_{air} = \frac{0.0789}{0.0789+0.0125} = 0.8632$$

And the mole fraction of O_2,

$$(X)_{O_2} = \frac{0.0125}{0.0879+0.0125} = 0.1368$$

Hence, the molecular weight of the mixture

$$M_{mixture} = (X)_{air}(M)_{air} + (X)_{O_2}(M)_{O_2}$$

$$= 0.8632 \times 28.84 + 0.1368 \times 32 \text{ kg/kmol}$$

$$= 29.27 \text{ kg/kmol}$$

86. An equimolar mixture of two ideal gases (A, B) expands isentropically in a nozzle. The gas mixture enters the nozzle at 300 kPa, 400 K and exits at 100 kPa. Assuming the mixture to be an ideal gas, the exit temperature of the gas mixture (in K) is ________.

	Molar mass (kg/kmol	**C_P (kJ/kg-K)**
Gas A	**28.013**	**1.04**
Gas B	**2.016**	**14.21**

[GATE-XE 2016: 2M]

Ans. (286 to 297) : The molar mass of the gas mixture,

$M_{mixture} = M_A X_A + M_B X_B$

= (28.013 × 0.5 + 2.016 × 0.5) kg/kmol = 15.015 kg/kmol

For mass of gas A present in 1 mole of the mixture,

$m_{A|mol}$ = 0.5 × 28.013 kg = 14.0065 kg

For mass of gas B present in 1 mole of the mixture,

$m_{B|mol}$ = 0.5 × 2.016 kg = 1.008 kg

Therefore, the mass of Gas A present in 1 kg of the mixture,

$$m_{A|mass} = \frac{14.0065}{14.0065+1.008} \text{ kg} = 0.9329 \text{ kg}$$

And the mass of gas B present in 1 kg of the mixture,

$$m_{B|mass} = \frac{1.008}{14.0065+1.008} \text{ kg} = 0.0671 \text{ kg}$$

Hence, the specific heat of the mixture,

$$(C_P)_{mixture} = \frac{m_A|_{mass}(C_P)_A + m_B|_{mass}(C_P)_B}{m_A|_{mass} + m_B|_{mass}}$$

$(C_P)_{mixture}$ = 1.9237 kJ/kg.K

Therefore, the molar specific heat at constant pressure of the mixture,

$(C_P)_{mixture|molar} = (C_P)_{mixture} \times M_{mixture}$ = 28.884 kJ/kmol.K

Hence, the molar specific heat at constant volume of the mixture,

$(C_v)_{mixture|molar}$

= $(C_P)_{mixture|molar}$ − R = (28.884 − 8.314) kJ/kmolK

= 20.57 kJ/kmol.K

Therefore, the adiabatic index,

$$\gamma = \frac{(C_P)_{mixture}|_{molar}}{(C_V)_{mixture}|_{molar}} = \frac{28.884}{20.57}$$

$\gamma = 1.4$

For an isentropic process of an ideal gas we have,

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$T_2 = 400 \times \left(\frac{100}{300}\right)^{\frac{1.4-1}{1.4}} \text{ K}$$

T_2 = 292.3 K

87. The absolute temperature of an ideal diatomic gas is quadrupled. What happens to the average speed of molecules?

(a) Quadruples
(b) Doubles
(c) Triples
(d) Increases by a factor of 1.41

AP PGECET 2016

Ans. (b) : From Maxwell-Boltzmann statistical theory the average speed of molecules of an ideal gas at the temperature T is given as,

$$v_{avg} = \sqrt{\frac{8kT}{\pi m}}$$

Where, m is the mass of molecules and K is Boltzmann constant.
Now, if the temperature from T becomes 4T.
Then,

$$V_{avg} = \sqrt{\frac{8k \times 4T}{\pi m}}$$

$$V_{avg} = 2\sqrt{\frac{8kT}{\pi m}}$$

$V_{avg} = 2 \times v_{avg.}$

88. An ideal gas mixture of oxygen (molecular weight = 32 kg/kmol) and carbon dioxide (molecular weight = 44 kg/kmol) has a mass composition of 40% and 60% respectively. If the total pressure is 200 kPa, the partial pressure of oxygen (in kPa) is ___

[GATE-XE 2015]

Ans. (95.66 kPa) : Mass composition of O_2 = 40%

$\therefore\ (m)_{o_2} = 40\,g$

Mass composition of CO_2 = 60%

$\therefore\ (m)_{CO_2} = 60\,g$

Mole fraction of O_2, $(X)_{O_2} = \frac{\text{number of moles of } O_2}{\text{total moles}}$

$$(X)_{O_2} = \frac{\frac{40}{32}}{\frac{40}{30} + \frac{60}{44}}$$

Using Dalton's law of partial pressure,

(Partial pressure) $O_2 = (X)_{O_2} \times P_{total}$

= 0.4783×200 kPa
= 95.66 kPa

89. The Vander Waals equation of state is $\left(p + \frac{a}{v^2}\right)(v - b) = RT$, where p is pressure, v is specific volume, T is temperature and R is characteristic gas constant. The SI unit of a is

(a) J/kg-K
(b) m^3/kg
(c) $m^5/kg\text{-}s^2$
(d) Pa/kg

[GATE-2015; Set-II: 1M]

Ans. (c) : From the Vander Waals equation,

$$\left(p + \frac{a}{V^2}\right)(v - b) = RT$$

For the unit of pressure and (a/v^2) should be same,

$\therefore$ unit of p = unit of $\frac{a}{V^2}$

$$\frac{kg}{m - s^2} = \frac{(kg)^2 \times a}{m^6}$$

$a = m^5/kg\text{–}s^2$

90. A mixture of ideal gases has the following composition by mass :

N_2	O_2	CO_2
60%	**30%**	**10%**

If the universal gas constant is 8314 J/kmol-K, the characteristic gas constant of the mixture (in J/kg-K) is ________

[GATE-2015; Set-III: 2M]

Ans. (274 to 276) : $R_{N_2} = \frac{\bar{R}}{M_{N_2}} = \frac{8314}{28} = 296.928\frac{J}{kgK}$

$$R_{O_2} = \frac{\bar{R}}{M_{O_2}} = \frac{8314}{32} = 259.8125\frac{J}{kgK}$$

$$R_{CO_2} = \frac{\bar{R}}{M_{CO_2}} = \frac{8314}{44} = 188.954\frac{J}{kgK}$$

$$R_{mix} = \frac{m_{N_2}R_{N_2} + m_{O_2}R_{O_2} + m_{CO_2}R_{CO_2}}{m_{N_2} + m_{O_2} + m_{CO_2}}$$

$$= \frac{0.6 \times 296.928 + 0.3 \times 259.8125 + 0.1 \times 188.955}{0.6 + 0.3 + 0.1}$$

= 275.9960 J/kg K

91. The gas constant (R) is equal to the

(a) Sum of two specific heats
(b) Difference of two specific heats
(c) Product of two specific heats
(d) Ratio of two specific heats

Karnataka PGCET 2015

Ans. (b) : We know that,
Mayer's equation for an ideal gas,

$R = C_p - C_v$

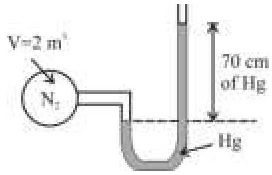
Where R is gas constant.
C_p is specific heat of the gas at constant pressure.
C_v is specific heat of the gas at constant volume.

92. Temperature of nitrogen in a vessel of volume 2 m^3 is 288 K. A U-tube manometer connected by the vessel shows a reading of 70 cm of mercury (level higher in the end open to atmosphere). The universal gas constant is 8314 J/kmol-K, atmospheric pressure is 1.01325 bar, acceleration due to gravity is 9.81 m/s^2 and density of mercury is 13600 kg/m^3. The mass of nitrogen (in kg) in the vessel is____

[GATE-2015;Set-I:2M]

Ans. (4.4 to 4.6) : Temperature of Nitrogen (T) = 288 K
Reacting of manometer (h) = 70 cm = 0.7 m
Universal gas constant $(\bar{R})$ = 8314 J/kmol K
Atmospheric pressure (P_{atm}) = 1.01325 bar = 101.3 kPa
Density of mercury (ρ_{Hg}) = 13600 kg/m^3
Volume of vessel (V) = 2 m^3

Now, Mercury gauge pressure = $\rho_{Hg} \times h \times g$
$= 13600 \times 0.7 \times 9.81$
$= 93.39$ kPa
$\because$ Absolute pressure (P) = 101.3 + 93.39
= 194.6 kPa



We know that,
Ideal gas equation,

$$PV = mRT \qquad \text{........(i)}$$

Where, R is specific gas constant,

$$R = \frac{\overline{R}}{\text{Molar mass}}$$

$$R = \frac{8.314}{28} = 0.296\,\text{kJ/kgK}$$

Value of R putting in the equation (i),

$$m = \frac{PV}{RT} = \frac{194.6 \times 2}{0.296 \times 288} = 4.56\,\text{kg}$$

m = 4.56 kg

93. For a gas obeying the equation of state given by $\left(P + \frac{a}{v^2}\right)v = RT$, the values of the critical volume and the critical temperature are 0.004 m^3/kg and 100°C, respectively. If the value of the gas constant is 250 J/(kg.K), then the value of the constant 'a' is __________ ($N.m^4/kg^2$). Note that the critical point is the point of inflection on the critical isotherm.

(a) 124.3 (b) 0.75
(c) 186.58 (d) 248.67

[GATE-XE 2014: 2M]

Ans. (c) : As the critical point is the point of inflection on critical isotherm,

$$\left(\frac{\partial P}{\partial V}\right)_{T=T_c} = 0 \qquad \text{… (i)}$$

Given,

$$\left(P + \frac{a}{v^2}\right)v = RT \qquad \text{… (ii)}$$

From equation (i), differentiating P w.r.t v at constant temperature, we get,

$$P = \frac{a}{v^2}$$

Substituting the value of P in equation (ii), we get

$$\frac{2a}{v} = RT$$

$\therefore$ 2a = 250 × 373 × 0.004
$\Rightarrow$ a = 186.58

94. The molecular weight of a mixture is 38.4 gm/mol. The mixture is composed of methane and carbon-dioxide gases. The atomic weights of the elements C, H, and O are 12, 1, and 16 gm/mol, respectively. The mole fraction of methane ($X_{methane}$) is ________ and that of carbon-dioxide ($X_{carbon\ dioxide}$) is _________.

(a) $X_{methane} = 0.2$; $X_{carbon\ dioxide} = 0.8$
(b) $X_{methane} = 0.8$; $X_{carbon\ dioxide} = 0.2$
(c) $X_{methane} = 0.3$; $X_{carbon\ dioxide} = 0.7$
(d) $X_{methane} = 0.7$; $X_{carbon\ dioxide} = 0.3$

[GATE-XE 2014: 1M]

Ans. (a) : Molecular weight of CH_4 (M_1) = 16 gm/mol
Molecular weight of CO_2 (M_2) = 44 gm/mol
Molecular weight of mixture (M_{mixt}) = 38.4 gm/mol
$M_{mixt} = M_1x_1 + M_2x_2$, where x_1 and x_2 are the mole fractions of CH_4 and CO_2 respectively.
$38.4 = 16\,x_1 + 44\,x_2$
$16\,x_1 + 44\,(1 - x_1) = 38.4$
$16\,x_1 + 44 - 44\,x_1 = 38.4$
$-28\,x_1 = -5.6$
Mole fraction of CH_4 (x_1) = 0.2
Mole fraction of CO_2 (x_2) = 0.8

95. In the Vander Waals equation of state given below:

$$\left(p + \frac{a}{v^2}\right)(v - b) = RT$$

The constant *a* represents the effect of

(a) attractive forces between molecules
(b) repulsive forces between molecules
(c) deviation from molecules being spherical
(d) finite size of the molecule

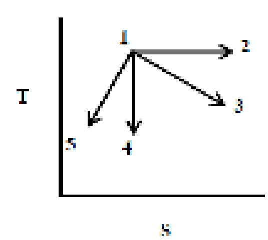
[GATE-XE 2013: 1M]

Ans. (a) : The Vander Waals law is based on the plausible reasons that real gases deviate from the ideal gas law. The ideal gas law treats gas molecules as point particles, which are neither attracted or repelled for, real gases, Vander Waals provided for intermolecular attraction, by adding to the observed pressure p in the equation of state a term a.

$$\left(p + \frac{a}{v^2}\right)(v - b) = RT$$

In the equation **a** represent attractive forces between the molecules.

96. Which of the following processes, shown in the figure below, represents the throttling of an ideal gas?



(a) 1 to 2 (b) 1 to 3
(c) 1 to 4 (d) 1 to 5

[GATE-XE 2013: 1M]

Ans. (a) : For ideal gas enthalpy is a function of temperature, i.e., $dh = nC_pdT$.
And in throttling, the enthalpy remains constant, therefore the temperature remains same.
In the graph, the line depicting constant temperature is 1-2.

97. For an ideal gas as a working fluid for a given heat input Q, the process that gives the maximum work among the following four processes is

(a) isothermal (b) constant volume
(c) constant pressure (d) isentropic

[GATE-XE 2013: 1M]

Ans. (a) : From the first law of thermodynamics,

$Q = \Delta U + W$

$W = Q - \Delta U$

For an isothermal process, dT = 0

$W = Q$

For an isochoric process, dV = 0

$W = 0$

For a constant pressure process,

$W = Q - \Delta U$

$= nC_p\Delta T - nC_v\Delta T$

$= n(C_p - C_v)\Delta T$

For an isentropic process,

$Q = \Delta U + W$

$T\Delta s = \Delta U + W$

$W = -\Delta U$

Therefore, the work done is the maximum in an isothermal process.

98. Which material has the lowest specific heat capacity at room temperature?

(a) Water (b) Mercury
(c) Copper (d) Silver

[GATE-XE 2012: 1M]

Ans. (b) : Specific heat capacity:- This is the amount of energy needed to raise the temperature of 1 kg of a material by 1°C.

$E = m \times C \times \theta$

Where,

E = Energy (J)

C = specific heat capacity ($J°C^{-1}\ kg^{-1}$)

θ = change in temperature (°C)

m = Mass (kg)

The specific heat capacity of substances at room temperature and atmospheric pressure is given below,

Substance	Specific heat capacity ($J\ kg^{-1}\ K^{-1}$)
Water	4186
Mercury	140
Silver	900
Copper	385

99. One kilomole of hydrogen (M = 2 kg/kmol) is mixed with certain number of kilomoles of argon (M = 40 kg/kmol) such that the mass fraction of argon in the resultant mixture is 0.8. The number of kilomoles of argon in the mixture is

(a) 0.05 (b) 0.10
(c) 0.15 (d) 0.20

[GATE-XE 2011:2M]

Ans. (d) : Let number of kilo moles of argon in mixture = x

$$m_{total} = m_A + m_B = m_{H_2} + m_{Ar}$$

The mass fraction of each component becomes,

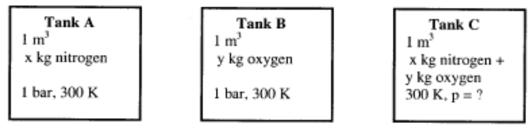
$$m_{H_2} = N_{H_2}M_{H_2}$$

$$m_{Ar} = N_{Ar}M_{Ar}$$

$$mf_{Ar} = \frac{m_{Ar}}{m_{total}} = \frac{m_{Ar}}{m_{H_2} + m_{Ar}} = \frac{N_{Ar}M_{Ar}}{N_{H_2}M_{H_2} + N_{Ar}M_{Ar}} = \frac{40x}{2+40x} = 0.8$$

Hence, number of kilo moles of argon in mixture is, x = 0.2 .

100. Consider three identical tanks A, B and C, shown below. What is the pressure p in tank C?



(a) 1 bar (b) 1.5 bar
(c) 2 bar (d) 2.5 bar

[GATE-XE 2011:1M]

Ans. (c) : For Tank A,

$P_A V_A = n_A RT_A$

$1 \times 1 = n_A \times R \times 300$

$$n_A = \frac{1}{300R}$$

For Tank B,

$P_BV_B = n_BRT_B$

$1 \times 1 = n_B \times R \times 300$

$$n_B = \frac{1}{300R}$$

For Tank C,

$P_C V_C = n_C RT_C$

$P_C V_C = n_C \times R \times 300$

$\therefore n_C = n_A + n_B$

$1 \times P_C = (n_A + n_B) \times R \times 300$

$$P_C = \left(\frac{1}{300R} + \frac{1}{300R}\right) \times 300R$$

$$P_C = \frac{2}{300R} \times 300R$$

P_C= 2 bar

101. Specific heat at constant pressure (C_p) of Helium is 5.19 kJ/Kkg and its molecular mass is 4 kg/kmol. The specific heat at constant volume, in kJ/Kkg, is

(a) 1.11 (b) 2.11
(c) 3.11 (d) 4.11

[GATE-XE 2011:1M]

Ans. (c) : Given,

C_p = 5.19 kJ/Kkg, m = 4 kg/kmol

We know that,

$C_p - C_v = R$

$C_v = C_p - R = 5.19 - (8.314/4)$

C_v = 3.11 kJ/Kkg

102. An ideal gas is known to obey following relationships; u = 200 + 0.718 T and Pν = 0.287 (T + 273), where u is specific internal energy (kJ/kg), T is temperature (°C), P is pressure (kPa) and ν is specific volume (m^3/kg). Specific heat (in kJ/kg-K) at constant pressure is

(a) 0.287 (b) 0.431
(c) 0.718 (d) 1.005

[GATE-XE 2010: 1M]

Ans. (d) : We know that,

$h = u + P_V$

$C_P\ (T + 273) = 200+0.718T + 0.287(T + 273) = 278.35+1.005T$

Let,

$T = 0^oC$

$C_P = 278.35 / 273$ kJ / kg-K

= 1.019 kJ/kg-K

The closest answer among the given options is 1.005 kJ/kg-K .

103. A mixture of Freon and air is supplied for cleaning a chamber. The mixture contains 70% by volume of air and 30% by volume of Freon. Specific heat ratios for Freon and air are 1.1 and 1.4 respectively. Molecular mass of Freon is 200 g/mole and that of air is 30 g/mole. Temperature of gas is 300 K. If, universal gas constant is 8.314 J/mole-K, specific heat ratio of the mixture is

(a) 1.16 (b) 1.21

(c) 1.25 (d) 1.31

[GATE-XE 2010: 2M]

Ans. (b) :

Component	Percent volume	Mole fraction	Molecular mass	Mass of gas
Freon	30%	0.3	200 g/mole	200× 0.3 = 60 g
Air	70%	0.7	30 g/mole	30× 0.7 = 21g

$$R_{air} = \frac{R_0}{M_{air}} = \frac{8.314}{30} \text{ J/g.K} = 0.277 \text{ J/g.K}$$

$$(C_P)_{air} = \frac{\gamma_{air} R_{air}}{\gamma_{air} - 1} = \frac{1.4 \times 0.277}{1.4 - 1} \text{ J/g.K} = 0.9695 \text{ J/g.K}$$

$$(C_V)_{air} = \frac{R_{air}}{\gamma_{air} - 1} = \frac{0.277}{1.4 - 1} \text{ J/g.K} = 0.6925 \text{ J/g.K}$$

$$R_{freon} = \frac{R_0}{M_{freon}} = \frac{8.314}{200} \text{ J/g.K} = 0.04157 \text{ J/g.K}$$

$$(C_P)_{freon} = \frac{\gamma_{freon} R_{freon}}{\gamma_{freon} - 1} = \frac{1.1 \times 0.04157}{1.1 - 1} \text{ J/g.K} = 0.45727 \text{ J/g.K}$$

$$(C_V)_{Freon} = \frac{R_{freon}}{\gamma_{freon} - 1} = \frac{0.04157}{1.1 - 1} \text{ J/g.K} = 0.4157 \text{ J/g.K} .$$

Now, $$(C_P)_{mixture} = \frac{m_{air}(C_P)_{air} + m_{freon}(C_p)_{freon}}{m_{air} + m_{freon}}$$

$$= \frac{21 \times 0.9695 + 60 \times 0.45727}{21 + 60} \text{ J/g.K}$$

= 0.59 J/g.K

Therefore,

$$\gamma_{mixture} = \frac{(C_P)_{mixture}}{(C_V)_{mixture}} = \frac{0.59}{0.4875} = 1.21$$

104. An ideal gas (γ = 1.39) flows in a pipeline at 450 °C and 20 bar. A rigid, insulated and initially evacuated vessel is connected to the pipeline through a valve. The valve is now opened and the gas is allowed to fill the empty vessel. The final temperature of the gas in the vessel is

(a) 247 °C (b) 450 °C

(c) 625 °C (d) 732° C

[GATE-XE 2009: 2M]

Ans. (d) : Initial temperature,

$T_1 = 450^oC = (450 + 273) = 723$ K

Final temperature, $T_2 = ?$

$\gamma = 1.39$

Now,

$T_2 = \gamma \times T_1 = 1.39 \times 723$

$T_2 = 1004.97 \text{ K} = 732^oC$

105. An equi-molar mixture of nitrogen (γ = 1.4) and helium (γ = 1.67) is initially at 5 bar and 300 °C. The mixture is expanded adiabatically to a pressure of 2 bar. The final temperature of the mixture is

(a) 149 °C (b) 200 °C

(c) 250 °C (d) 524 °C

[GATE-XE 2009: 2M]

Ans. (a) :

$$(C_P)_{mix} = \frac{n_1(C_P)_1 + n_1(C_P)_2}{n_1 + n_2} = \frac{1}{2}\left(\frac{\gamma_1 R_0}{\gamma_1 - 1} + \frac{\gamma_2 R_0}{\gamma_2 - 1}\right),$$

$$= \frac{R_0}{2}\left(\frac{1.4}{1.4-1} + \frac{1.67}{1.67-1}\right)$$

$= 2.996\ R_0$

$$(C_V)_{mix} = \frac{n_1(C_P)_1 + n_1(C_P)_2}{n_1 + n_2} = \frac{1}{2}\left(\frac{R_0}{\gamma_1 - 1} + \frac{R_0}{\gamma_2 - 1}\right),$$

$$= \frac{R_0}{2}\left(\frac{1}{1.4-1} + \frac{1}{1.67-1}\right) = 1966 R_0$$

Therefore, $\gamma_{mix} = 1.5$

Therefore,

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{\frac{\gamma_{mix}-1}{\gamma_{mix}}} = (300 + 273) \times \left(\frac{2}{5}\right)^{\left(\frac{1.5-1}{1.5}\right)} \text{K} = 422 \text{K}$$

$T_2 = 422 - 273 = 149^oC$

106. An ideal gas undergoes expansion according to process $PV^{0.5}$ = constant. The temperature of the gas during the expansion process

(a) does not change

(b) increases

(c) decreases

(d) changes depending on the initial condition

[GATE-XE 2009: 1M]

Ans. (b) : Given,

n = 0.5

For a polytropic process of an ideal gas,

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\left(\frac{n-1}{n}\right)}$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\left(\frac{0.5-1}{0.5}\right)}$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{-1} = \frac{P_1}{P_2}$$

Now, for an expansion process $P_1 > P_2$,

Therefore,

$T_2 > T_1$

Hence, the temperature of the gas during the expansion process is increases.

107. The ideal gas law is valid for

(a) inert gases

(b) gases at high pressure and high temperature

(c) gases at low pressure and low temperature

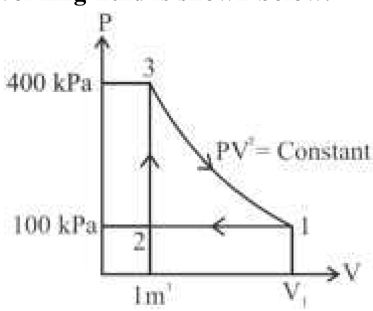
(d) gases at low pressure and high temperature

[GATE-XE 2009: 1M]

Ans. (d) : The ideal gas law is valid for gases at low pressure and high temperature.

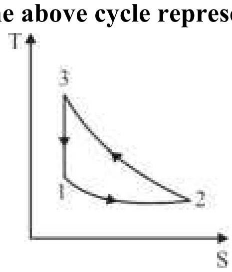
Common Data for Questions 108-109

A thermodynamic cycle with an ideal gas as working fluid is shown below.

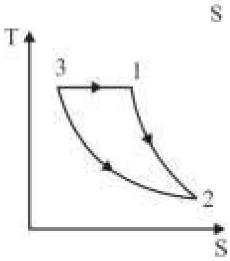


108. The above cycle represented on T-S plane by

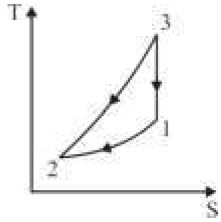
(a)



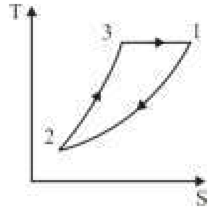
(b)



(c)



(d)



[GATE-2007: 2M]

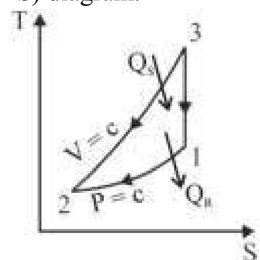
Ans. (c) : In the given (P–V) diagram process:

(1 – 2) → Isobaric compression

(2 – 3) → Isochoric heat addition

(3 – 1) → Isentropic expansion

∴ Cycle on (T – S) diagram.



109. If the specific heats of the working fluid are constant and the value of specific heat ratio is 1.4, the thermal efficiency (%) of the cycle is

(a) 21 (b) 40.9

(c) 42.6 (d) 59.7

[GATE-2007: 2M]

Ans. (a) : From the above (T – S) diagram.

Heat supplied, $Q_S = c_v (T_3 - T_2)$

Heat rejection, $Q_R = c_p (T_1 - T_2)$

Efficiency of the cycle,

$$\eta = 1 - \frac{Q_R}{Q_S}$$

$$= 1 - \frac{c_p(T_1 - T_2)}{c_v(T_3 - T_2)}$$

$$= 1 - \gamma\frac{P_1(V_1 - 1)}{(P_3 - P_2)}$$

Since, process (3 → 1) is isentropic,

So, $P_1V_1^\gamma = P_3V_3^\gamma$

$V_1 = (4)^{1/\gamma} = 2.692\ m^3$

$$\eta = 1 - 1.4\frac{100(2.692 - 1)}{300}$$

$$= 1 - \frac{1.4 \times 1.692}{3}$$

= 0.2104

η = 21.04%

110. The specific heats of an ideal gas depend on its
(a) Temperature
(b) Pressure
(c) Volume
(d) Molecular weight and structure

[GATE-1996: 1M]

Ans. (d) : The specific heat of an ideal gas.

$c_p = \frac{\gamma R}{\gamma - 1}$ and $c_v = \frac{R}{\gamma - 1}$

Where,
R = Gas constant and depends upon molecular weight as

$R = \frac{\overline{R}}{M}$ [M = Molecular weight]

and γ depends upon the molecular structure, i.e. Mono-atomic, diatomic and poly-atomic.

111. The slopes of constant volume and constant pressure lines in the T-S diagram are ………. and ……. respectively.

[GATE-1994, 2M]

Ans. (Higher, Lower) :
For unit mass of substance, the entropy changes are,

$$dS = c_v \frac{dT}{T} \quad \text{(For constant volume)}$$

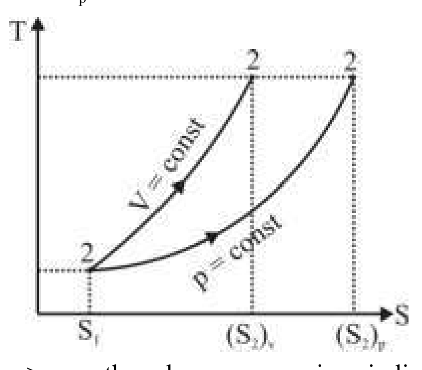
and $$dS = c_p \frac{dT}{T} \quad \text{(For constant pressure)}$$

Therefore, slope of the constant volume line on T-S diagram.

$$\frac{dT}{dS} = \frac{T}{c_v}$$

And slope of the constant pressure line T-S diagram,

$$\frac{dT}{dS} = \frac{T}{c_p}$$



Since, $c_p > c_v$, the above expression indicate that constant volume line on T-S diagram is steeper than constant pressure line working between the same temperature limits.
Hence, the slopes of constant volume and constant pressure lines in the T-S diagram are higher and lower respectively.

D. Zeroth Law of Thermodynamics

112. For the measurement of thermodynamic property known as temperature, is based on
(a) Zeroth law of thermodynamics
(b) First law of thermodynamics
(c) Second law of thermodynamics
(d) Third law of thermodynamics

AP PGECET 29.09.2020, Shift-II

Ans. (a) : The measurement of thermodynamic property of temperature is based on Zeroth law of thermodynamics.
The Zeroth law of thermodynamics :- If two bodies are each in thermal equilibrium with same third body, then they are also in equilibrium with each other. Thermal equilibrium means that when two bodies are brought into contact with each other and are separated by a barriers that is permeable to heat from one to the other.

113. The basis for measuring thermodynamic properties of temperature is given by
(a) zeroth law of thermodynamics
(b) first law of thermodynamics
(c) second law of thermodynamics
(d) third law of thermodynamics

AP PGECET 11.05.2017, Shift-II

Ans. (a) : Zeroth law of thermodynamics is the basis of temperature measurement.

114. Air with enthalpy of 100 kJ/kg. is compressed to a pressure and temperature where enthalpy becomes 200 kJ/kg. The loss of heat from compressor if 40 kJ/kg. Neglecting kinetic and potential energies, the energy required for air flow rate of 0.5 kg/s is
(a) 30 kW (b) 50 kW
(c) 70 kW (d) 90 kW

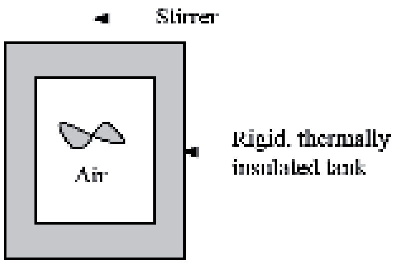
AP-PGECET 2015

Ans. (c) : Given,
Q = 40 kJ/kg
h_1 = 100 kJ/kg
h_2 = 200 kJ/kg
Air compressor steady flow of the energy equations is
$h_1 + W = h_2 + Q$
Per kg work required is
$W = (h_2 - h_1) + Q$
$= (200 - 100) + 40$
$= 100 + 40$
W = 140 kJ/kg
Therefore, The power required for the air mass flow is
P = 140 × 0.5
P = 70 kW
Hence, for mass flow rate of 0.5 kg/s, the work required is 70 kW.

02 FIRST LAW OF THERMODYNAMICS

A. Introduction

115. Air inside a rigid, thermally-insulated tank undergoes stirring as shown in the figure below. Which one of the following options is correct?



(a) The enthalpy of the air increases while the entropy of the air remains constant
(b) Both the enthalpy and the entropy of the air remain constant
(c) Both the enthalpy and the entropy of the air increase
(d) The enthalpy of the air decreases while the entropy of the air increases

[GATE-2025: 1M]

Ans. (c) : Insulated cylinder (Q) = 0
Rigid cylinder (dV) = 0 ⇒ $W_{exp} = PdV = 0$
Stirrer energy is converted to gain in energy of the gas i.e., temperature of gas increases. Since air is treated as an ideal gas, both internal energy and enthalpy increases.
The increase in temperature of air is an indication of increase in entropy of air.
At V = C

$$P\uparrow \propto T\uparrow \Rightarrow T_2 > T_1 \ \& \ P_2 > P_1$$

$$(dS)_{system} = c_p \, ln\left(\frac{T_2}{T_1}\right) - R \, ln\left(\frac{P_2}{P_1}\right)$$

116. Joule's experiment states that for a cycle process
(a) Change of pressure is proportional to temperature change
(b) Change of volume is proportional to temperature change
(c) Change of internal energy is proportional to temperature change
(d) Sum of all heat transfer is proportional to sum of all work transfer

AP-PGECET 30.05.2024, Shift-II

Ans. (d) : Joule's conducted a series of experiments which showed the relationship between heat and work in a thermodynamics cycle for a system.

$$(\Sigma W)_{cycle} = J.\ (\Sigma Q)_{cycle}$$

Where, J = Joule's equivalent.

117. Given below are two statements : One is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A) : First law of thermodynamics is the law of conservations of energy.
Reasons (R) : First law of thermodynamics is related to irreversibility in a system.
In the light of the above statements, choose the most appropriate answer from the options given below:
(a) Both (A) and (R) are true and (R) is the correct explanation of (A)
(b) Both (A) and (R) are true but (R) is **NOT** the correct explanation of (A)
(c) (A) is true but (R) is false
(d) (A) is false but (R) is true

NTA CUET-PG 14.06.2023

Ans. (c) : First law of thermodynamics is based on law of conservation of energy
$dQ = dU - dW$
Where dW is work done on the system.
This statement, the first law of thermodynamic is related to irreversible in a system is false.
The first law of thermodynamics is concerned with the conservation of energy and is applicable to all process, regardless of weather they are reversible or irreversible.

118. Joule's law states that the specific internal energy of a gas depends only on ______.
(a) the pressure of the gas
(b) the volume of the gas
(c) the temperature of the gas
(d) the density of the gas

AP PGECET 29.09.2020, Shift-II

Ans. (c) : Joule's law states that the specific internal energy of a gas depends on the temperature of the gas, because the internal energy of a gas is independent of its pressure and volume. This is because there are no intermolecular force of attraction and repulsion in an ideal gas.

119. The statement which is NOT a consequence of the first law of thermodynamics is
(a) Heat is a path function
(b) Energy is a property of a system
(c) Energy of an isolated system is not conserved
(d) A perpetual motion machine of the first kind is not possible

[GATE-XE 2018: 1M]

Ans. (c) : The first law of thermodynamics is energy of an isolated system is not conserved.

120. According to first law of thermodynamics,
(a) mass and energy are mutually convertible
(b) heat and work are mutually convertible
(c) Carnot engine is most efficient
(d) heat flows from hot substance to cold substance

AP PGECET 11.05.2018, Shift-II

Ans. (b) : The first law of thermodynamics.
"For a closed system undergoing a cycle net heat transfer is equal to network transfer"
$\sum Q = \sum W$
So, now
Heat and work are mutually convertible.

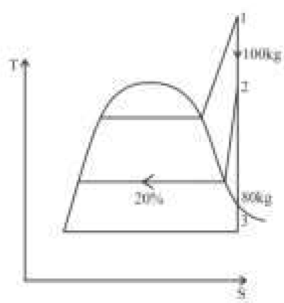
121. Which of the following statements are TRUE with respect to heat and work?
(i) They are boundary phenomena
(ii) They are exact differentials
(iii) They are path functions
(a) both (i) and (ii) (b) both (i) and (iii)
(c) both (ii) and (iii) (d) only (iii)
[GATE-2016; Set-1: 1M]

Ans. (b) : Heat:-
1. When heat is added to the system, it is taken as positive.
2. Heat transfer is path function.
3. Heat is not a property.
4. Heat is inexact differential.
5. Heat is boundary phenomena.
6. Heat is energy in transit.

Works:
1. Work transfer is path function.
2. It is not a property.
3. It is inexact differential.
4. It is boundary phenomena.
5. When work is added to the system, it is taken negative.
6. Work is energy in transit.

122. Steam enters a well insulated turbine and expands isentropically throughout. At an intermediate pressure, 20 percent of the mass is extracted for process heating and the remaining steam expands isentropically to 9 kPa. Inlet to turbine: P = 14 MPa, T = 560 °C, h = 3486 kJ/kg, s = 6.6 kJ/(kg. K)
Intermediate stage: h = 2776 kJ/kg
Exit of turbine: P = 9 kPa, h_f = 174 kJ/kg, h_g = 2574 kJ/kg, s_f = 0.6 kJ/(kg.K), s_g = 8.1 kJ/(kg.K).
If the flow rate of steam entering the turbine is 100 kg/s, then the work output (in MW) is_____
[GATE-2015; Set-I: 2M]

Ans. (123.56 to 127.56) : Given,



$h_1 = 3486$ kJ/kg, $h_2 = 2776$ kJ/kg
$h_3 = ?$
$s_1 = s_2 = s_3 = s_f + xs_{fg} = 6.6$
$s_f + xs_{fg} = 6.6$
$0.6 + xs_{fg}(8.1 - 0.6) = 6.6$
$x = 0.8$
$h_3 = 174 + 0.8\,(2574.174)$
$= 2094$ kJ/kg
$W_{net} = m_1(h_1 - h_2) + m_3(h_2 - h_3)$
$W_{net} = 100\{3486 - 2776\} + 80\{2776 - 2094\}$
$= 125560$ kW
$W_{net} = 125.56$ MW

123. Heat and work are
(a) Intensive properties
(b) Extensive properties
(c) Point function
(d) Path function
[GATE-2011: 1M]

Ans. (d) : Heat and work are path functions.

B. First Law of Thermodynamics-Closed System

124. During one cycle the working fluid in an engine engages in two work interactions: 15 kJ to the fluid and 45 kJ from the fluid, and three heat interactions, two of which are known: 75 kJ to the fluid and 40 kJ from the fluid. The magnitude and direction of the third heat transfer is
(a) 5 kJ from the system
(b) 55 kJ into the system
(c) 5 kJ into the system
(d) – 5 kJ from the system
AP-PGECET 30.05.2024, Shift-II

Ans. (d) : Given,
$W_1 = -15$ kJ
$W_2 = +45$ kJ
$Q_1 = +75$ kJ
$Q_2 = -\ 40$ kJ
According to first law thermodynamics
$\sum dQ = \sum dW$
$\therefore \quad Q_1 + Q_2 + Q_3 = W_1 + W_2$
$75 - 40 + Q_3 = -15 + 45$
$35 + Q_3 = 30$
$Q_3 = 30 - 35$
$Q_3 = -\,5$ kJ from the system

125. 1 kg of a substance receives 500 kJ heat and undergoes a temperature change from 100 °C to 200 °C. The average specific heat of the substance during the process (in kJ/kg K) will be
(a) 5 (b) 10
(c) 25 (d) 2.5
TS PGECET 06.11.2024

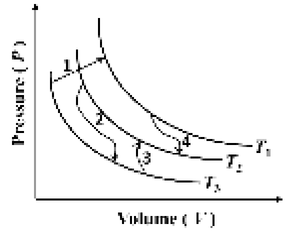
Ans. (a) Given,
Heat receives, Q = 500 kJ
Mass, m = 1 kg
$T_1 = 200°C$
$T_2 = 100°C$
Temperature change $\Delta T = T_1 - T_2$
$= 200 - 100 = 100°C$
We know that,
$Q = mC\Delta T$

$500 = 1 \times C \times 100$

$C = \frac{500}{100} = 5$ kJ/kg. K

The average specific heat, C = 5 kJ/kg. K

126. The figure shows four different processes labelled 1,2,3 and 4 for the same closed system containing an ideal gas. The curves labelled T_1, T_2 and T_3 are isotherms. For which one of these four processes the magnitude of internal energy change is the highest?



(a) Process 1 (b) Process 2
(c) Process 3 (d) Process 4

[GATE-XE 2024: 1M]

Ans. (a) : The internal energy is the function of temperature only

$\Delta U = C_V \Delta T$

Now, Then the ΔT is highest for process 1.

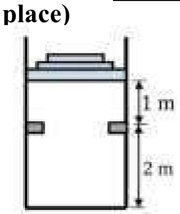
127. A closed system containing an unknown substance undergoes an adiabatic process governed by the relation PV^γ = constant, where P is pressure, V is volume, and γ is the ratio of specific heats. For this scenario, which of the following statements is/are always TRUE?

(a) The substance is an ideal gas and process is reversible
(b) The substance is a liquid and process is reversible
(c) The substance is a non-ideal gas and process is reversible
(d) The substance is an ideal gas and process is NOT reversible

[GATE-XE 2024: 1M]

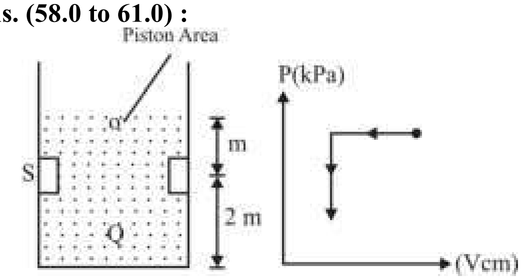
Ans. (a) : PV^γ = constant, is ideal gas equation for reversible adiabatic process.

128. A piston-cylinder arrangement shown in the figure has a stop located 2 m above the base. The cylinder initially contains air at 140 kPa and 350 °C and the piston is resting in equilibrium at a position which is 1 m above the stops. The system is now cooled to the ambient temperature of 25 °C. Consider air to be an ideal gas with a value of gas constant R = 0.287 kJ/(kg.K).
The absolute value of specific work done during the process is _____kJ/kg (rounded off to 1 decimal place)



[GATE-2024: 2M]

Ans. (58.0 to 61.0) :



Given,

$P_1 = 140$ kPa

$T_1 = 623$ K

$T_2 = 298$ K and let A_p be the area of piston

By formula,

$W_{1-2} = P_1 V_1 - P_2 V_2$

$W_{1-2} = mR (T_1 - T_2)$

For constant pressure Process-

$V \propto T$

$\frac{V_1}{V_2} = \frac{T_1}{T_2}$

So, $\frac{A_p \times 3}{A_p \times 2} = \frac{623}{T_2}$

$T_2 = 415.33$K

$W_{1-2} = mR (T_1 - T_2)$

$W_{1-2} = 1 \times 0.287 \times (623 - 415.33)$

$= 59.6$ kJ/kg

129. The temperature of 10 g of liquid water (c_p = 4.2J/g.K) in an insulated container is raised by 5 K by stirring. The amount of heat transferred to the water (in J) is

(a) 210 (b) 420
(c) 0 (d) 105

[GATE-XE 2024: 1M]

Ans. (c) : As container is insulated so heat transfer is zero the temperature is increases because at work transfer.

130. A rigid tank of 2 m^3 internal volume contains 5 kg of water as a saturated liquid-vapor mixture at 400 kPa. Half of the mass of the saturated liquid in the tank is drained out while maintaining constant pressure of 400 kPa in the tank. The final quality of the mixture remaining in the tank is __________ (rounded off to two decimal places).
Use the following data for water:
[At 400 kPa: v_f = 0.001084 m^3/kg, v_{fg} = 0.46138 m^3/kg, v_g = 0.46246 m^3/kg]

[GATE-XE 2023: 2M]

Ans. (0.90 to 0.95) : Given,

$V = 2\ m^3$

$m = 5$ kg

$P_1 = 400$ kPa

$v = \frac{V}{m} = \{v_{f_1} + x_1 v_{fg1}\}$

$\frac{2}{5} = 0.001084 + x_1\ 0.46138$

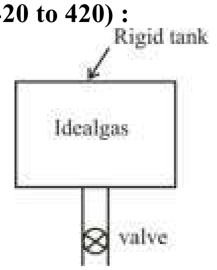
$x_1 = 0.8646$

$m_{g1} = 0.8646 \times 5$
$m_{g1} = 4.323$ kg
$m_{f1} = 5 - 4.323$ kg $= 0.677$ kg
$m_{f2} = \frac{1}{2} \times 0.677 = 0.3385$ kg
$m_{g2} = m_{g1} = 4.323$ kg
$x_2 = \frac{4.323}{0.3385 + 4.323}$
$x_2 = 0.93$

131. A rigid closed tank contains 2 kg of an ideal gas at 500 kPa and 350 K. A valve is opened, and half of the mass of the gas is allowed to escape. Then the valve is closed. If the final pressure in the tank is 300 kPa, the final temperature in the tank is ____________ K (in integer).

[GATE-XE 2023: 1M]

Ans. (420 to 420) :



Given,
$m_1 = 2$ kg
$P_1 = 500$ kPa
$T_1 = 350$ K
$m_2 = 1$ kg
$P_2 = 300$ kPa
$\because \quad V_1 = V_2$
$\therefore \quad \frac{m_1 RT1}{P_1} = \frac{m_2 RT_2}{P_2}$
$\frac{2 \times 350}{500} = \frac{1 \times T_2}{300}$
$T_2 = 420$ K

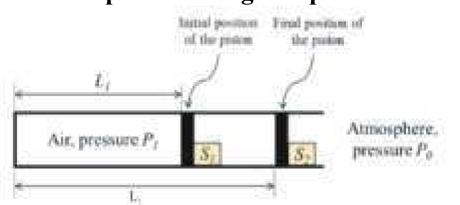
132. Air at 400 K and 200 kPa is heated at constant pressure to 600 K. Assuming that the internal energy is a function of temperature only, the magnitude of change in internal energy during this process is ____________ kJ/kmol (rounded off to one decimal place).
Use the following data:
Molar specific heat of air at constant volume : $\bar{c}_v\left(\text{kJ/k mol} - \text{K}\right) = a + bT + cT^2$
Where T is temperature in K, a = 19.686 KJ/k mol-K, b = 0.002 kJ/k mol-K^2 and c = 0.5 × 10^{-5} KJ/kmol-K^3.

[GATE-XE 2023: 1M]

Ans. (4389 to 4392) : $\overline{C}_v = a + bT + cT^2$
A = 19.686 kJ/kmol-K
b = 0.002 kJ/kmol-K^2
c = 0.5×10^{-5} kJ/kmol-K^3
$T_1 = 400$ K
$P_1 = 200$ kPa
$T_2 = 600$ K
$P_2 = P_1 = 200$ kPa

$$\int d\bar{u} = \int_{T_2} \overline{C}_v dT$$
$$\Delta\bar{u} = \int_{T_1}^{T_2} (a + bT + cT^2)dT$$
$$\Delta\bar{u} = a\left(T_2 - T_1\right) + b\frac{\left(T_2^2 - T_1^2\right)}{2} + c\frac{\left(T_2^3 - T_1^3\right)}{3}$$
$$\Delta\bar{u} = 19.686(600 - 400) + 0.002\frac{\left(600^2 - 400^2\right)}{2} + \frac{0.5}{10^5}\frac{\left(600^3 - 400^3\right)}{3}$$
$$\Delta\bar{u} = 4390.2 \text{ kJ / kmol}$$

133. Consider a fully adiabatic piston-cylinder arrangement as shown in the figure. The piston is massless and cross-sectional area of the cylinder is *A*. The fluid inside the cylinder is air (considered as a perfect gas), with γ being the ratio of the specific heat at constant pressure to the specific heat at constant volume for air. The piston is initially located at a position L_1. The initial pressure of the air inside the cylinder is $P_1 \gg P_0$, where P_0 is the atmospheric pressure. The stop S_1 is instantaneously removed and the piston moves to the position L_2, where the equilibrium pressure of air inside the cylinder is $P_2 \gg P_0$. What is the work done by the piston on the atmosphere during this process?



(a) 0
(b) $P_0A(L_2 - L_1)$
(c) $P_1AL_1 \ln\frac{L_1}{L_2}$
(d) $\frac{\left(P_2L_1 - P_1L_1\right)A}{\left(1 - \gamma\right)}$

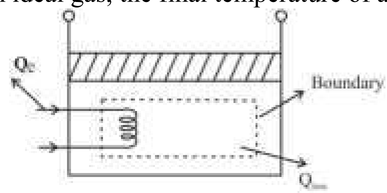
[GATE-2023:2M]

Ans. (b) : From the given data,
$V_1 = L_1 \times A$
$V_2 = L_2 \times A$
$W_{atm} = P_0 (V_2 - V_1)$
$= P_0 (L_2A - L_1A)$
$= P_0A (L_2 - L_1)$

134. A piston-cylinder device initially contains 1 m^3 of air at 200 kPa and 25 °C. Air expands at constant pressure while a heater of 250 W is switched on for 10 minutes. There is a heat loss of 4 kJ during this process. Assuming air as an ideal gas, the final temperature of air is ____________ °C (rounded off to one decimal place).
Use the following data for air: R = 0.287 kJ/kg-K, C_p = 1.005 kJ/kg-K

[GATE-XE 2023: 2M]

Ans. (85.0 to 88.0) : According to question, assuming air as an ideal gas, the final temperature of air is-



Given that,

$V_1 = 1\ m^3$

$P_1 = 200$ kPa

$T_1 = 25°C = 298$ K

$W_e = 250$ W

T = 10 min = 600 sec

$Q_{loss} = -4$kJ

Form the first law of thermodynamics process

$$Q = W + \Delta E$$
$$Q = W_e + W_d + \Delta U$$
$$Q = W_e + pdV + \Delta U$$

For isobaric process,

$$\Delta H = pdV + \Delta U$$
$$\therefore \quad Q = W_e + \Delta H$$
$$Q = W_e + mC_P (T_2 - T_1)$$
$$T_2 = T_1 + \frac{Q - W_e}{mC_P} \quad \text{.....(i)}$$
$$m = \frac{P_1V_1}{RT_1} = \frac{200 \times 10^3 \times 1}{287 \times 298}$$

m = 2.338 kg

$$T_2 = 298 + \left(\frac{-4000 + 250 \times 600}{2.338 \times 1005}\right)$$

$T_2 = 360.136$ K

Or $\quad T_2 = 86.9$ °C

135. Which one of the following statements is FALSE?

(a) For an ideal gas, the enthalpy is independent of pressure.

(b) For a real gas going through an adiabatic reversible process, the process equation is given by PV^γ = constant, where P is the pressure, V is the volume and γ is the ratio of the specific heats of the gas at constant pressure and constant volume.

(c) For an ideal gas undergoing a reversible polytropic process $PV^{1.5}$ = constant, the equation connecting the pressure, volume and temperature of the gas at any point along the process is $\frac{P}{R} = \frac{mT}{V}$, where R is the gas constant and m is the mass of the gas.

(d) Any real gas behaves as an ideal gas at sufficiently low pressure or sufficiently high temperature.

[GATE-2023:2M]

Ans. (b) : We know that,

The process $Pv^\gamma = C$ for reversible adiabatic process of the ideal gas.

136. An insulated rigid container is divided into two parts by a thin partition. One part of the container contains 6 kg of saturated liquid-vapor mixture with a dryness fraction of 0.7 at 0.3 MPa. The other part contains 12 kg of saturated liquid at 0.6 MPa of the same substance. When the partition is removed and the system attains equilibrium, the final specific volume of the mixture is _______ m^3/kg (round off to 2 decimal places).

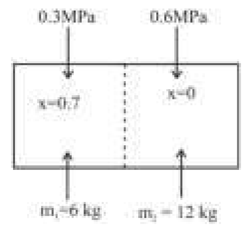
Use the following property values:

At 0.3 MPa : $v_f = 0.001073\ m^3/kg$, $v_g = 0.60582\ m^3/kg$

At 0.6 MPa : $v_f = 0.001101\ m^3/kg$, $v_g = 0.31560\ m^3/kg$

[GATE-XE 2022: 2M]

Ans. (0.13 to 0.15**) :**



Volume of part I,

$$(V_1) = 6\{0.001073 + 0.7\ (0.60582 - 0.001073)^2\}$$
$$= 2.5463\ m^3$$

Volume of part II,

$$(V_2) = 12 \times 0.001101$$
$$= 0.013212\ m^3$$

Total volume, $V = V_1 + V_2 = 2.5463 + 0.013212$

$= 2.559512\ m^3$

Total mass, $m = m_1 + m_2 = 6 + 12$

= 18 kg

$$\text{Specific volume} = \frac{2.559512}{18} = 0.142165\ m^3/kg$$
$$= 0.14\ m^3/kg$$

137. An insulated rigid tank of volume 10 m^3 contains air initially at 1 MPa and 600 K. A valve connected to the tank is opened, and air is allowed to escape until the temperature inside the tank drops to 400 K. The temperature of the discharged air can be approximated as the average of the initial and final temperatures of the air in the tank. Neglect kinetic and potential energies of the discharged air. Assume that air behaves as an ideal gas with constant specific heat so that internal energy, u = c_v T and enthalpy, h = c_p T. Then the final pressure of the air in the tank is _______ MPa (round off to 2 decimal places).

Assume c_p = 1.005 kJ/(kg K), $\gamma = c_p/c_v$ = 1.4

[GATE-XE 2022: 2M]

Ans. (0.20 to 0.24**) :** For the initial conditions in tank

Pressure, (P_1) = 1 MPa

Temperature, (T_1) = 600 K

Volume, $(V_1) = 10\ m^3$

We know that,

PV = mRT

$1 \times 10^6 \times 10 = m_1 \times 287 \times 600$

$$m_1 = \frac{1 \times 10^6 \times 10}{287 \times 600}$$
$m_1 = 58.07$ kg
Form, the final condition in tank
Pressure, P_2 = ?
Volume, $V_2 = 10\ m^3$
Temperature, $T_2 = 400$ K
For using formula
PV = mRT
$P_2 \times 10 = m_2 \times 287 \times 400$
$$m_2 = \frac{P_2 \times 10}{287 \times 400} \quad \ldots(i)$$
From, the conditions of air in pipeline
Mass $(m_p) = m_1 - m_2$
Temperature $(T_p) = \frac{600 + 400}{2}$
$T_p = 500$ K
According to unsteady flow equation
$m_1u_1 - m_2u_2 = m_p h_p$
$c_v (58.07 \times 600 - m_2 \times 400) = (m_1 - m_2)\ c_p \times 500$
$58.07 \times 600 - m_2 \times 400 = (m_1 - m_2) \times 1.4 \times 500$
$58.07 \times 600 - m_2 \times 400$
$= 58.07 \times 1.4 \times 500 - m_2 \times 1.4 \times 500$
$58.07 (600 - 1.4 \times 500) = m_2 (400 - 1.4 \times 500)$
$$m_2 = \frac{5807}{300}$$
$(m_2 = 19.35$ kg)
From equation (i),
$$\frac{P_2 \times 10}{287 \times 400} = 19.35$$
$P_2 = 222214$ Pa
$P_2 = 0.22$ MPa.

138. Air in a closed system undergoes a thermodynamic process from an initial temperature of 300 K to the final temperature of 400 K. The specific heat of air at constant volume, C_V varies linearly with the temperature, T (in K) as $C_v = (0.7 + 0.27 \times 10^{-3}T)$ kJ/(kg K).
Change in the specific internal energy of the air in the system is _______ kJ/kg (round off to 2 decimal places).

[GATE-XE 2022: 1M]

Ans. (79.00 to 80.00**) :** We know that,
$du = C_v\, dT$
$du = (0.7 + 0.27 \times 10^{-3})\, dT$
For the integrating with in limit
$$\int_{u_1}^{u_2} du = \int_{300}^{400} \left(0.7 + 0.27 \times 10^{-3} T\right) dT$$
$$u_2 - u_1 = \left(0.7T + \frac{0.27 \times 10^{-3} T^2}{2}\right)_{300}^{400}$$
$$u_2 - u_1 = (0.7 \times (400 - 300) + \frac{0.27 \times 10^{-3}\left(400^2 - 300^2\right)}{2}$$
$= 70 + 9.45$
$u_2 - u_1 = 79.45$ kJ/kg

139. The energy equation for a reversible non-flow process can be expressed as $\delta q = du + pdv$, where q is the heat transfer per unit mass, u is the internal energy per unit mass, p is the pressure, and v is the mass specific volume. This energy equation is not in exact differential form. It can be made exact differential by multiplying with the following integrating factor: (T is the absolute temperature)

(a) $\frac{1}{p}$ (b) $\frac{1}{v}$ (c) $\frac{1}{T}$ (d) $\frac{1}{uT}$

[GATE-XE 2022: 1M]

Ans. (c) : Energy equation,
$\delta q = du + Pdv$
δq is path function so it is not exact differential dividing both sides by T
$$\frac{\delta q}{T} = \frac{du}{T} + \frac{Pdv}{T}$$
As process is reversible so $\frac{\delta q}{T}$ can be written as ds (change in entropy)
So, $ds = \frac{du}{T} + \frac{Pdv}{T}$
In this equation all term i.e. q, u, T, P & V are point function so these are exact differential so are $\frac{1}{T}$

140. In a piston cylinder arrangement, the cylinder contains air at 320 kPa and 300 K. A constant pressure process given out 32 kJ of work, then the change in volume is calculated as
(a) $0.1\ m^3$ (b) $0.32\ m^3$
(c) $0.64\ m^3$ (d) $0.96\ m^3$

TS PGECET 03.08.2022, Shift-I

Ans. (a) : Given,
P = 320 kPa
$W_{1-2} = 32$ kJ
We know that,
For the constant pressure process (1-2) work done
$W_{1-2} = PdV$
$32 = 320\, dV$
$$dV = \frac{32}{320} = 0.1\, m^3$$

141. A polytropic process is carried out from an initial pressure of 110 kPa and volume of 5 m^3 to a final volume of 2.5 m^3. The polytropic index is given by $n = 1.2$. The absolute value of the work done during the process is _______ kJ (round off to 2 decimal places).

[GATE-2022;Set-I:1M]

Ans. (404.00 to 414.00**) :** Given,
Initial pressure $(P_1) = 110$ kPa,
Initial Volume $(V_1) = 5\ m^3$
Final Volume $(V_2) = 2.5\ m^3$
Polytropic index (n) = 1.2
Work done during the process (W) = ?
Now, Polytropic process,
$$P_1V_1^n = P_2V_2^n \quad \ldots\ldots (i)$$
So, putting the given value in equation (i)
$110 \times (5)^{1.2} = P_2(2.5)^{1.2}$

$$P_2 = \frac{110 \times (5)^{1.2}}{(2.5)^{1.2}}$$

$P_2 = 252.7$ kPa

∵ Work done,

$$W = \frac{P_1V_1 - P_2V_2}{n-1} = \frac{110 \times 5 - 252.7 \times 2.5}{1.2 - 1}$$

$= -408.75$ kJ

So, $W = 408.75$ kJ

142. Gas in a cylinder-piston device expands from state 1 (P_1, V_1, T_1) to state 2 (P_2 ,V_2 ,T_2). The expansion process is polytropic, i.e., PV^n = constant, n ≠ 1. Assuming the ideal gas behaviour, the expression for the work done, W by the system is given by

(a) $W = P_1V_1 ln\left(\frac{T_2}{T_1}\right)$ (b) $W = \frac{P_2V_2 - P_1V_1}{1-n}$

(c) $W = P_1V_1 ln\left(\frac{V_1}{V_2}\right)$ (d) $W = P_2V_2 ln\left(\frac{p_2}{p_1}\right)$

[GATE-XE 2022: 1M]

Ans. (b) : We know that,

$$\text{Work done} = \int_{V_1}^{V_2} Pdv \quad .... (i)$$

For polytrophic process,

$PV^n = C$

$$P = \frac{C}{V^n}$$

So,

$$W = \int_{V_1}^{V_2} \frac{C}{V^n} dv$$

$$W = \left[\frac{V^{-n+1}}{-n+1}\right]_{V_1}^{V_2}$$

$$W = C\left(\frac{V_2^{1-n} - V_1^{1-n}}{1-n}\right)$$

∵ $C = P_2V_2^n = P_1V_1^n$

∴ $$W = \frac{P_2V_2^nV_2^{1-n} - P_1V_1^nV_1^{1-n}}{1-n}$$

$$W = \frac{P_2V_2 - P_1V_1}{1-n}$$

143. Air at a pressure of 1 MPa and 300 K is flowing in a pipe. An insulated evacuated rigid tank is connected to this pipe through an insulated valve. The volume of the tank is 1 m^3. The valve is opened and the tank is filled with air until the pressure in the tank is 1 MPa. Subsequently, the valve is closed. Consider air to be an ideal gas and neglect bulk kinetic and potential energy. The final temperature of air in the tank is ______ K(1 decimal place).
Specific heat capacity of air at constant pressure, C_P = 1.005 kJ/(kgK) and characteristic gas constant for air, R = 0.287 kJ/(kgK)

[GATE-XE-2021: 2M]

Ans. (418.0 to 422.0) : Given,

$T_i = 300$ K, $P_i = 1$ MPa, $P_1 = 0$

$P_2 = P_i = 1$ MPa

$C_P = 1.005$ kJ/kg.K , R = 0.287 kJ/kg.K

∵ $C_V = C_P - R = 0.718$ kJ/kg.K

$$\therefore \ \gamma = \frac{C_P}{C_V} = \frac{1.005}{0.718} = 1.4$$

It is also given that the tank is initially evacuated,

∴ $(m_{cv})_1 = 0$

So, the work done and heat transfer during the process are zero.

Let the final temperature of air inside the tank be T_2

Therefore, the energy balance equation for the filling process is $(m_{cv})_2.u_2 = h_i(m_{cv})_2$

Where $(m_{cv})_2$ is the final mass of air inside the tank u_2 is final the specific internal energy of air inside the tank.

$C_VT_2 = C_PT_i$

$$T_2 = \frac{C_P}{C_V}T_i = \gamma T_i = 1.4 \times 300\,K = 420\,K$$

144. Work done on a closed system is 20 kJ/kg, and 40 kJ/kg of heat is rejected from the system, then its internal energy decreases by

(a) 20 kJ/kg (b) 60 kj/kg
(c) –20 kJ/kg (d) – 60 kJ/kg

AP PGECET 28.09.2021, Shift-II

Ans. (c) : Given,

The work done on a closed system (δW) = 20 kJ/kg

Heat rejected from the system (δQ)= – 40 kJ/kg

Change in internal Energy, ΔU = ?

According to first Law of thermodynamic

δQ = ΔU + δW

ΔU = δQ – δW

ΔU = – 40 + 20

ΔU = –20 kJ/kg

Here (–ve sign) indicate decrease in internal energy only no need to [apply –ve sign]

145. A rigid tank contains 1.0 kg of pure water consisting of liquid and vapour phases in equilibrium at 10 bar. If the liquid and vapour phase each occupies one half of the volume of the tank, then the net enthalpy of the contents of the tank is _____ kJ (1 decimal place).
For saturated liquid and vapour at 10 bar, the thermodynamic data table provides the following values:
$v_f = 1.127 \times 10^{-3}$ m^3/kg, $v_g = 194.3 \times 10^{-3}$ m^3/kg, h_f = 762.6 kJ/kg, h_g = 2776.2 kJ/kg

[GATE-XE-2021: 2M]

Ans. (773 to 775) : Given,

Total mass of the liquid water-vapour mixture (m) = 1 kg

Specific volume of saturate vapour (v_g) = 194.3×10^{-3} m^3/kg

Specific volume of saturate liquid (v_f) = 1.27×10^{-3} m^3/kg

Specific enthalpy of saturate liquid (h_f) = 762.6 kJ/kg

Specific enthalpy of saturate vapour (h_g) = 2776.2 kJ/kg

Let the mass of liquid water and vapour present in the mixture be m_f and m_g respectively, so that

$m_f + m_g = m$

$m_f = m - mg = 1 - mg$

Since both the liquid and vapour phases occupy one half of the value of the tank,
Therefore, Volume occupied by the liquid = volume occupied by the vapour

$m_f v_f = m_g v_g$

$m_f v_f = m_g v_g$

$(1-m_g) v_f = m_g v_g$

$$m_g = \frac{v_f}{v_f + v_g}$$

$$= \frac{1.127\times10^{-3}}{1.127\times10^{-3}+194.3\times10^{-3}} \Rightarrow 0.0058\,\text{kg}$$

Therefore, the enthalpy of the mixture,

$H = m_f h_f + m_g h_g$

$= (1-m_g) h_f + m_g h_g$

$= [(1-0.0058) \times 762.6 + 0.0058 \times 2776.2]$

$= 774.3$ kJ

146. A frictionless piston cylinder device contains 1 kg of an ideal gas. The gas is compressed according to $P\nu^{1.3}$ = constant (P is pressure and ν is mass specific volume), from 100 kPa, 250 K, till it reaches a temperature of 500 K. The heat transfer from the piston cylinder device to its surroundings is ______ kJ(2 decimal places). The characteristic gas constant is 287 J/(kgK) and the ratio of specific heat capacities is 1.4.

[GATE-XE-2021: 2M]

Ans. (56.80 to 62.78) : Given

The P − ν relation for the polytropic process is $P\nu^{1.3}$= constant

Mass of the gas, M = 1 kg

Initial pressure, P_1 = 100 kPa

Initial Temperature, T_1 = 250 K

Final Temperature, T_2 = 500 K

The gas constant of the ideal gas, R = 287 J/(kgK)

The ratio of specific heat capacities, γ = 1.4

Now, from the given polytropic process we have the polytropic index. n = 1.3

For a polytropic process $P\nu^n$ = constant, the work done by the system during a process 1-2 undergone by an ideal gas is given by

$$W_{1-2} = \frac{mR(T_1 - T_2)}{n-1}.$$

Therefore, for the present process we have

$$W_{1-2} \frac{1\times287\times(250-500)}{1.3-1} = -239166.7 \text{ J}$$

If C_V is the specific heat capacity of the gas at constant volume, then the change in internal energy during the process.

$$\Delta U = mC_V(T_2 - T_1) = \frac{mR}{\gamma-1}(T_2 - T_1) = 1\times287\times\left(\frac{500-250}{1.4-1}\right)$$

$= 179375$ J

Let the heat transfer during the process undergone by the closed system be Q_{1-2}

$$Q_{1-2} = \Delta U + W_{1-2} = (179375 - 239166.7)\text{J} = -59.79\text{kJ}$$

This means that the heat transfer from the piston – cylinder device to the surrounding is 59.79 kJ

147. One kg of air, initially at a temperature of 127°C, expands reversibly at a constant pressure until the volume is doubled. If the gas constant of air is 287 J/kg.K, the magnitude of work transfer is _______ kJ (round off to 2 decimal places).

[GATE-2020, Set-I, 2M]

Ans. (114.6 to 115.0) : Given,

m = 1kg

T_1 = 127ºC

= 127 + 273

= 400K

$P = C \cdot V_2 = 2V_1$

R = 0·287 kJ/kg·K

$W = P_1 (V_2 - V_1)$

$= P_1 (2V_1 - V_1)$

$W = P_1V_1 = mRT_1$

$W = mRT_1$

$= 1 \times 0{\cdot}287 \times 400$

= 114·80 kJ

148. A mass of 3 kg of Argon gas at 3 bar, 27 °C is contained in a rigid, insulated vessel. Paddle wheel work is done on the gas for 30 minutes at the rate of 0.015 kW. Specific heat at constant volume, C_v for Argon is 0.3122 kJ/kg-K. The final temperature of the gas (rounded off to one decimal place) in kelvin is _______.

[GATE PI-2020: 2M]

Ans. (328.827) : Given,

Mass of Argon gas (m)= 3kg

Initial pressure (P_1) = 3 bar

Initial temperature (T_1) = 27ºC

Power of paddle wheel (P) = 0.015 kW

Specific heat at constant volume, C_V = 0.3122 kJ/kgK

According to first law of thermodynamics,

$dQ = dW + dU \quad [\because dQ = 0]$

$-dW = dU$

Paddle work,

$dW = 0.015 \times 30\times60 = 27$ kJ

Work done on system, dW= –27 kJ

$dW = mc_v (dT)$

$-mc_v (T_2-T_1) = -27$

$$T_2 - 27 = \frac{27}{3\times0.3122}$$

T_2= 55.827+273

T_2= 328.8 K

149. A closed system containing 8 kg of gas undergoes an expansion process following the relation $PV^{1.2}$ = constant. The initial and final pressures are 1 MPa and 5 kPa, respectively, while the initial volume is 1m³. If the specific internal energy of the gas decreases by 40 kJ/kg during the process, the heat transfer (in kJ) associated with the process (rounded off to 1 decimal place) is ____________.

[GATE-XE 2020:2M]

Ans. (2610 to 2614) : We know that,

$$P_1 V_1^n = P_2 V_2^n$$

$P_1 \; V_1^{1.2} = P_2 V_2^{1.2}$ [∵ the polytropic index n = 1.2]

$$V_2 = V_1 \left(\frac{P_1}{P_2}\right)^{\frac{1}{1.2}}$$

$$= 1 \times \left(\frac{1000}{5}\right)^{\frac{1}{1.2}} m^3$$

$= 82.7 \; m^3$

Now, the work done by the system is obtained as

$$W = \frac{P_1 V_1 - P_2 V_2}{n-1}$$

$$= \frac{1000 \times 1 - 5 \times 82.7}{1.2 - 1}$$

$= 2932.5$ kJ

The total change in internal energy of the system

ΔU = The mass of the system × the change in specific internal energy

$\Delta U = 8 \times (-40)$ kJ $= -320$ kJ

Now, the first law of thermodynamics

$Q = \Delta U + W$

$Q = (-320 + 2932.5)$ kJ

$Q = 2612.5$ kJ

150. Temperature of nitrogen in a vessel of volume 2 m^3 is 288 K. A U-tube manometer connected to the vessel shows a reading of 700 mm of mercury (level higher in the end open to atmosphere.) The universal gas constant is 8314 J/kmol-K, atmospheric pressure is 1.01325 bar, acceleration due to gravity is 9.81 m/s^2 and density of mercury is 13600 kg/m^3. The mass of nitrogen (in kg) in the vessel is

(a) 4.56 kg (b) 5.46 kg
(c) 4.34 kg (d) 6.45 kg

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Ans. (a) : Given,

$P_{atm} = 1.013$ bar

$\rho = 13600 \; kg/m^3$

$T = 288$ K

$V = 2 \; m^3$

h = 700 mm of mercury.

R = 8314 J/k-mol-K

Pressure,

$P = \rho g h$

$= 13600 \times 9.81 \times 0.7$

$= 93391.2$ Pa

Actual Pressure,

$P_{actual} = P_{atm} + P = 101325 + 93391.2$

$= 194716.2$ Pa

We know that,

$P_{actual} V = mRT$

$$m = \frac{P_{actual} V}{RT}$$

$$m = \frac{194716.2 \times 2}{288 \times \left(\frac{8314}{28}\right)} = 4.56 \text{ kg}$$

151. A particular gas sample is initially maintained at 6000 cm^3 and 100 kPa. It is compressed during a quasistatic process following the relation PV^2 = constant. The compression continues till the volume becomes 2000 cm^3. The magnitude of the corresponding work transfer (in kJ) (rounded off to 2 decimal places is ________.

[GATE-XE 2020:2M]

Ans. (1.15 to 1.25) : Given date,

$P_1 = 100$ kPa

$V_1 = 6000 \; cm^3 = 0.006 \; m^3$

$V_2 = 2000 \; cm^3 = 0.002 \; m^3$

The compression process follows a polytrophic relation PV^2

It means polytropic Index n = 2

Let the pressure after compression be P_2,

Then,

$$P_2 = P_1 \left(\frac{V_1}{V_2}\right)^2$$

$$= 100 \times \left(\frac{0.006}{0.002}\right)^2$$

$= 900$ kPa

For the work supplied in the polytrophic compression process,

$$W = \frac{P_2 V_2 - P_1 V_1}{n-1}$$

$$W = \frac{900 \times 0.002 - 100 \times 0.006}{2-1}$$

$W = 1.20$ kJ

152. A piston-cylinder system has an initial volume of 0.1 m^3 and contains an ideal gas (c_v = 0.74 kJ/kg.K, R = 0.288 kJ/kg.K) at 1.5 bar and 298 K. The piston is moved to compress the gas until the pressure and temperature reach 10 bar and 423 K respectively. During this process, 20 kJ of work is done on the gas. The magnitude of heat transfer (kJ) during this process is

(a) 134.8 (b) 36.2
(c) 8.2 (d) 3.8

[GATE-XE 2019-2M]

Ans. (d) : Given,

$T_1 = 298$ K

$T_2 = 423$ K

$P_1 = 1.5$ bar $= 1.5 \times 10^5 \; N/m^2$

$V_1 = 0.1 \; m^3$

R = 0.288 kJ/kg. K = 288 J/kg. K

$c_v = 0.74$ kJ/kg. K

W = –20 kJ

We know that,

PV = mRT

$$m = \frac{P_1 V_1}{R T_1}$$

$$m = \frac{1.5 \times 10^5 \times 0.1}{288 \times 298}$$

m = 0.1748 kg

From the first law of thermodynamics for a closed system,

$Q = \Delta U + W$

$Q = mc_v (T_2 - T_1) + W$

$= 0.1748 \times 0.74 \times (423 - 298) - 20$

$= 16.169 - 20$

$Q = -3.8$ kJ

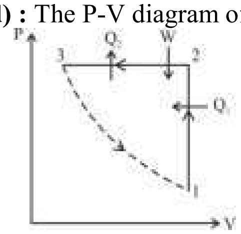
153. 85 kJ of heat is supplied to a closed system at constant volume. During the next process, the system rejects 90 kJ of heat at constant pressure while 20 kJ of work is done on it. The System is brought to the original state by an adiabatic process. The initial internal energy is 100 kJ. Then the quantity of work transfer during the process is

(a) 30 kJ (b) 25 kJ

(c) 20 kJ (d) 15 kJ

AP PGECET 03.05.2019, Shift-II

Ans. (d) : The P-V diagram of process is-



Given,

$Q_1 = 85$ kJ

$Q_2 = -90$ kJ

$W = 20$ kJ

$U_1 = 100$ kJ

In process 1-2,

$W_{1-2} = 0$

$Q_1 = U_2 - U_1$

$85 = U_2 - 100$

$U_2 = 185$ kJ

In process 2-3,

$Q_{2-3} = W_{2-3} + (U_3 - U_2)$

$-90 = -20 + U_3 - 185$

$U_3 = 115$ kJ

Process 3-1 is adiabatic,

So, $W_{3-1} + U_1 - U_3 = Q_{3-1} = 0$

$W_{3-1} + 100 - 115 = 0$

$W_{3-1} = 15$ kJ

154. One kilogram of air is compressed at constant temperature of 150 °C until its volume is halved. Considering gas constant R = 0.287 kJ/kg-K for air, magnitude of heat rejected (in kJ) in the compression process is ______ (round off to 2 decimal places)

[GATE PI-2019: 1M]

Ans. (84.14876) **:** Given,

Gas constant (R) = 0.287 kJ/kg K

Mass of air (m) = 1 kg

Temperature (T) = 150 °C = 423 K

Let initial volume = V_1

Final volume $V_2 = \frac{1}{2}V_1$

Here,

$\Delta U = mC_v (T_2 - T_1)$

$T_1 = T_2$

So, $\Delta U = 0$

$\Delta Q = \Delta W$

For an isothermal process,

$$\Delta W = P_1V_1 ln\left(\frac{P_1}{P_2}\right)$$

$$\Delta W = mRT\ ln\left(\frac{P_1}{P_2}\right)$$

For isothermal process,

$P_1V_1 = P_2V_2$

$$\left(\frac{P_1}{P_2}\right) = \left(\frac{V_2}{V_1}\right)$$

So, $$\Delta W = mRT\ ln\left(\frac{V_2}{V_1}\right)$$

$$\Delta W = 1 \times 0.287 \times 423\ ln\left(\frac{V_1}{2 \times V_1}\right)$$

$= -84.14876$ kJ

$Q = \Delta W = -84.15$ kJ

Magnitude of heat rejected = 84.15 kJ

155. Air at 150 kPa and 323 K is filled in a rigid vessel of 0.05 m^3 capacity. For air, assumed as an ideal gas, specific heat at constant volume is 0.7163 kJ/kg.K and the specific gas constant is 0.287 kJ/kg.K. Neglect kinetic and potential energy changes. If 30 kJ of heat is added, the final temperature (in K) of air (up to 1 decimal place) is _______.

[GATE-XE 2018: 2M]

Ans. (838.0 to 844.0) : Given,

P = 150 kPa

V = 0.05 m^3

R = 0.287 kJ/kg K

$T_1 = 323$ k

$c_v = 0.7163$ kJ/kg K

We know that,

PV = mRT

$$m = \frac{PV}{RT} = \frac{150 \times 0.05}{0.287 \times 323}$$

m = 0.0809 kg

Q = 30 kJ added,

$Q = \Delta U + W$

$Q = mc_v (T_2 - T_1) + 0$ (Since W = 0 for this process)

$30 = 0.0809 \times 0.7163 \times (T_2 - 323)$

$T_2 = 517.7 + 323$

$T_2 = 840.7$ K

156. A stationary mass of gas is compressed without friction from an initial state of 0.3 m³ and 0.105 MPa to a final state of 0.15 m³ and 0.105 MPa, the pressure remaining constant during the process. There is a transfer of 37.6 kJ of heat from the gas during the process. How much does the internal energy of the gas change?

(a) –21.85 kJ (b) 11.85 kJ

(c) – 11.85 kJ (d) – 52.12 kJ

TS PGECET 30.05.2018, Shift-I

Ans. (a) : Given,
$\Delta Q = -37.6$ kJ
P = 0.105 MPa
$V_1 = 0.3\ m^3$
$V_2 = 0.15\ m^3$
$W_{1-2} = P(V_2 - V_1)$
$= 0.105 \times 10^6 \times (0.15 - 0.3)$
$= -15750$ J $= -15.75$ kJ
We know that,
First law of thermodynamics,
$\Delta Q = \Delta U + W_{1-2}$
$-37.6 = \Delta U + (-15.75)$
$\Delta U = -21.85$ kJ

157. For a reversible isothermal expansion of one mole of an ideal gas from state 1 to state 2 the magnitude of work done is
(a) RT $ln(P_1/P_2)$ (b) $P_2V_2 - P_1V$
(c) $Rln(V_1/V_2)$ (d) 0
[GATE-XE 2018: 1M]

Ans. (a) : For isothermal process,
T = constant, $\Delta T = 0$, $\Delta U = 0$
Also for ideal gas the equation of state is $\frac{RT}{V}$. Now the work done for an infinitesimal expansion dV at a pressure P is given by
$\delta W = PdV$
The work done from state 1 to state 2 is given by
$$W = \int_{V_1}^{V_2} PdV = \int_{V_1}^{V_2} \frac{RT}{V} dV$$
$$= RT\int_{V_1}^{V_2} \frac{1}{V}.dV \quad \text{[since T = constant for, an isothermal process]}$$
$$= RT\ln\left(\frac{V_2}{V_1}\right)$$
$$= RT\ln\left(\frac{P_1}{P_2}\right) \quad \text{[since for an isothermal process of an ideal gas } \left(\frac{V_2}{V_1} = \frac{P_1}{P_2}\right)\text{]}$$

158. Consider the following statements for an ideal gas undergoing a reversible non-flow process :
P. If the process is adiabatic, the change in enthalpy of the gas is necessarily zero.
Q. If the process is adiabatic, the change in entropy of the gas is necessarily zero.
R. If the process is isothermal, the change in enthalpy of the gas is necessarily zero.
S. If the process is isothermal, the change in entropy of the gas is necessarily zero.
Which one of the following options is valid ?
(a) Only P is correct
(b) Only S is correct
(c) Only Q and R are correct
(d) Only P and S are correct
[GATE-XE 2018: 2M]

Ans. (c) : The Enthalpy depends on the temperature and the process is adiabatic and so the process is isentropic.
- For reversible adiabatic process, the entropy remain constant.
- For isothermal process and ideal gas the change in enthalpy of the gas is zero.

159. One kmol of an ideal gas at 300 K and 10 bar is reversibly heated in a constant volume process to 500 K. It is then reversibly and isothermally expanded to 2 bar. Take C_v = 20.8 kJ/kmol.K and R = 8.314 kJ/kmol.K. The total heat supplied (in kJ) to the gas (up to 1 decimal place) is ________.
[GATE-XE 2018: 2M]

Ans. (1295.0 to 13000.0) : Given data,
n = 1 kmol
$T_1 = 300$ k
$P_1 = 10$ bar $= 10^6$ Pa.
$T_2 = 500$ K
For the constant volume heating,
$Q_1 = \Delta U$
$Q_1 = nC_V\Delta T$
$Q_1 = 1 \times 20.8 \times (500 - 300)$ kJ
$Q_1 = 4160$ kJ
For Isothermal Expansion,
$P_1V_1 = n RT_1$
$$V_1 = V_2 = \frac{1\times 8.134\times 300\times 1000}{10^6}$$
$= 2.492$
$$V_3 = \frac{1\times 8.134\times 500\times 1000}{2\times 10^6}$$
$= 20.785$
$$Q_2 = \Delta U + \int_{V_2}^{V_3} pdV$$
$$Q_2 = P_2V_2 ln\frac{V_3}{V_2} \quad \text{[Since } \Delta U = 0\text{]}$$
$$Q_2 = 1 \times 8.314 \times 500\ ln\frac{20.785}{2.492}$$
$Q_2 = 8817.6$ kJ
Then, the total amount of heat supplied,
$Q = Q_1 + Q_2$
$Q = 4160 + 8817.6$
$Q = 12977.6$ kJ

160. A paddle wheel is installed in a rigid insulated tank containing 10 kg air (C_v = 0.718 kJ/kg.K). A torque of 100 N.m is applied on the paddle wheel to rotate it at 60 revolutions per minute for 2 minutes. At the end of the process, increase in temperature of air in °C is
(a) 0 (b) 5.25
(c) 10.50 (d) 21.50
[GATE-XE 2017]

Ans. (c) : Given,
m = 10 kg
$C_v = 0.718$ kJ/kg K
N = 60 rpm
T = 100 N-m
t = 2 min

$\because \quad \omega = 2\pi N$
$= 2 \times \pi \times 60$
$= 377$ rad/min

The angle turned,
$\theta = \omega t$
$= 377 \times 2$
$= 754$ rad

The work done on the system,
$W = T.\theta$
$= 100 \times 754$
$= 75400$ J

From the first law of thermodynamics,
$Q = \Delta U + W$ (For work done on the system)
$\Delta U - W = 0$ (Since rank is insulated, Q = 0)
$mC_v\Delta T = W$
$$\Delta T = \frac{W}{m.C_v}$$
$$= \frac{75400}{10 \times 718}$$
$= 10.50$ °C

161. In a polytropic compression process, one kg of an ideal gas having molecular weight of 40 kg/kmol is compressed from 100 kPa, 300 K to 400 kPa, 360 K. The magnitude of the work in kJ for the process is
(a) 52.3 (b) 62.3
(c) 72.3 (d) 82.3
[GATE-XE 2017]

Ans. (d) : Given data,
m = 1 kg, M = 40 kg/kmol
$P_1 = 100$ kPa, $T_1 = 300$ K
$P_2 = 400$ kPa, $T_2 = 360$ K
$P_1V_1 = nRT_1$
$$100 \times V_1 = \frac{1}{40} \times 8.314 \times 300$$
$V_1 = 0.62355$ m^3
$P_2 V_2 = nRT_2$
$$V_2 = \frac{\frac{1}{40} \times 8.314 \times 360}{400}$$
$V_2 = 0.187$ m^3
$$W = \frac{P_1V_1 - P_2V_2}{\gamma - 1}$$
Now, $$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$
$$\frac{360}{300} = \left(\frac{400}{100}\right)^{\frac{\gamma-1}{\gamma}}$$
$$ln\ 1.2 = \frac{\gamma - 1}{\gamma} ln\ 4$$
$$\frac{ln 1.2}{ln} = \frac{\gamma - 1}{\gamma}$$
$$0.131 = \frac{\gamma - 1}{\gamma}$$
$\gamma = 1.15$
$$\therefore \quad w = \frac{100 \times 0.623 - 400 \times 0.187}{1.15 - 1}$$
$= 82.3$ kJ

162. Consider two system each containing 20 kg of air at the same temperature and pressure. It is desired to increase the temperature of the air in both systems by 10°C. One system undergoes a constant pressure heat addition process and the other undergoes a constant volume heat addition. The difference in the values of heat transferred to the two systems in kJ is
(a) 30.5 (b) 44.2
(c) 57.5 (d) 73.2
[GATE-XE 2017]

Ans. (c) : Given that,
m = 20 kg
Air at the same temperature and pressure,
For constant pressure addition,
$\delta Q_1 = dH - vdP$ (vdP = 0 and) ($dH = mc_{pdt}$)
$\delta Q_1 = dH = mCpdT$
$Q_1 = \Delta H = mCp\Delta T$
For constant volume addition,
$\delta Q_2 = dU + dW$, dV = 0 (dW = PdV)
$\delta Q_2 = mCvdT$
$Q_2 = \Delta U = mCv\Delta T$
$\therefore \quad Q_1 - Q_2 = m(Cp - Cv)\,\Delta T$
$= 20 \times 10 \times R$
For air,
R = 0.287 kJ/kg.K
$= 20 \times 10 \times 0.287$
$= 57.4$
≈ 57.5 kJ

163. A 1 m^3 rigid vessel contains air at 200 kPa. A vacuum pump is connected to the vessel in order to control the pressure inside. The volume flow rate of air through the pump is maintained at a constant value of 0.1 m^3/s. If the pump operates for 10 seconds and the temperature of the air is maintained constant during operation, the pressure in the tank in kPa after 10 seconds (up to 2 decimal places) is ______
[GATE-XE 2017]

Ans. (73.5 to 73.8) : We know that,
$$Q = \frac{\dot{m}}{\rho}$$
$$-\dot{m} = Q\rho$$
$$-\frac{dm}{dt} = Q\frac{m}{V}$$
$$-\frac{dm}{m} = \frac{Q}{V}dt$$
$$-\int_{m_1}^{m_2}\frac{dm}{m} = \int_0^{10}\frac{0.1}{1}dt$$

$$l n\left(\frac{m_2}{m_1}\right) = -0.1 \times 10$$

$$\frac{m_2}{m_1} = 0.3678$$

Now, $PV = mRT$

$$\frac{P_2}{P_1} = \frac{m_2}{m_1} \times \frac{V_1}{V_2} \times \frac{T_2}{T_1}$$

For the tank V and T are constant,

$$\frac{P_2}{P_1} = \frac{m_2}{m_1} = 0.3678$$

$P_2 = 0.3678 \times 200$ kPa

$P_2 = 73.56$ kPa

164. A mass *m* of a perfect gas at pressure P_1 and volume V_1 undergoes an isothermal process. The final pressure is P_2 and volume is V_2. The work done on the system is considered positive. If R is the gas constant and *T* is the temperature, then the work done in the process is

(a) $P_1V_1 \, ln\frac{V_2}{V_1}$ (b) $-P_1V_1 \, ln\frac{P_1}{P_2}$

(c) $RT \, ln\frac{V_2}{V_1}$ (d) $-mRT \, ln\frac{P_2}{P_1}$

[GATE-2017;Set-II: 1M]

Ans. (b) : For Isothermal process. Involving Ideal Gas,

Work done, $W = -\int_{V_1}^{V_2} PdV$

Where $P = \frac{mRT}{V}$

$$W = -\int_{V_1}^{V_2} \frac{mRT}{V} dV$$

$$W = -mRT\int_{v_1}^{v_2} \frac{dV}{V}$$

$$W = -mRT \; ln \frac{V_2}{V_1}$$

$\because$ $mRT = P_1V_1 = P_2V_2$

Thus, $W = -P_1 V_1 \, ln \frac{V_2}{V_1}$

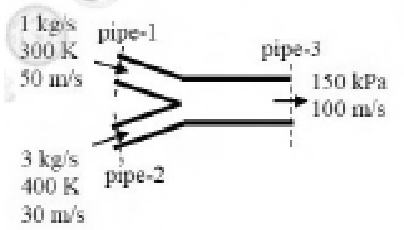
Since, $\frac{V_2}{V_1} = \frac{P_1}{P_2}$, we get in $\frac{V_2}{V_1} = ln\frac{P_1}{P_2}$

Therefore, $W = -P_1V_1 \; ln \frac{P_1}{P_2}$

The convention for Work done on the system (Positive) is typically expressed as a negative value because the system does work on the surroundings.

Hence, $W = -P_1V_1 \, ln \frac{P_1}{P_2}$

165. Two streams of air (C_p = 1005 J/kg.K) flow through insulated pipes 1 and 2 with the conditions as shown in figure. They mix in an insulated pipe-3 and the mixture steadily exists with a velocity of 100 m/s at 150 kPa. Neglecting the change in potential energy in all the pipes, the exit area of the pipe-3 in m^2 (up to 3 decimal places) is _____.



[GATE-XE 2017: 2M]

Ans. (0.026 to 0.030) : $\dot{m} = \frac{C \times A}{v}$

Where,

$\dot{m}$ = mass flow rate in (kg/s)

C = velocity in (m/s)

A = area in (m^2)

v = specific volume in (m^3/kg)

$\dot{m} = m_1 + m_2$

$= 1 + 3$

$= 4$ kg/s

Since system is insulated,

$\therefore$ $\dot{m}_1 C_p T_1 + \dot{m}_2 C_p T_2 = \dot{m}_3 C_p T_3$

$\dot{m}_1 T_1 + \dot{m}_2 T_2 = \dot{m}_3 T_3$

$1 \times 300 + 3 \times 400 = 4 \times T_3$

$4 T_3 = 1500$

$T_3 = 375$ K

$P_3V_3 = n_3RT_3$

$$P_3 \times V_3 = \frac{m_3}{29} \times RT_3$$

$$150 \times V_3 = \frac{m_3}{29} \times 8.314 \times 375$$

$$\frac{V_3}{m_3} = 0.717$$

Specific volume $(v_3) = \frac{V_3}{m_3} = 0.717$ m^3/kg

$\therefore$ $Area(A) = \frac{v_3 \times \dot{m}_3}{C}$

$$= \frac{0.717 \times 4}{100} = 0.0287$$

$A = 0.029$ m^2

166. The molar specific heat at constant volume of an ideal gas is equal to 2.5 times the universal gas constant (8.314 J/mol K). When the temperature increases by 100 K, the change in molar specific enthalpy is ------- J/mol.

[GATE-2017: Set-I: 1M]

Ans. (2908 to 2911) : Given,

Molar specific heat at constant volume,

$$\overline{C}_v = 2.5\overline{R}$$

Universal gas constant $(\overline{R}) = 8.314$ J/mol K

Temperature rise (ΔT) = 100 K

Specific enthalpy $(\Delta\overline{H}) = ?$

We know that,

$$\overline{C}_p - \overline{C}_v = \overline{R}$$

$$\overline{C}_p = \overline{R} + C_v = \overline{R} + 2.5\overline{R}$$

$$\overline{C}_p = 3.5\overline{R}$$

Molar specific enthalpy change of ideal gas,

$$\Delta H = n\overline{C}_p\Delta T$$

$$\overline{\Delta H} = \frac{\Delta H}{n}$$

$$\overline{\Delta H} = \overline{C}_p\Delta T$$

$$= 3.5 \times 8.314 \times 100$$

$$\overline{\Delta H} = 2909.9 \text{ J/mole}$$

167. A piston-cylinder device initially contains 0.4 m^3 of air (to be treated as an ideal gas) at 100 kPa and 80 ^{o}C. The air is now isothermally compressed to 0.1 m^3. The work done during this process is ________ kJ.
(Take the sign convention such that work done on the system is negative)

[GATE-2016; Set-II: 2M]

Ans. (–55.6 to –55.4) : Given data,

$V_1 = 0.4$ m^3

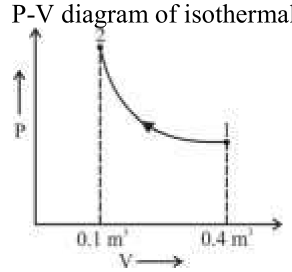
$P_1 = 100$ kPa

$T_1 = 80°C = (80 + 273)K = 353$ K

$V_2 = 0.1$ m^3

So,

P-V diagram of isothermal process is,



We know that,

$$W_{1-2} = P_1V_1\, ln\frac{V_2}{V_1}$$

$$= 100 \times 0.4\, ln\frac{0.1}{0.4} = -55.45 \text{ kJ}$$

168. The internal energy of an ideal gas is a function of

(a) temperature and pressure
(b) volume and pressure
(c) entropy and pressure
(d) temperature only

[GATE-2016; Set-II: 1M]

Ans. (d) : The internal energy of an ideal gas is a function of temperature only.

169. A closed system undergoes a cyclic process. For the net work done by the system on the surroundings, which of the following statements is FALSE:

(a) Net work is always zero
(b) Net work is $\oint P$ dV if the process is reversible
(c) Net work can be negative
(d) Net work can be positive

[GATE-XE 2016: 1M]

Ans. (a) : For closed system undergoes a cyclic process. For the net work done by the system on the surroundings, when the net work done by the system is not necessarily zero.

170. In a reversible, constant-pressure, non-flow process, heat input is given by

(a) change in internal energy
(b) change in enthalpy
(c) change in entropy
(d) Work output

[GATE-XE 2016: 1M]

Ans. (b) : In reversible,

Constant - pressure non flow process

$$Q = \Delta U + W$$

$$Q = \Delta U + \int_1^2 pdV$$

$$Q = \Delta U + p\int_1^2 dV$$

$$Q = U_2 - U_1 + p\,(V_2 - V_1)$$

$$Q = (U_2 + pV_2) - (U_1 + pV_1)$$

$$Q = H_2 - H_1$$

$$Q = \Delta H$$

171. Air pressure inside a spherical balloon is proportional to its diameter. The balloon undergoes a reversible, isothermal, non-flow process. During the process, the balloon maintains its spherical shape, and the air inside the balloon consumes 2 kJ of heat. Initial air pressure inside the balloon was 120 kPa, while the initial balloon diameter was 20 cm. Assuming air to be an ideal gas, the final diameter of the balloon (in cm) is ______.

[GATE-XE 2016: 2M]

Ans. (28 to 36) : $P \propto D$

Ideal gas, isothermal, non-flow process

$$\delta Q = dU + \delta W$$

$$Q = \int_1^2 pdV \qquad (\because, dU = 0)$$

$$2 \times 10^3 = \int_1^2 pdV$$

$$2 \times 10^3 = \int_1^2 \frac{p_1}{D_1} \times D \times \frac{\pi D^2}{2} dD$$

$$2 \times 10^3 = \frac{p_1\pi}{2D_1} \times \int_1^2 D^3 dD$$

$$2 \times 10^3 = \frac{120 \times 10^3 \times 3.14}{2 \times 0.2} \times \left[\frac{D^4}{4}\right]_{D_1}^{D_2}$$

$$2 = \frac{120 \times 3.14}{2 \times 0.2} \times \frac{D_2^4 - D_1^4}{4}$$

$$0.00212 = \frac{D_2^4 - (0.2)^4}{4}$$

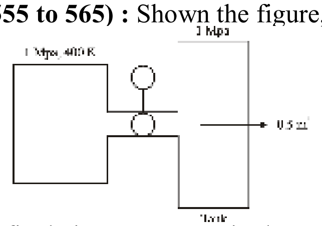
$$\therefore D_2^4 = 0.1008$$

$$D_2 = 0.316\,\text{m} = 31.6\,\text{cm}$$

172. Compressed air, at 1 MPa pressure, 400 K temperature flows through a large pipe. An evacuated, insulated rigid tank of 0.5 m^3 volume is connected to the pipe through a valve. The valve is opened to fill the tank and the valve closes automatically when the tank pressure reaches 1 MPa. Assuming ideal gas behavior, the final air temperature in the tank (in K) is __________.

[GATE-XE 2016: 2M]

Ans. (555 to 565) : Shown the figure,



For the final air temperature in the tank in

$H_1 = u_1 + RT_1 = u_2$

$C_vT_2 = (C_v + R)\, T_1 = C_pT_1$

$$T_2 = \left(\frac{C_v + R}{C_v}\right)T_1 = \gamma T_1$$

$T_2 = 1.4 \times 400$ K

$T_2 = 560$ K

173. An ideal gas undergoes a reversible process in which the pressure varies linearly with volume. The conditions at the start (subscript 1) and at the end (subscript 2) of the process with usual notation are: $p_1 = 100$ kPa, $V_1 = 0.2$ m^3 and $p_2 = 200$ kPa, $V_2 = 0.1$ m^3 and the gas constant, R = 0.275 kJ/kg-K. The magnitude of the work required for the process (in kJ) is _______

[GATE-2016; Set-1: 2M]

Ans. (14.75 to 15.25) :

Initial Pressure (p_1) = 100 kPa,

Final Pressure (p_2) = 200 kPa

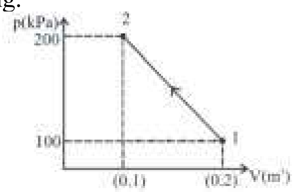
Initial Volume (V_1) = 0.2 m^3

Final Volume (V_2) = 0.1 m^3

Gas Contant (R) = 0.275 kJ/kg-K

Magnitude of the work = ?

Now, let the construction of figure in given condition according.



Work done is equal to area under p-V diagram,

$$\text{Work} = \frac{1}{2}(p_1 + p_2) \times (V_1 - V_2)$$

$$\therefore \ \text{Work} = \frac{1}{2}(100 + 200) \times (0.2 - 0.1) = 15 \text{ kJ}$$

174. One kg of saturated liquid-vapor mixture of water at 150 kPa ($u_f = 467$ kJ/kg, $v_f = 0.001053$ m^3/kg, $u_g = 2520$ kJ/kg and $v_g = 1.159$ m^3/kg) with quality of 0.7 is enclosed in a piston cylinder assembly. Heat is added at constant pressure to this system while a paddle wheel transfers a work of 50 kJ. The mixture eventually attains saturated vapor state. The amount of heat added to the mixture (in kJ) is ______

[GATE-XE 2015]

Ans. (618.1 kJ) : Given,

m = 1 kg , P = 150 kPa

$u_f = 467$ kJ/kg , $v_f = 0.001053$ m^3/kg

$u_g = 2520$ kJ/kg, $v_g = 1.159$ m^3/kg

x = 0.7, w = –50 kJ

$u_1 = u_f + x.u_{fg}$

$= 467 + 0.7\,(2520 - 467)$

$= 1904.1$ kJ/kg

$\Delta u = u_2 - u_1 = (2520 - 1904.1)$ kJ/kg = 615.9 kJ/kg

Initial specific volume of the liquid-vapour mixture,

$\therefore \ v_1 = v_f + x.v_{fg}$

$= 0.001053 + 0.7 \times (1.159 - 0.001053)$ m^3/kg

$= 0.811$ m^3/kg

$v_2 = v_g = 1.159$ m^3/kg (final state is saturated vapour state)

$v = v_2 - v_1 = (1.159 - 0.811)$ m^3/kg = 0.348 m^3/kg

$\therefore \ \Delta H = m(\Delta u + P\Delta v)$ (As, heat is added at constant pressure)

$= 1 \times \{(615.9) + 150 \times 0.348\}$ kJ = 668.1 kJ

$\therefore \ Q = \Delta H + W$ (as W is the work, which is transferred to the gas through a paddle wheel)

$= (668.1 - 50)$ kJ = 618.1 kJ

175. A gas expands following the relation PV^n = constant, from the initial state P_1, V_1 to final volume $V_2 = 2V_1$. For the values of 'n' mentioned below, maximum displacement work is obtained for

(a) n = –1 (b) n = 0

(c) n = 1 (d) n =1.4

[GATE-XE 2015]

Ans. (a) : Given,

PV^n = constant

Pressure & Volume of gas at initial and final state are respectively P_1, V_1 and P_2, V_2

For polytropic process,

$$P_1V_1^n = P_2V_2^n$$

$$\therefore \quad \frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^n \qquad [\because V_2 = 2V_1]$$

$$\frac{P_1}{P_2} = \left(\frac{2V_1}{V_1}\right)^n$$

$$\frac{P_1}{P_2} = 2^n$$

$$P_2 = \frac{P_1}{2^n}$$

Work done for polytropic process, ($n \neq 1$) is given by,

$$W = \frac{P_1V_1 - P_2V_2}{n-1}$$

$$= \frac{P_1V_1 - (P_2 \times 2V_1)}{n-1}$$

$$= \frac{P_1V_1\left\{1 - \frac{1}{2^n} \times 2\right\}}{n-1}$$

$$W = P_1V_1\left(\frac{1-2^{1-n}}{n-1}\right) \quad ...(i)$$

For an isothermal process n = 1 and
$PV = P_1V_1 = P_2V_2 = \text{Constant} = K$
The work done in isothermal process is given by,

$$W = \int_{V_1}^{V_2} PdV$$

$$W = \int_{V_1}^{V_2} \frac{K}{V} dV$$

$$= K\,ln\left(\frac{V_2}{V_1}\right)$$

$$= P_1V_1 \ln\left(\frac{2V_1}{V_1}\right) = P_1V_1 ln(2)$$

$W = 0.6931\ P_1V_1$
For the different values of n, work done is calculated by the above formula,

n = 0	n = –1	n = 1.4
$W = P_1V_1\left(\frac{1-2^1}{-1}\right)$ $W = P_1V_1$	$W = P_1V_1\left(\frac{1-2^2}{-2}\right)$ $W = 1.5\ P_1V_1$	$W = P_1V_1\left(\frac{1-2^{1-1.4}}{1.4-1}\right)$ $W = 0.6054\ P_1V_1$

So, the maximum displacements works corresponds to $W = 1.5\ P_1V_1$ for which n = –1

176. For an ideal gas with constant values of specific heats, for calculation of the specific enthalpy,
(a) it is sufficient to know only the temperature
(b) both temperature and pressure are required to be known
(c) both temperature and volume are required to be known
(d) both temperature and mass are required to be known

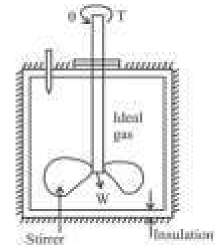
[GATE-2015; Set-I: 1M]

Ans. (a) : For an ideal gas with constant values of specific heats for calculation of the specific enthalpy it is sufficient to know only the temperature.
For the specific enthalpy is given as,
h = u + PV
∴ PV = RT
∴ h = u + RT
= u (T) + RT = H(T)
For the calculation of the specific enthalpy, it is sufficient to know only the temperature.

177. A well insulated rigid container of volume 1 m^3 contains 1.0 kg of an ideal gas [C_p = 1000 J/(kg.K) and C_v = 800 J/(kg.K)] at a pressure of 10^5 Pa. A stirrer is rotated at constant rpm in the container for 1000 rotations and the applied torque is 100 N-m. The final temperature of the gas (in K) is_______

[GATE-2015; Set-I:2M]

Ans. (1283.4 to 1287.4) :
Volume of container (V) = 1 m^3
Mass of ideal gas (m) = 1 kg
Specific heat of gas at constant pressure (C_p) = 1000 J/kgK
Specific heat of gas at constant volume (C_v) = 800 J/kgK



∵ Work done (W) = T × θ
= 100 × 2π × 1000 = – 628.318 kJ
Now ideal gas equation,
$P_1V_1 = mRT_1$
(Where, $R = C_p - C_v$ = 0.2 kJ/kg.K)

$$\because \quad T_1 = \frac{P_1V_1}{mR} = \frac{100\times1}{0.2\times1} = 500\,K$$

According to 1st law of thermodynamics,

$$\Delta Q - \Delta W = \Delta U$$
$$0-(-628.318) = mC_v(T_2 - T_1)$$
$$0-(-628.318) = 1\times0.8(T_2-500)$$
$$T_2 = 1285.398 \approx 1285.4\,K$$

178. A rigid closed vessel is initial filled with 2 kg of water which is a mixture of saturated liquid and saturated vapor states at 2 bar. The vessel is placed in an oven which heats the mixture to the critical state. Using the saturated and critical property values from the table given below, the heat transferred from the oven to the vessel is _______ kJ.

Pressure = 2 bar			
V_f(m^3/kg)	**V_g(m^3/kg)**	**U_f (kJ/kg)**	**U_g (kJ/kg)**
0.0010605	**0.8857**	**504.49**	**2529.5**
Critical pressure			
	v_C (m^3/kg)	**u_C (kJ/kg)**	
	0.003155	**2029.6**	

(a) 3035.8 (b) 3040.6
(c) 3036.2 (d) 3044.9

[GATE-XE 2014: 2M]

Ans. (b) : At P = 2 bar,
v_f = 0.0010605 m^3/kg
v_g = 0.8857 m^3/kg
u_f = 504.49 kJ/kg
u_g = 2529.5 kJ/kg
u_c = 2029.6 kJ/kg
v_c = 0.003155 m^3/kg
As the vessel is rigid, therefore the volume remains the same. i.e, $v = v_c$
So, $v = v_f + x.v_{fg} = v_c$
∴ v_c = 0.0010605 + x (0.8857 – 0.001605)
0.003155 = 0.0010605 + x (0.8857 – 0.0010605)
x = 0.002367
$u = u_f + x.u_{fg}$
= 504.49 + 0.002367 × (2529 – 504.49)
= 509.2831 kJ/kg

Change in internal energy per unit mass = $(u_c - u)$
$= (2029.6 - 509.283)$ kJ/kg = 1520.3 kJ/kg
Change in internal energy = 1520.3 × 2 kJ
= 3040.6 kJ

179. A gas at a pressure of 500 kPa and volume of 0.75 m^3 is contained in a cylinder-piston assembly. When the piston moves slowly in the cylinder, the pressure inside the cylinder varies as V$^{-1.2}$. If the final volume of gas becomes doubled, then the work done by the gas, in kJ, is _______

[GATE-PI 2014: 2M]

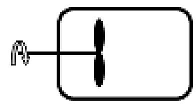
Ans. (240 to 250) : Given
Initial pressure $P_1 = 500$ kPa
Initial volume $V_1 = 0.75$ m^3
Variation at pressure,
$P \propto V^{-1.2}$
Final volume, $V_2 = 2V_1 = 1.5$ m^3
To find work done by the gas.
For the polytrophic process as,
$P \propto V^{-1.2}$
$$P \propto \frac{1}{V^{1.2}}$$
$$P = \frac{C}{V^{1.2}}$$
$P \times V^{1.2} = C$
This is polytrophic process with n = 1.2
Work done is given as
$$\frac{P_1V_1 - P_2V_2}{n-1}$$
$P_1V_1^{1.2} = P_2V_2^{1.2}$ on put the values.
We get, P_2 as
$500\,(0.75)^{1.2} = P_2\,(1.5)^{1.2}$
$P_2 = 217.64$ kPa
$$\text{Work done} = \frac{500 \times 0.75 - 217.64 \times 1.5}{1.2 - 1}$$
Work done = 242.7 kJ

180. The maximum pressure and temperature is an air standard diesel cycle are 44 bar and 1600 K, respectively. If the minimum pressure and temperature are 1 bar and 300 K, respectively, then the cut-off ratio (the ratio of the volume at the end of the heat addition process to that at the beginning of the heat addition process) is
(a) 1.000 (b) 14.920
(c) 2.809 (d) 1.809

[GATE-XE 2014: 2M]

Ans. (d) : Given,
$P_1 = 1$ bar, $P_2 = 44$ bar
T_3 (Maximum temp.) = 1600 K
T_1 (Minimum temp.) = 300 K
According to the condition of entropic compression for process (1-2) in diesel cycle.
$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$
$$T_2 = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \times T_1$$
$T_2 = 2.95 \times (300) = 885$ K
For the process (2-3) in diesel cycle.
P = Constant
$$\therefore \quad \frac{V_2}{T_2} = \frac{V_3}{T_3}$$
$$\frac{V_3}{V_2} = \frac{T_3}{T_2} = \frac{1600}{885} = 1.808 \approx 1.809$$

181. In a closed rigid vessel, air is initially at a pressure of 0.3 MPa and volume of 0.1 m^3 at 300 K. A stirrer supplies 100 kJ of work to the air, while 20 kJ of heat is lost to the atmosphere across the container walls. After these processes, the temperature of air changes to _________ K.



(a) 321.9 (b) 702.4
(c) 782.4 (d) 620.2

[GATE-XE 2014: 2M]

Ans. (d) : Given,
$P_1 = 0.3$ MPa
$V_1 = 0.1$ m^3
$T_1 = 300$ K
Q = – 20 kJ {–ve since heat is lost to the atmosphere}
W = – 100 kJ {–ve since work is done on the system}
From the first law of thermodynamics,
$Q = \Delta U + W$
$\Delta U = Q - W$
$\Delta U = [-20 - (-100)]$ kJ
$\Delta U = 80$ kJ …(i)
From the ideal gas law,
$p_1V_1 = mRT_1$
$0.3 \times 1000 \times 0.1 = m \times 0.287 \times 300$
$m = 0.348$ kg …(ii)
Now, from equation (i) and (ii),
$\Delta U = mC_v\Delta T$
$80 = 0.348 \times 0.717 \times (T_2 - 300)$
$T_2 = 620.6$ K

182. A small container has gas at high pressure. It is placed in an evacuated space. If the container is punctured, work done by the gas is
(a) Positive (b) Negative
(c) Zero (d) ∞

[GATE-XE 2014: 1M]

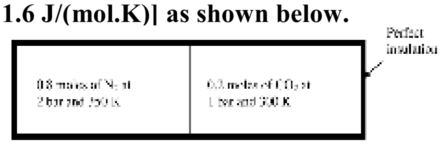
Ans. (c) : A small container has gas at high pressure. It is placed in an evacuated space. If the container is punctured, work done by the gas is zero.
But when the container is punctured, the gas in the container expands in the evacuated space. Until the pressure inside the container and space becomes equal. This represents the case of free expansion, and the work done by the gas, becomes zero.

183. A system undergoes a change from state 1 to state 2. During this process, the change in the internal energy is ΔU. The change in internal energy of the system when executing the cycle 1-2-1 is equal to
(a) ΔU (b) 2ΔU
(c) Zero (d) –2ΔU

[GATE-XE 2014: 1M]

Ans. (c) : The change in internal energy of a system undergoing a cyclic process is always zero,
The initial state 1-2-1 is a cyclic process and the final state are the same hence the change is zero.

184. A thin insulating membrane separates two tanks initially filled with nitrogen [mean C_v = 21.6 J/(mol.K)] and carbon-dioxide [mean C_v = 11.6 J/(mol.K)] as shown below.



The membrane is ruptured and the gases are allowed to mix to form homogeneous mixture at equilibrium. During this process there are no heat or work interactions between the tank contents and the surroundings. The final temperature at the equilibrium state in Kelvin is

(a) 344.1 (b) 306.3
(c) 325.0 (d) 346.1

[GATE-XE 2014: 2M]

Ans. (a) : Given,
For N_2 (Nitrogen),
$n_1 = 0.8$
$m_1 = 0.8 \times 28$ gm
$C_{V1} = 21.6$ J/mol.K
$T_1 = 350$ K
For CO_2 (Carbon-dioxide),
$n_2 = 0.2$
$m_2 = 0.2 \times 44$ gm
$C_{V2} = 11.6$ J/mol.K
$T_2 = 300$ K
As, there are no heat interactions between the tank contents and the surroundings and also the work transfer is zero.
$\therefore \quad Q = 0$ and $W = 0$
Therefore,
$$n_1C_{V1}\Delta T_1 = n_2C_{V2}\Delta T_2$$
$$n_1C_{V1}(T_1 - T_f) = n_2C_{V2}(T_2 - T_1)$$
$$T_f = \frac{n_1C_{V1}T_1 + n_2C_{V2}T_2}{n_1C_{V1} + n_2C_{V2}}$$
$$T_f = \frac{0.8\times21.6\times350 + 0.2\times11.6\times300}{0.8\times21.6 + 0.2\times11.6}$$
$T_f = 344.1$ K

185. A cylinder contains $5m^3$ of an ideal gas at a pressure of 1 *bar*. This gas is compressed in a reversible isothermal process till its pressure increases to 5 *bar*. The work in kJ required for this process is

(a) 804.7 (b) 953.2
(c) 981.7 (d) 1012.2

[GATE-2013:1M]

Ans. (a) : Given data,
$P_1 = 1$ bar $= 100$ kPa
$V_1 = 5\ m^3$
$P_2 = 5$ bar
$\therefore$ The work done in a reversible isothermal process is
$$W = P_1V_1\, ln\left(\frac{P_1}{P_2}\right)$$
$$W = (1 \times 10^5) \times 5 \times ln\left(\frac{1}{5}\right) = -804.719 \text{ kJ}$$
Note- –ve sign shows that work is done on the system.

186. In which of the following processes work done (during the process) can be determined by $\int pdv$?

(a) Isothermal (b) Adiabatic
(c) Quasi-static (d) Isentropic

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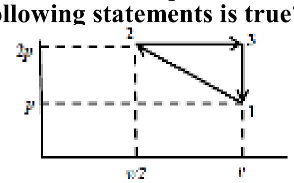
Ans. (d) : The work done can be
Determined by Quasi – static process.
$$W = \int pdv$$
Quasi – static : - In a quasi-static process, the system changes slowly enough to remain in internal thermodynamic equilibrium.

187. A closed system containing an ideal gas undergoes a cycle as shown in the figure shown below. For the process 1-2, which one of the following statements is true?



(a) Heat added $= \frac{3}{4}pv$

(b) Heat rejected $= \frac{3}{4}pv$

(c) Heat added $= \frac{1}{2}pv$

(d) Heat rejected $= \frac{1}{4}pv$

[GATE-XE 2013: 2M]

Ans. (b) : For the process 1-2
At the initial state (1), flow energy = p × v
At the final state (2), flow energy = 2p × v/2 = pv
$\because$ pv = nRT
d(pv) = nRdT
as the value of pv remains constant,
$\therefore$ d(pv) = 0
$\because \quad \delta Q = dU + \delta W \qquad$ ….(i)
For an ideal gas, the internal energy is a function of temperature only.
$\therefore$ dU = 0(for the process 1-2)
$\delta Q = \delta W$
Work done for the process (1-2) = area under the process (1-2),
$$\delta W = \frac{1}{2}\times\frac{v}{2}\times p + \frac{pv}{2} = \frac{3pv}{4}$$
$$\therefore \quad \delta Q = \delta W = \frac{3pv}{4}$$

188. The isothermal compressibility of a liquid is 5 × 10^{-6} /kPa. If it is compressed at constant temperature from 5000 to 10000kPa, what is the ratio of final volume to initial volume, to second decimal place accuracy? _________

[GATE-XE 2013: 2M]