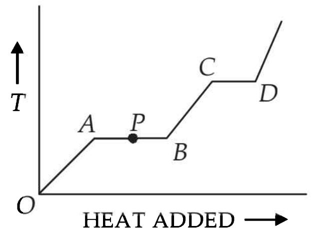
CHAPTER 9

Heat & Thermodynamics and Gases

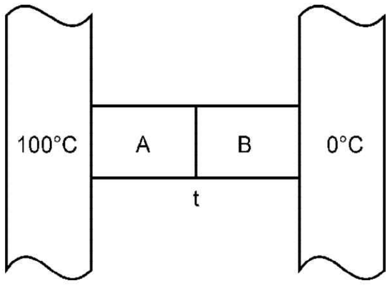
Section-A JEE Advanced/ IIT-JEE

A Fill in the Blanks

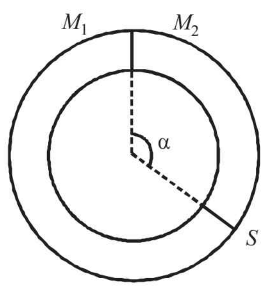
1. One mole of a mono-atomic ideal gas is mixed with one mole of a diatomic ideal gas. The molar specific heat of the mixture at constant volume is .... *(1984- 2 Marks)*
2. The variation of temperature of a material as heat is given to it at a constant rate is shown in the figure. The material is in solid state at the point O. The state of the material at the point P is .... *(1985 - 2 Marks)*



3. During an experiment, an ideal gas is found to obey an additional law VP^2 =constant, The gas is initially at a temperature T, and volume V. When it expands to a volume $2V$, the temperature becomes.......... *(1987 - 2 Marks)*
4. 300 grams of water at 25° C is added to 100 grams of ice at 0°C. The final temperature of the mixture is .....°C. *(1989 - 2 Marks)*
5. The earth receives at its surface radiation from the sun at the rate of 1400 W m^{-2}. The distance of the centre of the sun from the surface of the earth is 1.5×10^{11} m and the radius of the sun is 7×10^8 m. Treating the sun as a black body, it follows from the above data that its surface temperature is...........K. *(1989 - 2 Marks)*
6. A solid copper sphere (density ρ and specific heat c) of radius r at an initial temperature 200 K is suspended inside a chamber whose walls are at almost 0K. The time required for the temperature of the sphere to drop to 100K is .... *(1991 - 2 Marks)*
7. A point source of heat of power P is placed at the centre of a spherical shell of mean radius R. The material of the shell has thermal conductivity K. If the temperature difference between the outer and inner surface of the shell in not to exceed T, the thickness of the shell should not be less than .... *(1991 - 1 Mark)*
8. A substance of mass M kg requires a power input of P watts to remain in the molten state at its melting point. When the power source is turned off, the sample completely solidifies in time t seconds. The latent heat of fusion of the substance is .... *(1992 - 1 Mark)*
9. A container of volume $1 m^3$ is divided into two equal parts by a partition. One part has an ideal gas at 300K and the other part is vacuum. The whole system is thermally isolated from the surroundings. When the partition is removed, the gas expands to occupy the whole volume. Its temperature will now be....... *(1993-1 Mark)*
10. An ideal gas with pressure P, volume V and temperature T is expanded isothermally to a volume $2V$ and a final pressure P_i. If the same gas is expanded adiabatically to a volume $2V$, the final pressure is P_a. The ratio of the specific heats of the gas is 1.67 . The ratio $\frac{P_a}{P_1}$ is ..... *(1994 - 2 Marks)*
11. Two metal cubes A and B of same size are arranged as shown in Figure. The extreme ends of the combination are maintained at the indicated temperatures. The arrangement is thermally insulated. The coefficients of thermal conductivity of A and B are 300 W/m °C and 200 W/m°C, respectively. After steady state is reached the temperature t of the interface will be ..... *(1996 - 2 Marks)*



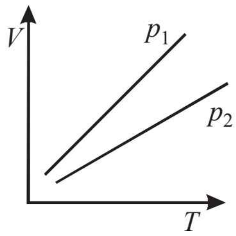
12. A ring shaped tube contains two ideal gases with equal masses and relative molar masses $M_1 = 32$ and $M_2 = 28$. The gases are separated by one fixed partition and another movable stopper S which can move freely without friction inside the ring. The angle α as shown in the figure is .... degrees. *(1997 - 2 Marks)*



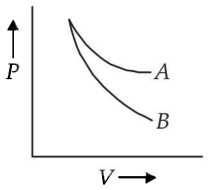
13. Earth receives 1400 W/m^2 of solar power. If all the solar energy falling on a lens of area 0.2 m^2 is focused on to a block of ice of mass 280 grams, the time taken to melt the ice will be... minutes. (Latent heat of fusion of ice = 3.3×10^5 J/kg.) *(1997 - 2 Marks)*

B True/False

1. The root-mean square speeds of the molecules of different ideal gases, maintained at the same temperature are the same. *(1981- 2 Marks)*
2. The volume V versus temperature T graphs for a certain amount of a perfect gas at two pressure p_1 and p_2 are as shown in Fig. It follows from the graphs that p_1 is greater than p_2. *(1982 - 2 Marks)*



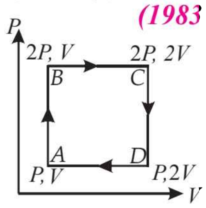
3. Two different gases at the same temperature have equal root mean square velocities. *(1982 - 2 Marks)*
4. The ratio of the velocity of sound in Hydrogen gas ($\gamma = \frac{7}{5}$) to that in Helium gas ($\gamma = \frac{5}{3}$) at the same temperature is $\sqrt{\frac{21}{5}}$. *(1983 - 2 Marks)*
5. The curves A and B in the figure shown P-V graphs for an isothermal and an adiabatic process for an ideal gas. The isothermal process is represented by the curve A. *(1985 - 3 Marks)*



6. At a given temperature, the specific heat of a gas at constant pressure is always greater than its specific heat at constant volume. *(1987 - 2 Marks)*
7. The root mean square (rms) speed of oxygen molecules (O_2) at a certain temperature T (degree absolute) is V. If the temperature is doubled and oxygen gas dissociates into atomic oxygen, the rms speed remains unchanged. *(1987 - 2 Marks)*
8. Two spheres of the same meterial have radii 1 m and 4 m and temperatures 4000K and 2000K respectively. The energy radiated per second by the first sphere is greater than that by the second. *(1988 - 2 Marks)*

C MCQs with One Correct Answer

1. A constant volume gas thermometer works on *(1980)*
   (a) The Principle of Archimedes
   (b) Boyle's Law
   (c) Pascal's Law
   (d) Charle's Law
2. A metal ball immersed in alcohol weighs W_1 at 0°C and W_2 at 50°C. The coefficient of expansion of cubical the metal is less than that of the alcohal. Assuming that the density of the metal is large compared to that of alcohol, it can be shown that *(1980)*
   (a) $W_1 > W_2$ (b) $W_1 = W_2$
   (c) $W_1 < W_2$ (d) None of these
3. A wall has two layers A and B, each made of different material. Both the layers have the same thickness. The thermal conductivity of the meterial of A is twice that of B. Under thermal equilibrium, the temperature difference across the wall is 36°C. The temperature difference across the layer A is *(1980)*
   (a) 6°C (b) 12°C (c) 18°C (d) 24°C
4. An ideal monatomic gas is taken round the cycle $ABCDA$ as shown in the $P-V$ diagram (see Fig.). The work done during the cycle is *(1983 - 1 Mark)*
   (a) PV
   (b) $2PV$
   (c) $\frac{1}{2}PV$
   (d) zero



5. If one mole of a monatomic gas $\left(\gamma = \frac{5}{3}\right)$ is mixed with one mole of a diatomic gas $\left(\gamma = \frac{7}{5}\right)$, the value of γ for mixture is *(1988 - 1 Mark)*
   (a) 1.40 (b) 1.50 (c) 1.53 (d) 3.07
6. From the following statements concerning ideal gas at any given temperature T, select the correct one(s) *(1995S)*
   (a) The coefficient of volume expansion at constant pressure is the same for all ideal gases
   (b) The average translational kinetic energy per molecule of oxygen gas is 3kT, k being Boltzmann constant
   (c) The mean-free path of molecules increases with increases in the pressure
   (d) In a gaseous mixture, the average translational kinetic energy of the molecules of each component is different
7. Three rods of identical cross-sectional area and made from the same metal from the sides of an isosceles traingle ABC, right-angled at B. The points A and B are maintained at temperatures T and $(\sqrt{2})\,T$ respectively. In the steady state, the temperature of the point C is T_c. Assuming that only heat conduction takes place, T_c / T is *(1995S)*
   (a) $\frac{1}{2(\sqrt{2}-1)}$ (b) $\frac{3}{\sqrt{2}+1}$
   (c) $\frac{1}{\sqrt{3}(\sqrt{2}-1)}$ (d) $\frac{1}{\sqrt{2}+1}$
8. Two metallic spheres S_1 and S_2 are made of the same material and have got identical surface finish. The mass of S_1 is thrice that of S_2. Both the spheres are heated to the same high temperature and placed in the same room having lower temperature but are thermally insulated from each other. The ratio of the initial rate of cooling of S_1 to that of S_2 is *(1995S)*
   (a) $\frac{1}{3}$ (b) $\frac{1}{\sqrt{3}}$ (c) $\frac{\sqrt{3}}{1}$ (d) $\left(\frac{1}{3}\right)^{\frac{1}{3}}$

9. The average translational kinetic energy of O_2 (relative molar mass 32) molecules at a particular temperature is 0.048 eV. The translational kinetic energy of N_2 (relative molar mass 28) molecules in eV at the same temperature is ***(1997 - 1 Mark)***

(a) 0.0015 (b) 0.003 (c) 0.048 (d) 0.768

10. A vessel contains 1 mole of O_2 gas (relative molar mass 32) at a temperature T. The pressure of the gas is P. An identical vessel containing one mole of He gas (relative molar mass 4) at a temperature 2T has a pressure of ***(1997 - 1 Mark)***

(a) P/8 (b) P (c) 2P (d) 8P

11. A spherical black body with a radius of 12 cm radiates 450 W power at 500 K. if the radius were halved and the temperature doubled, the power radiated in watt would be ***(1997 - 1 Mark)***

(a) 225 (b) 450 (c) 900 (d) 1800

12. A closed compartment containing gas is moving with some acceleration in horizontal direction. Neglect effect of gravity. Then the pressure in the compartment is ***(1999S - 2 Marks)***

(a) same everywhere (b) lower in the front side
(c) lower in the rear side (d) lower in the upper side

13. A gas mixture consists of 2 moles of oxygen and 4 moles of argon at temperature T. Neglecting all vibrational modes, the total internal energy of the system is ***(1999S - 2 Marks)***

(a) 4 RT (b) 15 RT (c) 9 RT (d) 11 RT

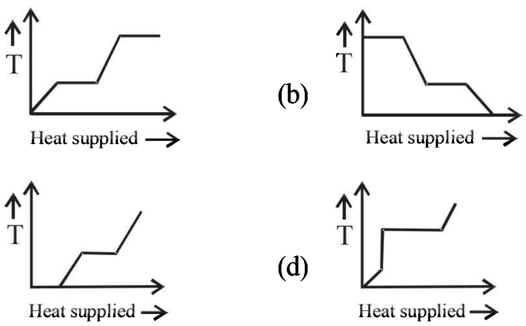
14. The ratio of the speed of sound in nitrogen gas to that in helium gas, at 300 K is ***(1999S - 2 Marks)***

(a) $\sqrt{(2/7)}$ (b) $\sqrt{(1/7)}$ (c) $(\sqrt{3})/5$ (d) $(\sqrt{6})/5$

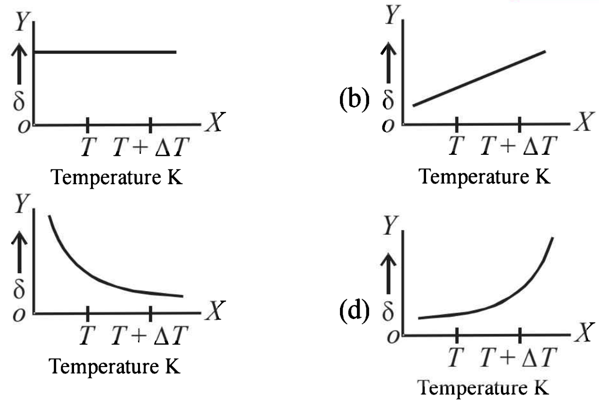
15. A monatomic ideal gas, initially at temperature T_1, is enclosed in a cylinder fitted with a frictionless piston. The gas is allowed to expand adiabatically to a temperature T_2 by releasing the piston suddenly. If L_1 and L_2 are the length of the gas column before and after expansion respectively, then $\frac{T_1}{T_2}$ is given by ***(2000S)***

(a) $\left(\frac{L_1}{L_2}\right)^{2/3}$ (b) $\frac{L_1}{L_2}$ (c) $\frac{L_2}{L_1}$ (d) $\left(\frac{L_2}{L_1}\right)^{2/3}$

16. A block of ice at –10°C is slowly heated and converted to steam at 100°C. Which of the following curves represents the phenomenon qualitatively? ***(2000S)***

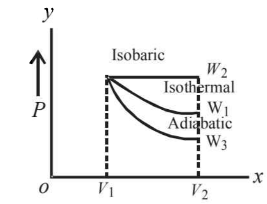


17. An ideal gas is initially at temperature T and volume V. Its volume is increased by ΔV due to an increase in temperature ΔT, pressure remaining constant. The quantity $\delta = \frac{\Delta V}{V \Delta T}$ varies with temperature as ***(2000S)***

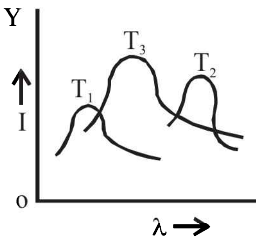


18. Starting with the same initial conditions, an ideal gas expands from volume V_1 to V_2 in three different ways. The work done by the gas is W_1 if the process is purely isothermal, W_2 if purely isobaric and W_3 if purely adiabatic. Then ***(2000S)***

(a) $W_2 > W_1 > W_3$
(b) $W_2 > W_3 > W_1$
(c) $W_1 > W_2 > W_3$
(d) $W_1 > W_3 > W_2$



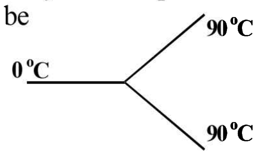
19. The plots of intensity versus wavelength for three black bodies at temperature T_1, T_2 and T_3 respectively are as shown. Their temperatures are such that ***(2000S)***



(a) $T_1 > T_2 > T_3$ (b) $T_1 > T_3 > T_2$
(c) $T_2 > T_3 > T_1$ (d) $T_3 > T_2 > T_1$

20. Three rods made of same material and having the same cross-section have been joined as shown in the figure. Each rod is of the same length. The left and right ends are kept at 0°C and 90°C respectively. The temperature of the junction of the three rods will be ***(2001S)***

(a) 45°C
(b) 60°C
(c) 30°C
(d) 20°C

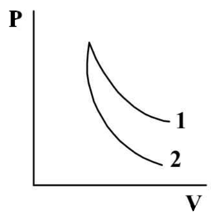


21. In a given process on an ideal gas, $dW = 0$ and $dQ < 0$. Then for the gas ***(2001S)***

(a) the temperature will decrease
(b) the volume will increase
(c) the pressure will remain constant
(d) the temperature will increase

22. P-V plots for two gases during adiabatic processes are shown in the figure. Plots 1 and 2 should correspond respectively to ***(2001S)***

(a) He and O_2
(b) O_2 and He
(c) He and Ar
(d) O_2 and N_2

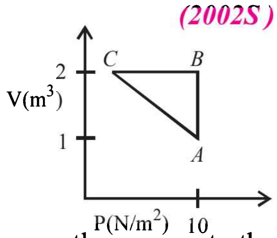


23. When a block of iron floats in mercury at 0°C, fraction k_1 of its volume is submerged, while at the temperature 60 °C, a fraction k_2 is seen to be submerged. If the coefficient of volume expansion of iron is γ_{Fe} and that of mercury is γ_{Hg}, then the ratio k_1/k_2 can be expressed as *(2001S)*

(a) $\frac{1+60\gamma_{Fe}}{1+60\gamma_{hg}}$ (b) $\frac{1-60\gamma_{Fe}}{1+60\gamma_{Hg}}$

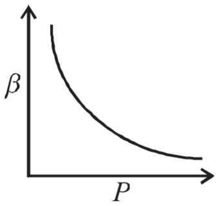
(c) $\frac{1+60\gamma_{Fe}}{1-60\gamma_{Hg}}$ (d) $\frac{1+60\gamma_{Hg}}{1+60\gamma_{Fe}}$

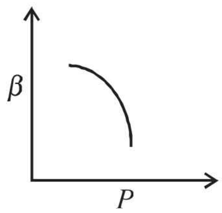
24. An ideal gas is taken through the cycle $A \to B \to C \to A$, as shown in the figure. If the net heat supplied to the gas in the cycle is 5J, the work done by the gas in the process $C \to A$ is *(2002S)*

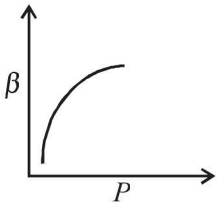


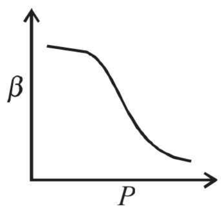
(a) –5 J
(b) –10 J
(c) –15 J
(d) –20 J

25. Which of the following graphs correctly represents the variation of $\beta = -\frac{dV/dP}{V}$ with P for an ideal gas at constant temperature? *(2002S)*

(a) 

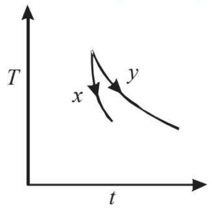
(b) 

(c) 

(d) 

26. An ideal Black-body at room temperature is thrown into a furnace. It is observed that *(2002S)*
(a) initially it is the darkest body and at later times the brightest
(b) it is the darkest body at all times
(c) it cannot be distinguished at all times
(d) initially it is the darkest body and at later times it cannot be distinguished

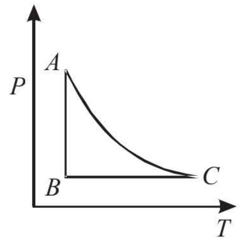
27. The graph, shown in the adjacent diagram, represents the variation of temperature (T) of two bodies, x and y having same surface area, with time (t) due to the emission of radiation. Find the correct relation between the emissivity and absorptivity power of the two bodies *(2003S)*

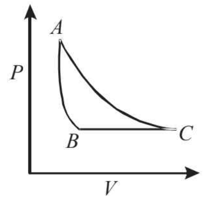


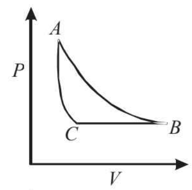
(a) $E_x > E_y$ & $a_x < a_y$
(b) $E_x < E_y$ & $a_x > a_y$
(c) $E_x > E_y$ & $a_x > a_y$
(d) $E_x < E_y$ & $a_x < a_y$

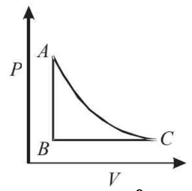
28. Two rods, one of aluminum and the other made of steel, having initial length ℓ_1 and ℓ_2 are connected together to form a single rod of length $\ell_1 + \ell_2$. The coefficients of linear expansion for aluminum and steel are α_a and α_s and respectively. If the length of each rod increases by the same amount when their temperature are raised by t^0C, then find the ratio $\ell_1/(\ell_1+\ell_2)$ *(2003S)*
(a) α_s/α_a (b) α_a/α_s
(c) $\alpha_s/(\alpha_a+\alpha_s)$ (d) $\alpha_a/(\alpha_a+\alpha_s)$

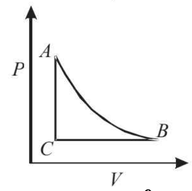
29. The PT diagram for an ideal gas is shown in the figure, where AC is an adiabatic process, find the corresponding PV diagram. *(2003S)*



(a) 

(b) 

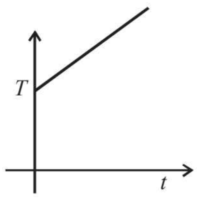
(c) 

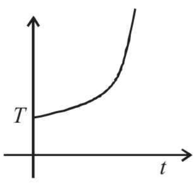
(d) 

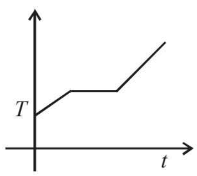
30. 2 kg of ice at –20⁰C is mixed with 5kg of water at 20⁰C in an insulating vessel having a negligible heat capacity. Calculate the final mass of water remaining in the container. It is given that the specific heats of water & ice are 1kcal/kg/⁰C & 0.5 kcal/kg/⁰C while the latent heat of fusion of ice is 80 kcal/kg
(a) 7 kg (b) 6 kg *(2003S)*
(c) 4 kg (d) 2 kg

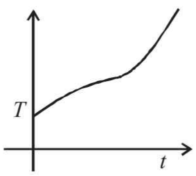
31. Three discs A, B and C having radii 2, 4, and 6 cm respectively are coated with carbon black. Wavelength for maximum intensity for the three discs are 300, 400 and 500 nm respectively. If Q_A, Q_B and Q_C are power emitted by A, B and D respectively, then *(2004S)*
(a) Q_A will be maximum (b) Q_B will be maximum
(c) Q_C will be maximum (d) $Q_A = Q_B = Q_C$

32. If liquefied oxygen at 1 atmospheric pressure is heated from 50 k to 300 k by supplying heat at constant rate. The graph of temperature vs time will be *(2004S)*

(a) 

(b) 

(c) 

(d) 

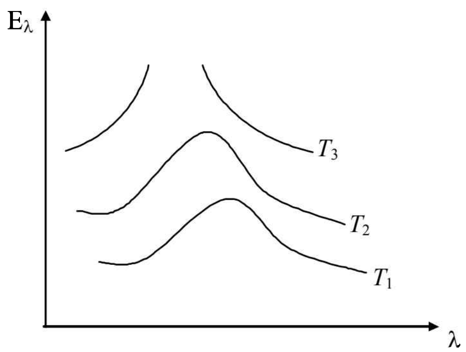
33. Two identical rods are connected between two containers one of them is at 100°C and another is at 0°C. If rods are connected in parallel then the rate of melting of ice is q_1 gm/sec. If they are connected in series then the rate is q_2. The ratio q_2/q_1 is *(2004S)*

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

34. An ideal gas is initially at P_1, V_1 is expanded to P_2, V_2 and then compressed adiabatically to the same volume V_1 and pressure P_3. If W is the net work done by the gas in complete process which of the following is true *(2004S)*

(a) $W > 0$; $P_3 > P_1$ (b) $W < 0$; $P_3 > P_1$
(c) $W > 0$; $P_3 < P_1$ (d) $W < 0$; $P_3 < P_1$

35. Variation of radiant energy emitted by sun, filament of tungsten lamp and welding arc as a function of its wavelength is shown in figure. Which of the following option is the correct match ? *(2005S)*



(a) Sun-T_3, tungsten filament - T_1, welding arc - T_2
(b) Sun-T_2, tungsten filament - T_1, welding arc - T_3
(c) Sun-T_3, tungsten filament - T_2, welding arc - T_1
(d) Sun-T_1, tungsten filament - T_2, welding arc - T_3

36. In which of the following process, convection does not take place primarily *(2005S)*

(a) sea and land breeze
(b) boiling of water
(c) heating air around a furnace
(d) warming of glass of bulb due to filament

37. A spherical body of area A and emissivity $e = 0.6$ is kept inside a perfectly black body. Total heat radiated by the body at temperature T (2005S)

(a) $0.4AT^4$ (b) $0.8AT^4$
(c) $0.6AT^4$ (d) $1.0AT^4$

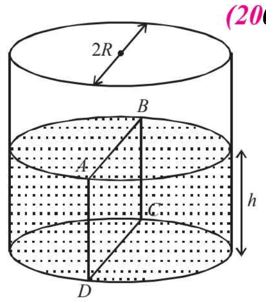
38. Calorie is defined as the amount of heat required to raise temperature of 1 g of water by 1°C and it is defined under which of the following conditions? *(2005S)*

(a) From 14.5 °C to 15.5 °C at 760 mm of Hg
(b) From 98.5 °C to 99.5 °C at 760 mm of Hg
(c) From 13.5 °C to 14.5 °C at 76 mm of Hg
(d) From 3.5 °C to 4.5°C at 76 mm of Hg

39. Water of volume 2 litre in a container is heated with a coil of 1 kW at 27 °C. The lid of the container is open and energy dissipates at rate of 160 J/s. In how much time temperature will rise from 27°C to 77°C [Given specific heat of water is 4.2 kJ/kg] *(2005S)*

(a) 7 min (b) 6 min 2 s (c) 8 min 20 s (d) 14 min

40. Water is filled up to a height h in a beaker of radius R as shown in the figure. The density of water is ρ, the surface tension of water is T and the atmospheric pressure is P_0. Consider a vertical section $ABCD$ of the water column through a diameter of the beaker. The force on water on one side of this section by water on the other side of this section has magnitude *(2007)*



(a) $|2P_0Rh + \pi R^2 \rho g h - 2RT|$
(b) $|2P_0Rh + R\rho g h^2 - 2RT|$
(c) $|P_0 \pi R^2 + R\rho g h^2 - 2RT|$
(d) $|P_0 \pi R^2 + R\rho g h^2 + 2RT|$

41. An ideal gas is expanding such that PT^2 = constant. The coefficient of volume expansion of the gas is – *(2008)*

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

42. A real gas behaves like an ideal gas if its *(2010)*

(a) pressure and temperature are both high
(b) pressure and temperature are both low
(c) pressure is high and temperature is low
(d) pressure is low and temperature is high

43. 5.6 liter of helium gas at STP is adiabatically compressed to 0.7 liter. Taking the initial temperature to be T_1, the work done in the process is *(2011)*

(a) $\frac{9}{8}RT_1$ (b) $\frac{3}{2}RT_1$ (c) $\frac{15}{8}RT_1$ (d) $\frac{9}{2}RT_1$

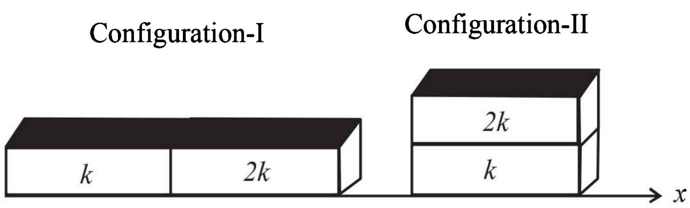
44. A mixture of 2 moles of helium gas (atomic mass = 4 amu) and 1 mole of argon gas (atomic mass = 40 amu) is kept at 300 K in a container. The ratio of the rms speeds $\left(\frac{v_{rms}(\text{helium})}{v_{rms}(\text{argon})}\right)$ is *(2012)*

(a) 0.32 (b) 0.45 (c) 2.24 (d) 3.16

45. Two moles of ideal helium gas are in a rubber balloon at 30°C. The balloon is fully expandable and can be assumed to require no energy in its expansion. The temperature of the gas in the balloon is slowly changed to 35°C. The amount of heat required in raising the temperature is nearly (take R = 8.31 J/mol.K) *(2012)*

(a) 62 J (b) 104 J (c) 124 J (d) 208 J

46. Two rectangular blocks, having identical dimensions, can be arranged either in configuration-I or in configuration-II as shown in the figure. One of the blocks has thermal conductivity k and the other $2k$. The temperature difference between the ends along the x-axis is the same in both the configurations. It takes 9 s to transport a certain amount of heat from the hot end to the cold end in the configuration-I. The time to transport the same amount of heat in the configuration-II is *(JEE Adv. 2013)*



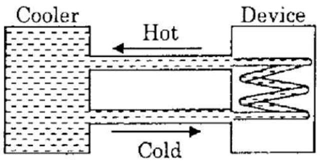
(a) 2.0 s (b) 4.5 s (c) 3.0 s (d) 6.0 s

47. Two non-reactive monoatomic ideal gases have their atomic masses in the ratio 2 : 3. The ratio of their partial pressures, when enclosed in a vessel kept at a constant temperature, is 4 : 3. The ratio of their densities is *(JEE Adv. 2013)*

(a) 1 : 4 (b) 1 : 2 (c) 6 : 9 (d) 8 : 9

48. Parallel rays of light of intensity $I = 912$ Wm^{-2} are incident on a spherical black body kept in surroundings of temperature 300 K. Take Stefan-Boltzmann constant $\sigma = 5.7 \times 10^{-8}$ Wm^{-2}K^{-4} and assume that the energy exchange with the surroundings is only through radiation. The final steady state temperature of the black body is close to *(JEE Adv. 2014)*
(a) 330 K (b) 660 K (c) 990 K (d) 1550 K

49. A water cooler of storage capacity 120 litres can cool water at a constant rate of P watts. In a closed circulation system (as shown schematically in the figure), the water from the cooler is used to cool an external device that generates constantly 3 kW of heat (thermal load). The temperature of water fed into the device cannot exceed 30°C and the entire stored 120 litres of water is initially cooled to 10°C. The entire system is thermally insulated. The minimum value of P (in watts) for which the device can be operated for 3 hours is *(JEE Adv. 2016)*



(Specific heat of water is 4.2 kJ kg^{-1}K^{-1} and the density of water is 1000 kg m^{-3})
(a) 1600 (b) 2067 (c) 2533 (d) 3933

50. A gas is enclosed in a cylinder with a movable frictionless piston. Its initial thermodynamic state at pressure $P_i = 10^5$ Pa and volume $V_i = 10^{-3}$ m^3 changes to a final state at $P_f = (1/32) \times 10^5$ Pa and $V_f = 8 \times 10^{-3}$ m^3 in an adiabatic quasi-static process, such that P^3V^5 = constant. Consider another thermodynamic process that brings the system from the same initial state to the same final state in two steps: an isobaric expansion at P_i followed by an isochoric (isovolumetric) process at volume V_f. The amount of heat supplied to the system in the two-step process is approximately *(JEE Adv. 2016)*
(a) 112 J (b) 294 J (c) 588 J (d) 813 J

51. The ends Q and R of two thin wires, PQ and RS, are soldered (joined) together. Initially each of the wires has a length of 1 m at 10°C. Now the end P is maintained at 10°C, while the end S is heated and maintained at 400 °C. The system is thermally insulated from its surroundings. If the thermal conductivity of wire PQ is twice that of the wire RS and the coefficient of linear thermal expansion of PQ is 1.2×10^{-5} K^{-1}, the change in length of the wire PQ is *(JEE Adv. 2016)*
(a) 0.78 mm (b) 0.90 mm (c) 1.56 mm (d) 2.34 mm

D MCQs with One or More than One Correct

1. At room temperature, the rms speed of the molecules of a certain diatomic gas is found to be 1930 m/s. The gas is *(1984- 2 Marks)*
(a) H_2 (b) F_2 (c) O_2 (d) Cl_2

2. 70 calories of heat required to raise the temperature of 2 moles of an ideal gas at constant pressure from 30°C to 35°C. The amount of heat required (in calories) to raise the temperature of the same gas through the same range (30°C to 35°C) at constant volume is : *(1985 - 2 Marks)*
(a) 30 (b) 50 (c) 70 (d) 90

3. Steam at 100°C is passed into 1.1 kg of water contained in a calorimeter of water equivalent 0.02 kg at 15°C till the temperature of the calorimeter and its contents rises to 80°C. The mass of the steam condensed in kilogram is *(1986 - 2 Marks)*
(a) 0.130 (b) 0.065 (c) 0.260 (d) 0.135

4. A cylinder of radius R made of a material of thermal conductivity K_1 is surrounded by a cylindrical shell of inner radius R and outer radius $2R$ made of a material of thermal conductivity K_2. The two ends of the combined system are maintained at two different temperatures. There is no loss of heat across the cylindrical surface and the system is in steady state. The effective thermal conductivity of the system is *(1988 - 2 Marks)*
(a) $K_1 + K_2$ (b) $K_1K_2/(K_1 + K_2)$
(c) $(K_1 + 3K_2)/4$ (d) $(3K_1 + 3K_2)/4$

5. For an ideal gas : *(1989 - 2 Marks)*
(a) the change in internal energy in a constant pressure process from temperature T_1 to T_2 is equal to $nC_v(T_2 - T_1)$, where C_v is the molar specific heat at constant volume and n the number of moles of the gas.
(b) the change in internal energy of the gas and the work done by the gas are equal in magnitude in an adiabatic process.
(c) the internal energy does not change in an isothermal process.
(d) no heat is added or removed in an adiabatic process.

6. When an ideal diatomic gas is heated at constant pressure, the fraction of the heat energy supplied which increases the internal energy of the gas is *(1990 - 2 Marks)*
(a) $\frac{2}{5}$ (b) $\frac{3}{5}$ (c) $\frac{3}{7}$ (d) $\frac{5}{7}$

7. Three closed vessels A, B and C are at the same temperature T and contain gases which obey the Maxwellian distribution of velocities. Vessel A contain only O_2, B only N_2 and C a mixture of equal quantities of O_2 and N_2. If the average speed of the O_2 molecules in vessel A is v_1 that of the N_2 molecules in vessel B is v_2, the average speed of the O_2 molecules in vessel C is *(1992 - 2 Marks)*
(a) $\frac{v_1 + v_2}{2}$ (b) v_1 (c) $(v_1.v_2)^{\frac{1}{2}}$ (d) $\sqrt{\frac{3kT}{M}}$
where M is the mass of an oxygen molecule.

8. An ideal gas is taken from the state A (pressure P, volume V) to the state B (pressure $P/2$, volume $2V$) along a straight line path in the P-V diagram. Select the correct statement (s) from the following: *(1993-2 Marks)*
(a) The work done by the gas in the process A to B exceeds the work that would be done by it if the system were taken from A to B along the isotherm.
(b) In the T-V diagram, the path AB becomes a part of a parabola
(c) In the P-T diagram, the path AB becomes a part of a hyperbola
(d) In going from A to B, the temperature T of the gas first increases to a maximum value and then decreases.

9. Two bodies A and B ahave thermal emissivities of 0.01 and 0.81 respectively. The outer surface areas of the two bodies are the same. The two bodies emit total radiant power of the same rate. The wavelength λ_B corresponding to maximum spectral radiancy in the radiation from B shifted from the wavelenth corresponding to maximum spectral radiancy in the radiation from A, by 1.00 μm. If the temperature of A is 5802 K: *(1994 - 2 Marks)*
(a) the temperature of B is 1934 K
(b) $\lambda_B = 1.5\ \mu m$
(c) the temperature of B is 11604 K
(d) the temperature of B is 2901 K

10. The temperature of an ideal gas is increased from 120 K to 480 K. If at 120 K the root-mean-square velocity of the gas molecules is v, at 480 K it becomes **(1996 - 2 Marks)**
(a) 4v (b) 2v (c) v/2 (d) v/4

11. A given quantity of a ideal gas is at pressure P and absolute temperature T. The isothermal bulk modulus of the gas is *(1998S - 2 Marks)*
(a) $\frac{2}{3}P$ (b) P (c) $\frac{3}{2}P$ (d) $2P$

12. Two cylinders A and B fitted with pistons contain equal amounts of an ideal diatomic gas at 300 K. The piston of A is free to move, while that B is held fixed. The same amount of heat is given to the gas in each cylinder. If the rise in temperature of the gas in A is 30 K, then the rise in temperature of the gas in B is *(1998S - 2 Marks)*
(a) 30 K (b) 18 K (c) 50 K (d) 42 K

13. During the melting of a slab of ice at 273 K at atmospheric pressure, *(1998S - 2 Marks)*
(a) positive work is done by the ice-water system on the atmosphere.
(b) positive work is done on the ice- water system by the atmosphere.
(c) the internal energy of the ice-water system increases.
(d) the internal energy of the ice-water system decreases.

14. A blackbody is at a temperature of 2880 K. The energy of radiation emitted by this object with wavelength between 499 *nm* and 500 nm is U_1, between 999 *nm* and 1000 *nm* is U_2 and between 1499 *nm* and 1500nm is U_3. The Wien constant $b = 2.88 \times 10^6 nm\ K$. Then *(1998S - 2 Marks)*
(a) $U_1 = 0$ (b) $U_3 = 0$ (c) $U_1 > U_2$ (d) $U_2 > U_1$

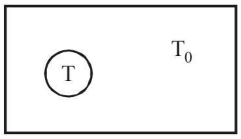
15. A bimetallic strip is formed out of two identical strips one of copper and the other of brass. The coefficients of linear expansion of the two metals are α_c and α_B. On heating, the temperature of the strip goes up by ΔT and the strip bends to form an arc of radius of curvature R. Then R is. *(1999S - 3 Marks)*
(a) proportional to ΔT
(b) inversely proportional to ΔT
(c) proportional to $|\alpha_B - \alpha_C|$
(d) inversely proportional to $|\alpha_B - \alpha_C|$

16. Two identical containers A and B with frictionless pistons contain the same ideal gas at the same temperature and the same volume V. The mass of the gas in A is m_A, and that in B is m_B. The gas in each cylinder is now allowed to expand isothermally to the same final volume 2V. The changes in the pressure in A and B are found to be ΔP and 1.5 ΔP respectively. Then *(1998S - 2 Marks)*
(a) $4m_A = 9m_B$ (b) $2m_A = 3m_B$
(c) $3m_A = 2m_B$ (d) $9m_A = 4m_B$

17. Let $\bar{v}, v_{rms}$ and v_p respectively denote the mean speed. root mean square speed, and most probable speed of the molecules in an ideal monatomic gas at absolute temperature T. The mass of a molecule is m. Then *(1998S - 2 Marks)*
(a) no molecule can have a speed greater than $\sqrt{2}\, v_{rms}$
(b) no molecule can have a speed less than $v_p / \sqrt{2}$
(c) $v_p < \bar{v} < v_{rms}$
(d) the average kinetic energy of a molecule is $\frac{3}{4} m v_p^2$.

18. A vessel contains a mixture of one mole of oxygen and two moles of nitrogen at 300 K. The ratio of the average rotational kinetic energy per O_2 molecule to that per N_2 molecule is *(1998S - 2 Marks)*
(a) 1 : 1
(b) 1 : 2
(c) 2 : 1
(d) depends on the moments of inertia of the two molecules

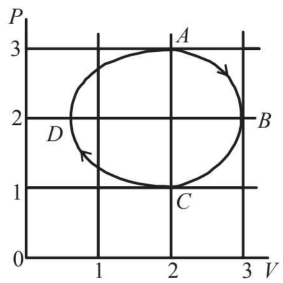
19. A black body of temperature T is inside chamber of T_0 temperature initially. Sun rays are allowed to fall from a hole in the top of chamber. If the temperature of black body (T) and chamber (T_0) remains constant, then *(2006 - 5M, –1)*



(a) Black body will absorb more radiation
(b) Black body will absorb less radiation
(c) Black body emit more energy
(d) Black body emit energy equal to energy absorbed by it

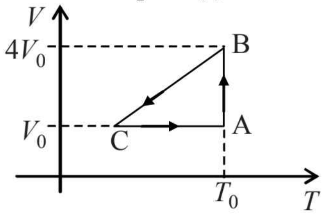
20. C_v and C_p denote the molar specific heat capacities of a gas at constant volume and constant pressure, respectively. Then *(2009)*
(a) $C_p - C_v$ is larger for a diatomic ideal gas than for a monoatomic ideal gas
(b) $C_p + C_v$ is larger for a diatomic ideal gas than for a monatomic ideal gas
(c) C_p / C_v is larger for a diatomic ideal gas than for a monoatomic ideal gas
(d) $C_p \cdot C_v$ is larger for a diatomic ideal gas than for a monoatomic ideal gas

21. The figure shows the *P-V* plot of an ideal gas taken through a cycle *ABCDA*. The part *ABC* is a semi-circle and *CDA* is half of an ellipse. Then, *(2009)*



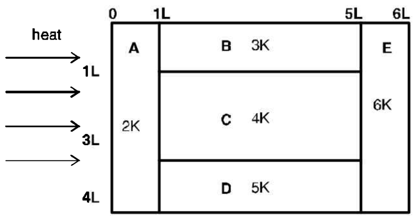
(a) the process during the path $A \rightarrow B$ is isothermal
(b) heat flows out of the gas during the path $B \rightarrow C \rightarrow D$
(c) work done during the path $A \rightarrow B \rightarrow C$ is zero
(d) positive work is done by the gas in the cycle *ABCDA*

22. One mole of an ideal gas in initial state A undergoes a cyclic process ABCA, as shown in the figure. Its pressure at A is P_0. Choose the correct option(s) from the following ***(2010)***



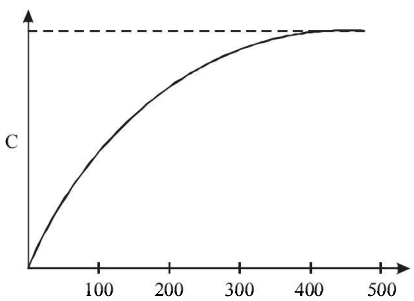
(a) Internal energies at A and B are the same
(b) Work done by the gas in process AB is $P_0V_0 \ln 4$
(c) Pressure at C is $\frac{P_0}{4}$
(d) Temperature at C is $\frac{T_0}{4}$

23. A composite block is made of slabs A, B, C, D and E of different thermal conductivities (given in terms of a constant K and sizes (given in terms of length, L) as shown in the figure. All slabs are of same width. Heat 'Q' flows only from left to right through the blocks. Then in steady state ***(2011)***



(a) heat flow through A and E slabs are same.
(b) heat flow through slab E is maximum.
(c) temperature difference across slab E is smallest.
(d) heat flow through C = heat flow through B + heat flow through D.

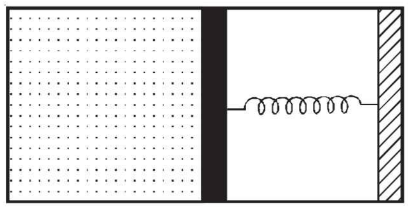
24. The figure below shows the variation of specific heat capacity (C) of a solid as a function of temperature (T). The temperature is increased continuously from 0 to 500 K at a constant rate. Ignoring any volume change, the following statement(s) is (are) correct to a reasonable approximation. ***(JEE Adv. 2013)***



(a) The rate at which heat is absorbed in the range 0 -100 K varies linearly with temperature T.
(b) Heat absorbed in increasing the temperature from 0-100 K is less than the heat required for increasing the temperature from 400-500 K.
(c) There is no change in the rate of heat absorption in the range 400-500 K.
(d) The rate of heat absorption increases in the range 200-300 K.

25. A container of fixed volume has a mixture of one mole of hydrogen and one mole of helium in equilibrium at temperature T. Assuming the gases are ideal, the correct statement(s) is (are) ***(JEE Adv. 2015)***
(a) The average energy per mole of the gas mixture is $2RT$
(b) The ratio of speed of sound in the gas mixture to that in helium gas is $\sqrt{6/5}$
(c) The ratio of the rms speed of helium atoms to that of hydrogen molecules is 1/2
(d) The ratio of the rms speed of helium atoms to that of hydrogen molecules is $\frac{1}{\sqrt{2}}$

26. An ideal monoatomic gas is confined in a horizontal cylinder by a spring loaded piston (as shown in the figure). Initially the gas is at temperature T_1, pressure P_1 and volume V_1 and the spring is in its relaxed state. The gas is then heated very slowly to temperature T_2, pressure P_2 and volume V_2. During this process the piston moves out by a distance x. Ignoring the friction between the piston and the cylinder, the correct statement(s) is (are) ***(JEE Adv. 2015)***

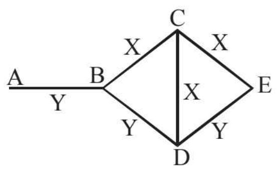


(a) If $V_2 = 2V_1$ and $T_2 = 3T_1$, then the energy stored in the spring is $\frac{1}{4}P_1V_1$
(b) If $V_2 = 2V_1$ and $T_2 = 3T_1$, then the change in internal energy is $3P_1V_1$
(c) If $V_2 = 3V_1$ and $T_2 = 4T_1$, then the work done by the gas is $\frac{7}{3}P_1V_1$
(d) If $V_2 = 3V_1$ and $T_2 = 4T_1$, then the heat supplied to the gas is $\frac{17}{6}P_1V_1$

E Subjective Problems

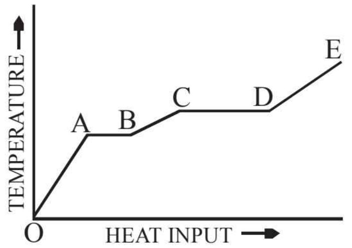
1. A sinker of weight w_0 has an apparent weight w_1 when weighed in a liquid at a temperature t_1 and w_2 when weight in the same liquid at temperature t_2. The coefficient of cubical expansion of the material of sinker is β. What is the coefficient of volume expansion of the liquid. ***(1978)***

2. Three rods of material X and three rods of material Y are connected as shown in the figure. All the rods are of identical length and cross-sectional area. If the end A is maintained at 60°C and the junction E at 10°C. Calculate the temperature of the junctions B, C and D. The thermal conductivity of X is 0.92 cal/sec-cm-°C and that of Y is 0.46 cal/sec-cm-°C. **(1978)**



3. Given samples of 1 c.c. of hydrogen and 1c.c. of oxygen, both at N.T.P. which sample has a larger number of molecules? *(1979)*

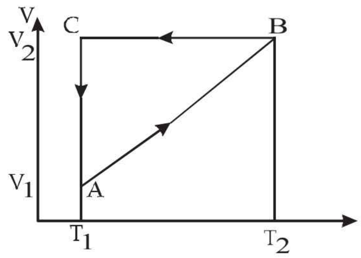
4. A Solid material is supplied with heat at a constant rate. The temperature of the material is changing with the heat input as shown in the graph in figure. Study the graph carefully and answer the following questions : *(1980)*



(i) What do the horizontal regions *AB* and *CD* represent?
(ii) If *CD* is equal to 2*AB*, what do you infer?
(iii) What does the slope of *DE* represent?
(iv) The slope of *OA* > the slope of *BC*. What does this indicate?

5. A jar contains a gas and a few drops of water at T°K. The pressure in the jar is 830 mm of Hg. The temperature of the jar is reduced by 1%. The saturated vapour pressures of water at the two temperatures are 30 and 25 mm of Hg. *(1980)* Calculate the new pressure in the jar.

6. A cyclic process *ABCA* shown in the *V-T* diagram (fig) is performed with a constant mass of an ideal gas. Show the same process on a *P-V* diagram *(1981- 4 Marks)*



(In the figure, *CA* is parallel to the *V*-axis and *BC* is parallel to the *T*-axis)

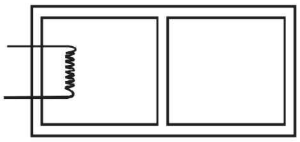
7. A lead bullet just melts when stopped by an obstacle. Assuming that 25 per cent of the heat is absorbed by the obstacle, find the velocity of the bullet if its initial temperature is 27°C.
(Melting point of lead = 327°C, specific heat of lead = 0.03 calories /gm/°C, latent heat of fusion of lead = 6 calories / gm, J = 4.2 joules /calorie). *(1981- 3 Marks)*

8. Calculate the work done when one mole of a perfect gas is compressed adiabatically. The initial pressure and volume of the gas are 105 N/m^2 and 6 litres respectively. The final volume of the gas is 2litre. Molar specific heat of the gas at constant volume is 3R/2. *(1982 - 8 Marks)*

9. A solid sphere of copper of radius *R* and a hollow sphere of the same material of inner radius *r* and outer radius *A* are heated to the same temperature and allowed to cool in the same environment. Which of them starts cooling faster ? *(1982 - 2 Marks)*

10. One gram mole of oxygen at 27° and one atmospheric pressure is enclosed in a vessel. *(1983 - 8 Marks)*
(i) Assuming the molecules to be moving with V*rms*, Find the number of collisions per second which the molecules make with one square metre area of the vessel wall.
(ii) The vessel is next thermally insulated and moved with a constant speed V*o*. It is then suddenly stopped. The process results in a rise of the temperature of the gas by 1°C. Calculate the speed V*o*.

11. The rectangular box shown in Fig has a partition which can slide without friction along the length of the box. Initially each of the two chambers of the box has one mole of a mono-atomic ideal gas ($\gamma = 5/3$) at a pressure P_0, volume V_0 and temperature T_0. The chamber on the left is slowly heated by an electric heater. The walls of the box and the partition are thermally insulated. Heat loss through the lead wires of the heater is negligible. The gas in the left chamber expands pushing the partition until the final pressure in both chambers becomes 243 P_0/32. Determine (i) the final temperature of the gas in each chamber and (ii) the work done by the gas in the right chamber. *(1984- 8 Marks)*



12. Two glass bulbs of equal volume are connected by a narrow tube and are filled with a gas at 0°C and a pressure of 76 cm of mercury. One of the bulbs is then placed in melting ice and the other is placed in a water bath maintained at 62°C. What is the new value of the pressure inside the bulbs? The volume of the connecting tube is negligible. *(1985 - 6 Marks)*

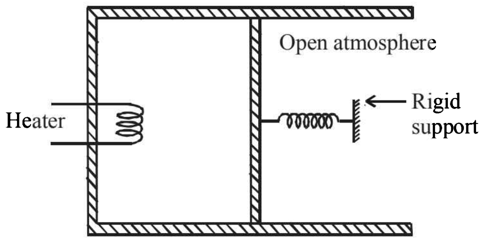
13. A thin tube of uniform cross-section is sealed at both ends. It lies horizontally, the middle 5 cm containing mercury and the two equal end containing air at the same pressure P. When the tube is held at an angle of 60° with the vertical direction, the length of the air column above and below the mercury column are 46cm and 44.5 cm respectively. Calculate the pressure P in centimeters of mercury. (The temperature of the system is kept at 30°C). *(1986 - 6 Marks)*

14. An ideal gas has a specific heat at constant pressure $C_P = \frac{5R}{2}$. The gas is kept in a closed vessel of volume 0.0083 m^3, at a temperature of 300 K and a pressure of 1.6×10^6 N/m^2. An amount of 2.49×10^4 Joules of heat energy is supplied to the gas. Calculate the final temperature and pressure of the gas. *(1987 - 7 Marks)*

15. Two moles of helium gas ($\gamma = 5/3$) are initially at temperature 27°C and occupy a volume of 20 litres. The gas is first expanded at constant pressure until the volume is doubled. Then it undergoes an adiabatic change until the temperature returns to its initial value. *(1988 - 6 Marks)*
(i) Sketch the process on a *p-V* diagram.
(ii) What are the final volume and pressure of the gas ?
(iii) What is the work done by the gas ?

16. An ideal monatomic gas is confined in a cylinder by a spring-loaded piston of cross-section 8.0×10^{-3} m^2. Initially the gas is at 300 K and occupies a volume of 2.4×10^{-3} m^3 and the spring is in its relaxed (unstretched, uncompressed) state, fig. The gas is heated by a small electric heater until the piston moves out slowly by 0.1 m. Calculate the final temperature of the gas and the heat supplied (in joules) by the heater. The force constant of the spring is 8000 N/m, atmospheric pressure is 1.0×10^5 Nm^{-2}. The cylinder and the piston are thermally insulated. The piston is massless

and there is no friction between the piston and the cylinder. Neglect heat loss through lead wires of the heater. The heat capacity of the heater coil is negligible. Assume the spring to be massless. *(1989 - 8 Mark)*



17. An ideal gas having initial pressure P, volume V and temperature T is allowed to expand adiabatically until its volume becomes 5.66 V while its temperature falls to $\frac{T}{2}$. *(1990 - 7 Mark)*

(i) How many degrees of freedom do the gas molecules have?

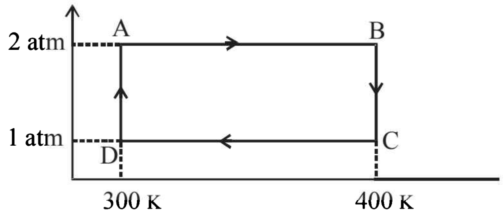
(ii) Obtain the work done by the gas during the expansion as a function of the initial pressure P and volume V.

18. Three moles of an ideal gas $\left(C_p = \frac{7}{2}R\right)$ at pressure, P_A and temperature T_A is isothermally expanded to twice its initial volume. It is then compressed at constant pressure to its original volume. Finally gas is compressed at constant volume to its original pressure P_A. *(1991 - 4 + 4 Marks)*

(a) Sketch P - V and P - T diagrams for the complete process.

(b) Calculate the net work done by the gas, and net heat supplied to the gas during the complete process.

19. Two moles of helium gas undergo a cyclic process as shown in Fig. Assuming the gas to be ideal, calculate the following quantities in this process *(1992 - 8 Marks)*



(a) The net change in the heat energy

(b) The net work done

(c) The net change in internal energy

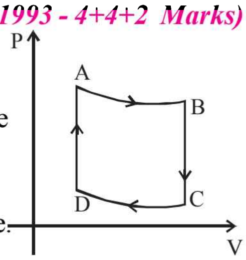
20. One mole of a mono atomic ideal gas is taken through the cycle shown in Fig: *(1993 - 4+4+2 Marks)*

$A \to B$: adiabatic expansion

$B \to C$: cooling at constant volume

$C \to D$: adiabatic compression

$D \to A$: heating at constant volume.



The pressure and temperature at A, B, etc. are denoted by P_A, T_A, P_B, T_B etc., respectively. Given that T_A = 1000 K, P_B = $(2/3)P_A$ and $P_C = (1/3)P_A$, calculate the following quantities :

(i) The work done by the gas in the process $A \to B$

(ii) The heat lost by the gas in the process $B \to C$.

(iii) The temperature T_D. [Given : $(2/3)^{2/5} = 0.85$]

21. An ideal gas is taken through a cyclic thermodynamic process through four steps. The amounts of heat involved in these steps are Q_1 = 5960 J, Q_2 = –5585 J, Q_3 = –2980J and Q_4 = 3645J, respectively. The corresponding quantities of work involved are W_1 = 2200 J, W_2 = – 825 J, W_3 = – 1100 J and W_4 respectively. *(1994 - 6 Marks)*

1. Find the value of W_4.
2. What is the efficiency of the cycle

22. A closed container of volume 0.02 m^3 contains a mixture of neon and argon gases, at a temperature of 27°C and pressure of 1×10^5 Nm^{-2}. The total mass of the mixture is 28 g. If the molar masses of neon and argon are 20 and 40 g mol^{-1} respectively, find the masses of the individual gases in the container assuming them to be ideal (Universal gas constant R = 8.314 J/mol – K). *(1994 - 6 Marks)*

23. A gaseous mixture enclosed in a vessel of volume V consists of one mole of a gas A with $\gamma\ (=C_p/C_v) = 5/3$ and another gas B with $\gamma = 7/5$ at a certain temperature T. The relative molar masses of the gases A and B are 4 and 32, respectively. The gases A and B do not react with each other and are assumed to be ideal. The gaseous mixture follows the equation $PV^{19/13}$ = constant, in adiabatic processes. *(1995 - 10 Marks)*

(a) Find the number of moles of the gas B in the gaseous mixture.

(b) Compute the speed of sound in the gaseous mixture at T = 300 K.

(c) If T is raised by 1K from 300 K, find the % change in the speed of sound in the gaseous mixture.

(d) The mixture is compressed adiabatically to 1/5 of its initial volume V. Find the change in its adiabatic compressibility in terms of the given quantities.

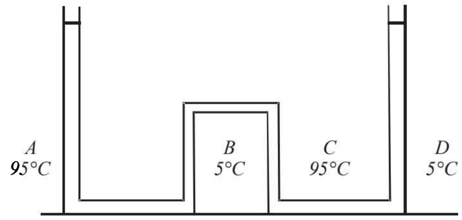
24. At 27°C two moles of an ideal monoatomic gas occupy a volume V. The gas expands adiabaticallly to a volume 2V. Calculate (i) the final temperature of the gas, (ii) change in its internal energy, and (iii) the work done by the gas during this process. *(1996 - 5 Marks)*

25. The temperature of 100g of water is to be raised from 24°C to 90°C by adding steam to it. Calculate the mass of the steam required for this purpose. *(1996 - 2 Marks)*

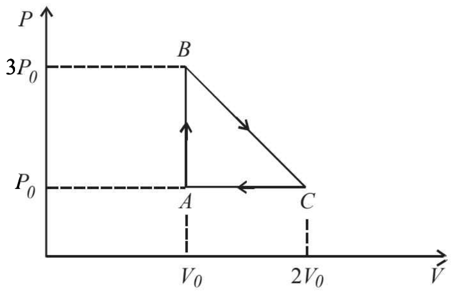
26. One mole of a diatomic ideal gas (γ = 1.4) is taken through a cyclic process starting from point A. The process $A \to B$ is an adiabatic compression, $B \to C$ is isobaric expansion, $C \to D$ is an adiabatic expansion, and $D \to A$ is isochoric. The volume ratios are V_A / V_B = 16 and V_C / V_B = 2 and the temperature at A is T_A = 300 K.Calculate the temperature of the gas at the points B and D and find the efficiency of the cycle. *(1997 - 5 Marks)*

27. The apparatus shown in the figure consists of four glass columns connected by horizontal sections. The height of two central columns B and C are 49 cm each. The two outer columns A and D are open to the atmosphere. A and C are maintained at a temperature of 95° C while the columns B and D are maintained at 5°C. The height of the liquid in A

and D measured from the base the are 52.8 cm and 51cm respectively. Determine the coefficient of thermal expansion of the liquid. *(1997 - 5 Marks)*



28. One mole of an ideal monatomic gas is taken round the cyclic process $ABCA$ as shown in Figure. Calculate *(1998 - 8 Marks)*



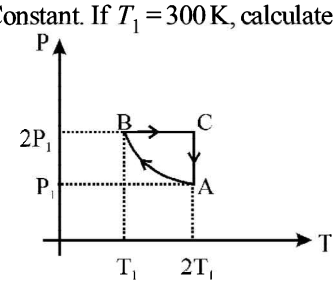
(a) the work done by the gas.
(b) the heat rejected by the gas in the path CA and the heat absorbed by the gas in the path AB;
(c) the net heat absorbed by the gas in the path BC;
(d) the maximum temperature attained by the gas during the cycle.

29. A solid body X of heat capacity C is kept in an atmosphere whose temperature is $T_A = 300$ K. At time $t = 0$ the temperature of X is $T_0 = 400$ K. It cools according to Newton's law of cooling. At time t_1, its temperature is found to be 350 K. *(1998 - 8 Marks)*

At this time (t_1), the body X is connected to a large box Y at atmospheric temperature T_A, through a conducting rod of length L, cross-sectional area A and thermal conductivity K. The heat capacity of Y is so large that any variation in its temperature may be neglected. The cross-sectional area A of the connecting rod is small compared to the surface area of X. Find the temperature of X at time $t = 3t_1$.

30. Two moles of an ideal monatomic gas, initially at pressure p_1 and volume V_1, undergo an adiabatic compression until its volume is V_2. Then the gas is given heat Q at constant volume V_2. *(1999 - 10 Marks)*
(a) Sketch the complete process on a $p - V$ diagram.
(b) Find the total work done by the gas, the total change in its internal energy and the final temperature of the gas. [Give your answer in terms of p_1, V_1, V_2, Q and R]

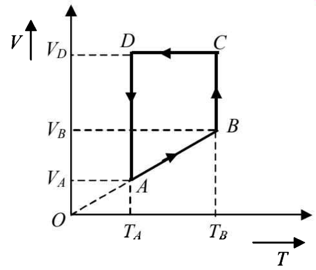
31. Two moles of an ideal monatomic gas is taken through a cycle $ABCA$ as shown in the P-T diagram. During the process AB, pressure and temperature of the gas vary such that PT = Constant. If $T_1 = 300$ K, calculate *(2000 - 10 Marks)*



(a) the work done on the gas in the process AB and
(b) the heat absorbed or released by the gas in each of the processes.
Give answer in terms of the gas constant R.

32. An ice cube of mass 0.1 kg at 0°C is placed in an isolated container which is at 227°C. The specific heat S of the container varies with temperature T according to the empirical relation $S = A + BT$, where $A = 100$ cal/kg-K and $B = 2 \times 10^{-2}$ cal/kg-K^2. If the final temperature of the container is 27°C, determine the mass of the container. (Latent heat of fusion of water $= 8 \times 10^4$ cal/kg, Specific heat of water $= 10^3$ cal/kg-K). *(2001-5 Marks)*

33. A monoatomic ideal gas of two moles is taken through a cyclic process starting from A as shown in figure. The volume ratios are $\frac{V_B}{V_A} = 2$ and $\frac{V_D}{V_A} = 4$. If the temperature T_A at A is 27°C. *(2001-10 Marks)*

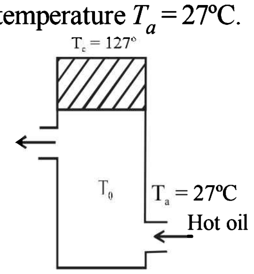


Calculate,
(a) the temperature of the gas at point B,
(b) heat absorbed or released by the gas in each process,
(c) the total work done by the gas during the complete cycle. Express your answer in terms of the gas constant R.

34. A cubical box of side 1 meter contains helium gas (atomic weight 4) at a pressure of 100 N/m^2. During an observation time of 1 second, an atom travelling with the root-mean-square speed parallel to one of the edges of the cube, was found to make 500 hits with a particular wall, without any collision with other atoms. Take R $= \frac{25}{3}$ J/mol-K and k $= 1.38 \times 10^{-23}$ J/K *(2002 - 5 Marks)*
(a) Evaluate the temperature of the gas.
(b) Evaluate the average kinetic energy per atom.
(c) Evaluate the total mass of helium gas in the box.

35. An insulated container containing monoatomic gas of molar mass m is moving with a velocity v_0. If the container is suddenly stopped, find the change in temperature. *(2003 - 2 Marks)*

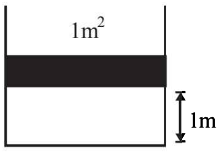
36. Hot oil is circulated through an insulated container with a wooden lid at the top whose conductivity $K = 0.149$ J/(m-°C-sec), thickness $t = 5$ mm, emissivity $= 0.6$. Temperature of the top of the lid is maintained at $T_\ell = 127$°C. If the ambient temperature $T_a = 27$°C. *(2003 - 4 Marks)*



Calculate :
(a) rate of heat loss per unit area due to radiation from the lid.
(b) temperature of the oil.

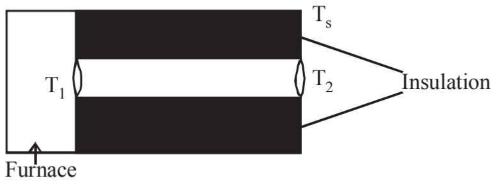
(Given $\sigma = \frac{17}{3} \times 10^{-8}\ Wm^{-2}K^{-4}$)

37. A diatomic gas is enclosed in a vessel fitted with massless movable piston. Area of cross section of vessel is 1 m^2. Initial height of the piston is 1 m (see the figure). The initial temperature of the gas is 300 K. The temperature of the gas is increased to 400 K, keeping pressure constant, calculate the new height of the piston. The piston is brought to its initial position with no heat exchange. Calculate the final temperature of the gas. You can leave answer in fraction. *(2004 - 2 Marks)*



38. A small spherical body of radius r is falling under gravity in a viscous medium. Due to friction the medium gets heated. How does the rate of heating depends on radius of body when it attains terminal velocity? *(2004 - 2 Marks)*

39. A cylindrical rod of length l, thermal conductivity K and area of cross section A has one end in the furnace at temperature T_1 and the other end in surrounding at temperature T_2. Surface of the rod exposed to the surrounding has emissivity e. Also $T_2 = T_s + \Delta T$ and $T_s >> \Delta T$. If $T_1 - T_s \propto \Delta T$, find the proportionality constant. *(2004 - 4 Marks)*



40. A cubical block of co-efficient of linear expansion α_s is submerged partially inside a liquid of co-efficient of volume expansion γ_ℓ. On increasing the temperature of the system by ΔT, the height of the cube inside the liquid remains unchanged. Find the relation between α_s and γ_ℓ. *(2004 - 4 Marks)*

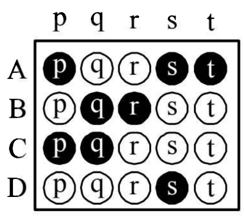
41. A cylinder of mass 1 kg is given heat of 20,000J at atmospheric pressure. If initially the temperature of cylinder is 20°C, find *(2005 - 6 Marks)*
(a) final temperature of the cylinder.
(b) work done by the cylinder.
(c) change in internal energy of the cylinder
(Given that specific heat of cylinder = 400 J kg^{-1} °C^{-1}, coefficient of volume expansion = 9×10^{-5} °C^{-1}, Atmospheric pressure = 10^5 N/m^2 and Density of cylinder = 9000 kg/m^3)

42. 0.05 kg steam at 373 K and 0.45 kg of ice at 253K are mixed in an insulated vessel. Find the equilibrium temperature of the mixture. Given, L_{fusion} = 80 cal/g = 336 J/g, $L_{vaporization}$ = 540 cal/g = 2268 J/g, S_{ice} = 2100 J/Kg K = 0.5 cal/gK and S_{water} = 4200 J/Kg K = 1 cal/gK *(2006 - 6M)*

F Match the Following

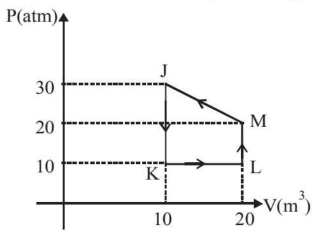
DIRECTIONS (Q. No. 1-3) : *Each question contains statements given in two columns, which have to be matched. The statements in Column-I are labelled A, B, C and D, while the statements in Column-II are labelled p, q, r and s. Any given statement in Column-I can have correct matching with ONE OR MORE statement(s) in Column-II. The appropriate bubbles corresponding to the answers to these questions have to be darkened as illustrated in the following example :*

If the correct matches are A-p, s and t; B-q and r; C-p and q; and D-s then the correct darkening of bubbles will look like the given.



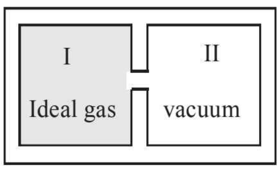
1. Heat given to process is positive, match the following option of Column I with the corresponding option of column II : *(2006 - 6M)*

Column I	Column II
(A) JK	(p) $\Delta W > 0$
(B) KL	(q) $\Delta Q < 0$
(C) LM	(r) $\Delta W < 0$
(D) MJ	(s) $\Delta Q > 0$

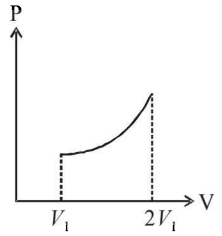


2. Column I contains a list of processes involving expansion of an ideal gas. Match this with Column II describing the thermodynamic change during this process. Indicate your answer by darkening the appropriate bubbles of the 4 × 4 matrix given in the ORS. *(2008)*

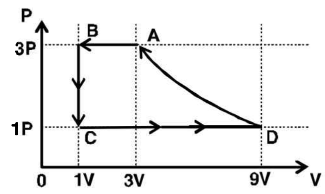
Column I	Column II
(A) An insulated container has two chambers separated by a valve. Chamber I contains an ideal gas and the Chamber II has vacuum. The valve is opened.	(p) The temperature of the gas decreases



(B)	An ideal monoatomic gas expands to twice its remains original volume such that its pressure $P \propto 1/V^2$ where V is the volume of the gas	(q)	The temperature of the gas increases or constant
(C)	An ideal monoatomic gas expands to twice its original volume such that its pressure $P \propto 1/V^{4/3}$	(r)	The gas loses heat where V is its volume
(D)	An ideal monoatomic gas expands such that its pressure P and volume V follows the behaviour shown in the graph	(s)	The gas gains heat



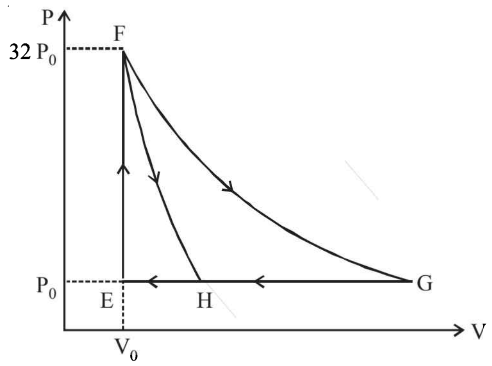
3. One mole of a monatomic gas is taken through a cycle ABCDA as shown in the P-V diagram. Column II give the characteristics involved in the cycle. Match them with each of the processes given in Column I. *(2011)*



Column I		**Column II**	
(A)	Process $A \rightarrow B$	(p)	Internal energy decreases
(B)	Process $B \rightarrow C$	(q)	Internal energy increases
(C)	Process $C \rightarrow D$	(r)	Heat is lost
(D)	Process $D \rightarrow A$	(s)	Heat is gained
		(t)	Work is done on the gas

DIRECTIONS Q. No. 4 : Following question has matching lists. The codes for the list have choices (a), (b), (c) and (d) out of which ONLY ONE is correct.

4. One mole of a monatomic ideal gas is taken along two cyclic processes $E \rightarrow F \rightarrow G \rightarrow E$ and $E \rightarrow F \rightarrow H \rightarrow E$ as shown in the PV diagram. The processes involved are purely isochoric, isobaric, isothermal or adiabatic. *(JEE Adv. 2013)*



Match the paths in List I with the magnitudes of the work done in List II and select the correct answer using the codes given below the lists.

List I		**List II**	
P.	$G \rightarrow E$	1.	$160\ P_0V_0 \ln 2$
Q.	$G \rightarrow H$	2.	$36\ P_0V_0$
R.	$F \rightarrow H$	3.	$24\ P_0V_0$
S.	$F \rightarrow G$	4.	$31\ P_0V_0$

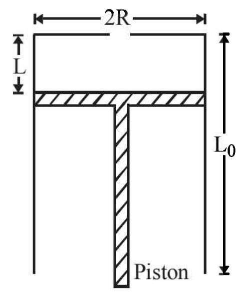
Codes:

	P	Q	R	S
(a)	4	3	2	1
(b)	4	3	1	2
(c)	3	1	2	4
(d)	1	3	2	4

G Comprehension Based Questions

PASSAGE – 1

A fixed thermally conducting cylinder has a radius R and height L_0. The cylinder is open at its bottom and has a small hole at its top. A piston of mass M is held at a distance L from the top surface, as shown in the figure. The atmospheric pressure is P_0.



1. The piston is now pulled out slowly and held at a distance 2L from the top. The pressure in the cylinder between its top and the piston will then be *(2007)*

(a) P_0 (b) $\frac{P_0}{2}$

(c) $\frac{P_0}{2}+\frac{Mg}{\pi R^2}$ (d) $\frac{P_0}{2}-\frac{Mg}{\pi R^2}$

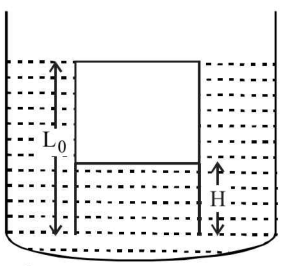
Therefore the pressure inside the cylinder is P_0 throughout the slow pulling process.

2. While the piston is at a distance 2L from the top, the hole at the top is sealed. The piston is then released, to a position where it can stay in equilibrium. In this condition, the distance of the piston from the top is *(2007)*

(a) $\left(\frac{2P_0\pi R^2}{\pi R^2 P_0+Mg}\right)(2L)$ (b) $\left(\frac{P_0\pi R^2-Mg}{\pi R^2 P_0}\right)(2L)$

(c) $\left(\frac{P_0\pi R^2+Mg}{\pi R^2 P_0}\right)(2L)$ (d) $\left(\frac{P_0\pi R^2}{\pi R^2 P_0-Mg}\right)(2L)$

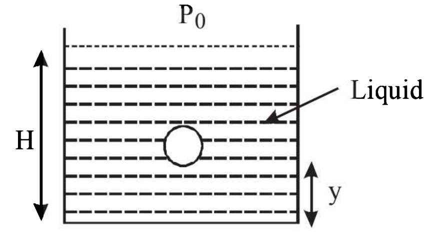
3. The piston is taken completely out of the cylinder. The hole at the top is sealed. A water tank is brought below the cylinder and put in a position so that the water surface in the tank is at the same level as the top of the cylinder as shown in the figure. The density of the water is ρ. In equilibrium, the height H of the water column in the cylinder satisfies *(2007)*



(a) $\rho g(L_0-H)^2+P_0(L_0-H)+L_0P_0=0$
(b) $\rho g(L_0-H)^2-P_0(L_0-H)-L_0P_0=0$
(c) $\rho g(L_0-H)^2+P_0(L_0-H)-L_0P_0=0$
(d) $\rho g(L_0-H)^2-P_0(L_0-H)+L_0P_0=0$

PASSAGE – 2

A small spherical monoatomic ideal gas bubble ($\gamma = 5/3$) is trapped inside a liquid of density ρ (see figure). Assume that the bubble does not exchange any heat with the liquid. The bubble contains n moles of gas. The temperature of the gas when the bubble is at the bottom is T_0, the height of the liquid is H and the atmospheric pressure is P_0 (Neglect surface tension). *(2008)*



4. As the bubble moves upwards, besides the buoyancy force the following forces are acting on it

(a) Only the force of gravity
(b) The force due to gravity and the force due to the pressure of the liquid
(c) The force due to gravity, the force due to the pressure of the liquid and the force due to viscosity of the liquid
(d) The force due to gravity and the force due to viscosity of the liquid

5. When the gas bubble is at a height y from the bottom, its temperature is –

(a) $T_0\left(\frac{P_0+\rho_\ell gH}{P_0+\rho_\ell gy}\right)^{2/5}$

(b) $T_0\left(\frac{P_0+\rho_\ell g(H-y)}{P_0+\rho_\ell gH}\right)^{2/5}$

(c) $T_0\left(\frac{P_0+\rho_\ell gH}{P_0+\rho_\ell gy}\right)^{3/5}$

(d) $T_0\left(\frac{P_0+\rho_\ell g(H-y)}{P_0+\rho_\ell gH}\right)^{3/5}$

6. The buoyancy force acting on the gas bubble is (Assume R is the universal gas constant)

(a) $\rho_\ell nRgT_0\frac{(P_0+\rho_\ell gH)^{2/5}}{(P_0+\rho_\ell gy)^{7/5}}$

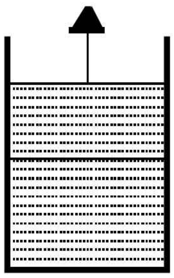
(b) $\frac{\rho_\ell nRgT_0}{(P_0+\rho_\ell gH)^{2/5}[P_0+\rho_\ell g(H-y)]^{3/5}}$

(c) $\rho_\ell nRgT_0\frac{(P_0+\rho_\ell gH)^{3/5}}{(P_0+\rho_\ell gy)^{8/5}}$

(d) $\frac{\rho_\ell nRgT_0}{(P_0+\rho_\ell gH)^{3/5}[P_0+\rho_\ell g(H-y)]^{2/5}}$

PASSAGE – 3

In the figure, a container is shown to have a movable (without friction) piston on top. The container and the piston are all made of perfectly insulated material allowing no heat transfer between outside and inside the container. The container is divided into two compartments by a rigid partition made of a thermally conducting material that allows slow transfer of heat. The lower compartment of the container is filled with 2 moles of an ideal monatomic gas at 700 K and the upper compartment is filled with 2 moles of an ideal diatomic gas at 400 K. The heat capacities per mole of an ideal monatomic gas are $C_V = \frac{3}{2}R$, $C_P = \frac{5}{2}R$, and those for an ideal diatomic gas are $C_V = \frac{5}{2}R$, $C_P = \frac{7}{2}R$.



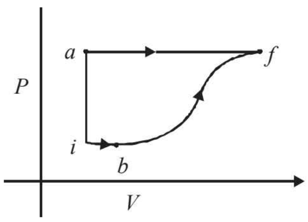
7. Consider the partition to be rigidly fixed so that it does not move. When equilibrium is achieved, the final temperature of the gases will be *(JEE Adv. 2014)*
   (a) 550 K (b) 525 K
   (c) 513 K (d) 490 K
8. Now consider the partition to be free to move without friction so that the pressure of gases in both compartments is the same. The total work done by the gases till the time they achieve equilibrium will be *(JEE Adv. 2014)*
   (a) 250 *R* (b) 200 *R*
   (c) 100 *R* (d) – 100 *R*

H Assertion & Reason Type Questions

1. **Statement-1 :** The total translational kinetic energy of all the molecules of a given mass of an ideal gas is 1.5 times the product of its pressure and its volume. *(2007)*
   because
   Statement-2 : The molecules of a gas collide with each other and the velocities of the molecules change due to the collision.
   (a) Statement-1 is True, Statement-2 is True; Statement-2 is a correct explanation for Statement-1
   (b) Statement-1 is True, Statement-2 is True; Statement-2 is NOT a correct explanation for Statement-1
   (c) Statement-1 is True, Statement-2 is False
   (d) Statement-2 is False, Statement-2 is True

I Integer Value Correct Type

1. A metal rod AB of length $10x$ has its one end *A* in ice at 0.°*C*, and the other end B in water at 100 °C. If a point P onthe rod is maintained at 400 °C, then it is found that equal amounts of water and ice evaporate and melt per unit time. The latent heat of evaporation of water is 540 *cal/g* and latent heat of melting of ice is 80 *cal/g*. If the point *P* is at a distance of λx from the ice end *A*, find the value λ.
   [Neglect any heat loss to the surrounding.] *(2009)*
2. A piece of ice (heat capacity = 2100 J kg^{-1} °C^{-1} and latent heat = 3.36×10^5 J kg^{-1}) of mass m grams is at –5°C at atmospheric pressure. It is given 420 J of heat so that the ice starts melting. Finally when the ice-water mixture is in equilibrium, it is found that 1 gm of ice has melted. Assuming there is no other heat exchange in the process, the value of m is *(2010)*
3. Two spherical bodies A (radius 6 cm) and B(radius 18 cm) are at temperature T_1 and T_2, respectively. The maximum intensity in the emission spectrum of A is at 500 nm and in that of B is at 1500 nm. Considering them to be black bodies, what will be the ratio of the rate of total energy radiated by A to that of B? *(2010)*
4. A diatomic ideal gas is compressed adiabatically to $\frac{1}{32}$ of its initial volume. If the initial temperature of the gas is T_i (in Kelvin) and the final temperature is a T_i, the value of *a* is *(2010)*
5. Steel wire of lenght 'L' at 40°C is suspended from the ceiling and then a mass 'm' is hung from its free end. The wire is cooled down from 40°C to 30°C to regain its original length 'L'. The coefficient of linear thermal expansion of the steel is 10^{-5}/° C, Young's modulus of steel is 10^{11} N/m² and radius of the wire is 1 mm. Assume that L>>diameter of the wire. Then the value of 'm' in kg is nearly *(2011)*
6. A thermodynamic system is taken from an initial state *i* with internal energy U_i = 100 J to the final state *f* along two different paths *iaf* and *ibf*, as schematically shown in the figure. The work done by the system along the paths *af*, *ib* and *bf* are W_{af} = 200 J, W_{ib} = 50 J and W_{bf} = 100 J respectively. The heat supplied to the system along the path iaf, ib and bf are Q_{iaf}, Q_{ib} and Q_{bf} respectively. If the internal energy of the system in the state b is U_b = 200 J and Q_{iaf} = 500 J, The ratio $\frac{Q_{bf}}{Q_{ib}}$ is *(JEE Adv. 2014)*

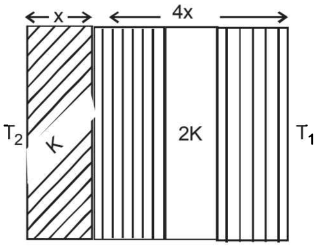


7. Two spherical stars *A* and *B* emit blackbody radiation. The radius of *A* is 400 times that of *B* and *A* emits 10^4 times the power emitted from *B*. The ratio $\left(\frac{\lambda_A}{\lambda_B}\right)$ of their wavelengths λ_A and λ_B at which the peaks occur in their respective radiation curves is *(JEE Adv. 2015)*
8. A metal is heated in a furnace where a sensor is kept above the metal surface to read the power radiated (P) by the metal. The sensor has a scale that displays $\log_2$, (P/P_0), where P_0 is a constant. When the metal surface is at a temperature of 487°C, the sensor shows a value 1. Assume that the emissivity of the metallic surface remains constant. What is the value displayed by the sensor when the temperature of the metal surface is raised to 2767°C? *(JEE Adv. 2016)*

Section-B JEE Main / AIEEE

1. Which statement is incorrect? [2002]
   (a) all reversible cycles have same efficiency
   (b) reversible cycle has more efficiency than an irreversible one
   (c) Carnot cycle is a reversible one
   (d) Carnot cycle has the maximum efficiency in all cycles.
2. Heat given to a body which raises its temperature by 1°C is
   (a) water equivalent (b) thermal capacity [2002]
   (c) specific heat (d) temperature gradient
3. Infrared radiation is detected by [2002]
   (a) spectrometer (b) pyrometer
   (c) nanometer (d) photometer
4. Which of the following is more close to a black body?
   (a) black board paint (b) green leaves [2002]
   (c) black holes (d) red roses
5. Cooking gas containers are kept in a lorry moving with uniform speed. The temperature of the gas molecules inside will [2002]
   (a) increase
   (b) decrease
   (c) remain same
   (d) decrease for some, while increase for others
6. If mass-energy equivalence is taken into account, when water is cooled to form ice, the mass of water should
   (a) increase [2002]
   (b) remain unchanged
   (c) decrease
   (d) first increase then decrease
7. At what temperature is the r.m.s velocity of a hydrogen molecule equal to that of an oxygen molecule at 47°C?
   (a) 80 K (b) –73 K [2002]
   (c) 3 K (d) 20 K.
8. Even Carnot engine cannot give 100% efficiency because we cannot [2002]
   (a) prevent radiation
   (b) find ideal sources
   (c) reach absolute zero temperature
   (d) eliminate friction.
9. 1 mole of a gas with γ = 7/5 is mixed with 1 mole of a gas with γ = 5/3, then the value of γ for the resulting mixture is
   (a) 7/5 (b) 2/5 [2002]
   (c) 24/16 (d) 12/7.
10. Two spheres of the same material have radii 1 m and 4 m and temperatures 4000 K and 2000 K respectively. The ratio of the energy radiated per second by the first sphere to that by the second is [2002]
    (a) 1 : 1 (b) 16 : 1
    (c) 4 : 1 (d) 1 : 9.
11. "Heat cannot by itself flow from a body at lower temperature to a body at higher temperature" is a statement or consequence of [2003]
    (a) second law of thermodynamics
    (b) conservation of momentum
    (c) conservation of mass
    (d) first law of thermodynamics
12. During an adiabatic process, the pressure of a gas is found to be proportional to the cube of its absolute temperature. The ratio C_P / C_V for the gas is [2003]
    (a) $\frac{4}{3}$ (b) 2
    (c) $\frac{5}{3}$ (d) $\frac{3}{2}$
13. Which of the following parameters does not characterize the thermodynamic state of matter? [2003]
    (a) Temperature (b) Pressure
    (c) Work (d) Volume
14. A Carnot engine takes 3×10^6 cal. of heat from a reservoir at $627^\circ C$, and gives it to a sink at $27^\circ C$. The work done by the engine is [2003]
    (a) 4.2×10^6 J (b) 8.4×10^6 J
    (c) 16.8×10^6 J (d) zero
15. The earth radiates in the infra-red region of the spectrum. The spectrum is correctly given by [2003]
    (a) Rayleigh Jeans law
    (b) Planck's law of radiation
    (c) Stefan's law of radiation
    (d) Wien's law
16. According to Newton's law of cooling, the rate of cooling of a body is proportional to $(\Delta\theta)^n$, where $\Delta\theta$ is the difference of the temperature of the body and the surroundings, and n is equal to [2003]
    (a) two (b) three (c) four (d) one
17. One mole of ideal monatomic gas $(\gamma = 5/3)$ is mixed with one mole of diatomic gas $(\gamma = 7/5)$. What is γ for the mixture? γ Denotes the ratio of specific heat at constant pressure, to that at constant volume [2004]
    (a) 35/23 (b) 23/15 (c) 3/2 (d) 4/3
18. If the temperature of the sun were to increase from T to $2T$ and its radius from R to $2R$, then the ratio of the radiant energy received on earth to what it was previously will be
    (a) 32 (b) 16 [2004]
    (c) 4 (d) 64
19. Which of the following statements is **correct** for any thermodynamic system ? [2004]
    (a) The change in entropy can never be zero
    (b) Internal energy and entropy and state functions
    (c) The internal energy changes in all processes
    (d) The work done in an adiabatic process is always zero.
20. Two thermally insulated vessels 1 and 2 are filled with air at temperatures (T_1, T_2), volume (V_1, V_2) and pressure (P_1, P_2) respectively. If the valve joining the two vessels is opened, the temperature inside the vessel at equilibrium will be [2004]
    (a) $T_1T_2(P_1V_1 + P_2V_2)/(P_1V_1T_2 + P_2V_2T_1)$
    (b) $(T_1 + T_2)/2$
    (c) $T_1 + T_2$
    (d) $T_1T_2(P_1V_1 + P_2V_2)/(P_1V_1T_1 + P_2V_2T_2)$

21. The temperature of the two outer surfaces of a composite slab, consisting of two materials having coefficients of thermal conductivity K and $2K$ and thickness x and $4x$, respectively, are T_2 and $T_1 (T_2 > T_1)$. The rate of heat transfer through the slab, in a steady state is $\left(\frac{A(T_2 - T_1)K}{x}\right) f$, with f equal to **[2004]**



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

22. Which of the following is **incorrect** regarding the first law of thermodynamics? **[2005]**
(a) It is a restatement of the principle of conservation of energy
(b) It is not applicable to any cyclic process
(c) It introduces the concept of the entropy
(d) It introduces the concept of the internal energy

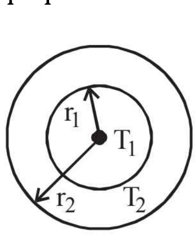
23. The figure shows a system of two concentric spheres of radii r_1 and r_2 are kept at temperatures T_1 and T_2, respectively. The radial rate of flow of heat in a substance between the two concentric spheres is proportional to **[2005]**

(a) $ln\left(\frac{r_2}{r_1}\right)$

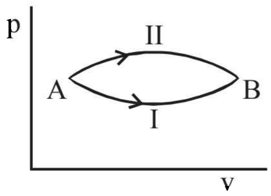
(b) $\frac{(r_2 - r_1)}{(r_1 r_2)}$

(c) $(r_2 - r_1)$

(d) $\frac{r_1 r_2}{(r_2 - r_1)}$



24. A system goes from A to B via two processes I and II as shown in figure. If ΔU_1 and ΔU_2 are the changes in internal energies in the processes I and II respectively, then **[2005]**
(a) relation between ΔU_1 and ΔU_2 can not be determined
(b) $\Delta U_1 = \Delta U_2$
(c) $\Delta U_2 < \Delta U_1$
(d) $\Delta U_2 > \Delta U_1$



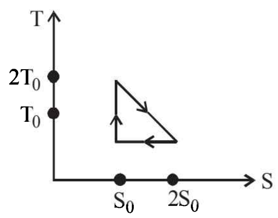
25. The temperature-entropy diagram of a reversible engine cycle is given in the figure. Its efficiency is **[2005]**

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

(b) $\frac{1}{2}$

(c) $\frac{2}{3}$

(d) $\frac{1}{3}$



26. A gaseous mixture consists of 16 g of helium and 16 g of oxygen. The ratio $\frac{C_p}{C_v}$ of the mixture is **[2005]**
(a) 1.62 (b) 1.59 (c) 1.54 (d) 1.4

27. Assuming the Sun to be a spherical body of radius R at a temperature of TK, evaluate the total radiant powerd incident of Earth at a distance r from the Sun **[2006]**

(a) $4\pi r_0^2 R^2 \sigma \frac{T^4}{r^2}$ (b) $\pi r_0^2 R^2 \sigma \frac{T^4}{r^2}$

(c) $r_0^2 R^2 \sigma \frac{T^4}{4\pi r^2}$ (d) $R^2 \sigma \frac{T^4}{r^2}$

where r_0 is the radius of the Earth and σ is Stefan's constant.

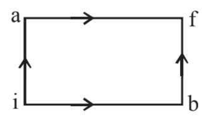
28. Two rigid boxes containing different ideal gases are placed on a table. Box A contains one mole of nitrogen at temperature T_0, while Box contains one mole of helium at temperature $\left(\frac{7}{3}\right)T_0$. The boxes are then put into thermal contact with each other, and heat flows between them until the gases reach a common final temperature (ignore the heat capacity of boxes). Then, the final temperature of the gases, T_f in terms of T_0 is **[2006]**

(a) $T_f = \frac{3}{7}T_0$ (b) $T_f = \frac{7}{3}T_0$

(c) $T_f = \frac{3}{2}T_0$ (d) $T_f = \frac{5}{2}T_0$

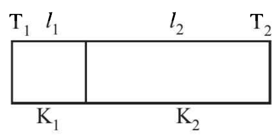
29. The work of 146 kJ is performed in order to compress one kilo mole of gas adiabatically and in this process the temperature of the gas increases by 7°C. The gas is ($R = 8.3$ J mol^{-1} K^{-1}) **[2006]**
(a) diatomic
(b) triatomic
(c) a mixture of monoatomic and diatomic
(d) monoatomic

30. When a system is taken from state i to state f along the path iaf, it is found that $Q = 50$ cal and $W = 20$ cal. Along the path ibf $Q = 36$ cal. W along the path ibf is **[2007]**
(a) 14 cal
(b) 6 cal
(c) 16 cal
(d) 66 cal



31. A Carnot engine, having an efficiency of $\eta = 1/10$ as heat engine, is used as a refrigerator. If the work done on the system is 10 J, the amount of energy absorbed from the reservoir at lower temperature is **[2007]**
(a) 100 J (b) 99 J (c) 90 J (d) 1 J

32. One end of a thermally insulated rod is kept at a temperature T_1 and the other at T_2. The rod is composed of two sections of length l_1 and l_2 and thermal conductivities K_1 and K_2 respectively. The temperature at the interface of the two section is **[2007]**



(a) $\frac{(K_1 l_1 T_1 + K_2 l_2 T_2)}{(K_1 l_1 + K_2 l_2)}$ (b) $\frac{(K_2 l_2 T_1 + K_1 l_1 T_2)}{(K_1 l_1 + K_2 l_2)}$

(c) $\frac{(K_2 l_1 T_1 + K_1 l_2 T_2)}{(K_2 l_1 + K_1 l_2)}$ (d) $\frac{(K_1 l_2 T_1 + K_2 l_1 T_2)}{(K_1 l_2 + K_2 l_1)}$

33. If C_P and C_V denote the specific heats of nitrogen per unit mass at constant pressure and constant volume respectively, then **[2007]**

(a) $C_P - C_V = 28R$ (b) $C_P - C_V = R/28$
(c) $C_P - C_V = R/14$ (d) $C_P - C_V = R$

34. The speed of sound in oxygen (O_2) at a certain temperature is 460 ms^{-1}. The speed of sound in helium (He) at the same temperature will be (assume both gases to be ideal) **[2008]**

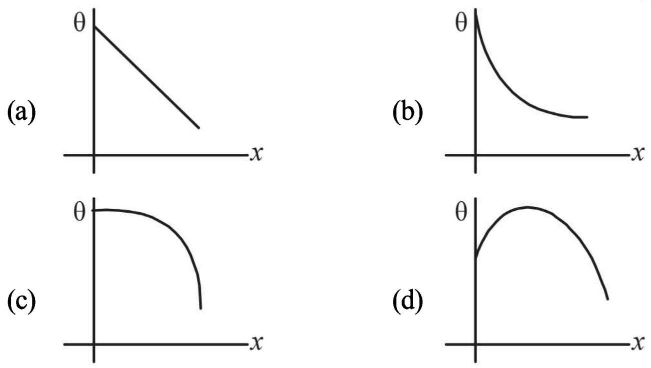
(a) 1421 ms^{-1} (b) 500 ms^{-1}
(c) 650 ms^{-1} (d) 330 ms^{-1}

35. An insulated container of gas has two chambers separated by an insulating partition. One of the chambers has volume V_1 and contains ideal gas at pressure P_1 and temperature T_1. The other chamber has volume V_2 and contains ideal gas at pressure P_2 and temperature T_2. If the partition is removed without doing any work on the gas, the final equilibrium temperature of the gas in the container will be **[2008]**

(a) $\dfrac{T_1T_2(P_1V_1 + P_2V_2)}{P_1V_1T_2 + P_2V_2T_1}$ (b) $\dfrac{P_1V_1T_1 + P_2V_2T_2}{P_1V_1 + P_2V_2}$

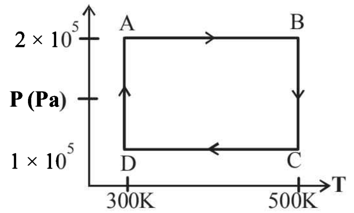
(c) $\dfrac{P_1V_1T_2 + P_2V_2T_1}{P_1V_1 + P_2V_2}$ (d) $\dfrac{T_1T_2(P_1V_1 + P_2V_2)}{P_1V_1T_1 + P_2V_2T_2}$

36. A long metallic bar is carrying heat from one of its ends to the other end under steady–state. The variation of temperature θ along the length x of the bar from its hot end is best described by which of the following figures? **[2009]**



DIRECTIONS for questions 37 to 39 : *Questions are based on the following paragraph.*

Two moles of helium gas are taken over the cycle *ABCDA*, as shown in the *P-T* diagram.



37. Assuming the gas to be ideal the work done on the gas in taking it from *A* to *B* is :

(a) 300 R (b) 400 R
(c) 500 R (d) 200 R

38. The work done on the gas in taking it from *D* to *A* is :

(a) +414 R (b) −690 R
(c) +690 R (d) −414 R

39. The net work done on the gas in the cycle *ABCDA* is :

(a) 276 R (b) 1076 R
(c) 1904 R (d) zero

40. One kg of a diatomic gas is at a pressure of 8×10^4 N/m^2. The density of the gas is 4kg/m^3. What is the energy of the gas due to its thermal motion? **[2009]**

(a) 5×10^4 J (b) 6×10^4 J
(c) 7×10^4 J (d) 3×10^4 J

41. **Statement 1 :** The temperature dependence of resistance is usually given as $R = R_o(1 + \alpha\,\Delta t)$. The resistance of a wire changes from 100Ω to 150Ω when its temperature is increased from 27°C to 227°C. This implies that $\alpha = 2.5 \times 10^{-3}$/°C.

Statement 2 : $R = R_o(1 + \alpha\,\Delta t)$ is valid only when the change in the temperature ΔT is small and $\Delta R = (R - R_0) << R_o$. **[2009]**

(a) Statement-1 is true, Statement-2 is true; Statement-2 is the correct explanation of Statement-1.
(b) Statement-1 is true, Statement-2 is true; Statement-2 is not the correct explanation of Statement-1.
(c) Statement-1 is false, Statement-2 is true.
(d) Statement-1 is true, Statement-2 is false.

42. A diatomic ideal gas is used in a Carnot engine as the working substance. If during the adiabatic expansion part of the cycle the volume of the gas increases from V to 32 V, the efficiency of the engine is **[2010]**

(a) 0.5 (b) 0.75 (c) 0.99 (d) 0.25

43. A thermally insulated vessel contains an ideal gas of molecular mass M and ratio of specific heats γ. It is moving with speed v and it's suddenly brought to rest. Assuming no heat is lost to the surroundings, its temperature increases by: **[2011]**

(a) $\dfrac{(\gamma-1)}{2\gamma R}Mv^2K$ (b) $\dfrac{\gamma M^2 v}{2R}K$

(c) $\dfrac{(\gamma-1)}{2R}Mv^2K$ (d) $\dfrac{(\gamma-1)}{2(\gamma+1)R}Mv^2K$

44. Three perfect gases at absolute temperatures T_1, T_2 and T_3 are mixed. The masses of molecules are m_1, m_2 and m_3 and the number of molecules are n_1, n_2 and n_3 respectively. Assuming no loss of energy, the final temperature of the mixture is : **[2011]**

(a) $\dfrac{n_1T_1 + n_2T_2 + n_3T_3}{n_1 + n_2 + n_3}$ (b) $\dfrac{n_1T_1^2 + n_2T_2^2 + n_3T_3^2}{n_1T_1 + n_2T_2 + n_3T_3}$

(c) $\dfrac{n_1^2T_1^2 + n_2^2T_2^2 + n_3^2T_3^2}{n_1T_1 + n_2T_2 + n_3T_3}$ (d) $\dfrac{(T_1 + T_2 + T_3)}{3}$

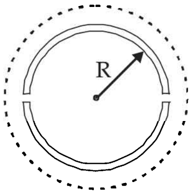
45. A Carnot engine operating between temperatures T_1 and T_2 has efficiency $\dfrac{1}{6}$. When T_2 is lowered by 62 K its efficiency increases to $\dfrac{1}{3}$. Then T_1 and T_2 are, respectively: **[2011]**

(a) 372 K and 330 K (b) 330 K and 268 K
(c) 310 K and 248 K (d) 372 K and 310 K

46. 100g of water is heated from 30°C to 50°C. Ignoring the slight expansion of the water, the change in its internal energy is (specific heat of water is 4184 J/kg/K): **[2011]**

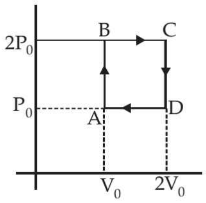
(a) 8.4 kJ (b) 84 kJ
(c) 2.1 kJ (d) 4.2 kJ

47. A wooden wheel of radius R is made of two semicircular part (see figure). The two parts are held together by a ring made of a metal strip of cross sectional area S and length L. L is slightly less than $2\pi R$. To fit the ring on the wheel, it is heated so that its temperature rises by ΔT and it just steps over the wheel. As it cools down to surrounding temperature, it presses the semicircular parts together. If the coefficient of linear expansion of the metal is α, and its Young's modulus is Y, the force that one part of the wheel applies on the other part is : **[2012]**



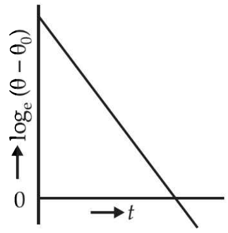
(a) $2\pi SY\alpha\Delta T$
(b) $SY\alpha\Delta T$
(c) $\pi SY\alpha\Delta T$
(d) $2SY\alpha\Delta T$

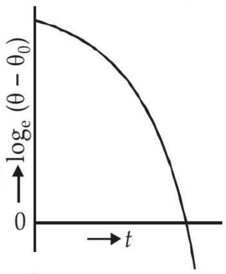
48. Helium gas goes through a cycle ABCDA (consisting of two isochoric and isobaric lines) as shown in figure Efficiency of this cycle is nearly : (Assume the gas to be close to ideal gas) **[2012]**



(a) 15.4%
(b) 9.1 %
(c) 10.5%
(d) 12.5%

49. A liquid in a beaker has temperature $\theta(t)$ at time t and θ_0 is temperature of surroundings, then according to Newton's law of cooling the correct graph between $\log_e(\theta - \theta_0)$ and t is : **[2012]**

(a)


(b)


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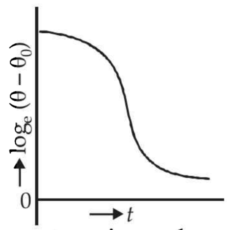

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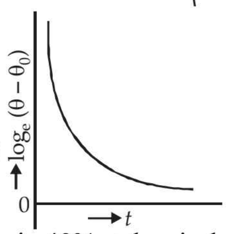
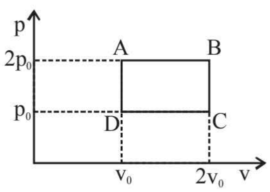


50. A Carnot engine, whose efficiency is 40%, takes in heat from a source maintained at a temperature of 500K. It is desired to have an engine of efficiency 60%. Then, the intake temperature for the same exhaust (sink) temperature must be : **[2012]**

(a) efficiency of Carnot engine cannot be made larger than 50%
(b) 1200 K (c) 750 K (d) 600 K

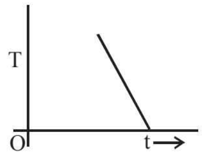
51.

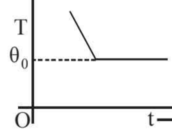


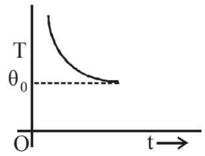
The above p-v diagram represents the thermodynamic cycle of an engine, operatingwith an ideal monatomic gas. The amount of heat, extracted from the source in a single cycle is **[JEE Main 2013]**

(a) p_0v_0 (b) $\left(\frac{13}{2}\right)p_0v_0$ (c) $\left(\frac{11}{2}\right)p_0v_0$ (d) $4p_0v_0$

52. If a piece of metal is heated to temperature θ and then allowed to cool in a room which is at temperature θ_0, the graph between the temperature T of the metal and time t will be closest to **[JEE Main 2013]**

(a)


(b)


(c)


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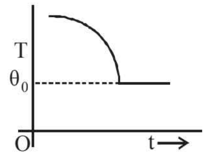
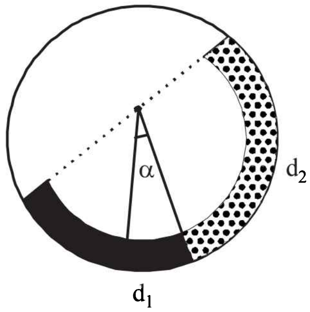


53. The pressure that has to be applied to the ends of a steel wire of length 10 cm to keep its length constant when its temperature is raised by 100°C is:

(For steel Young's modulus is $2\times10^{11}\,Nm^{-2}$ and coefficient of thermal expansion is $1.1\times10^{-5}K^{-1}$) **[JEE Main 2014]**

(a) 2.2×10^8 Pa (b) 2.2×10^9 Pa
(c) 2.2×10^7 Pa (d) 2.2×10^6 Pa

54. There is a circular tube in a vertical plane. Two liquids which do not mix and of densities d_1 and d_2 are filled in the tube. Each liquid subtends 90° angle at centre. Radius joining their interface makes an angle α with vertical. Ratio $\frac{d_1}{d_2}$ is: **[JEE Main 2014]**

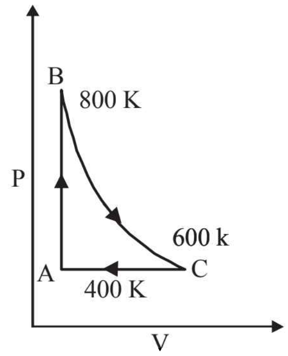


(a) $\frac{1+\sin\alpha}{1-\sin\alpha}$
(b) $\frac{1+\cos\alpha}{1-\cos\alpha}$
(c) $\frac{1+\tan\alpha}{1-\tan\alpha}$
(d) $\frac{1+\sin\alpha}{1-\cos\alpha}$

55. Three rods of Copper, Brass and Steel are welded together to form a Y shaped structure. Area of cross - section of each rod $= 4cm^2$. End of copper rod is maintained at $100°C$ where as ends of brass and steel are kept at $0°C$. Lengths of the copper, brass and steel rods are 46, 13 and 12 cms respectively. The rods are thermally insulated from surroundings excepts at ends. Thermal conductivities of copper, brass and steel are 0.92, 0.26 and 0.12 CGS units respectively. Rate of heat flow through copper rod is: **[JEE Main 2014]**

(a) 1.2 cal/s (b) 2.4 cal/s
(c) 4.8 cal/s (d) 6.0 cal/s

56. One mole of a diatomic ideal gas undergoes a cyclic process ABC as shown in figure. The process BC is adiabatic. The temperatures at A, B and C are 400 K, 800 K and 600 K respectively. Choose the correct statement: **[JEE Main 2014]**



(a) The change in internal energy in whole cyclic process is 250 R.
(b) The change in internal energy in the process CA is 700 R.
(c) The change in internal energy in the process AB is -350 R.
(d) The change in internal energy in the process BC is -500 R.

57. A solid body of constant heat capacity 1 J/°C is being heated by keeping it in contact with reservoirs in two ways : **[JEE Main 2015]**

(i) Sequentially keeping in contact with 2 reservoirs such that each reservoir supplies same amount of heat.
(ii) Sequentially keeping in contact with 8 reservoirs such that each reservoir supplies same amount of heat.

In both the cases body is brought from initial temperature 100°C to final temperature 200°C. Entropy change of the body in the two cases respectively is :

(a) *ln2, 2ln2* (b) *2ln2, 8ln2*
(c) *ln2, 4ln2* (d) *ln2, ln2*

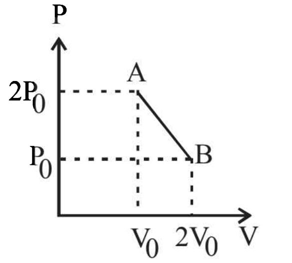
58. Consider a spherical shell of radius R at temperature T. The black body radiation inside it can be considered as an ideal gas of photons with internal energy per unit volume $u = \frac{U}{V} \propto T^4$ and pressure $p = \frac{1}{3}\left(\frac{U}{V}\right)$. If the shell now undergoes an adiabatic expansion the relation between T and R is : **[JEE Main 2015]**

(a) $T \propto \frac{1}{R}$ (b) $T \propto \frac{1}{R^3}$
(c) $T \propto e^{-R}$ (d) $T \propto e^{-3R}$

59. Consider an ideal gas confined in an isolated closed chamber. As the gas undergoes an adiabatic expansion, the average time of collision between molecules increases as V^q, where V is the volume of the gas. The value of q is : $\left(\gamma = \frac{C_p}{C_v}\right)$ **[JEE Main 2015]**

(a) $\frac{\gamma+1}{2}$ (b) $\frac{\gamma-1}{2}$
(c) $\frac{3\gamma+5}{6}$ (d) $\frac{3\gamma-5}{6}$

60. 'n' moles of an ideal gas undergoes a process A $\rightarrow$ B as shown in the figure. The maximum temperature of the gas during the process will be : **[JEE Main 2016]**



(a) $\frac{9P_0V_0}{2nR}$ (b) $\frac{9P_0V_0}{nR}$
(c) $\frac{9P_0V_0}{4nR}$ (d) $\frac{3P_0V_0}{2nR}$

61. A pendulum clock loses 12 s a day if the temperature is 40°C and gains 4 s a day if the temperature is 20° C. The temperature at which the clock will show correct time, and the co-efficient of linear expansion (α) of the metal of the pendulum shaft are respectively : **[JEE Main 2016]**

(a) 30°C; $\alpha = 1.85 \times 10^{-3}$/°C
(b) 55°C; $\alpha = 1.85 \times 10^{-2}$/°C
(c) 25°C; $\alpha = 1.85 \times 10^{-5}$/°C
(d) 60°C; $\alpha = 1.85 \times 10^{-4}$/°C

62. An ideal gas undergoes a quasi static, reversible process in which its molar heat capacity C remains constant. If during this process the relation of pressure P and volume V is given by PV^n = constant, then n is given by (Here C_P and C_V are molar specific heat at constant pressure and constant volume, respectively) : **[JEE Main 2016]**

(a) $n = \frac{C_P - C}{C - C_V}$ (b) $n = \frac{C - C_V}{C - C_P}$
(c) $n = \frac{C_P}{C_V}$ (d) $n = \frac{C - C_P}{C - C_V}$

9 Heat & Thermodynamics and Gases

Section-A : JEE Advanced/ IIT-JEE

A
1. 4 cal. 2. Partly solid and partly liquid. 3. $\sqrt{2}T$ 4. 0°C 5. 5803K
6. $1.71\rho rc$ 7. $t=\dfrac{4\pi R^2KT}{P}$ 8. $L_{fusion}=\dfrac{P\times t}{m}$ 9. 300 K
10. 0.628 11. 60°C 12. 192° 13. 5.5 min.

B
1. F 2. F 3. F 4. F 5. T 6. T
7. F 8. F

C
1. (d) 2. (c) 3. (b) 4. (a) 5. (b) 6. (a) 7. (b) 8. (d)
9. (c) 10. (c) 11. (d) 12. (b) 13. (d) 14. (c) 15. (d) 16. (a)
17. (c) 18. (a) 19. (b) 20. (b) 21. (a) 22. (b) 23. (a) 24. (a)
25. (a) 26. (a) 27. (c) 28. (c) 29. (b) 30. (b) 31. (b) 32. (c)
33. (d) 34. (b) 35. (a) 36. (d) 37. (d) 38. (a) 39. (c) 40. (b)
41. (c) 42. (d) 43. (a) 44. (d) 45. (d) 46. (a) 47. (d) 48. (a)
49. (b) 50. (c) 51. (a)

D
1. (a) 2. (b) 3. (a) 4. (c) 5. (a, b, c, d) 6. (d) 7. (b)
8. (a, b, d) 9. (a, b) 10. (b) 11. (b) 12. (d) 13. (b, c) 14. (d)
15. (b, d) 16. (c) 17. (c, d) 18. (a) 19. (a, c, d) 20. (b,d) 21. (b,d)
22. (a, b) 23. (a, c, d) 24. (a, b, c, d) 25. (a, b, c) 26. (b, c)

E
1. $\dfrac{w_2-w_1}{(w_0-w_2)(t_2-t_1)}+\dfrac{\beta(w_0-w_1)}{(w_0-w_2)}$ 2. $T_B=30°C, T_C=T_D=20°C$ 3. Same
5. 817 mmHg 7. 12.96 m/s 8. –973.1 J
9. hollow sphere 10. 1.97×10^{27}, 35.6 m/s 11. 12.9 T_0, 2.25 T_0, $-15.58T_0$
12. 83.75 cm Hg 13. 75.4 cm 14. 675 K, 3.6×10^6 N/m^2
15. **(ii)** 113 l, 0.44×10^5 N/m^2 **(iii)** 12450 J 16. 800 K, 720 J 17. **(i)** 5 **(ii)** 1.25 PV
18. **(b)** 0.58 RT_A, 0.58 RT_A 19. **(a)** 1153 J **(b)** 1153J **(c)** Zero 20. **(i)** 1870 J **(ii)** –5298 J **(iii)** 500 K
21. **(i)** 765 J **(ii)** 10.82% 22. Mass of Neon = 4gm, mass of Argon = 24gm
23. **(a)** 2 mole **(b)** 400.03 m/s **(c)** 1/6 **(d)** $-8.27\times10^{-5}V$ 24. **(i)** 189 K **(ii)** –2767 J **(iii)** 2767 J
25. 0.0122 Kg 26. $T_B=909$ K, $T_D=791$ K, 61.4% 27. 6.67×10^{-5} per °C
28. **(a)** P_0V_0 **(b)** $-\dfrac{5}{2}P_0V_0$, $3P_0V_0$ **(c)** $\dfrac{P_0V_0}{2}$ **(d)** $\dfrac{25P_0V_0}{8R}$ 29. $\left[300+12.5e^{\frac{-2KAt_1}{CL}}\right]$ Kelvin
30. **(b)** $\dfrac{3}{2}P_1V_1\left[1-\left(\dfrac{V_1}{V_2}\right)^{2/3}\right]$, $Q-\dfrac{3}{2}P_1V_1\left[1-\left(\dfrac{V_1}{V_2}\right)^{2/3}\right]$, $\dfrac{P_1V_1^{5/3}V_2^{-2/3}}{2R}+\dfrac{Q}{3R}$ 31. **(a)** 1200R **(b)** –2100R, 831.6R
32. 0.495 Kg 33. **(a)** 600 K **(b)** 1500R, 831.8R, –900R, –831.8R **(c)** 600R
34. **(a)** 160K **(b)** 3.312×10^{-21} J **(c)** 0.3012 gm
35. $\dfrac{mv_0^2}{3R}$ 36. **(a)** 595 W/m^2 **(b)** 419.83 K 37. $\dfrac{4}{3}$m, $400\left(\dfrac{4}{3}\right)^{2/5}$ K 38. Rate of heat produced $\propto r^5$
39. $\left[1+\dfrac{4e\sigma\ell T_s^3}{K}\right]$ 40. $\gamma=2\alpha$ 41. 69.99°C, 0.0499J, 19999.95 J 42. 273K or 0°C

F
1. (A)-(q); (B)-(p, s); (C)-(s); (D)-(q, r) 2. (A)-(q); (B)-(p, r); (C)-(p, s); (D)-(q, s)
3. (A)-(p, r, t); (B)-(p, r); (C)-(q, s); (D)-(r, t) 4. (a)

G	**1.** (a)	**2.** (d)	**3.** (c)	**4.** (d)	**5.** (b)	**6.** (b)	**7.** (d)	**8.** (d)
H.	**1.** (b)							
I.	**1.** 9	**2.** 8	**3.** 9	**4.** 4	**5.** 3	**6.** 2		
	7. 2	**8.** 9						

Section-B : JEE Main/ AIEEE

1. (a)	**2.** (b)	**3.** (b)	**4.** (a)	**5.** (a)	**6.** (c)	**7.** (d)	**8.** (c)
9. (c)	**10.** (a)	**11.** (a)	**12.** (d)	**13.** (c)	**14.** (b)	**15.** (d)	**16.** (d)
17. (c)	**18.** (d)	**19.** (b)	**20.** (a)	**21.** (d)	**22.** (b, c)	**23.** (d)	**24.** (b)
25. (d)	**26.** (a)	**27.** (b)	**28.** (c)	**29.** (a)	**30.** (b)	**31.** (c)	**32.** (d)
33. (b)	**34.** (a)	**35.** (a)	**36.** (a)	**37.** (b)	**38.** (a)	**39.** (a)	**40.** (a)
41. (c)	**42.** (b)	**43.** (c)	**44.** (a)	**45.** (d)	**46.** (a)	**47.** (d)	**48.** (a)
49. (a)	**50.** (c)	**51.** (b)	**52.** (c)	**53.** (a)	**54.** (c)	**55.** (c)	**56.** (d)
57. (d)	**58.** (a)	**59.** (a)	**60.** (c)	**61.** (c)	**62.** (d)		

Section-A JEE Advanced/ IIT-JEE

A. Fill in the Blanks

1. $$\bar{C}_v = \frac{n_1 C_{v_1} + n_2 C_{V_2}}{n_1 + n_2}$$

$$= \frac{1 \times \frac{3}{2} R + 1 \times \frac{5}{2} R}{1+1} = 2R$$

2. AB represent a process when physical state changes from solid to liquid and the temperature remains unchanged. Since P is a point between A and B, therefore the material is partly solid and partly liquid.

3. $PV = RT$ (Ideal gas equation)

$$\Rightarrow P = \frac{RT}{V} \quad \text{...(i)}$$

Given that VP^2 = const ...(ii)

From (i) and (ii)

$$\therefore \frac{T^2}{V} = \text{const.}$$

$$\therefore \frac{T_1^2}{V_1} = \frac{T_2^2}{V_2} \Rightarrow T_2 = T_1\sqrt{\frac{V_2}{V_1}} = T\sqrt{\frac{2V}{V}} = \sqrt{2}\,T$$

4. The heat required for 100 g of ice at 0° C to change into water at 0°C $= mL = 100 \times 80 \times 4.2 = 33{,}600$ J ... (i)

The heat released by 300g of water at 25°C to change its temperature to 0°C $= mc\Delta T = 300 \times 4.2 \times 25 = 31{,}500$ J ... (ii)

Since the energy in eq. (ii) is less than of eq. (i) therefore the final temperature will be 0°C.

5. The energy received per second per unit area from Sun at a distance of 1.5×10^{11} m is 1400 J/sm^2. The total energy released by Sun/per second.

$= 1400 \times 4\pi \times (1.5 \times 10^{11})^2$.

$\therefore$ The total energy released per second per unit surface area of the Sun

$$= \frac{1400 \times 4\pi \times (1.5 \times 10^{11})^2}{4\pi \times (7 \times 10^8)^2}$$

This energy E is also equal to $E = \sigma T^4$

$$\therefore T = \left[\frac{1400 \times 4\pi \times (1.5 \times 10^{11})^2}{4\pi \times (7 \times 10^8)^2 \times 5.67 \times 10^{-8}}\right]^{\frac{1}{4}} \approx 5803\,K$$

6. The energy emitted per second when the temperature of the copper sphere is T and the surrounding temperature T_0

$$= \sigma(T^4 - T_0^4) \times A = \sigma . T^4 A \quad [\because T_0 = 0] \quad \text{...(i)}$$

We know that

$$dQ = mcdT \Rightarrow \frac{dQ}{dt} = mc\frac{dT}{dt} \quad \text{...(ii)}$$

From (i) and (ii)

$$\sigma T^4 A = mc\frac{dT}{dt}$$

$$\Rightarrow dt = \frac{mcdT}{\sigma T^4 A} = \frac{\rho \times \frac{4}{3}\pi r^3 cdT}{\sigma T^4 \times 4\pi r^2} \quad \left[\because m = \rho \times \frac{4}{3}\pi r^3\right]$$

$$\Rightarrow dt = \frac{\rho rc}{3\sigma}\frac{dT}{T^4}$$

Integrating both sides

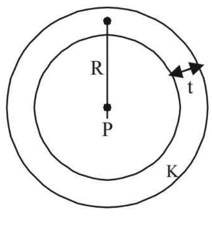
$$\int_0^t dt = \frac{\rho rc}{3\sigma}\int_{200}^{100}\frac{dT}{T^4} = \frac{\rho rc}{3\sigma}\left[-\frac{1}{3T^3}\right]_{200}^{100}$$

$$t = -\frac{\rho rc}{9\sigma}\left[\frac{1}{(100)^3} - \frac{1}{(200)^3}\right]$$

$$t = \frac{7\rho rc}{(72 \times 10^6)\sigma} \approx \frac{7\rho rc}{72 \times 10^6 (5.67 \times 10^{-8})} = 1.71\rho rc$$

7. **KEY CONCEPT :** When the spherical shell is thin, $t << R$. In this case, The rate of flow of heat from the sphere to the surroundings

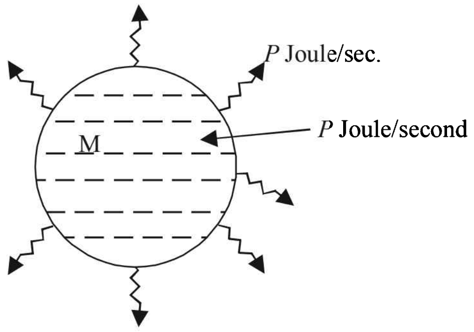
$$P = \frac{K(4\pi R^2)T}{t}$$



where T is the temperature difference and t is the thickness of steel then

$$t = \frac{4\pi R^2 KT}{P}$$

8. Since P joules per second of heat is supplied to keep the substance in molten state, it means that the substance in the molten state at its melting point releases P Joule of heat in one second.



The power is turned off then the heat input becomes zero. But heat output continues. It takes t seconds for the substance to solidify (given). Therefore total heat released in t seconds $= P \times t = mL_{fusion}$

$$L_{fusion} = \frac{P \times t}{m}$$

9. In this expansion, no work is done because the gas expands in vacuum. Therefore $\Delta W = 0$
As the process is a adiabatic, $Q = 0$. From first law of thermodynamics, $\Delta U = 0$ i.e. temperature remains constant.

10. For isothermal expansion

$$P \times V = P_i \times 2V \Rightarrow P_i = \frac{P}{2}$$

For adiabatic expansion

$$PV^\gamma = P_a \times (2V)^\gamma \Rightarrow P_a = \frac{P}{2^\gamma} = \frac{P}{2^{1.67}}$$

$$\therefore \quad \frac{P_a}{P_i} = \frac{P}{2^{1.67}} \times \frac{2}{P} = \frac{2}{2^{1.67}} = 0.628$$

11. The heat transferred through A per second
$Q_1 = K_1 A(100 - t)$
The heat transferred through B per second
$Q_2 = K_2 A(t - 0)$
At steady state $K_1 A(100 - t) = K_2 A(t - 0)$
$\Rightarrow 300(100 - t) = 200(t - 0) \Rightarrow 300 - 3t = 2t \Rightarrow t = 60° C$

12. The movable stopper will adjust to a position with equal pressure on either sides. Applying ideal gas equation to the two gases, we get

$$PV_1 = n_1RT = \frac{m}{M_1}RT, \; PV_2 = n_2RT = \frac{m}{M_2}RT$$

Hence, $\dfrac{V_2}{V_1} = \dfrac{M_1}{M_2} = \dfrac{32}{28} = \dfrac{8}{7}$

$$\alpha = \frac{360°}{(8+7)} \times 8 = 192°$$

13. Solar power received by earth = 1400 W/m^2
Solar power received by 0.2 m^2 area
$= (1400 \text{ W/m}^2)(0.2 \text{ m}^2) = 280$ W
Mass of ice = 280 g = 0.280 kg
Heat required to melt ice
$= (0.280)(3.3 \times 10^5) = 9.24 \times 10^4$ J

If t is the time taken for the ice to melt, we will have

$$(280)t = 9.24 \times 10^4 \text{ J} \qquad \left[\because P = \frac{E}{t}\right]$$

$$t = \frac{9.24 \times 10^4}{280} \text{s} = 330 \text{s} \equiv 5.5 \text{min}$$

B. True/ False

1. **KEY CONCEPT :** $c = \sqrt{\dfrac{3RT}{M}}$

At the same temperature $c \propto \dfrac{1}{\sqrt{M}}$

i.e., dependent on molar mass and hence rms speed c will be different for different ideal gases.

2. For a particular temperature T, $V \propto \dfrac{1}{P}$
Volume is greater for pressure P_1
$\therefore \quad p_1 < p_2$

3. For a particular termperature $C_{rms} \propto \dfrac{1}{\sqrt{M}}$
i.e., C_{rms} will have different values for different gases.

4.
$$\frac{(C_{H_2})_1}{(C_{H_e})_2} = \frac{\sqrt{\dfrac{\gamma_1 RT}{M_1}}}{\sqrt{\dfrac{\gamma_2 RT}{M_2}}} = \sqrt{\frac{\gamma_1}{\gamma_2} \times \frac{M_2}{M_1}}$$

$$= \sqrt{\frac{7/5}{5/3} \times \frac{4}{2}} = \sqrt{\frac{7}{5} \times \frac{3}{5} \times 2} = \sqrt{\frac{42}{25}}$$

5. The slope of P-V curve is more for adiabatic process than for isothermal process. From the graph it is clear that slope for B is greater than the slope for A.

6. $C_p - C_v = R$

7. We know that

$$v = \sqrt{\frac{3RT}{M}} \text{ then } v' = \sqrt{\frac{3R(2T)}{M/2}}$$

$\therefore \quad v' = 2v$

8. Energy radiated per second by the first sphere
$E_1 = \varepsilon\sigma T^4 A = \varepsilon\sigma(4000)^4 \times 4\pi \times 11 \times 1$
$= 1024 \times \pi \times 10^{12} \times \varepsilon\sigma$
Energy radiated per second by the second sphere
$E_2 = \varepsilon\sigma \times (2000)^4 \times 4\pi \times 4 \times 4$
$= 1024\,\pi \times 10^{12} \times \varepsilon\sigma$
$E_1 = E_2$

C. MCQs with ONE Correct Answer

1. **(d)** **Note :** At constant volume, Charle's law is used.

2. **(c)** $W_1 = mg - Vd_a g$

$$W_2 = mg - V'd'_a g = mg - V(1 + 50\,\gamma_b)\frac{d_a g}{(1 + 50\gamma_a)}$$

$$= mg - V d_a g \left[\frac{1 + 50\gamma_b}{1 + 50\gamma_a}\right]$$

Given $\gamma_b < \gamma_a$

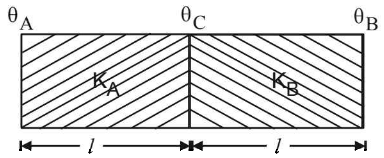
$\therefore \quad 1+50\,\gamma_b < 1+50\,\gamma_a \quad \therefore \quad \frac{1+50\gamma_b}{1+50\gamma_a} < 1$

$\therefore \quad W_2 > W_1$ or $W_1 < W_2$

3. **(b)** $\theta_A - \theta_B = 36°C$ (Given)

$K_A = 2K_B$ (Given)

$$\theta_C = \frac{\frac{K_A}{\ell}\theta_A + \frac{K_B}{\ell}\theta_B}{\frac{K_A}{\ell} + \frac{K_B}{\ell}}$$



$$\therefore \quad \theta_C = \frac{2\theta_A + \theta_B}{3} = \frac{2\theta_A + \theta_A - 36}{3} = \frac{3(\theta_A - 12)}{3}$$

$\therefore \quad \theta_A - \theta_C = 12$

4. **(a)** The work done during the cycle = area enclosed in the curve

5. **(b)** $\frac{n_1 + n_2}{\gamma - 1} = \frac{n_1}{\gamma_1 - 1} + \frac{n_2}{\gamma_2 - 1}$

Here, $n_1 = n_2 = 1, \gamma_1 = \frac{2}{5}, \gamma_2 = \frac{5}{3}$

6. **(a)** For an ideal gas PV = nRT

$\Rightarrow$ Coefficient of volume expansion

$$\left(\frac{\Delta V}{\Delta T}\right)_p = \frac{nR}{P} = \text{Constant}$$

Note : Average translation K.E. for O_2 is $\frac{3}{2}$kT

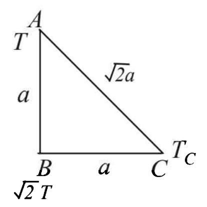
(Three degrees of freedom for translational motion).

Now decrease in pressure increases the volume.

$\Rightarrow$ It increases mean free path of the molecules. Also average K.E. does not depend on the gas, so molecules of each component of mixture of gases have same average translational energy.

7. **(b)** Heat flow from B to A, A to C and C to B (for steady state condition, $\Delta Q/\Delta t$ is same)

Where $\frac{\Delta Q}{\Delta t} = \frac{k A \Delta T}{\ell}$



For sides AC and CB $\left(\frac{\Delta T}{\sqrt{2}a}\right)_{AC}$

$= \left(\frac{\Delta T}{a}\right)_{CB}$

$$\Rightarrow \frac{T - T_c}{\sqrt{2}a} = \frac{T_c - \sqrt{2}T}{a} \Rightarrow T - T_c = \sqrt{2}T_c - 2T$$

$$\Rightarrow 3T = T_c(\sqrt{2}+1) \Rightarrow \frac{T_c}{T} = \frac{3}{\sqrt{2}+1}$$

8. **(d)** According to Stefan's law

$\Delta Q = e\sigma A T^4 \Delta t$

also, $\Delta Q = mc\,\Delta T$

or, $mc\,\Delta T = e\sigma A T^4 \Delta t$

$$\text{or, } \frac{\Delta T}{\Delta t} = \frac{e\sigma A T^4}{mc} = \frac{e\sigma T^4}{mc}\left[\pi\left(\frac{3m}{4\pi\rho}\right)^{2/3}\right] = k\left(\frac{1}{m}\right)^{1/3}$$

$$\therefore \quad \frac{\Delta T_1/\Delta t_1}{\Delta T_2/\Delta t_2} = \left(\frac{m_2}{m_1}\right)^{1/3} = \left(\frac{1}{3}\right)^{1/3}$$

9. **(c)** Average translational kinetic energy of an ideal gas molecule is $\frac{3}{2}$kT which depends on temperature only.

Therefore, if temperature is same, translational kinetic energy of O_2 and N_2 both will be equal.

10. **(c)** PV = nRT or $P = \frac{nRT}{V}$ or $P \propto T$

($\because$ V and n are same.)

Therefore, if T is doubled, pressure also becomes two times, i.e.., 2P.

11. **(d)** The energy radiated per second by a black body is given by Stefan's Law

$\frac{E}{t} = \sigma T^4 \times A$, where A is the surface area.

$\frac{E}{t} = \sigma T^4 \times 4\pi r^2$ ($\because$ For a sphere, $A = 4\pi r^2$)

Case (i) : $\frac{E}{t} = 450, T = 500\,K, r = 0.12$ m

$\therefore \quad 450 = 4\pi\sigma(500)^4(0.12)^2$ ...(i)

Case (ii) : $\frac{E}{t} = ?, T = 1000\,K, r = 0.06$ m

$\therefore \quad \frac{E}{t} = 4\pi\sigma(1000)^4(0.06)^2$ ...(ii)

Dividing (ii) and (i), we get

$$\frac{E/t}{450} = \frac{(1000)^4(0.06)^2}{(500)^4(0.12)^2} = \frac{2^4}{2^2} = 4$$

$$\Rightarrow \frac{E}{t} = 450 \times 4 = 1800\text{ W}$$

12. **(b)** When a enclosed gas is accelerated in the positive x-direction then the pressure of the gas decreases along the positive x-axis and follows the equation

$\Delta P = -\rho\, a\, dx$

where ρ is the density and a the acceleration of the container.

The result will be more pressure on the rear side and less pressure on the front side.

13. **(d)** The internal energy of n moles of a gas is

$U = \frac{1}{2}nFRT$

where F = number of degrees of freedom.

Internal energy of 2 moles of oxygen at temperature T is

$U_1 = \frac{1}{2} \times 2 \times 5RT = 5RT$ [F = 5 for oxygen molecule]

Internal energy of 4 moles of argon at temperature T is

$U_2 = \frac{1}{2} \times 4 \times 3RT = 6RT$

Total internal energy = 11 RT

14. (c) $\frac{V_N}{V_{He}} = \sqrt{\frac{\gamma_{N_2} M_{He}}{\gamma_{He} M_{N_2}}} = \sqrt{\frac{7/5 \times 4}{5/3 \times 28}} = \frac{\sqrt{3}}{5}$

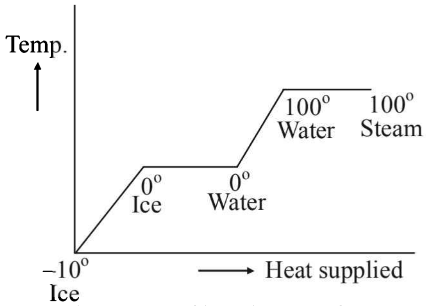
15. (d) Here $TV^{\gamma-1}$ = constant

As $\gamma = \frac{5}{3}$, hence $TV^{2/3}$ = constant

Now $T_1 L_1^{2/3} = T_2 L_2^{2/3}$ ($\because V \propto L$);

Hence, $\frac{T_1}{T_2} = \left(\frac{L_2}{L_1}\right)^{2/3}$

16. (a)



1. The temp. of ice changes from –10°C to 0°C.
2. Ice at 0°C melts into water at 0°C.
3. Water at 0°C changes into water at 100°C.
4. Water at 100°C changes into steam at 100°C.

17. (c) We know that V/T = constant

$\therefore \frac{V + \Delta V}{T + \Delta T} = \frac{V}{T}$ or $\frac{\Delta V}{V \Delta T} = \frac{1}{T}$

18. (a) Work done is equal to area under the curve on *PV* diagram.

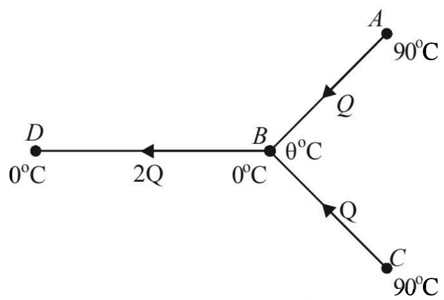
19. (b) According to Wien's law, λT = constant

From graph $\lambda_1 < \lambda_3 < \lambda_2$

$\therefore T_1 > T_3 > T_2$.

20. (b) Let θ°C be the temperature at *B*. Let *Q* is the heat flowing per second from *A* to *B* on account of temperature difference.

$\therefore Q = \frac{KA(90 - \theta)}{\ell}$ ... (i)



By symmetry, the same will be the case for heat flow from *C* to *B*.

$\therefore$ The heat flowing per second from *B* to *D* will be

$2Q = \frac{KA(\theta - 0)}{\ell}$ ... (ii)

Dividing eq. (ii) by eq. (i)

$2 = \frac{\theta}{90 - \theta} \Rightarrow \theta = 60°$

21. (a) From the first law of thermodynamics

$dQ = dU + dW$

Here $dW = 0$ (given)

$\therefore dQ = dU$

Now since $dQ < 0$ (given)

$\therefore$ dQ is negative

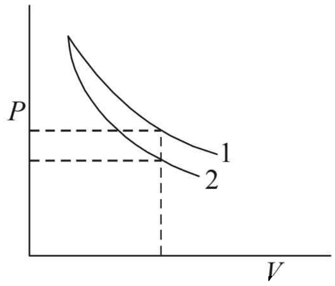
$\Rightarrow dU = -$ve $\Rightarrow dU$ decreases.

$\Rightarrow$ Temperature decreases.

22. (b) For adiabatic process PV^γ = constant

Also for monoatomic gas $\gamma = \frac{C_p}{C_V} = 1.67$

for diatomic gas $\gamma = 1.4$



Since, $\gamma_{\text{diatomic}} < \gamma_{\text{mono atomic}}$

$\therefore P_{\text{diatomic}} > P_{\text{mono atomic}}$

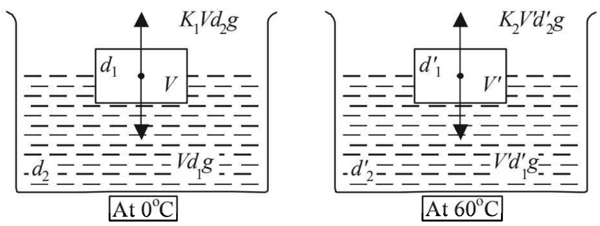
$\Rightarrow$ Graph 1 is for diatomic and graph 2 is for mono atomic.

23. (a) **For equilibrium in case 1 at 0° C**

Upthrust = Wt. of body

$\therefore K_1 V d_2 g = V d_1 g$

$\Rightarrow K_1 = \frac{d_1}{d_2}$ ... (i)



For equilibrium in case 2 at 60° C

Note : When the temperature is increased the density will decrease.

$\therefore d_1' = d_1(1 + \gamma_{Fe} \times 60)$

and $d_2' = d_2(1 + \gamma_{Hg} \times 60)$

Again upthrust = Wt. of body

$\therefore K_2 V' d_2' g = V' d_1' g$

$\therefore K_2 \left[\frac{d_2}{1 + \gamma_{Hg} \times 60}\right] = \frac{d_1}{1 + \gamma_{Fe} \times 60}$

$\therefore K_2 \left[\frac{1 + \gamma_{Fe} \times 60}{1 + \gamma_{Hg} \times 60}\right] = \frac{d_1}{d_2} \Rightarrow \frac{K_1}{K_2} = \frac{1 + \gamma_{Fe} \times 60}{1 + \gamma_{Hg} \times 60}$

24. **(a)** For cyclic process;
$Q_{cyclic} = W_{AB} + W_{BC} + W_{CA} = 10\,J + 0 + W_{CA} = 5\,J$
$\Rightarrow\ W_{CA} = -5\,J$

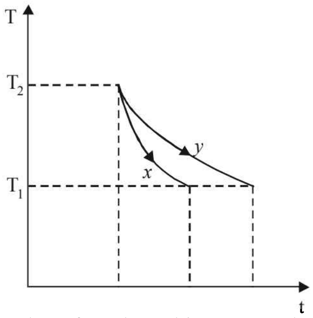
25. **(a)** PV = constant. Differentiating,

$$\frac{PdV}{dP} = -V; \beta = -\left(\frac{1}{V}\right)\left(\frac{dV}{dP}\right) = \left(\frac{1}{P}\right) \Rightarrow \beta \times P = 1$$

$\therefore$ Graph between β and P will be a rectangular hyperbola.

26. **(a)** **Note :** According to Kirchoff's law, good absorbers are good emitters as well.
At high temperature (in the furnace), since it absorbs more energy, it emits more radiations as well and hence is the brightest.

27. **(c)** The graph shows that for the same temperature difference $(T_2 - T_1)$, less time is taken for x. This means the emissivity is more for x. According to Kirchoff's law, a good emitter is a good absorber as well.



28. **(c)** The lengths of each rod increases by the same amount

$\therefore\ \Delta\ell_a = \Delta\ell_s$

$\Rightarrow\ \ell_1\alpha_a t = \ell_2\alpha_s t$

$\Rightarrow\ \dfrac{\ell_2}{\ell_1} = \dfrac{\alpha_a}{\alpha_s} \Rightarrow \dfrac{\ell_2}{\ell_1} + 1 = \dfrac{\alpha_a}{\alpha_s} + 1$

$\Rightarrow\ \dfrac{\ell_2 + \ell_1}{\ell_1} = \dfrac{\alpha_a + \alpha_s}{\alpha_s} \Rightarrow \dfrac{\ell_1}{\ell_1 + \ell_2} = \dfrac{\alpha_s}{\alpha_a + \alpha_s}$

29. **(b)** If we study the $P - T$ graph we find AB to be a isothermal process, AC is adiabatic process given. Also for an expansion process, the slope of adiabatic curve is more (or we can say that the area under the $P - V$ graph for isothermal process is more than adiabatic process for same increase in volume).
Only graph (b) fits the above criteria.

30. **(b)** Heat required to convert 5 kg of water at 20°C to 5 kg of water at 0°C
$= mC_\omega \Delta T = 5 \times 1 \times 20 = 100$ kcal
Heat released by 2 kg. Ice at – 20°C to convert into 2 kg of ice at 0°C
$= mC_{ice}\Delta T = 2 \times 0.5 \times 20 = 20$ k cal.
How much ice at 0°C will convert into water at 0°C for giving another 80 kcal of heat
$Q = mL \Rightarrow 80 = m \times 80$
$\Rightarrow\ m = 1$ kg
Therefore the amount of water at 0°C
$= 5$ kg $+ 1$kg $= 6$ kg
Thus, at equilibrium, we have, [6 kg water at 0°C + 1kg ice at 0°C].

31. **(b)** We know that
$\lambda_m T$ = Constant
$\lambda_A < \lambda_B < \lambda_C$
So, $T_A > T_B > T_C$

$$\left\{\because T_A = \frac{C}{3\times10^{-7}}, T_B = \frac{C}{4\times10^{-7}}, T_C = \frac{C}{5\times10^{-7}}\right\}$$

$Q = e\sigma AT^4$
$e = 1$ black body
$\therefore\ Q = \sigma AT^4$

$$\therefore\ Q_A = \sigma.\pi(2\times10^{-2})^2 \times \frac{C^4}{27\times10^{-28}}$$

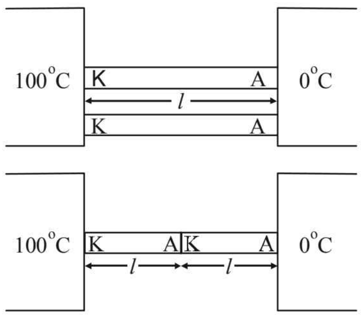
$$Q_B = \sigma.\pi(4\times10^{-2})^2 \times \frac{C^2}{64\times10^{-28}}$$

$$\text{and } Q_C = \sigma.\pi(6\times10^{-2})^2 \times \frac{C^2}{625\times10^{-28}}$$

From comparison Q_B is maximum.

32. **(c)** $Q = mc\,\Delta T$
$\Rightarrow\ Q = mc\,(T - t_0)$ ... (i)
$\therefore$ From 50 K to boiling temperature, T increases linearly.
During boiling, equation is
$Q = mL$
Temperature remains constant till boiling is complete
After that, again eqn. (i) is followed and temperature increases linearly.

33. **(d)**

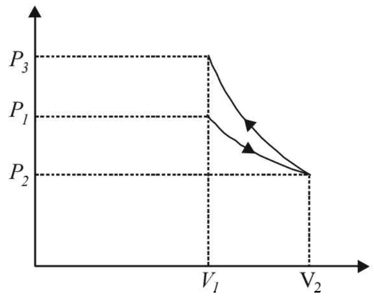


$$q_1 = \frac{K\,2A(100)}{\ell}$$

$$q_2 = \frac{A(100)}{\dfrac{\ell}{K} + \dfrac{\ell}{K}} = \frac{KA(100)}{2}$$

$$\therefore\ \frac{q_2}{q_1} = \frac{KA(100)}{2\ell} \times \frac{\ell}{K2A(100)} = \frac{1}{4}$$

34. **(b)** In the first process W is + ve as ΔV is positive, in the second process W is – ve as ΔV is – ve and area under the curve of second process is more
$\therefore$ Net Work < 0 and also $P_3 > P_1$.

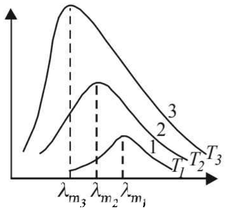


35. (a) According to Wein's displacement law

$\lambda_m \times T =$ constant

Here, $\lambda_{m_3} < \lambda_{m_2} < \lambda_{m_1}$

$\Rightarrow T_3 > T_2 > T_1$



The temperature of Sun is higher than that of welding arc which in turn is greater than tungsten filament.

36. (d) Heat transfer of glass bulb from filament is through radiation. A medium is required for convection process. As a bulb is almost evacuated, heat from the filament is transmitted through radiation.

37. (d) In this question the given options are wrong as all the four options contain e in place of σ.

When a spherical body is kept inside a perfectly block body then the total heat radiated by the body is equal to that of the black body.

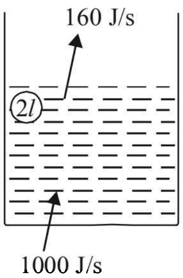
38. (a) 1 Calorie is the amount of heat required to raise temperature of 1 gm of water from 14.5°C to 15.5°C at 760 mm of Hg.

39. (c) As shown in the figure, the net heat absorbed by the water to raise its temperature

$= (1000 - 160) = 840$ J/s

Now, the heat required to raise the temperature of water from 27°C to 77°C is

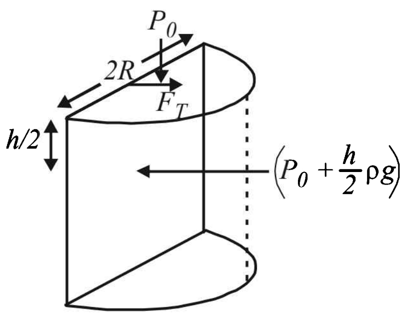
$Q = mc\,\Delta t = 2 \times 4200 \times 50$ J



Therefore the time required

$$t = \frac{Q}{840} = \frac{2 \times 4200 \times 50}{840} = 500 \text{ sec} = 8 \text{ min } 20 \text{ sec}$$

40. (b) The force is $\left[\left(P_0 + \frac{h\rho g}{2}\right) \times (2R \times h)\right] - 2RT$



Note : In the first part the force is created due to pressure and in the second part the force is due to surface tension T.

$\therefore$ Force $= 2P_0Rh + R\rho gh^2 - 2RT$

41. (c) $PT^2 =$ constant (given)

Also for an ideal gas $\frac{PV}{T} =$ constt

From the above two equations, after eliminating P.

$$\frac{V}{T^3} = \text{constt} \Rightarrow V = kT^3 \text{ where } k = \text{constant}$$

$$\Rightarrow \frac{dV}{V} = 3\frac{dT}{T}$$

$$\Rightarrow dv = \left(\frac{3}{T}\right) VdT \qquad ...(i)$$

We know that change in volume due to thermal expansion is given by $dV = V\gamma\, dT$ ...(ii)

where γ = coefficient of volume expansion.

From (i) and (ii)

$$V\gamma\, dT = \left(\frac{3}{T}\right) VdT \Rightarrow \gamma = \frac{3}{T}$$

42. (d) A real gas behaves as an ideal gas when the average distance between the gas molecules is large enough so that (i) the force of attraction between the gas molecules becomes almost zero (ii) the actual volume of the gas molecules is negligible as compared to the occupied volume of the gas.

The above conditions are true for low pressure and high temperature.

43. (a) Initially

$V_1 = 5.6\ell, T_1 = 273K, P_1 = 1$ atm,

$\gamma = \frac{5}{3}$ (For monoatomic gas)

The number of moles of gas is $n = \frac{5.6\ell}{22.4\ell} = \frac{1}{4}$

Finally (after adiabatic compression)

$V_2 = 0.7\ell$

For adiabatic compression $T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1}$

$$\therefore T_2 = T_1\left(\frac{V_1}{V_2}\right)^{\gamma-1} = T_1\left(\frac{5.6}{0.7}\right)^{\frac{5}{3}-1} = T_1(8)^{2/3} = 4T_1$$

We know that work done in adiabatic process is

$$W = \frac{nR\Delta T}{\gamma - 1} = \frac{9}{8}RT_1$$

44. (d) $\frac{v_{\text{rms (helium)}}}{v_{\text{rms (argon)}}} = \sqrt{\frac{M_{\text{argon}}}{M_{\text{helium}}}} = \sqrt{\frac{40}{4}} = \sqrt{10} \approx 3.16$

45. (d) The heat is supplied at constant pressure. Therefore,

$$Q = nC_p\Delta t$$

$$= 2\left[\frac{5}{2}R\right] \times \Delta t = 2 \times \frac{5}{2} \times 8.31 \times 5 = 208 \text{ J}$$

$$\left(\because C_p = \frac{5}{2}R \text{ for mono-atomic gas}\right)$$

46. (a) Given $H_I = H_{II}$

$$k_1\frac{A\Delta T}{\ell + \ell} \times t_1 = k_2\frac{(A + A)\Delta T}{\ell} \times t_2$$

$$\therefore t_2 = \frac{k_1}{k_2} \times \frac{t_1}{4} \qquad ...(i)$$

Where k_1 and k_2 are the equivalent conductivities in configuration I and II respectively.

For configuration I :

$$\frac{\ell+\ell}{k_1}=\frac{\ell}{k}+\frac{\ell}{2k} \qquad \therefore \frac{2}{k_1}=\frac{3}{2k}$$

$$\therefore k_1=\frac{4k}{3} \qquad \text{...(ii)}$$

For configuration II :

$k_2(A+A)=kA+2kA$

$$\therefore k_2=\frac{3k}{2} \qquad \text{...(iii)}$$

From (i), (ii) and (iii) $t_2=\dfrac{\frac{4k}{3}}{\frac{3k}{2}}\times\dfrac{9}{4}=2\,\text{sec}$

option (a) is correct

47. (d) $P_1M_1=d_1RT$; $P_2M_2=d_2RT$

$$\therefore \frac{P_1}{P_2}\times\frac{M_1}{M_2}=\frac{d_1}{d_2}$$

$$\frac{4}{3}\times\frac{2}{3}=\frac{d_1}{d_2} \qquad \therefore \frac{d_1}{d_2}=\frac{8}{9}$$

48. (a) In steady state

Energy lost = Energy gained

$$\sigma\left(T^4-T_0^4\right)\times 4\pi R^2=I\left(\pi R^2\right)$$

$$\therefore\ 5.7\times10^{-8}\left[T^4-(300)^4\right]\times4=912$$

$\therefore\ T=330\,K$

49. (b) $P_{heater}-P_{cooler}=\dfrac{mc\Delta T}{t}=\dfrac{V\rho c\Delta T}{t}$

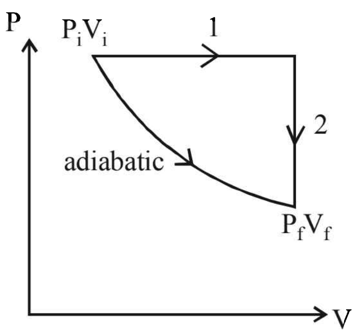
$$\therefore (3000-P_{cooler})=\frac{0.12\times1000\times4.2\times10^3\times20}{3\times60\times60}$$

$\therefore P_{cooler}=2067W$

50. (c) $P^3V^5=\text{constant}\Rightarrow PV^{5/3}=\text{constant}\Rightarrow\gamma=\dfrac{5}{3}$

$\Rightarrow$ monoatomic gas

For adiabatic process



$$W=\frac{P_fV_f-P_iV_i}{1-\gamma}=\frac{\frac{1}{32}\times10^5\times8\times10^{-3}-10^5\times10^{-3}}{1-\frac{5}{3}}$$

$$\therefore\ W=\frac{25-100}{(3-5)/3}=\frac{75\times3}{2}=112.5J$$

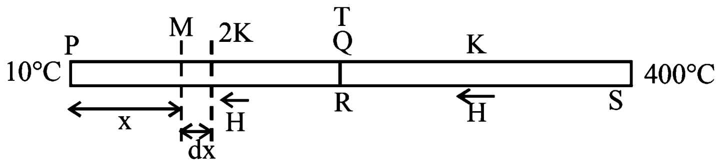
From first law of thermodynamics $q=\Delta U+w\ \therefore\ \Delta U=-w$

$\therefore\ \Delta U=-112.5\,J$

Now applying first law of thermodynamics for process 1 & 2 and adding $q_1+q_2=\Delta U+P_i(V_f-V_i)$

$=-112.5+10^5(8-1)\times10^{-3}=587.55$

51. (a) The heat flow rate is same



$$\therefore\ \frac{KA(400-T)}{\ell}=\frac{2KA(T-10)}{\ell}$$

$\therefore\ T=140°C$

The temperature gradient access Pd is

$$\frac{dT}{dx}=\frac{140-10}{1} \qquad \therefore\ dt=130\,dx$$

Therefore change temperature at a cross-section M distant 'x' from P is

$\Delta T=130x$

Extension in a small elemental length 'dx' is

$dl=dx\alpha\ \Delta T=dx\ \alpha(130x)$

$$\therefore\ \int dl=130\alpha\int_0^1 x\,dx$$

$$\therefore\ \Delta l=130\times1.2\times10^{-5}\times\frac{1}{2}=78\times10^{-5}\,m$$

D. MCQs with ONE or MORE THAN ONE Correct

1. (a) $M=\dfrac{3RT}{C_{rms}^2}=\dfrac{3\times8.314\times298}{1930\times1930}\times1000=2\,gm$

$\therefore$ The gas is H_2

2. (b) $\dfrac{Q_2}{Q_1}=\dfrac{nC_v\Delta T}{nC_p\Delta T}=\dfrac{1}{\gamma}\Rightarrow Q_2=\dfrac{Q_1}{\gamma}$

$$\Rightarrow\ Q_2=\frac{70}{1.4}=50\,cal$$

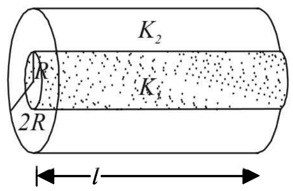
3. (a) Heat lost by steam = Heat gained by (water + calorimeter)

$mL+m\times c\times(100-80)=1.12\times c\times(80-15)$

$m[540+1\times20]=1.12\times1\times65$

$m=0.13\,kg$

4. (c) Total transfer of heat per second through the composite = Heat transfer per second from material with thermal conductivity K_1 + Heat transfer per second from material with thermal conductivity K_2.



$$\frac{KA\Delta T}{\ell} = \frac{K_1 A_1 \Delta T}{\ell} + \frac{K_2 A_2 \Delta T}{\ell}$$

or, $K\pi(2R)^2 = K_1 \pi R^2 + K_2 \pi [(2R)^2 - R^2]$

or, $K = \dfrac{K_1 + 3K_2}{4}$

5. **(a, b, c, d)**

(a) For all thermal processes.

$\Delta U = nC_v \Delta T$ where $\Delta T = (T_2 - T_1)$

(b) According to first law of thermodynamics.

$\Delta Q = \Delta U + \Delta W$

In an adiabatic process $\Delta Q = 0$.

or, $0 = \Delta U + \Delta W$

or, $|\Delta U| = |\Delta W|$

(c) In the isothermal process, $\Delta T = 0$.

$\because \Delta U = 0$

(d) In the adiabatic process, $\Delta Q = 0$.

6. **(d)** $\dfrac{\Delta U}{Q_p} = \dfrac{nC_v \Delta T}{nC_p \Delta T} = \dfrac{C_v}{C_p} = \dfrac{1}{\gamma} = \dfrac{1}{7/5} = \dfrac{5}{7}$

7. **(b)** **Note :** All three vessels are at same temperature. According to Maxwell's distribution of speed, average speed of molecules of a gas $v \propto \sqrt{T}$.

$\therefore$ The velocity of oxygen molecules will be same in A as well as C.

8. **(a, b, d)**

The work done by the gas in the process *A* to *B* exceeds the work that would be done by it if the system were taken from *A* to *B* along the isothermal line. This is because the work done is the area under the *P*-*V* indicator diagram. As shown by the diagram the area under the graph in first diagram will be more than in second diagram. When we extrapolate the graph shown in figure (i). Let P_0 be the intercept on *P*-axis and V_0 be the intercept on *V*-axis. The equation of the line *AB* can be written as

$$P = -\frac{P_0}{V_0}V + P_0 \quad \text{... (i)} \quad [\because y = mx + c]$$

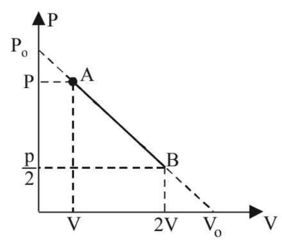


Fig (i)

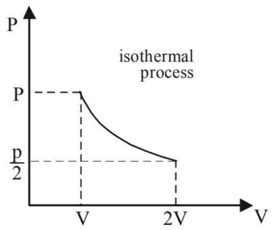


Fig (ii)

$$\therefore \quad P = -\frac{P_0}{V_0} \times \frac{RT}{P} + P_0 \quad [\because V = \frac{RT}{P}]$$

$\Rightarrow \quad P^2 V_0 - PP_0 V_0 = -P_0 RT$ ... (ii)

Relation between *P* and *T* is the equation of a parabola.

Also, $P = \dfrac{RT}{V}$

From (i) and (ii)

$$\frac{RT}{V} = -\frac{P_0}{V_0}V + P_0 \Rightarrow T = -\frac{P_0}{V_0 R}V^2 + \frac{P_0}{R}V$$

Note : The above equation is of a parabola (between *T* and *V*)

Differentiating the above equation w.r.t. *V*, we get

$$\frac{dT}{dV} = -\frac{P_0}{V_0 R} \times 2V + \frac{P_0}{R}$$

For $\dfrac{dT}{dV} = 0$, $V = \dfrac{V_0}{2}$

Also, $\dfrac{d^2T}{dV^2} = \dfrac{-2P_0}{V_0 R} = -\text{ve}$

$\Rightarrow V = \dfrac{V_0}{2}$ is the value for maxima of temperature

Also, $P_A V_A = P_B V_B$

$\Rightarrow T_A = T_B$ (From Boyle's law)

$\Rightarrow$ In going from *A* to *B*, the temperature of the gas first increase to a maximum (at $V = \dfrac{V_0}{2}$) and the decreases and reaches back to the same value.

9. **(a, b)**

Energy emitted per second by body $A = \varepsilon_A \sigma T_A^4 A$

Energy emitted per second by body $B = \varepsilon_B \sigma T_B^4 A$

Given that power radiated are equal $\varepsilon_A \sigma T_A^4 A = \varepsilon_B \sigma T_B^4 A$

$$\Rightarrow T_B = \left(\frac{\varepsilon_A}{\varepsilon_B}\right)^{1/4} \times T_A = 1934 \text{ K}$$

According to Wein's displacement law $\lambda_m \propto \dfrac{1}{T}$

Since temperature of *A* is more therefore $(\lambda_m)_A$ is less

$\therefore \quad (\lambda_m)_B - (\lambda_m)_A = 1 \times 10^{-6}$ m (given) ... (i)

Also according to Wein's displacement law

$(\lambda_m)_A T_A = (\lambda_m)_B T_B$

$\Rightarrow \dfrac{(\lambda_m)_A}{(\lambda_m)_B} = \dfrac{T_B}{T_A} = \dfrac{5802}{1934}$ ... (ii)

On solving (i) and (ii), we get

$\lambda_B = 1.5 \times 10^{-6}$ m.

10. **(b)** $\dfrac{(V_{rms})_1}{(V_{rms})_2} = \sqrt{\dfrac{T_1}{T_2}} \Rightarrow \dfrac{V}{(V_{rms})_2} = \sqrt{\dfrac{120}{480}}$

$\Rightarrow \dfrac{V}{(V_{rms})_2} = \dfrac{1}{2} \Rightarrow (V_{rms})_2 = 2V$

11. **(b)** For an isothermal process; PV = constant

On differentiating, we get ; $PdV + VdP = 0$

$\Rightarrow P = \dfrac{dP}{dV/V} = K$ (Bulk modulus)

12. **(d)** A is free to move, therefore heat will be supplied at constant pressure

$\therefore \quad \Delta Q_A = nC_p\Delta T_A \quad$ ... (i)

B is held fixed, therefore heat will be supplied at constant volume.

$\therefore \quad \Delta Q_B = nC_v\Delta T_B \quad$ ... (ii)

But $\Delta Q_A = \Delta Q_B \quad$ (given)

$$\therefore \quad nC_p\Delta T_A = nC_v\Delta T_B \quad \therefore \; \Delta T_B = \left(\frac{C_p}{C_v}\right)\Delta T_A$$

$= \gamma(\Delta T_A) \quad [\gamma = 1.4 \text{ (diatomic)}]$

$= (1.4)(30\text{ K})$

$\therefore \quad \Delta T_B = 42\text{ K}$

13. **(b, c)**

There is a decrease in volume during melting of an ice slab at 273 K. Therefore, negative work is done by ice-water system on the atmosphere or positive work is done on the ice-water system by the atmosphere. Hence, option (b) is correct.

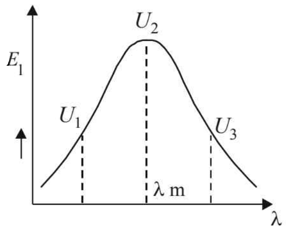
NOTE : Secondly heat is absorbed during melting (i.e. dQ is positive) and as we have seen, work done by ice-water system is negative (dW is negative.) Therefore, from first law of thermodynamics $dU = dQ - dW$

change in internal energy of ice-water system, dU will be positive or internal energy will increase.

14. **(d)** According to Wien's displacement law,

$\lambda_m T = 2.88 \times 10^6\, nmK$

The wavelength at the peak of the spectrum becomes



$$\lambda_m = \frac{2.88\times10^6\, nmK}{2880\, K} = 10^3\, nm$$

NOTE : Thus, the maximum energy is radiated for 10^3 nm wavelength. It follows that the energy radiated between 499 nm to 500 nm will be less than that emitted between 999 nm to 1000 nm, i.e., $U_1 < U_2$ or $U_2 > U_1$.

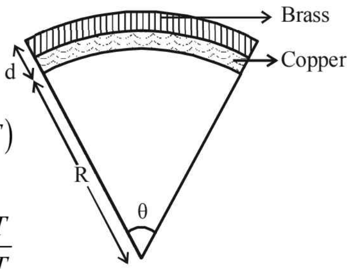
15. **(b, d)**

Co-efficient of linear expansion of brass is greater than that of copper i.e., $\alpha_B > \alpha_C$. Now,

$$L_B = L_0\left(1+\alpha_B\,\Delta T\right)$$

or,

$$(R+d)\theta = L_0\left(1+\alpha_B\,\Delta T\right)$$



Again, $L_C = L_0\left(1+\alpha_C\Delta T\right)$

or, $\quad R\theta = L_0\left(1+\alpha_C\Delta T\right)$

$$\therefore \quad \frac{(R+d)\theta}{R\,\theta} = \frac{1+\alpha_B\,\Delta T}{1+\alpha_C\,\Delta T}$$

or, $\dfrac{R+d}{R} = \left(1+\alpha_B\,\Delta T\right)\left(1-\alpha_C\,\Delta T\right)$, by binomial theorem.

or, $\quad 1+\dfrac{d}{R} = 1+(\alpha_B-\alpha_C)\Delta T - \alpha_B\alpha_C(\Delta T)^2$

or, $\quad \dfrac{d}{R} = (\alpha_B-\alpha_C)\,\Delta T$ or $R = \dfrac{d}{(\alpha_B-\alpha_C)\Delta T}$

$\therefore \quad R \propto \dfrac{1}{\Delta T}$ and $R \propto \dfrac{1}{|\alpha_B-\alpha_C|}$.

16. **(c)**

Container A	Container B
$P_A V = \dfrac{m_A}{M}RT$	$P_B V = \dfrac{m_B}{M}RT$
$P'_A(2V) = \dfrac{m_A}{M}RT$	$P'_B(2V) = \dfrac{m_B}{M}RT$

$$\Rightarrow \; P_A - P'_A = \frac{m_A RT}{MV} - \frac{m_A RT}{M(2V)}$$

$$\Rightarrow \; \Delta P = \frac{m_A RT}{2MV} \quad \text{... (i)}$$

and $P_B - P'_B = \dfrac{m_B RT}{MV} - \dfrac{m_B RT}{M(2V)}$

$$1.5\,\Delta P = \frac{m_B RT}{2MV} \quad \text{... (ii)}$$

Dividing (i) and (ii)

$$\frac{1.5\Delta P}{\Delta P} = \frac{m_B}{M_A} \Rightarrow \frac{3}{2} = \frac{m_B}{m_A} \Rightarrow 3m_A = 2m_B$$

17. **(c, d)**

We know that

$$\bar{v} = \sqrt{\frac{8RT}{\pi M}};\, v_{rms} = \sqrt{\frac{3RT}{M}} \text{ and } v_p = \sqrt{\frac{2RT}{M}}$$

From these expressions, we can conclude that

$$v_p < \bar{v} < v_{rms}$$

Also the average kinetic energy of gaseous molecules is

$$\bar{E} = \frac{1}{2}mv_{rms}^2 = \frac{1}{2}m\left(\frac{3}{2}v_p^2\right) = \frac{3}{4}mv_p^2$$

18. **(a)** **NOTE :** The law of equipartition of energy states that 'For a dynamical system in thermal equilibrium, the energy of a system is equally distributed among its various degrees of freedom and the energy associated with each degree of freedom per molecule is $\frac{1}{2}$k.T. In this case, O_2 and N_2 both have two degrees of rotational kinetic energy and since the temperature is also same, the ratio of the average rotational kinetic energy is 1 : 1.

19. **(a, c, d)**

Since sun rays fall on the black body, it will absorb more radiation and since, its temperature is constant it will emit more radiation. The temperature will remain same only when energy emitted is equal to energy absorbed.

20. **(b, d)**

$C_p - C_v = R$ for all gases

For monoatomic gas : $C_v = \dfrac{3}{2}R$; $C_p = \dfrac{5}{2}R$; $\gamma = \dfrac{5}{3}$

$$C_p.C_v = \frac{15}{4}\;;\; C_p + C_v = 4$$

For diatomic gas : $C_v = \dfrac{5}{2}R$; $C_p = \dfrac{7}{2}R$; $\gamma = \dfrac{7}{5}$

and $\quad C_p.C_v = \dfrac{35}{4}$; $C_p + C_v = 6$

21. **(b, d)**

In case of an isothermal process we get a rectangular hyperbola in a P-V diagram. Therefore option (a) is wrong.

$T_D < T_B$. Therefore in process $B \to C \to D$, ΔU is negative. PV decreases and volume also decreases, therefore W is negative. From first law of thermodynamic, Q is negative i.e., there is a heat loss option (b) is correct.

$W_{AB} > W_{BC}$.

Therefore work done during path $A \to B \to C$ is positive, option (c) is wrong.

Work done is clockwise cycle in a PV diagram is positive. Option (d) is correct.

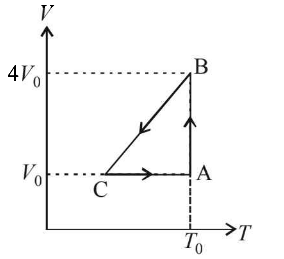
22. **(a, b)**

Process A to B

As the temperature remains the same, this process is isothermal. Therefore there is no change in the internal energy. Option (a) is correct.

Also $P_0 V_0 = P_B \times 4 V_0$

$$\Rightarrow P_B = \frac{P_0}{4}$$



Work done

$$W = nRT_0 \log_e \frac{4V_0}{V_0}$$

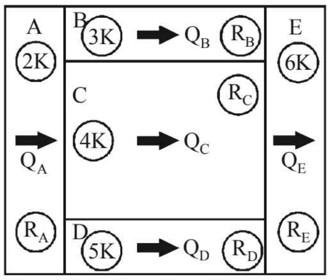
$$= P_0V_0 \log_e 4 \qquad [\because P_0V_0 = nRT_0]$$

The process BC is not clear. Therefore no judgement can be made for point C.

23. **(a, c, d)**

It is given that heat Q flows only from left to right through the blocks. Therefore heat flow through A and E slabs are the same.

$\therefore$ [a] is correct option



$Q_A = Q_B + Q_C + Q_D = Q_E$

Since heat flow through slabs A and E is same, [b] is not correct.

We know that resistance to heat flow is $R = \frac{\ell}{KA}$

Let the width of slabs be Z. Then

$$R_A = \frac{L}{2K(4L)Z} = \frac{1}{8KZ}, \quad R_B = \frac{4L}{3K(LZ)} = \frac{4}{3KZ}$$

$$R_C = \frac{4L}{4K(2LZ)} = \frac{1}{2KZ}, \quad R_D = \frac{4L}{5K(LZ)} = \frac{4}{5KZ}$$

$$R_E = \frac{L}{6K(4LZ)} = \frac{1}{24KZ}$$

Now, $\Delta T = QR$

As R_E is least, ΔT_E is also smallest ie since the resistance to heat flow is least for slab E, the temperature difference across is smallest.

$\therefore$ Option (c) is the correct answer.

Also

$$Q_C = \frac{\Delta T_C}{R_C} = \frac{\Delta T_C}{1/2\,KZ} = 2KZ(\Delta T_C)$$

$$Q_B = \frac{\Delta T_B}{R_B} = \frac{\Delta T_C}{4/3KZ} = \frac{3KZ(\Delta T_C)}{4} \qquad [\because \Delta T_B = \Delta T_C]$$

$$Q_D = \frac{\Delta T_D}{R_D} = \frac{\Delta T_C}{4/5KZ} = \frac{5KZ(\Delta T_c)}{4} \qquad [\because \Delta T_D = \Delta T_C]$$

$$Q_B + Q_D = \frac{3KZ(\Delta T_C)}{4} + \frac{5KZ(\Delta T_C)}{4}$$

$$= \frac{8KZ(\Delta T_C)}{4} = 2KZ(\Delta T_C) = Q_C$$

$\therefore$ (d) is the correct option.

24. **(a, b, c, d)**

We know that dQ = m C dT in the range 0 to 100K

From the graph, C increases linearly with temperature therefore the rate at which heat is absorbed varies linearly with temperature. Option (a) is correct

As the value of C is greater in the temperature range 400-500K, the heat absorbed in increasing the temperature from 0 - 100K is less than the heat required for increasing the temperature from 400 - 500K option (b) is correct.

From the graph it is clear that the value of C does not change in the temperature range 400-500K, therefore there is no change in the rate of heat absorption in this range. Option (c) is correct.

As the value of C increases from 200-300K, the rate of heat absorption increases in the range 200-300K. Option (d) is also correct.

25. **(a, b, c)**

$$\text{Total energy} = \frac{3}{2}RT + \frac{5}{2}RT = 4RT$$

$$\therefore \text{Average energy per mole} = \frac{4RT}{2} = 2RT$$

$$\text{We know that } V_{sound} = \sqrt{\frac{\gamma RT}{M}}$$

$$\frac{n_1 + n_2}{\gamma_{mix} - 1} = \frac{n_1}{\gamma_1 - 1} + \frac{n_2}{\gamma_2 - 1}$$

$$\Rightarrow \frac{2}{\gamma_{mix} - 1} = \frac{1}{\frac{5}{3} - 1} + \frac{1}{\frac{7}{5} - 1}$$

$$\frac{2}{\gamma_{mix} - 1} = \frac{3}{2} + \frac{5}{2} = 4$$

$$\therefore \gamma_{mix} - 1 = \frac{1}{2} \qquad \therefore \gamma_{mix} = \frac{3}{2}$$

$$\frac{(V_s)_{mix}}{(V_s)_{He}} = \sqrt{\frac{\gamma_{mix}}{M_{mix}} \times \frac{M_{He}}{\gamma_{He}}}$$

$$= \sqrt{\frac{\frac{3}{2}\times 4}{3\times\frac{5}{3}}} \qquad \left[\because M_{mix} = \frac{1\times 2 + 1\times 4}{2} = 3\right]$$

$$= \sqrt{\frac{6}{5}}$$

We know that $V_{rms} = \sqrt{\frac{3RT}{M}}$

$$\therefore \frac{(V_{rms})_{He}}{(V_{rms})_{H_2}} = \sqrt{\frac{M_{H_2}}{M_{H_E}}} = \sqrt{\frac{2}{4}} = \frac{1}{\sqrt{2}}$$

$\therefore$ options [A], [B] and [C] are correct.

26. (b, c)

Applying combined gas law

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

If $V_2 = 2V_1$ and $T_2 = 3T_1$ then

$$\frac{P_1V_1}{T_1} = \frac{P_2\times 2V_1}{3T_1} \Rightarrow P_1 = \frac{2}{3}P_2$$

Now change in internal energy

$$\Delta U = \frac{f}{2}[nR(T_2 - T_1)] = \frac{f}{2}[P_2V_2 - P_1V_1]$$

For monoatomic gas f = 3

$$\Delta U = \frac{3}{2}\left[\frac{3}{2}P_1\times 2V_1 - P_1V_1\right] = 3P_1V_1$$

$\therefore$ (b) is the correct option.

Now assuming that the pressure on the piston on the right hand side (not considering the affect of spring) remains the same throughout the motion of the piston then,

Pressure of gas $= P_1 + \frac{kx}{A} \Rightarrow P_2 = P_1 + \frac{kx}{A}$

where k is spring constant and A = area of piston

Energy stored $= \frac{1}{2}kx^2$

$$P_2 = P_1 + \frac{kx}{A} \Rightarrow \frac{3}{2}P_1 = P_1 + \frac{kx}{A}$$

$$\frac{P_1}{2} = \frac{kx}{A}$$

$$\therefore \quad kx = \frac{P_1A}{2}$$

Also,

$V_2 = V_1 + Ax$

$V_1 = Ax$

$$\therefore \quad x = \frac{V_1}{A}$$

$$\therefore \quad \text{Energy} = \frac{1}{2}\frac{P_1A}{2}\times\frac{V_1}{A} = \frac{1}{4}P_1V_1$$

$\therefore$ A is correct

Now

$$W = \int PdV = \int\left(P_1 + \frac{kx}{A}\right)dV = \int P_1dV + \int\frac{kx}{A}dV$$

$$\therefore \quad W = \int P_1dV + \int\frac{kx}{A}\times(dx)\,A$$

$$\therefore \quad W = P_1(V_2 - V_1) + \frac{kx^2}{2}$$

$$\left[\begin{array}{l}\text{Here on applying } \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \text{ we get } P_2 = \frac{4P_1}{3} \\ \text{and } V_2 = V_1 + Ax \Rightarrow x = \frac{2V_1}{A}\ [\because V_2 = 3V_1]\end{array}\right]$$

$$\therefore W = 2P_1V_1 + \frac{1}{2}\times\frac{P_1A}{3}\times\frac{2V_1}{A} = \frac{7}{3}P_1V_1$$

C is correct option

Heat supplied

$Q = W + \Delta U$

$$= \frac{7}{3}\frac{P_1V_1}{3} + \frac{3}{2}(P_2V_2 - P_1V_1)$$

$$= \frac{7P_1V_1}{3} + \frac{3}{2}\left[\frac{4}{3}P_1\,3V_1 - P_1V_1\right] = \frac{41}{6}P_1V_1$$

E. Subjective Problems

1. $W_0 - W_1 = V\times d_\ell\times g$ ... (i)

$W_0 - W_2 = V'\times d'_\ell\times g$ ... (ii)

Also, $V' = V(1 + \beta\Delta T)$ ... (iii)

and $d_\ell = d_\ell'(1 + \gamma_\ell\Delta T)$ ... (iv)

From (ii), (iii) and (iv)

$$W_0 - W_2 = \frac{V(1+\beta\Delta T)\times d_\ell}{1+\gamma_\ell\Delta T}\times g \quad \text{... (v)}$$

Dividing (i) and (v), we get

$$\frac{W_0 - W_1}{W_0 - W_2} = \frac{Vd_\ell g(1+\gamma_\ell\Delta T)}{V(1+\beta\Delta T)d_\ell g}$$

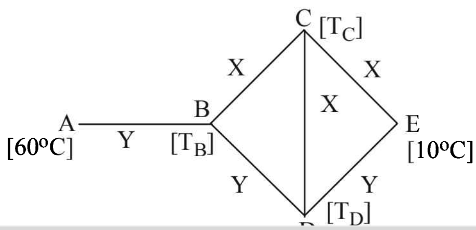
$$\Rightarrow \frac{W_0 - W_1}{W_0 - W_2} = \frac{1+\gamma_\ell\Delta T}{1+\beta\Delta T} \Rightarrow \frac{W_0 - W_1}{W_0 - W_2} = \frac{1+\gamma_\ell(t_2 - t_1)}{1+\beta(t_2 - t_1)}$$

$$\Rightarrow (W_0 - W_1)[1 + \beta(t_2 - t_1) = (W_0 - W_2)[1 + \gamma_\ell(t_2 - t_1)]$$

$$\Rightarrow \gamma_\ell = \frac{W_2 - W_1}{(W_0 - W_2)(t_2 - t_1)} + \frac{\beta(W_0 - W_1)}{(W_0 - W_2)}$$

2. $K_X = 0.92$ cal/sec-cm-°C

$K_Y = 0.46$ cal/sec-cm-°C



NOTE THIS STEP : The heat flow through AB is divided into two path BC and BD. Symmetry shows that no heat will flow through CD. Therefore

$$\frac{K_Y A(60-T_B)}{\ell} = \frac{K_X A(T_B-10)}{2\ell} + \frac{K_Y A(T_B-10)}{2\ell}$$

On solving the above equation, we get

$T_B = 30°C$

As C is a point at the middle of BE therefore temperature at C is 20°C.

Similarly temperature at D is also 20°C.

3. PV = nRT

When P, T are same $n \propto V$

As volumes are same, both samples will have equal number of molecules

4. **(i)** **Region AB :** Heat is absorbed by the material at a constant temperature called the melting point. The phase changes from solid to liquid.

Region CD : Heat is absorbed by the material at a constant temperature called the boiling point. The phase changes from liquid to gas.

(ii) Latent heat of vaporisation = 2 (latent heat of fusion)

(iii) $Q = mc_g \Delta T$.

The slope $DE = \dfrac{\Delta T}{Q} = \dfrac{1}{mc_g}$

NOTE : The slope DE indicates that the temperature of the solid begins to rise.

(iv) The reciprocal of heat capacity in solid state is greater than the reciprocal of heat capacity in liquid state

$$\left(\frac{1}{mc}\right)_{solid} > \left(\frac{1}{mc}\right)_{liquid} \Rightarrow (mc)_{liquid} > (mc)_{solid}$$

$\Rightarrow c_{liquid} > c_{solid}$

5. $P_1 = 830 - 30 = 800$ mm Hg ; P_2 ?

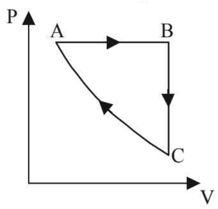
$V_1 = V$; $V_2 = V$; $T_1 = T$; $T_2 = T - 0.01\,T = 0.99\,T$

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \quad \therefore P_2 = \frac{P_1T_2}{T_1} = \frac{800 \times 0.099T}{T} = 792 \text{ mmHg}$$

$\therefore$ Total pressure in the jar = 792 + 25 = 817 mm Hg

6. **A → B** A straight line between A and B in V-T graph indicates $V \propto T$

⇒ Pressure is constant.



B → C Volume is constant. Since the temperature is decreasing, the pressure should also decrease.

C → A The temperature is constant but volume decreases. The process is isothermal.

7. Lead bullet just melts when stopped by an obstacle. Given that 25% of the heat is absorbed by the obstacle. Therefore 75% heat is used in melting of lead. Initial temp. = 27°C

M.P. = 300°C

(0.75) K.E. = Heat utilised in increasing the temperature and heat utilised to melt lead at 300°C

$$(0.75) \times \frac{1}{2}Mv^2 = Mc\,\Delta T + ML$$

$$(0.75) \times \frac{1}{2}v^2 = (0.03 \times 300 + 6) \times 4.2$$

[4.2 to convert into S.I. system]

$v = 12.96$ m/s

8. Work don in an adiabatic process is

$$W = \frac{1}{1-\gamma}[P_2V_2 - P_1V_1]$$

Here, $P_1 = 10^5$ N/m², $V_1 = 6\,\ell = 6 \times 10^{-3}$ m³

$$P_2 = P_1\left(\frac{V_1}{V_2}\right)^{\gamma}, \; V_2 = 2\,\ell = 2 \times 10^{-3}$$

Given that $C_v = \dfrac{3}{2}R$

$\therefore \quad C_p = \dfrac{5}{2}R \qquad [\because C_p - C_v = R]$

$\therefore \quad \gamma = \dfrac{C_p}{C_v} = 1.67$

$$\therefore \quad P_2 = 10^5\left[\frac{6}{2}\right]^{1.67} = 10^5 \times (3)^{1.67} = 6.26 \times 10^5 \text{ N/m}^2$$

$$\therefore \quad W = \frac{1}{1-1.67}[6.26 \times 10^5 \times 2 \times 10^{-3} - 10^5 \times 6 \times 10^{-3}]$$

$$W = \frac{1}{-0.67}[1252 - 600] = -\frac{652}{0.67} = -973.1 \text{ J}$$

Work done is negative because the gas is compressed.

9. **NOTE :** Since the temperature and surface area is same, therefore the energy emitted per second by both spheres is same.

We know that $Q = mc\Delta T$

Since Q is same and c is also same (both copper).

$\therefore \quad m \propto \dfrac{1}{\Delta T}$

Mass of hollow sphere is less;

∴ Temperature change will be more.

∴ Hollow sphere will cool faster.

10. **(i)** $F = P \times A = 10^5 \times 1 = 10^5$ N

$$F = \frac{\Delta p}{\Delta t} \Rightarrow \Delta p = F \times \Delta t = 10^5 \times 1 = 10^5 \qquad \text{..(i)}$$

Now, momentum change per second

$(\Delta p) = n \times 2mv$ ...(ii)

Where n is the number of collisions per second per square metre area

From (i) and (ii)

$$n \times 2mv = 10^5 \qquad \therefore n = \frac{10^5}{2mv}$$

Root mean square velocity

$$v = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3 \times 8.314 \times 300}{32/1000}} = 483.4 \text{ m/s}$$

According to mole concept 6.023×10^{23} molecules will have mass 32 g

$\therefore \quad$ 1 molecule will have mass $\dfrac{32}{6.023 \times 10^{23}}$ g

$$\therefore \quad n = \frac{10^5 \times 6.023 \times 10^{23}}{2 \times 32 \times 483.4} = 1.97 \times 10^{27}$$

(ii) The kinetic energy of motion of molecules will be converted into heat energy.

K.E. of 1 gm mole of oxygen $= \frac{1}{2}Mv_0^2$ ... (i)

where v_0 is the velocity with which the vessel was moving.

The heat gained by 1 gm mole of molecules at constant volume for 1°C rise in temperature

$= nC_v\Delta T = 1 \times C_v \times 1 = C_v$ ... (ii)

From (i) and (ii)

$$\frac{1}{2}Mv_0^2 = C_v \quad \text{But, } C_v = \frac{R}{\gamma - 1}$$

$$\frac{1}{2}Mv_0^2 = \frac{R}{\gamma-1}$$

$$\therefore \quad v_0 = \sqrt{\frac{2R}{M(\gamma-1)}} = \sqrt{\frac{2\times 8.314}{\frac{32}{100}\times(1.41-1)}} = 35.6\ \text{ms}^{-1}$$

[$\because \gamma = 1.41$ for O_2 (diatomic gas)]

11. For the left chamber

$$\frac{P_0V_0}{T_0} = \frac{P_0\times 243}{32\times T_1}\times V_1$$

$$\Rightarrow T_1 = \frac{243}{32}\times\frac{V_1T_0}{V_0} \quad \text{... (i)}$$

For the right chamber for adiabatic compression

We get, $P_0V_0^\gamma = P_0\times\frac{243}{32}\times V_2^\gamma$

$$\Rightarrow \frac{V_2}{V_0} = \left(\frac{32}{243}\right)^{3/5} \Rightarrow V_2 = \frac{8}{27}V_0$$

But $V_1 + V_2 = 2V_0$

$$\therefore \quad V_1 = 2V_0 - V_2 = 2V_0 - \frac{8}{27}V_0 = \frac{46}{27}V_0 \quad \text{... (ii)}$$

From (i) and (ii) $T_1 = \frac{243}{32}\times\frac{46\times V_0}{V_0\times 27}\times T_0$

or, $T_1 = \frac{207}{16}T_0 = 12.9T_0$ (approx.)

To find the temperature in the second chamber (right), we apply

$$\left(\frac{T_1}{T_2}\right)^\gamma = \left(\frac{P_2}{P_1}\right)^{1-\gamma}$$

$$\Rightarrow \left(\frac{T_0}{T_2}\right)^{5/3} = \left(\frac{243P_0}{32P_0}\right)^{1-5/3} \Rightarrow T_2 = 2.25\,T_0$$

Work done in right chamber (adiabatic process)

$$W = \frac{1}{1-\gamma}(P_2V_2 - P_0V_0)$$

$$= -\frac{3}{2}\left[\frac{243}{32}P_0\times\frac{8}{27}V_0 - P_0V_0\right]$$

$$= -\frac{3}{2}\left(\frac{9}{4}-1\right)P_0V_0 = -\frac{15}{8}\times RT_0 = -15.8\,T_0$$

12. Let x moles shift from high temperature side to low temperature side.

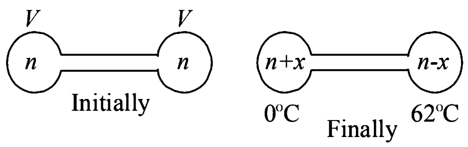
for left bulb $PV = nRT$

$76\times V = nR\times 273$ Initially

$P'\times V = (n+x)R\times 273$ Finally

Dividing, we get

$$\frac{P'}{76} = \frac{n+x}{n} \quad \text{... (i)}$$



For right bulb

$76\times V = nR\times 273$ Initially

$P'\times V = (n-x)R\times 335$ Finally

On dividing,

$$\frac{P'}{76} = \frac{n-x}{x}\times\frac{335}{273} \quad \text{... (ii)}$$

From (i) and (ii)

$$\frac{n+x}{n} = \frac{n-x}{n}\times\frac{335}{273}$$

$$\Rightarrow n = \frac{608}{62}x. \quad \text{... (iii)}$$

Substituting the value of (iii) in (i), we get

$$\frac{P'}{76} = 1 + \frac{62}{608}$$

$$\Rightarrow P' = \frac{670}{608}\times 76 = 83.75\ \text{cm Hg}$$

13. Let A be the area of cross-section of the tube.

Since temperature is the same, applying Boyle's law on the side AB

$P\times(x\times A) = P_2\times(x_2\times A)$ ... (i)

Applying Boyle's law in section CD

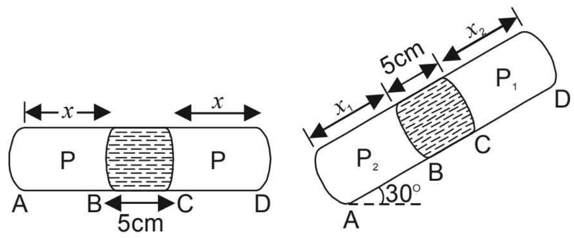
$P\times(x\times A) = P_1\times(x_1\times A)$ ... (ii)

From (i) and (ii)

$P_1\times(x_1\times A) = P_2\times(x_2\times A)$

$\Rightarrow P_1x_1 = P_2x_2$

where $P_2 = P_1$ + Pressure due to mercury column



Pressure due to mercury column

$$P = \frac{F}{A} = \frac{mg\sin 30°}{A} = \frac{Vdg\sin 30°}{A}$$

$$= \frac{(A\times 5)\times dg\sin 30°}{A} = 5\sin 30°\ \text{cm of Hg}$$

$P_2 = P_1 + 5\sin 30° = P_1 + 2.5$

Substituting this value in (iii)

$P_1\times x_1 = [P_1 + 2.5]\times x_2$

$P_1 \times 46 = [P_1 + 2.5] \times 44.5$

$\therefore \quad P_1 = \dfrac{44.5 \times 2.5}{1.5}$

Substituting this value in (ii)

$P \times x = \dfrac{44.5 \times 2.5}{1.5} \times 46$

$\Rightarrow \quad P \times \left[\dfrac{46 + 44.5}{2}\right] = \dfrac{44.5 \times 2.5}{1.5} \times 46$

$[\because x = \dfrac{x_1 + x_2}{2}] \Rightarrow P = 75.4\,\text{cm}$

14. We know that $PV = nRT$

$\therefore \quad n = \dfrac{PV}{RT} = \dfrac{1.6 \times 10^6 \times 0.0083}{8.3 \times 300} = \dfrac{16}{3} = 5.33$ moles

$C_p = \dfrac{5R}{2} \Rightarrow C_v = \dfrac{3R}{2}$

When 2.49×10^4 J of heat energy is supplied at constant volume then we can use the following relationship to find change in temperature.

$Q = nC_v\Delta T$

$\therefore \quad \Delta T = \dfrac{Q}{nC_v} = \dfrac{2.49 \times 10^4}{5.33 \times \frac{3}{2} \times 8.3} = 375\,\text{K}$

Therefore, the final temperature

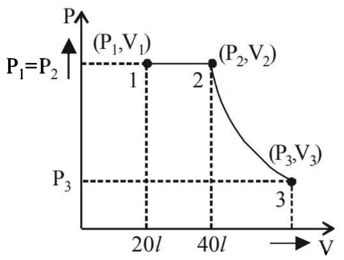
$= 300 + 375 = 675\,\text{K}$

Applying Gay Lussac's Law, to find pressure.

$\dfrac{P_1}{T_1} = \dfrac{P_2}{T_2}$

$\Rightarrow \quad P_2 = \dfrac{P_1 T_2}{T_1} = \dfrac{1.6 \times 10^6 \times 675}{300} = 3.6 \times 10^6\,\text{Nm}^{-2}$

15. **(i)** $P - V$ diagram is drawn below.



(ii) $P_1V_1 = nRT_1$

$\therefore \quad P_1 \times 20 \times 10^{-3} = 2 \times 8.3 \times 300$

$P_1 = 2.49 \times 10^5\,\text{Nm}^{-2}$

Applying $\dfrac{P_1V_1}{T_1} = \dfrac{P_2V_2}{T_2}$

For 1 → 2

$\dfrac{20}{300} = \dfrac{40}{T_2} \Rightarrow T_2 = 600\,\text{K}$

2 → 3 is adiabatic expansion.

$T_2V_2^{\gamma-1} = T_3V_3^{\gamma-1}$

$\therefore \quad V_3 = V_2\left[\dfrac{T_2}{T_3}\right]^{\frac{1}{\gamma-1}} = 40\left[\dfrac{600}{300}\right]^{\frac{1}{\frac{5}{3}-1}} = 113\ell$

$[\because \gamma = \dfrac{5}{3}$ for mono atomic gas$]$

Now, $P_3V_3 = nRT_3$

$\Rightarrow \quad P_3 = \dfrac{nRT_3}{V_3} = \dfrac{2 \times 8.3 \times 300}{113 \times 10^{-3}} = 0.44 \times 10^5\,\text{N/m}^2$

(NOTE : $T_3 = T_1$ given)

(iii) $W = W_{12} + W_{23}$

$= P_1(V_2 - V_1) + \dfrac{nR}{\gamma - 1}(T_2 - T_3)$

W_{12} = work done at constant pressure

W_{23} = work done in adiabatic condition

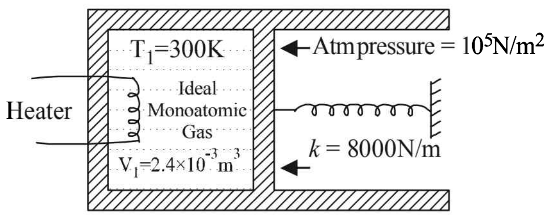
$= 2.49 \times 10^5 (40 - 20)\,10^{-3} + \dfrac{2 \times 8.3}{\frac{5}{3} - 1}(600 - 300)$

$= 4980 + 7470 = 12450\,\text{J}$

16. **KEY CONCEPT :** The final pressure on the gas = atm pressure + pressure due to compression of spring

$P_2 = P_{atm} + \dfrac{kx}{A}$

$\Rightarrow \quad P_2 = 10^5 + \dfrac{8000 \times 0.1}{8 \times 10^{-3}} = 2 \times 10^5\,\text{N/m}^2$



The final volume,

$V_2 = V_1 + xA$

$= 2.4 \times 10^{-3} + 0.1 \times 8 \times 10^{-3} = 3.2 \times 10^{-3}\,\text{m}^3$

Applying $\dfrac{P_1V_1}{T_1} = \dfrac{P_2V_2}{T_2} \Rightarrow T_2 = \dfrac{P_2V_2T_1}{P_1V_1}$

$\Rightarrow \quad T_2 = \dfrac{2 \times 10^5 \times 3.2 \times 10^{-3} \times 300}{10^5 \times 2.4 \times 10^{-3}} = 800\,\text{K}.$

NOTE : Heat supplied by the heater is used for expansion of the gas, increasing its temperature and storing potential energy in the spring.

$\therefore$ Heat supplied

$= P\Delta V + nC_v\Delta T + \dfrac{1}{2}kx^2$

$= 10^5[0.8 \times 10^{-3}] + \dfrac{P_1V_1}{RT_1}C_v\Delta T + \dfrac{1}{2}kx^2$

$= 80 + \dfrac{10^5 \times 2.4 \times 10^{-3}}{2 \times 300} \times \dfrac{3}{2} \times 2 \times 500 + \dfrac{1}{2} \times 8000 \times 0.1$

$= 720\,\text{J}$

17. **(i)** Let pressure = P, Volume = V and Temperature = T be the initial quantities and Pressure = P', Volume = 5.66 V Temperature = $T/2$ be the final quantities.

For adiabatic process

$$TV^{\gamma-1} = \frac{T}{2}(5.66V)^{\gamma-1} \Rightarrow 2 = (5.66)^{\gamma-1}$$

Taking log on both sides, $\log 2 = (\gamma - 1) \log 5.66$

$\Rightarrow \gamma = 1.4$

$$\text{But } \gamma = 1 + \frac{2}{f} \Rightarrow 1.4 = 1 + \frac{2}{f}$$

$$\Rightarrow f = \frac{2}{0.4} = 5$$

Thus degrees of freedom of gas molecules = 5

(ii) For adiabatic process the pressure-volume relationship is

$$P_1V_1^{\gamma} = P_2V_2^{\gamma}$$

$$\Rightarrow P_2 = \frac{P}{(5.66)^{1.4}} = \frac{P}{11.32}$$

Work done for adiabatic process

$$W = \frac{P_1V_1 - P_2V_2}{\gamma - 1} = \frac{PV - \left(\frac{P}{11.32}\right)(5.66V)}{1.4 - 1} = 1.25\,PV$$

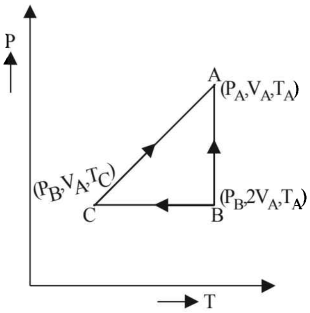
18. **(a)** **Process *A* to *B*** (isothermal expansion)

$P_AV_A = P_BV_B$

$\Rightarrow P_AV_A = P_B \times 2V_A$

$$\Rightarrow P_B = \frac{P_A}{2}$$

Process *B* to *C* (isobaric compression)



$$\frac{V_B}{T_B} = \frac{V_C}{T_C}$$

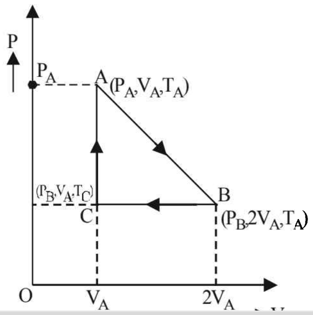
$$\Rightarrow \frac{2V_A}{T_A} = \frac{V_A}{T_C}$$

$$\Rightarrow T_C = \frac{T_A}{2}$$

Process *C* to *A* [volume is constant]

$$\frac{P_C}{T_C} = \frac{P_A}{T_A} \Rightarrow \frac{P_B}{T_C} = \frac{P_A}{T_A}$$

$$\Rightarrow \frac{P_A/2}{T_C} = \frac{P_A}{T_A} \Rightarrow T_C = \frac{T_A}{2}$$



Let the system initially be at point A at pressure P_A and temp T_A and volume V_A.

Process *A* to *B*

The system is isothermally expanded and reaches a new state B (P_B, $2V_A$, T_A) as shown in the figure.

Process *B* to *C*

The system is the compressed at constant pressure to its original volume to reach at state C (P_B, V_A, T_C)

Process *C* to *A*

Finally at constant volume, the pressure is increased to its original pressure to reach the state A again.

(b) The total work done

$$W = W_{A\to B} + W_{B\to C} + W_{C\to A}$$

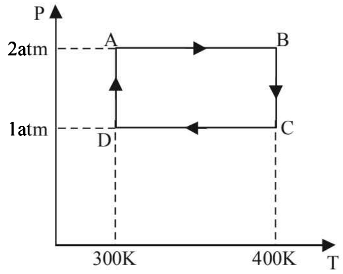
$$= nRT_A \log_e \frac{V_B}{V_A} + nR(T_C - T_A) + 0$$

$$= 2.303 \times 3 \times R \times T_A \log_{10} \frac{2V_A}{V_A} + 3R\left(\frac{T_A}{2} - T_A\right)$$

$$= 2.08\,RT_A - \frac{3}{2}RT_A = 0.58RT_A$$

NOTE : The total work done is equal to the heat exchanged as the process is cyclic.

19. Let us find out the work done in the cycle



Work done from *A* to *B* (Isobaric process)

$W_{AB} = nR(T_B - T_A)$

$= nR \times 100 = 2 \times 200 \times 8.32 = 1664$ J

Work done from *B* to *C* (Isothermal process)

$$W_{BC} = 2.303nRT \log_{10} \frac{P_B}{P_C}$$

$$= 2.303nR \times 400 \log_{10} \frac{2}{1} = 277.2\,nR$$

$= 554.4 \times 8.32 = 4612.6$

Work done from *C* to *D* (Isobaric process)

$W_{CD} = nR(T_D - T_C) = nR(300 - 400)$

$= -100nR = -200 \times 8.32 = -1664$ J

Work done from *D* to *A* (Isothermal process)

$$W_{DA} = 2.303nRT \log_{10} \frac{P_D}{P_A} = 2.303nR \times 300 \log_{10} \frac{1}{2}$$

$= -207.9nR$

$= -415.8 \times 8.32 = -3459.5$ J

The total work done $= W_{AB} + W_{BC} + W_{CD} + W_{DA}$

$= 1153$ J

(a) $\Delta U = Q - W$

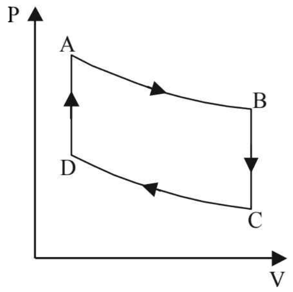
For complete cycle $\Delta U = 0$

$\therefore \quad Q = W = 1153$ J

(b) $W = 1153$ J

(c) $\Delta U = 0$. Since, the process is cyclic.

20. Given $T_A = 1000\text{ K}$



$$P_B = \frac{2}{3}P_A$$

$$P_C = \frac{1}{3}P_A$$

(i) W_{AB} (adiabatic expansion)

$$W_{AB} = \frac{nR[T_A - T_B]}{\gamma - 1}$$

Here, $n = 1, R = 8.31\text{ J mol}^{-1}k^{-1}, T_A = 1000\text{ K}$

$$\gamma = \frac{5}{3} \quad \text{(For mono atomic gas)}$$

To find T_B, we use

$$T_A^{\gamma}P_A^{1-\gamma} = T_B^{\gamma}P_B^{1-\gamma} \Rightarrow \left(\frac{P_A}{P_B}\right)^{\gamma-1} = \left(\frac{T_A}{T_B}\right)^{\gamma} \quad \text{... (i)}$$

$$\Rightarrow T_B = T_A\left[\frac{P_A}{P_B}\right]^{\frac{1-\gamma}{\gamma}} = 1000\left[\frac{3}{2}\right]^{\frac{1-5/3}{5/3}} = 850\text{ K}$$

$$\therefore \quad W_{AB} = \frac{1 \times 8.31[1000 - 850]}{5/3 - 1} = 1870\text{ J}$$

(ii) Heat Lost B → C

$Q = nC_v\Delta T = nC_v(T_B - T_C)$

Here, $n = 1, C_v = \frac{3}{2}R$ (For mono atomic gas),

$T_B = 850\text{ K}$

To find T_C, we use $\frac{P_B}{T_B} = \frac{P_C}{T_C}$ (volume constant)

$$\Rightarrow \frac{P_C}{P_B} = \frac{T_C}{T_B} \quad \text{..(ii)}$$

$$\Rightarrow T_C = \frac{P_C}{P_B} \times T_B = \frac{1}{2} \times 850 = 425\,K \left[\because \frac{P_C}{P_A} = \frac{\frac{1}{3}P_A}{\frac{2}{3}P_A} = \frac{1}{2}\right]$$

$$\therefore \quad Q = 1 \times \frac{3}{2} \times 8.31\,[425 - 850] = -5298\text{ J}$$

(iii) Temperature T_D : C to D is adiabatic compression

$$\left(\frac{P_C}{P_D}\right)^{\gamma-1} = \left(\frac{T_C}{T_D}\right)^{\gamma} \quad \text{...(iii)}$$

D to A is isochoric process $\frac{P_D}{T_D} = \frac{P_A}{T_A}$

$$\Rightarrow \frac{P_A}{P_D} = \frac{T_A}{T_D} \quad \text{... (iv)}$$

Multiplying (i) and (iii)

$$\left(\frac{P_C P_A}{P_D P_B}\right)^{\gamma-1} = \left(\frac{T_C}{T_D} \times \frac{T_A}{T_B}\right)^{\gamma} \quad \text{.... (v)}$$

Multiplying (ii) and (iv)

$$\left(\frac{P_A P_C}{P_B P_D}\right) = \left(\frac{T_C T_A}{T_B T_D}\right) \quad \text{... (vi)}$$

From (v) and (vi)

$$\left(\frac{T_C T_A}{T_B T_D}\right)^{\gamma-1} = \left(\frac{T_C T_A}{T_B T_D}\right)^{\gamma} \Rightarrow \frac{T_A T_C}{T_B T_D} = 1$$

$$\Rightarrow T_D = \frac{T_A T_C}{T_B} = \frac{1000 \times 425}{850} = 500K$$

21. (i) The process is cyclic, therefore $\Delta U = 0$

Now, $\Delta Q = \Delta U + \Delta W$

$\Rightarrow \Delta Q = \Delta W$

$\Rightarrow Q_1 + Q_2 + Q_3 + Q_4 = W_1 + W_2 + W_3 + W_4$

$\Rightarrow 5960 - 5585 - 2980 + 3645 = 2200 - 825 - 1100 + W_4$

$\Rightarrow W_4 = 765\text{ J}$

(ii) Key Concept: $\eta = \frac{\text{Work done}}{\text{Heat supplied}}$

$$= \frac{W_1 + W_2 + W_3 + W_4}{Q_1 + Q_4}$$

$$\Rightarrow = \frac{1040}{9605} = 10.82\%$$

22. The total pressure exerted by the mixture $P = 10^5\text{ Nm}^{-2}$

Temperature $T = 300\text{ K}$; Volume $= 0.02\text{ m}^3$

Let there be x gram of Ne. Then mass of Ar will be $28 - x$.

Number of moles of Neon $= \frac{x}{20}$;

Number of moles of Argon $= \frac{28 - x}{40}$

Partial pressure due to Neon;

$$p_1 = \frac{(x/20)RT}{V}$$

Partial pressure due to Argon

$$p_2 = \frac{[(28 - x)/40]RT}{V}$$

But according to Dalton's law of partial pressure

$P = p_1 + p_2$

$$10^5 = \frac{xRT}{20V} + \frac{(28 - x)RT}{40V}$$

$$\Rightarrow \frac{10^5 \times 40 \times 0.02}{8.314 \times 300} = x + 28 \Rightarrow x = 4\text{g}$$

$\Rightarrow$ Mass of Neon = 4g

$\therefore$ Mass of Argon = 24g

23. (a) $\frac{5+7n_B}{3+5n_B}=\frac{19}{13} \Rightarrow n_B=2$ mol.

We know that

$$\frac{n_A+n_B}{\gamma_m-1}=\frac{n_A}{\gamma_A-1}+\frac{n_B}{\gamma_B-1}$$

where γ_m = Ratio of specific heats of mixture

Here, $n_A=1,\ \gamma_A=5/3,\ \gamma_B=7/5$

According to the relationship

$$PV^{\frac{19}{13}}=\text{constant, we get } \gamma_m=\frac{19}{13}$$

(b) On substituting the values we get $n_B=2$ mol.

We know that velocity of sound in air is given by the relationship

$$v=\sqrt{\frac{\gamma P}{d}} \text{ where } d=\text{density}=\frac{m}{V}$$

Also, $PV=(n_A+n_B)RT \Rightarrow PV=\frac{(n_A+n_B)}{V}RT$

$$\therefore \quad v=\sqrt{\frac{\gamma(n_A+n_B)RT}{V\times\frac{m}{V}}}=\sqrt{\frac{\gamma(n_A+n_B)RT}{m}}$$

Mass of the gas, $m=n_AM_A+n_BM_B=1\times4+2\times32$
$=68$ g/mol $=0.068$ kg/mol

$$\therefore \quad v=\sqrt{\frac{19(1+2)\times8.314\times300}{13\times0.068}}=400.03\ \text{ms}^{-1}$$

(c) Velocity of sound,

$$v=\sqrt{\frac{\gamma RT}{M}} \text{ and } v+\Delta v=\sqrt{\frac{\gamma R(T+\Delta T)}{M}}$$

$$\Rightarrow \frac{v+\Delta v}{v}=\sqrt{\frac{T+\Delta T}{T}}=\left(1+\frac{\Delta T}{T}\right)^{1/2}$$

When $\Delta T << T$ then $\frac{\Delta T}{T}<<1$

$$\therefore \quad 1+\frac{\Delta v}{v}=1+\frac{1}{2}\frac{\Delta T}{T}$$

Percentage change $\frac{\Delta v}{v}\times100=\frac{1}{2}\times\frac{\Delta T}{T}\times100$

$$\frac{\Delta v}{v}\times100=\frac{1}{2}\frac{1}{300}\times100=\frac{1}{6}\%$$

(d) $PV^\gamma=$ Const.

Differentiating the above equation

$V^\gamma(dP)-P(\gamma V^{\gamma-1}dV)=0$

$\Rightarrow V^\gamma dP=\gamma PV^{\gamma-1}dV$

$$\Rightarrow \frac{dP}{dV}=\frac{\gamma PV^{\gamma-1}}{V^\gamma}=\gamma PV^{\gamma-1-\gamma}=\frac{\gamma P}{V}$$

$$\Rightarrow \frac{-dP}{dV/V}=-\gamma P$$

$\therefore$ Bulk Modulus $B=\gamma P$

$\therefore$ Compressibility $K=\frac{1}{B}=\frac{1}{\gamma P}$

$\therefore$ $K_1=\frac{1}{\gamma P_1}$ and $K_2=\frac{1}{\gamma P_2}$

$$\Delta K=K_2-K_1=\frac{1}{\gamma P_2}-\frac{1}{\gamma P_1}=\frac{1}{\gamma}\left(\frac{1}{P_2}-\frac{1}{P_1}\right)$$

Since the process is adiabatic, $P_2V_2^\gamma=P_1V_1^\gamma$

$$\therefore \quad P_2=P_1\left(\frac{V_1}{V_2}\right)^\gamma=P_1\left(\frac{V_1}{V_1/5}\right)^\gamma=P_15^\gamma$$

$$\therefore \quad \Delta K=\frac{1}{\gamma}\left(\frac{1}{P_15^\gamma}-\frac{1}{P_1}\right)=\frac{1}{\gamma P_1}\left(\frac{1}{5^\gamma}-1\right)$$

$$P_1=\frac{(n_A+n_B)RT}{V}=\frac{(1+2)\times8.31\times T}{V}=\frac{24.93T}{V}$$

$$\Rightarrow \Delta K=\frac{1}{\frac{19}{13}\times24.93\times\frac{T}{V}}\left(\frac{1}{5^{19/13}}-1\right)$$

$=-8.27\times10^{-5}$ V $\quad [\because T=300\text{ K}]$

24. (i) $T_1=27+273=300\,K;\ \gamma=\frac{5}{3}$ (for monoatomic gas)

$V_1=V$
$V_2=2V$
$T_2=?$

Since the gas expands adiabatically.

$$T_1V_1^{\gamma-1}=T_2V_2^{\gamma-1}$$

$$\Rightarrow T_2=T_1\left(\frac{V_1}{V_2}\right)^{\gamma-1}=300\left[\frac{V}{2V}\right]^{5/3-1}=189\,K$$

(ii) $W=\frac{-nR(T_2-T_1)}{\gamma-1}=\frac{-2\times8.31(189-300)}{5/3-1}$

$$=\frac{+8.31\times111\times3}{2}=+2767\text{J}$$

Change in internal Energy

According to first law of thermodynamics

$\Delta Q=\Delta U+\Delta W$ $\quad$ But $\Delta Q=0$ (as the process is adiabatic)

$\therefore \quad \Delta U=-\Delta W=-2767$ J

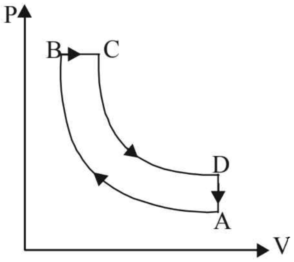
(iii) $W=2767$ J

25. Heat lost by steam = Heat gained by water

$m_sL_{fus}=m_wc\,\Delta T$

$$\Rightarrow m_s=\frac{m_wc\Delta T}{L_{fus}}=\frac{0.1\times4200\times66}{540\times10^3\times4.2}=0.0122\text{ kg}$$

26. $n = 1$, for diatomic gas,



$$\gamma = 1 + \frac{2}{5} = \frac{7}{5} = 1.4$$

$A \to B$, adiabatic compression
$B \to C$, isobaric expansion
$C \to D$, adiabatic expansion
$D \to A$, isochoric process

Given $\frac{V_A}{V_B} = 16, \frac{V_C}{V_B} = 2$

$T_A = 300\,K, T_B = ?, T_D = ?, \eta = ?$

For adiabatic compression process $A \to B$

$$T_A V_A^{\gamma-1} = T_B V_B^{\gamma-1} \text{ or}$$

$$T_B = \left(\frac{V_A}{V_B}\right)^{\gamma-1} T_A = (16)^{2/5} \times 300 = 909\,K$$

$\therefore$ For isobaric process $B \to C$: According to Charles' law

As $\frac{V_B}{T_B} = \frac{V_C}{T_C}$ or $T_C = T_B\left(\frac{V_C}{V_B}\right) = 909\,[2] = 1818\,K$

For adiabatic expansion process $C \to D$:

As $\frac{V_A}{V_B} = 16$ and $\frac{V_C}{V_B} = 2$; hence $\frac{V_A}{V_C} = 8$

According to Poisson's law,

$$T_C V_C^{\gamma-1} = T_D V_D^{\gamma-1}$$

$$\therefore \quad T_D = T_C\left[\frac{V_C}{V_D}\right]^{\gamma-1} = 1818\left[\frac{1}{8}\right]^{2/5} = \frac{1818}{(64)^{1/5}} = 791K$$

For $B \to C$ process : Heat absorbed

$$Q_1 = nC_p(T_C - T_B)$$

$$= n\frac{\gamma R}{\gamma - 1}(T_C - T_B) = 1\frac{(7/5)R}{(2/5)}(1818 - 909)$$

$$= \frac{7R}{2} \times 909 \cong 3182\,R$$

For $D \to A$ process : Heat released

$$Q_2 = nC_v(T_D - T_A) = n\frac{R}{\gamma - 1}(T_D - T_A)$$

$$= 1.\frac{R}{(2/5)}(791 - 300) = \frac{5R}{2} \times 491$$

($\because$ No heat is exchanged in adiabatic processes).

Now, $W_{AB} = -\frac{nR}{\gamma - 1}(T_B - T_A)$

$$= -\frac{R}{(2/5)}(900 - 300) = -\frac{5R}{2} \times 609$$

$$W_{BC} = -nR(T_C - T_B) = 1 \times R(1818 - 909) = 909\,R$$

$$W_{CD} = -\frac{nR}{\gamma - 1}(T_C - T_D) = +\frac{R}{(2/5)}(1818 - 791)$$

$$= \frac{5R}{2} \times 1027$$

$$W_{net} = 909\,R + \frac{5R}{2}(1027 - 609) = 909\,R + \frac{5R}{2} \times 418$$

$$= 909\,R + 1045\,R = 1954\,R$$

$\therefore$ Efficiency $= 100 \times (W_{net}/Q_1) = 100 \times \frac{1954\,R}{3182\,R} = 61.4\%$

27. Let the pressure at point O be P_0. Since the liquid is at equilibrium at M

$P_A + h_1\rho_{95°}g = P_0 + h\,\rho_{5°}\,g$

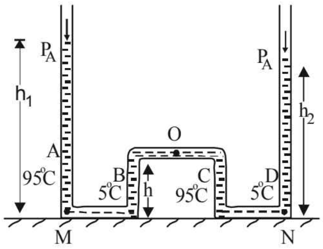
$\Rightarrow P_0 = P_A + h_1\rho_{95°}\,g - h\,\rho_{5°}\,g$ ...(i)

Since the liquid is at equilibrium at N

$\Rightarrow P_A + h_2\rho_{5°}\,g = P_0 + h\,\rho_{95°}\,g$

$\Rightarrow P_0 = P_A + h_2\rho_{5°}\,g - h\,\rho_{95°}\,g$ ...(ii)

From (i) and (ii)



$P_A + h_1\rho_{95°}\,g - h\,\rho_{5°}\,g$
$= P_A + h_2\rho_{5°}\,g - h\,\rho_{95°}\,g$

$$\Rightarrow \frac{\rho_{5°}}{\rho_{95°}} = 1.018 \text{ ... (i)}$$

We know that

$\rho_0 = \rho_1(1 + \gamma\Delta T)$

Applying the above formula, we get

$\rho_0 = \rho_{95°}(1 + \gamma \times 95)$
$\rho_0 = \rho_{5°}(1 + \gamma \times 5)$

$$\therefore \quad \frac{\rho_{5°}}{\rho_{95°}} = \frac{1 + 95\gamma}{1 + 5\gamma} \text{ ...(ii)}$$

From (i) and (ii)

$$\frac{1 + 95\gamma}{1 + 5\gamma} = 1.018 \Rightarrow \gamma = 2.002 \times 10^{-4}$$

But $\gamma = 3\alpha$

$$\Rightarrow \alpha = \frac{\gamma}{3} = \frac{2.002 \times 10^{-4}}{3} = 6.67 \times 10^{-5}\,°C^{-1}$$

28. $n = 1$, For monoatomic gas : $C_p = \frac{5R}{2}, C_v = \frac{3R}{2}$

Cyclic process
$A \to B \Rightarrow$ Isochoric process
$C \to A \Rightarrow$ Isobaric compression

(a) Work done = Area of closed curve $ABCA$ during cyclic process. i.e. ΔABC

$$\Delta W = \frac{1}{2} \times \text{base} \times \text{height} = \frac{1}{2}V_0 \times 2P_0 = P_0V_0$$

(b) Heat rejected by the gas in the path CA during isobaric compression process

$\Delta Q_{CA} = nC_p\Delta T = 1 \times (5R/2)(T_A - T_C)$

$$T_C = \frac{2P_0V_0}{I \times R}, T_A = \frac{P_0V_0}{I \times R}$$

$$\Delta Q_{CA} = \frac{5R}{2}\left[\frac{P_0V_0}{R} - \frac{2P_0V_0}{R}\right] = -\frac{5}{2}P_0V_0$$

Heat absorbed by the gas on the path AB during isochoric process

$\Delta Q_{AB} = nC_V\Delta T = 1 \times (3R/2)(T_B - T_A)$

$$= \frac{3R}{2}\left[\frac{3P_0V_0}{1\times R} - \frac{P_0V_0}{1\times R}\right] = 3P_0V_0$$

(c) As $\Delta U = 0$ in cyclic process, hence,

$\Delta Q = \Delta W$

$\Delta Q_{AB} + \Delta Q_{CA} + \Delta Q_{BC} = \Delta W$

$$\Delta Q_{BC} = P_0V_0 - \frac{P_0V_0}{2} = \frac{P_0V_0}{2}$$

NOTE : As net heat is absorbed by the gas during path BC, temp. will reach maximum between B and C.

(d) Equation for Line BC is $P = -\left[\frac{2P_0}{V_0}\right]V + 5P_0,$

$P = \frac{RT}{V}$ [For one mole]

$$\therefore \quad RT = -\frac{2P_0}{V_0}V^2 + 5P_0V \quad \text{... (i)}$$

For maximum; $\frac{dT}{dV} = 0, \ -\frac{2P_0}{V_0}\times 2V + 5P_0 = 0;$

$$\therefore \quad V = \frac{5V_0}{4} \quad \text{... (ii)}$$

Hence from equation (i) and (ii)

$$RT_{max} = \frac{-2P_0}{V_0}\times\left(\frac{5V_0}{4}\right)^2 + 5P_0\left(\frac{5V_0}{4}\right)$$

$$= -2P_0V_0 \times \frac{25}{16} + \frac{25P_0V_0}{4} = \frac{25}{8}P_0V_0$$

$$\therefore \quad T_{max} = \frac{25}{8}\frac{P_0V_0}{R}$$

29. Case (i)

According to Newton's law of cooling

$$\frac{dT}{dt} = -K'(T - T_A) \Rightarrow \frac{dT}{T - T_A} = -K'dt$$

On integrating, we get

$$\int_{400}^{350}\frac{dT}{T - T_A} = K\int_0^{t_1}dt$$

$$-[\log_e(T - T_A)]_{400}^{350} = K'[t]_0^{t_1}$$

$$\Rightarrow -\log_e\frac{350 - 300}{400 - 300} = K't_1$$

$$\Rightarrow \log_e\frac{100}{50} = K't_1 \text{ or } K't_1 = \log_e 2 \quad \text{... (i)}$$

Case (ii)

NOTE : When the body X is connected to a large box Y. In this case cooling occurs by Newton's law of cooling as well as by conduction

$$\therefore \quad -\frac{dT}{dt} = K'(T - T_A) + \frac{KA(T - T_A)}{CL}$$

$$\Rightarrow \quad -\frac{dT}{dt} = \left[K' + \frac{KA}{CL}\right](T - T_A) \qquad (\text{for } t > t_1]$$

Where K = coefficient of thermal conductivity of the rod.

$$\Rightarrow \quad \frac{-dT}{T - T_A} = \left[K' + \frac{KA}{CL}\right]dt$$

On integrating, we get

$$-\int_{350}^{T}\frac{dT}{T - T_A} = \int_{t_1}^{3t_1}\left(K' + \frac{KA}{CL}\right)dt$$

$$\Rightarrow -[\log_e(T - T_A)]_{350}^{T} = \left(K' + \frac{KA}{CL}\right)[t]_{t_1}^{3t_1}$$

$$\Rightarrow \log_e\frac{350 - 300}{T - 300} = \left(K' + \frac{KA}{CL}\right)2t = 2K't_1$$

$$\Rightarrow \log_e\frac{50}{T - 300} = 2(\log_e 2) + \frac{2KA}{CL}t_1$$

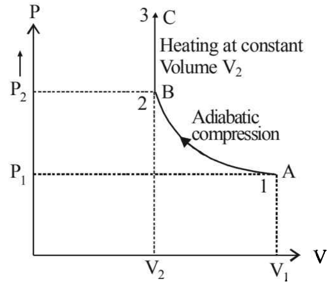
$$\frac{50}{T - 300} = e^{\{\log_e 4 + \frac{2KA}{CL}t_1\}}$$

$$\Rightarrow T - 300 = 50\, e^{-[\log_e 4]} \times e^{\frac{-2KAt_1}{CL}}$$

$$\Rightarrow T = [300 + 12.5\, e^{\frac{-2KAt_1}{CL}}] \text{ Kelvin}$$

30. n = no. of moles = 2,

(A) The complete process is shown on P-V diagram in the figure.



(B) (i) Total work done

$$W = W_{AB} + W_{BC} = \frac{(P_1V_1 - P_2V_2)}{(\gamma - 1)} + 0$$

$[\because W_{BC} = P\Delta V = P \times 0 = 0]$

According to Poisson's law, $P_2 = P_1\left(\frac{V_1}{V_2}\right)^\gamma$

$$\therefore \quad W = \frac{1}{\gamma - 1}\left[P_1V_1 - P_1\left(\frac{V_1}{V_2}\right)^\gamma V_2\right]$$

$$= \frac{1}{\gamma - 1}\left[P_1V_1 - P_1V_2.\frac{V_1}{V_2}.\left(\frac{V_1}{V_2}\right)^{\gamma-1}\right]$$

For monoatomic gas,

$\gamma = 1 + \frac{2}{3} = \frac{5}{3}$,

$$W = \frac{3}{2}\left[P_1V_1 - P_1V_1\left(\frac{V_1}{V_2}\right)^{2/3}\right] = \frac{3}{2}P_1V_1\left[1 - \left(\frac{V_1}{V_2}\right)^{2/3}\right]$$

(ii) $\Delta U = \Delta U_{AB} + \Delta U_{BC} = Q - W$

$$= Q - \frac{3}{2}P_1V_1\left[1 - \left(\frac{V_1}{V_2}\right)^{2/3}\right]$$

[according to first law of thermodynamics]

$$\begin{bmatrix} B \to C & Q = \Delta U_{BC} + 0 \\ A \to B & Q = \Delta U_{AB} + W \end{bmatrix}$$

(iii) For process BC : $\Delta U_{BC} = nC_v\Delta T = Q$ $[\because W_{BC} = 0]$

For monoatomic gas $C_v = \frac{R}{\gamma - 1} = \frac{3}{2}R$,

$\therefore \quad \Delta U_{BC} = Q = 2 \times \frac{3R}{2}.\Delta T$

Hence $\Delta T = \frac{Q}{3R}$.

According to Poission's Law :

For the process AB, $T_A V_B^{\gamma-1} = T_B V_B^{\gamma-1}$

or $\quad T_B = T_A\left(\frac{V_1}{V_2}\right)^{\gamma-1} = \frac{P_1V_1}{nR}\left(\frac{V_1}{V_2}\right)^{\gamma-1}$

$\therefore \quad T_B = \frac{P_1}{2R}.V_1^{\gamma}.V_2^{1-\gamma} = \frac{P_1V_1^{5/3}V_2^{-2/3}}{2R}$

Hence, $T_C = T_B + \Delta T = \frac{P_1V_1^{5/3}V_2^{-2/3}}{2R} + \frac{Q}{3R}$

31. For PV^x = Constt., Molar heat capacity

$$C = \frac{R}{\gamma - 1} + \frac{R}{1 - x} = \frac{R}{\frac{5}{3} - 1} + \frac{R}{1 - \frac{1}{2}}$$

Here P^2V = constant or $PV^{1/2}$ = constant

$\therefore x = \frac{1}{2}$

$\Rightarrow C = 3.5R$

$Q_{A \to B} = nC\,\Delta T = 2(3.5\,R)(300 - 600) = -2100\,R$

Process B – C: Process is isobaric therefore

$$Q_{B \to C} = nC_p\,\Delta T = (2)\left(\frac{5}{2}R\right)(T_C - T_B)$$

$$= 2\left(\frac{5}{2}R\right)(2T_1 - T_1) = (5R)(600 - 300) = 1500R$$

Heat is absorbed

Process C – A: Process is isothermal

$\Delta T = 0$ and $Q_{C \to A} = W_{C \to A} = nRT_C \ln\left(\frac{P_C}{P_A}\right)$

$$= nR(2T_1)\ln\left(\frac{2P_1}{P_1}\right) = (2)(R)(600)\ln(2) = 1200R \times 0.6932$$

$Q_{C \to A} = 831.6$ R (absorbed)

32. Here the equilibrium temperature is $273 + 27 = 300\,K$

Also according to the principle of calorimetry

Heat lost by container = Heat gained by ice.

Heat lost by container :

NOTE : Since specific heat is variable, we need to take the help of calculus to find the heat lost by the container.

Let dQ be the heat lost when the temperature decreases by dT at any instant when the temperature of the container is T.

$\therefore \quad dQ = mc\,dT$

where m is the mass of the container and $C = A + BT$ is specific heat at that temperature

$\therefore \quad dQ = m(A + BT)\,dT$

On integrating, we get

$$Q = \int_{500}^{300} m(A + BT)\,dT = m\left[AT + \frac{BT^2}{2}\right]_{500}^{300}$$

$= -21600$ m calorie (heat lost)

Heat gained by ice

This heat is to be divided into two parts

(i) 0° ice → 0° water

(ii) 0° water → 27° water

$Q_1 = mL$	$Q_2 = mc\Delta T$
$= 0.1 \times 80{,}000$	$= 0.1 \times 10^3 \times 27$
$= 8000$ cal	$= 2700$ cal

$\therefore \quad Q_1 + Q_2 = 8000 + 2700 = 10{,}700$ cal ... (i)

Heat lost = heat gained

$21600\,m = 10{,}700$

$\Rightarrow \quad m = 0.495$ kg

33. **(a)** Since AB is a straight line in V-T graph

$\therefore \quad \frac{V}{T}$ = Constant (Isobaric process)

$\therefore \quad \frac{V_A}{T_A} = \frac{V_B}{T_B}$

$T_B = \frac{V_B}{V_A} \times T_A = 2 \times 300 = 600\,K \quad \left[\because \frac{V_B}{V_A} = 2\right]$

(b) (i) A to B is a isobaric process

$\therefore \quad Q = nC_p\Delta T = 2 \times \frac{5}{2}R \times 300$

$= 1500\,R \quad \left[\because C_p = \frac{5}{2}R \text{ for monoatomic gas}\right]$

NOTE : Heat is absorbed as Q is positive.

(ii) B to C is an isothermal process.

Since the temperature is not changing

$\therefore$ Internal energy change $dU = 0$

$\therefore$ From first law of thermodynamics $dQ = dW$

$\therefore \quad Q = 2.303 \times nRT \log_{10} \dfrac{V_f}{V_i}$

$= 2.30. \times 2 \times R \times 600 \times \log_{10} 2$

$= 2763.6 \times \log_{10} 2 \times R = 831.8\,R$

NOTE : Heat is absorbed since temperature is same but volume increases.

(iii) C To D is a isochoric process

$\therefore \quad dW = 0$

$\therefore Q = nC_v \Delta T = n\left(\dfrac{3}{2}R\right)(T_A - T_B)$

$= 2 \times \dfrac{3}{2} R \times (-300) = -900\,R$

Volume is constant as heat is released.

(iv) D to A is an isothermal process

$\therefore Q = 2.303 \times nRT \log_{10} \dfrac{V_f}{V_i}$

$= 2.303 \times 2R \times 300 \times \log\left(\dfrac{V_f}{V_i}\right) = -831.8\,R$

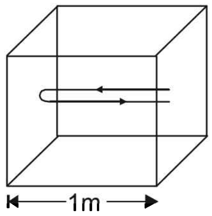
Heat is released as Q is positive.

(c) Total work done

$= Q_{A \to B} + Q_{B \to C} + Q_{C \to D} + Q_{D \to A}$

$= (1500\,R + 831.8\,R) - (900\,R + 831.8\,R) = 600\,R$

34. The distance travelled by an atom of helium in $\dfrac{1}{500}$ sec (time between two successive collision) is 2m. Therefore root mean square speed



$$C_{rms} = \frac{\text{distance}}{\text{time}} = \frac{2}{1/500} = 1000 \text{ m/s}$$

(a) But $C_{rms} = \sqrt{\dfrac{3RT}{M}}$

$\Rightarrow \quad 1000 = \sqrt{\dfrac{3 \times 25/3 \times T}{4 \times 10^{-3}}} \Rightarrow T = 160\text{ K}$

(b) Average kinetic energy of an atom of a monoatomic gas $= \dfrac{3}{2}\text{kT}$

$\therefore E_{av} = \dfrac{3}{2}\text{kT} = \dfrac{3}{2} \times \left(1.38 \times 10^{-23}\right) \times 160$

$= 3.312 \times 10^{-21}$ Joules

(c) From gas equation $PV = \dfrac{m}{M}RT$

$m = \dfrac{PVM}{RT} = \dfrac{100 \times 1 \times 4}{25/3 \times 160} \Rightarrow m = 0.3012$ gm

35. When container is stopped, velocity decreases by v_0.

Therefore change in kinetic energy $= \dfrac{1}{2}(nm)v_0^2$ ... (i)

Here n = number of moles of gas present in the container.

The kinetic energy at a given temperature for a monatomic gas is $= \dfrac{3}{2} \times nRT$

$\therefore$ Change in kinetic energy $= \dfrac{3}{2} \times nR(\Delta T)$ .... (ii)

where ΔT = Change in temperature

From (i) and (ii)

$\dfrac{3}{2} nR(\Delta T) = \dfrac{1}{2}(nm)v_0^2 \quad \therefore \quad \Delta T = \dfrac{mv_0^2}{3R}$

36. (a) The rate of heat loss per unit area per second due to radiation is given by Stefan's-Boltzmann law

$E = e\sigma(T^4 - T_0^4)$

$= 0.6 \times \dfrac{17}{3} \times 10^{-8}[(400)^4 - (300)^4] = 595 \text{ watt/m}^2$

(b) Let T_{oil} be the temperature of the oil. Then rate of heat flow through conduction = Rate of heat flow through radiation

$\dfrac{KA(T_{oil} - T)}{\ell} = 595 \times A$

where A is the area of the top of lid

$\Rightarrow T_{oil} = \dfrac{595 \times \ell}{k} + T = \dfrac{595 \times 5 \times 10^{-3}}{0.149} + 400 = 419.83$ K

37. At constant pressure, we have $\dfrac{T_1}{V_1} = \dfrac{T_2}{V_2}$

also, $V = A \times h$

$\therefore \dfrac{T_1}{Ah_1} = \dfrac{T_2}{Ah_2}$

$\Rightarrow \quad h_2 = \dfrac{T_2 h_1}{T_1} = \dfrac{400}{300} \times 1 = \dfrac{4}{3}$m

when the gas is compressed without heat exchange, the process is adiabatic

$\therefore \quad T'_1 = T_2\left(\dfrac{V_2}{V_1}\right)^{\gamma - 1} = 400\left(\dfrac{4}{3}\right)^{2/5} K$

38. Rate of heat produced $= F \times v$

$= (6\pi\eta r v)v$ $\quad [\because$ Viscous $F = 6\pi\eta r v]$

$= (6\pi\eta r)\left[\dfrac{2}{9}\dfrac{(\sigma - \rho)r^2 g}{\eta}\right]^2$

$\left[\because \text{Terminal velocity} = \dfrac{2}{9}\dfrac{(\sigma - \rho)r^2 g}{\eta}\right]$

$\Rightarrow$ Rate of heat produced $\propto r^5$

39. From the figure it is clear that emission takes place from the surface at temperature T_2 (circular cross section). Heat conduction and radiation through lateral surface is zero. Heat conducted through rod is

$Q = \dfrac{KA(T_1 - T_2)\Delta t}{\ell}$

Energy emitted by surface of rod in same time Δt, is

$$E = e\sigma A(T_2^4 - T_s^4)\Delta t$$

Since rod is at thermal equilibrium therefore $E = Q$

hence, $$\frac{KA(T_1 - T_2)\Delta t}{\ell} = e\sigma A(T_2^4 - T_s^4)\Delta t$$

$$\Rightarrow \quad T_1 - T_2 = \frac{e\sigma(T_2^4 - T_s^4)\ell}{K}$$

Here $T_2 - T_s = \Delta T$ and $T_s >> \Delta T$

$$T_1 - (\Delta T + T_s) = \frac{e\sigma\ell}{K}\left[(\Delta T + T_s)^4 - T_s^4\right]$$

$$T_1 - (\Delta T + T_s) = \frac{e\sigma\ell}{K} \times T_s^4\left[\left(1 + \frac{\Delta T}{T_s}\right)^4 - 1\right]$$

$$T_1 - (\Delta T + T_s) = \frac{e\sigma\ell}{K} \times T_s^4\left[1 + \frac{4\Delta T}{T_s} - 1\right]$$

or $$T_1 - (T_s + \Delta T) = \frac{4e\sigma\,\ell}{K}T_s^3\Delta T$$

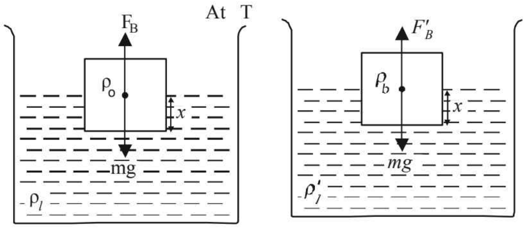
or $$T_1 - T_s = \left(\frac{4e\sigma\ell T_s^3}{K} + 1\right)\Delta T$$

$\therefore$ The proportionality constant $= \left(1 + \dfrac{4e\sigma\ell T_s^3}{K}\right)$

40. Initially, at temperature T

$$F_B = mg$$

$$Ax\rho_\ell g = AL\rho_b g$$



$\Rightarrow \quad x\rho_\ell = L\rho_b$ ... (i)

At temperature $T + \Delta T$

$$F_B' = mg$$

$A'x\rho'_\ell g = AL\rho_b g$ [mg remains the same as above]

Now, $A' = A(1 + 2\alpha\Delta T)$

$$\rho'_\ell = \rho_\ell(1 - \gamma\Delta T)$$

$\therefore \quad A(1 + 2\alpha\,\Delta T)\,x\,\rho_\ell(1 - \gamma\Delta T)g = AL\rho_b g$

$\Rightarrow \quad x\rho_\ell(1 + 2\alpha\,\Delta T)(1 - \gamma\Delta T) = L\rho_b$

$\Rightarrow \quad x\rho_\ell(1 + 2\alpha\,\Delta T)(1 - \gamma\Delta T) = x\rho_\ell$ [From (i)]

$\Rightarrow \quad 1 + 2\alpha\,\Delta T - \gamma\,\Delta T = 1$

$\Rightarrow \quad \gamma = 2\alpha$

41. (a) Heat supplied to the cylinder = Energy used to raise the temperature of cylinder + Energy used for work done by the cylinder.

Energy used to raise the temperature $= mc\Delta T$

$= 1 \times 400 \times (T - 20)$ ... (i)

where T°C is the final temperature of the cylinder.

Energy used for work done

$= P_{atm}(V_2 - V_1) = 10^5(V_2 - V_1)$ ... (ii)

The final volume $V_2 = V_1[1 + \gamma(T - 20)]$

$\Rightarrow \quad V_2 - V_1 = V_1\gamma(T - 20)$ ... (iii)

From (ii) and (iii),

Energy used for work done $= 10^5\,V_1\gamma(T - 20)$

$= 10^5 \times \dfrac{1}{9000} \times 9 \times 10^{-5}(T - 20)$ $\left[\because V_1 = \dfrac{m}{d} = \dfrac{1}{9000}\right]$

$= 0.001\,(T - 20)$ ... (iv)

$\therefore$ Heat supplied to the cylinder

$= 400\,(T - 20) + 0.001\,(T - 20)$

$20{,}000 = 400.001\,(T - 20)$

$\Rightarrow \quad T = 69.99°C \approx 70°C$

(b) Work done $= 0.001\,(69.99 - 20) = 0.0499$ J

(c) Change in internal energy $= 20{,}000 - 0.0499 = 19999.95$ J.

42. (1) Heat lost by steam at 100°C to change to 100°C water

$mL_{vap} = 0.05 \times 2268 \times 1000 = 1{,}13{,}400$ J

(2) Heat lost by 100°C water to change to 0°C water

$= 0.05 \times 4200 \times 100 = 21{,}000$ J

(3) Heat required by 0.45 kg of ice to change its temperature from 253 K to 273 K

$= m \times S_{ice} \times \Delta T = 0.45 \times 2100 \times 20 = 18{,}900$ J

(4) Heat required by 0.45 kg ice at 273 K to convert into 0.45 kg water at 273 K

$= mL_{fusion} = 0.45 \times 336 \times 1000 = 151{,}200$ J

From the above data it is clear that the amount of heat required by 0.45 kg of ice at 253 K to convert into 0.45 kg of water at 273 K (1,70,100 J) cannot be provided by heat lost by 0.05 kg of steam at 373 K to convert into water at 273 K. Therefore the final temperature will be 273 K or 0°C.

F. Match the Following

1. **(A) → (q) :** JK is a isovolumic process. Therefore work done is zero. But there is decrease in pressure. Now $\Delta Q = \Delta U + \Delta W$. Therefore $\Delta Q = \Delta U$. In this case $\Delta U = nC_v\Delta T$ and $P \propto T$. Since pressure has decreased means temperature has decreased. Therefore ΔU is negative and so is ΔQ.

(B) → (p, s) : KL is a isobaric process. Pressure is constant. The volume is increasing therefore $\Delta W > 0$. Also there is an increase in temperature. For both the case heat is absorbed. Therefore $\Delta Q > 0$.

(C) → (s) : LM is a isovolumic process. Therefore work done is zero. The process is accompanied by increases in pressure. In this case, the temperature has increased and therefore $\Delta U > 0$. Therefore $\Delta Q > 0$.

(D) → (q, r) : The process MJ is accompanied with decrease in volume. Therefore $\Delta W < 0$. Also from the graph we can conclude that the temperature in the process decreases. Therefore ΔU is also negative

$\Rightarrow \quad \Delta Q < 0$.

2. **(A)-(q) :** As the ideal gas expands in vacuum, no work is done (W = 0). Also the container is insulated therefore no heat is lost or gained (Q = 0). According to first law of thermodynamics

$\Delta U = Q + W$

$\therefore \ \Delta U = 0$

$\Rightarrow$ There is no change in the temparature of the gas

(B)-(p, r) : Given $PV^2 = \text{constant}$ ....(i)

Also for an ideal gas $\frac{PV}{T} = \text{constant}$

From (i) & (ii) $V \times T = \text{constant}$

As the gas expands its volume increases and temperature decreases

$\therefore$ (p) is the correct option

To find whether heat is released or absorbed let us find a relationship between Q and change in temperature ΔT.

We know that $Q = nC\Delta T$ ...(i)

where C = molar specific heat

Also for a polytropic process we have

$$C = C_v + \frac{R}{1-n} \quad \text{and} \quad PV^n = \text{constant}$$

Here $PV^2 = \text{Constant}$. Therefore $n = 2$

$$\therefore C = C_v + \frac{R}{1-2} = C_v - R$$

For monoatomic gas $C_v = \frac{3}{2}R$

$$\therefore C = \frac{3}{2}R - R = \frac{R}{2}$$

Substituting this value in (1) we get

$$Q = n \times \frac{R}{2} \times \Delta T.$$

In this case the temperature decreases i.e. ΔT is negative. Therefore Q is negative. This in turn means that heat is lost by the gas during the process. (r) is the correct option.

(C)-(p, s) : Proceeding in the same way we get in this case $V^{1/3} \times T = \text{constant}$

$\Rightarrow$ As the gas expands and volume increases, the temperature decreases. Therefore (p) is the correct option

In this process, $x = \frac{4}{3}$.

$$\therefore C = C_v + \frac{R}{1-\frac{4}{3}} = \frac{3}{2}R + \frac{3R}{-1} = \frac{3}{2}R - 3R = \frac{-3R}{2}$$

$$\therefore Q = n\left(\frac{-3R}{2}\right)\Delta t$$

As ΔT is negative, Q is positive. This in turn means that heat is gained by the gas during the process (s) is the correct option.

(D)-(q, s) : Also $\Delta T = \frac{\Delta(PV)}{nR}$

Here $\Delta(PV)$ is positive $\therefore \Delta T$ is positive

$\therefore$ temperature increase s (q) is the correct option

From the graph it is clear that during the process the pressure of the gas increases which shows that the internal energy of the gas has increased. Also the volume increases which means work is done by the system which needs energy. From these two interpretation we can comfortably conclude that the gas gains heat during the process.

(s) is the correct option.

3. **A-p,r,t; B-p,r; C-q,s; D-r,t**

(A) Process $A \to B$

This is an isobaric process in which the volume of the gas decreases. Therefore work is done on the gas.

$W = P(3V - V) = 2PV$

Also temerature at B is less than temperature at A

$\therefore$ Heat is lost & internal energy decreases.

(p, r, t) are correct matching

(B) Process $B \to C$

This is an isovolumic/isochoric process in which the pressure decreases

Here temperature at B is less than temperature at C.

$\therefore$ Heat is lost and internal energy decreases.

(p, r) are correct matching.

(C) Process $C \to D$

This is isobaric expansion where temperature at D is greater than temperature at C. Therefore internal energy increases and heat is gained.

(q, s) are correct matching

(D) $D \to A$

This is a process in which volume decreases. Therefore work is done on the gas.

Applying $PV = nRT$

for D $P(9V) = 1\,RT_D \therefore T_D = \frac{9PV}{R}$

for A $3P(3V) = 1RT_A \therefore T_A = \frac{9PV}{R}$

$\Rightarrow T_A = T_D$ $\quad \therefore \Delta U = 0$

Now, $\Delta Q = \Delta U + W$ $\quad \therefore \Delta Q = W$.

The energy obtained by the gas by work done on it is lost to the surroundings as $\Delta U = 0$.

$\therefore$ (r, t) are correct matching.

4. **(a)** $W_{GE} = P_0(V_0 - 32V_0) = -31P_0V_0$

$W_{GH} = P_0(8V_0 - 32V_0) = -24P_0V_0$

$$(W_{FH})_{adiabatic} = \frac{P_0(8V_0) - 32P_0(V_0)}{1-\frac{5}{3}} = 36P_0V_0$$

$$(W_{FG})_{isothermal} = 1(32P_0V_0)\log_e\frac{32V_0}{V_0}$$

$= 32P_0V_0\log_e 2^5$

$= 160P_0V_0\log_e 2$

(a) is the correct option

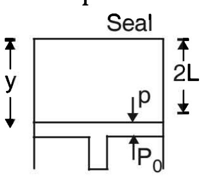
G. Comprehension Based Questions

1. **(a)** **NOTE :** When the piston is pulled out slowly, the pressure drop produced inside the cylinder is almost instantaneously neutralised by the air entering from outside into the cylinder (through the small hole at the top).

Therefore, the pressure inside the cylinder is P_0 throughout the slow pulling process.

2. **(d)** **KEY CONCEPT :** The condition for equilibrium of the piston is

$Mg = (P_0 - p)\,\pi R^2$



$\Rightarrow \; p = \dfrac{-Mg}{\pi R^2} + P_0$

NOTE : Since the cylinder is thermally conducting, the temperature remains the same.

Therefore

$P_0 \times (2L \times \pi R^2) = py \times \pi R^2 \Rightarrow y = \dfrac{P_0}{p} \times 2L$

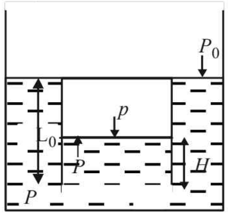
$= \dfrac{P_0}{\left[P_0 - \dfrac{Mg}{\pi R^2}\right]} \times 2L = \left[\dfrac{P_0 \times \pi R^2}{P_0\,\pi R^2 - Mg}\right] \times 2L$

3. **(c)** At equilibrium, $p = P$

$\Rightarrow \; p = P_0 + (L_0 - H)\,\rho g$ ... (i)

Also $P_0 \times (\pi R^2 L_0) = p\,[\pi R^2 (L_0 - H)]$

$\Rightarrow \; p = \dfrac{L_0 P_0}{L_0 - H}$ ... (ii)



From (i) and (ii)

$\dfrac{L_0 P_0}{L_0 - H} = P_0 + (L_0 - H)\rho g$

$\Rightarrow \; L_0 P_0 = P_0 (L_0 - H) + (L_0 - H)^2 \rho g$

$\Rightarrow \; \rho g (L_0 - H)^2 + P_0 (L_0 - H) - L_0 P_0 = 0$

4. **(d)** The forces acting besides buoyancy force are

(a) Force of gravity (vertically downwards)

(b) Viscous force (vertically downwards)

Force due to pressure of the liquid is the buoyant force.

5. **(b)** It is given that the bubble does not exchange any heat with the liquid. This means that while the bubble moves up and expand, the process is adiabatic.

For adiabatic expansion the pressure -temperature relationship is

$T_2 = T_1 \left[\dfrac{P_1}{P_2}\right]^{\frac{1-\gamma}{\gamma}}$

Here $T_1 = T_0,\; P_1 = P_0 + H\rho_\ell g$,

$P_2 = P_0 + (H - y)\rho_\ell g \;,\; \gamma = \dfrac{5}{3}$

$\therefore \; T_2 = T_0 \left[\dfrac{P_0 + H\rho_\ell g}{P_0 + (H - y)\rho_\ell g}\right]^{1-\frac{5}{3}/5/3}$

$= T_0 \left[\dfrac{P_0 + H\rho_\ell g}{P_0 + (H - y)\rho_\ell g}\right]^{\frac{-2}{3}\times\frac{3}{5}}$

$T_2 = T_0 \left[\dfrac{P_0 + (H - y)\rho_\ell g}{P_0 + H\rho_\ell g}\right]^{\frac{2}{5}}$

6. **(b)** Buoyancy force = weight of fluid displaced

= (mass of fluid displaced) g

= $V\rho_\ell g$ ...(ii)

where V = Volume of fluid displaced

= Volume of the bubble.

Now, $PV = nRT$

$\Rightarrow V = \dfrac{nRT}{P} = \dfrac{nRT}{P_0 + (H - y)\rho_\ell g}$

Where P is pressure of the bubble at an arbitrary location distant y from the bottom.

Substituting the value of tempertaure from equtaion (i) we get

$V = \dfrac{nR}{[P_0 + (H - y)\rho_\ell g]} \times \dfrac{T_0 [P_0 + (H - y)\rho_\ell g]^{\frac{2}{5}}}{[P_0 + H\rho_\ell g]^{\frac{2}{5}}}$

$= \dfrac{nRT_0}{[P_0 + (H - y)\rho_\ell g]^{\frac{3}{5}}\,[P_0 + H\rho_\ell g]^{\frac{2}{5}}}$ ...(iii)

From (ii) and (iii)

Buoyancy force $= \dfrac{nRT_0 \rho_\ell g}{[P_0 + (H - y)\rho_\ell g]^{\frac{3}{5}}\,[P_0 + H\rho_\ell g]^{\frac{2}{5}}}$

7. **(d)** Heat lost by monatomic gas at constant volume = Heat gained by diatomic gas at constant pressure

$\therefore \; nC_{v_1}(700 - T) = nC_{P2}(T - 400)$

$\dfrac{3}{2}R(700 - T) = \dfrac{7}{2}R(T - 400)$

$\Rightarrow \; 2100 - 3T = 7T - 2800$

$\Rightarrow \; 10T = 4900$

$\therefore \; T = 490\text{ K}$

8. **(d)** In this case both the gases are at constant pressure.

$\therefore \; nC_{P1}(700 - T) = nC_{P2}(T - 400)$

$\dfrac{5}{2}R(700 - T) = \dfrac{7}{2}R(T - 400)$

$3500 - 5T = 7T - 2800$

$\Rightarrow \; 12T = 6300$

$\therefore \; T = 525\text{ K}$

Applying first law of thermodynamics

$\Delta W_1 + \Delta U_1 = \Delta Q_1$

and $\Delta W_2 + \Delta U_2 = \Delta Q_2$

As the gas two system is thermally insulated, therefore

$\Delta Q_1 + \Delta Q_2 = 0$

$-(\Delta W_1 + \Delta W_2) = \Delta U_1 + \Delta U_2$

$= nC_{v_1}(525 - 700) + n_2 C_{v_2}(525 - 400)$

$= -2 \times \dfrac{3R}{2} \times 175 + 2 \times \dfrac{5R}{2} \times 125$

$= -525R + 625R = -100R$

Therefore, total work done = –100 R

H. Assetion & Reason Type Questions

1. (b) **Statement 1 :** The total kinetic energy of n moles of gas is $K = \frac{3}{2} nRT$

But $PV = nRT$

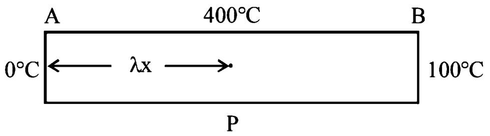
$\therefore \quad K = 1.5\,PV$

Statement one is true.

Statement 2 : The molecules of a gas collide with each other and the velocities of the molecules change due to collision.

But statement 2 is not a correct explanation of statement 1.

I. Integer Value Correct Type

1. 

For heat flow from P to 0

$$L_f \frac{dm_1}{dt} = \frac{KA\,400}{\lambda x} \quad \text{..... (i)}$$

For heat flow from P to B

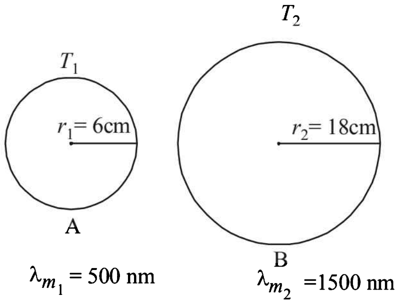
$$L_{vap} \frac{dm_2}{dt} = \frac{KA\,300}{10x - \lambda x} \quad \text{..... (ii)} \quad \left[\text{Given } \frac{dm_1}{dt} = \frac{dm_2}{dt}\right]$$

On solving (i) and (ii), we get $\lambda = 9$

2. Heat supplied = Heat used in converting m grams of ice from –5°C to 0°C + Heat used in converting 1 gram of ice at 0°C to water at 0°C

$$\Rightarrow 420 = m \times \frac{2100}{1000} \times 5 + \frac{1 \times 3.36 \times 10^5}{1000}$$

$$\Rightarrow 420 = m \times 10.5 + 336 \qquad \therefore m = \frac{84}{10.5} = \mathbf{8} \text{ grams}$$

3. 

$$\frac{\text{Rate of total energy radiated by A}}{\text{Rate of total energy radiated by B}}$$

$$= \frac{\sigma T_1^4 (4\pi r_1^2)}{\sigma T_2^4 (4\pi r_2^2)} = \left(\frac{T_1}{T_2}\right)^4 \times \left(\frac{r_1}{r_2}\right)^2$$

$$= \left(\frac{\lambda_{m_2}}{\lambda_{m_1}}\right)^4 \left(\frac{r_1}{r_2}\right)^2 \quad \left[\because \frac{T_1}{T_2} = \frac{\lambda_{m_2}}{\lambda_{m_1}} \text{ by Wein's law}\right]$$

$$= \left(\frac{1500}{500}\right)^4 \left(\frac{6}{18}\right)^2 = \mathbf{9}$$

4. For an adiabatic process, the temperature-volume relationship is

$$T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1} \Rightarrow T_1 = T_2 \left(\frac{V_2}{V_1}\right)^{\gamma-1}$$

Here $\gamma = 1.4$ (for diatomic gas). $V_2 = \frac{V_1}{32}, T_1 = T_i, T_2 = aT_i$

$$\therefore T_i = aT_i \left[\frac{1}{32}\right]^{1.4-1} = aT_i \left[\frac{1}{2^5}\right]^{0.4} = \frac{aT_i}{4} \qquad \therefore a = \mathbf{4}$$

5. (3) We know that

$$Y = \frac{mg/A}{\Delta\ell/\ell} = \frac{mg\ell}{A\Delta\ell} \quad \text{....(1)}$$

Also $\Delta\ell = \ell\,\alpha\,\Delta T$ ...(2)

From (1) and (2)

$$Y = \frac{mg\ell}{A\ell\,\alpha\,\Delta T} = \frac{mg}{A\,\alpha\,\Delta T}$$

$$\therefore \; m = \frac{YA\,\alpha\,\Delta T}{g} = \frac{10^{11} \times \pi (10^{-3})^2 \times 10^{-5} \times 10}{10} = \pi \approx 3$$

6. (2) Applying first law of thermodynamics to path iaf

$$Q_{iaf} = \Delta U_{iaf} + W_{iaf}$$

$$500 = \Delta U_{iaf} + 200 \qquad \therefore \Delta U_{iaf} = 300\text{ J}$$

Now,

$$Q_{ibf} = \Delta U_{ibf} + W_{ib} + W_{bf}$$

$$= 300 + 50 + 100$$

$$Q_{ib} + Q_{bf} = 450\text{ J} \quad \text{...(1)}$$

Also $Q_{ib} = \Delta U_{ib} + W_{ib}$

$\therefore Q_{ib} = 100 + 50 = 150\text{ J}$ ...(2)

From (1) & (2) $\frac{Q_{bf}}{Q_{ib}} = \frac{300}{150} = 2$

7. (2) $\frac{P_A}{P_B} = \frac{A_A}{A_B}\frac{T_A^4}{T_B^4} = \frac{A_A}{A_B} \times \frac{\lambda_B^4}{\lambda_A^4}$

$$\therefore \frac{\lambda_A}{\lambda_B} = \left[\frac{A_A}{A_B} \times \frac{P_B}{P_A}\right]^{\frac{1}{4}} = \left[\frac{R_A^2}{R_B^2} \times \frac{P_B}{P_A}\right]^{\frac{1}{4}} = \left[\frac{400 \times 400}{10^4}\right]^{\frac{1}{4}}$$

$$\therefore \frac{\lambda_A}{\lambda_B} = 2$$

8. (9) Here $P \propto T^4$ or $P = P_0 T^4$

$$\therefore \log_2 P = \log_2 P_0 + \log_2 T^4 \quad \therefore \log_2 \frac{P}{P_0} = 4 \log_2 T$$

At T = 487°C = 760 K, $\log_2 \frac{P}{P_0} = 4 \log_2 760 = 1$ ... (1)

At T = 2767°C = 3040K,

$$\log_e \frac{\rho}{\rho_0} = 4 \log_2 3040 = 4 \log_2 (760 \times 4)$$

$$= 4\left[\log_2 760 + \log_2 2^2\right]$$

$$= 4 \log_2 760 + 8 = 1 + 8 = 9$$

Section-B JEE Main/ AIEEE

1. **(a)** All reversible engines working for the same temperature of source and sink have same efficiencies. If the temperatures are different, the efficiency is different.
2. **(b)** Heat required for raising the temperature of the whole body by 1°C is called the thermal capacity of the body.
3. **(b)** Pyrometer is used to detect infra-red radiation.
4. **(a)** Black board paint is quite approximately equal to black bodies.
5. **(c)** Since pressure and volume are not changing, so temperature remains same.
6. **(c)** When water is cooled to form ice, energy is released from water in the form of heat. As energy is equivalent to mass therefore when water is cooled to ice, its mass decreases.
7. **(d)** $v_{rms} = \sqrt{\frac{8RT}{\pi M}}$

   For v_{rms} to be equal $\frac{T_{H_2}}{M_{H_2}} = \frac{T_{O_2}}{M_{O_2}}$

   Here $M_{H_2} = 2$; $M_{O_2} = 32$;

   $T_{O_2} = 47 + 273 = 320\,K$

   $\therefore \frac{T_{H_2}}{2} = \frac{320}{32} \Rightarrow T_{H_2} = 20\,K$
8. **(c)** $\eta = 1 - \frac{T_2}{T_1}$

   For $\eta = 1$ or 100 %, $T_2 = 0$ K.
   The temperature of 0 K (absolute zero) can not be obtained .
9. **(c)** If n_1 moles of adiabatic exponent γ_1 is mixed with n_2 moles of adiabatic exponent γ_2 then the adiabatic component of the resulting mixture is given by

   $$\frac{n_1 + n_2}{\gamma - 1} = \frac{n_1}{\gamma_1 - 1} + \frac{n_2}{\gamma_2 - 1}$$

   $$\frac{1+1}{\gamma - 1} = \frac{1}{\frac{7}{5} - 1} + \frac{1}{\frac{5}{3} - 1} \quad \therefore \frac{2}{\gamma - 1} = \frac{5}{2} + \frac{3}{2} = 4$$

   $$\therefore 2 = 4\gamma - 4 \Rightarrow \gamma = \frac{6}{4} = \frac{3}{2}$$
10. **(a)** The energy radiated per second is given by $E = e\sigma T^4 A$

    For same material e is same. σ is stefan's constant

    $$\therefore \frac{E_1}{E_2} = \frac{T_1^4 A_1}{T_2^4 A_2} = \frac{T_1^4 4\pi r_1^2}{T_2^4 4\pi r_2^2} = \frac{(4000)^4 \times 1^2}{(2000)^4 \times 4^2} = \frac{1}{1}$$
11. **(a)** This is a statement of second law of thermodynamics
12. **(d)** $P \propto T^3 \Rightarrow PT^{-3} = \text{constant}$ ....(i)

    But for an adiabatic process, the pressure temperature relationship is given by

    $$P^{1-\gamma}\, T^{\gamma} = \text{constant} \Rightarrow PT^{\frac{\gamma}{1-\gamma}} = \text{constt.} \quad ....(ii)$$

    From (i) and (ii) $\frac{\gamma}{1-\gamma} = -3 \Rightarrow \gamma = -3 + 3\gamma \Rightarrow \gamma = \frac{3}{2}$
13. **(c)** Work is a path function. The remaining three parameters are state function.
14. **(b)** $\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{(273+27)}{(273+627)} = 1 - \frac{300}{900} = 1 - \frac{1}{3} = \frac{2}{3}$

    But $\eta = \frac{W}{Q}$ $\therefore$ $\frac{W}{Q} = \frac{2}{3} \Rightarrow W = \frac{2}{3} \times Q = \frac{2}{3} \times 3 \times 10^6$

    $= 2 \times 10^6\,\text{cal} = 2 \times 10^6 \times 4.2\ \text{J} = 8.4 \times 10^6\,\text{J}$
15. **(d)** Wein's law correctly explains the spectrum
16. **(d)** $-\frac{dQ}{dt} \propto (\Delta\theta)$
17. **(c)** $\frac{n_1 + n_2}{\gamma - 1} = \frac{n_1}{\gamma_1 - 1} + \frac{n_2}{\gamma_2 - 1}$

    $$\Rightarrow \frac{1+1}{\gamma - 1} = \frac{1}{\frac{5}{3} - 1} + \frac{1}{\frac{7}{5} - 1} \Rightarrow \gamma = \frac{3}{2}$$
18. **(d)** $E = \sigma A T^4$; $A \propto R^2$ $\therefore E \propto R^2 T^4$

    $$\therefore \frac{E_2}{E_1} = \frac{R_2^2 T_2^4}{R_1^2 T_1^4}$$

    $$\Rightarrow \frac{E_2}{E_1} = \frac{(2R)^2 (2T)^4}{R^2 T^4} = 64$$
19. **(b)** Internal energy and entropy are state function, they do not depend upon path taken.
20. **(a)** Here $Q = 0$ and $W = 0$. Therefore from first law of thermodynamics $\Delta U = Q + W = 0$

    $\therefore$ Internal energy of the system with partition = Internal energy of the system without partition.

    $$n_1 C_v T_1 + n_2 C_v T_2 = (n_1 + n_2) C_v T$$

    $$\therefore T = \frac{n_1 T_1 + n_2 T_2}{n_1 + n_2}$$

    But $n_1 = \frac{P_1 V_1}{R T_1}$ and $n_2 = \frac{P_2 V_2}{R T_2}$

    $$\therefore T = \frac{\frac{P_1 V_1}{R T_1} \times T_1 + \frac{P_2 V_2}{R T_2} \times T_2}{\frac{P_1 V_1}{R T_1} + \frac{P_2 V_2}{R T_2}} = \frac{T_1 T_2 (P_1 V_1 + P_2 V_2)}{P_1 V_1 T_2 + P_2 V_2 T_1}$$

21. **(d)** The thermal resistance

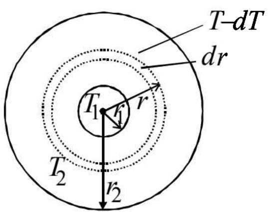
$$\frac{x}{KA}+\frac{4x}{2KA}=\frac{3x}{KA}$$

$$\therefore \frac{dQ}{dt}=\frac{\Delta T}{\frac{3x}{KA}}=\frac{(T_2-T_1)KA}{3x}=\frac{1}{3}\left\{\frac{A(T_2-T_1)K}{x}\right\}$$

$$\therefore f=\frac{1}{3}$$

22. **(b, c)** First law is applicable to a cyclic process. Concept of entropy is introduced by the second law.

23. **(d)**



Consider a shell of thickness (dr) and of radius (r) and the temperature of inner and outer surfaces of this shell be T, $(T-dT)$

$$H=\frac{KA[(T-dT)-T]}{dr}=\frac{-KAdT}{dr}$$

$$H=-4\pi Kr^2\frac{dT}{dr} \qquad (\because A=4\pi r^2)$$

Then, $$(H)\int_{r_1}^{r_2}\frac{1}{r^2}dr=-4\pi K\int_{T_1}^{T_2}dT$$

$$H\left[\frac{1}{r_1}-\frac{1}{r_2}\right]=-4\pi K[T_2-T_1]$$

or $$H=\frac{-4\pi Kr_1r_2(T_2-T_1)}{(r_2-r_1)}$$

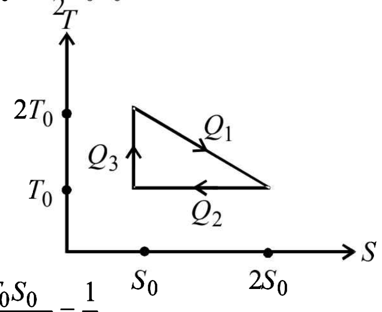
24. **(b)** Change in internal energy do not depend upon the path followed by the process. It only depends on initial and final states i.e., $\Delta U_1=\Delta U_2$

25. **(d)** $Q_1=T_0S_0+\frac{1}{2}T_0S_0=\frac{3}{2}T_0S_0$

$Q_2=T_0(2S_0-S_0)$

$=T_0S_0$

and $Q_3=0$



$$\eta=1-\frac{Q_2}{Q_1}=1-\frac{T_0S_0}{\frac{3}{2}T_0S_0}=\frac{1}{3}$$

26. **(a)** $$\frac{n_1+n_2}{r-1}=\frac{n_1}{r_1-1}+\frac{n_2}{r_2-1}$$

$$\frac{\frac{16}{4}+\frac{16}{32}}{r-1}=\frac{16/4}{\frac{5}{3}-1}+\frac{16/32}{1.4-1}$$

$\therefore\ \gamma=1.62$

27. **(b)** Total power radiated by Sun = $\sigma T^4\times 4\pi R^2$

The intensity of power at earth's surface $=\frac{\sigma T^4\times 4\pi R^2}{4\pi r^2}$

Total power received by Earth $=\frac{\sigma T^4R^2}{r^2}(\pi r_0^2)$

28. **(c)** Heat lost by He = Heat gained by N_2

$$n_1C_{v_1}\Delta T_1=n_2C_{v_2}\Delta T_2$$

$$\frac{3}{2}R\left[\frac{7}{3}T_0-T_f\right]=\frac{5}{2}R\left[T_f-T_0\right]\Rightarrow T_f=\frac{3}{2}T_0$$

29. **(a)** $$W=\frac{nR\Delta T}{1-\gamma}\Rightarrow -146000=\frac{1000\times 8.3\times 7}{1-\gamma}$$

or $$1-\gamma=-\frac{58.1}{146}\Rightarrow \gamma=1+\frac{58.1}{146}=1.4$$

Hence the gas is diatomic.

30. **(b)** For path iaf, $\Delta U=Q-W=50-20=30$ cal.

For path ibf $W=Q-\Delta U=36-30=6$ cal.

31. **(c)** The efficiency (η) of a Carnot engine and the coefficient of performance (β) of a refrigerator are related as

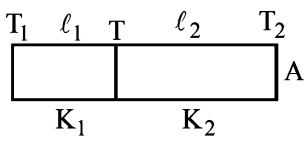
$$\beta=\frac{1-\eta}{\eta} \qquad \text{Here, } \eta=\frac{1}{10} \qquad \therefore\ \beta=\frac{1-\frac{1}{10}}{\left(\frac{1}{10}\right)}=9.$$

Also, Coefficient of performance (β) is given by $\beta=\frac{Q_2}{W}$,

where Q_2 is the energy absorbed from the reservoir.

or, $9=\frac{Q_2}{10}$ $\qquad\therefore\ Q_2=90$ J.

32. **(d)**



$$\frac{K_1A(T_1-T)}{\ell_1}=\frac{K_2A(T-T_2)}{\ell_2},$$

$$\therefore\ T=\frac{K_1T_1\ell_2+K_2T_2\ell_1}{K_2\ell_1+K_1\ell_2}=\frac{K_1\ell_2T_1+K_2\ell_1T_2}{K_1\ell_2+K_2\ell_1}.$$

33. **(b)** According to Mayer's relationship $C_P-C_V=R$

$$\therefore\ \frac{C_P}{M}-\frac{C_V}{M}=\frac{R}{M} \qquad \text{Here } M=28.$$

34. **(a)** The speed of sound in a gas is given by $v=\sqrt{\frac{\gamma RT}{M}}$

$$\therefore \frac{v_{O_2}}{v_{He}}=\sqrt{\frac{\gamma_{O_2}}{M_{O_2}}\times\frac{M_{He}}{\gamma_{He}}}=\sqrt{\frac{1.4}{32}\times\frac{4}{1.67}}=0.3237$$

$$\therefore v_{He}=\frac{v_{O_2}}{0.3237}=\frac{460}{0.3237}=1421\ \text{m/s}$$

35. **(a)** Same as A . 20

36. **(a)** The heat flow rate is given by

$$\frac{dQ}{dt}=\frac{kA(\theta_1-\theta)}{x}$$

$$\Rightarrow \theta_1-\theta=\frac{x}{kA}\frac{dQ}{dt}\Rightarrow \theta=\theta_1-\frac{x}{kA}\frac{dQ}{dt}$$

where θ_1 is the temperature of hot end and θ is temperature at a distance x from hot end.
The above equation can be graphically represented by option (a) .

37. **(b)** A to B is an isobaric process. The work done

$$W=nR(T_2-T_1)=2R(500-300)=400R$$

38. **(a)** Work done by the system in the isothermal process DA is $W=2.303\,nRT\log_{10}\frac{P_D}{P_A}$

$$=2.303\times 2\,R\times 300\log_{10}\frac{1\times10^5}{2\times10^5}=-414\,R$$

Therefore work done on the gas is $+414\,R$.

39. **(a)** The net work in the cycle $ABCDA$ is

$$W=W_{AB}+W_{BC}+W_{CD}+W_{DA}$$

$$=400R+2.303nRT\log\frac{P_B}{P_C}+(-400R)-414R$$

$$=2.303\times 2R\times 500\log\frac{2\times10^5}{1\times10^5}-414\,R$$

$$=693.2\,R-414\,R=279.2\,R$$

40. **(a)** $\text{Volume}=\frac{\text{mass}}{\text{density}}=\frac{1}{4}\ \text{m}^3$

$$\text{K.E}=\frac{5}{2}PV=\frac{5}{2}\times8\times10^4\times\frac{1}{4}=5\times10^4\,J$$

41. **(c)** (The relation $R=R_0(1+\alpha\Delta t)$ is valid for small values of Δt and R_0 is resistance at 0°C and also $(R-R_0)$ should be much smaller than R_0. So, statement (1) is wrong but statement (2) is correct.

42. **(b)** $T_1V^{\gamma-1}=T_2(32V)^{\gamma-1}\Rightarrow T_1=(32)^{\gamma-1}.T_2$

For diatomic gas, $\gamma=\frac{7}{5}$ $\quad\therefore \gamma-1=\frac{2}{5}$

$$\therefore T_1=(32)^{\frac{2}{5}}.T_2\Rightarrow T_1=4T_2$$

$$\text{Now, efficiency}=1-\frac{T_2}{T_1}=1-\frac{T_2}{4T_2}=1-\frac{1}{4}=\frac{3}{4}=0.75.$$

43. **(c)** Here, work done is zero.
So, loss in kinetic energy = change in internal energy of gas

$$\frac{1}{2}mv^2=nC_v\Delta T=n\frac{R}{\gamma-1}\Delta T$$

$$\frac{1}{2}mv^2=\frac{m}{M}\frac{R}{\gamma-1}\Delta T\quad\therefore \Delta T=\frac{Mv^2(\gamma-1)}{2R}K$$

44. **(a)** Number of moles of first gas $=\frac{n_1}{N_A}$

Number of moles of second gas $=\frac{n_2}{N_A}$

Number of moles of third gas $=\frac{n_3}{N_A}$

If there is no loss of energy then
$P_1V_1+P_2V_2+P_3V_3=PV$

$$\frac{n_1}{N_A}RT_1+\frac{n_2}{N_A}RT_2+\frac{n_3}{N_A}RT_3$$

$$=\frac{n_1+n_2+n_3}{N_A}RT_{mix}\quad T_{\text{mix}}=\frac{n_1T_1+n_2T_2+n_3T_3}{n_1+n_2+n_3}$$

45. **(d)** Efficiency of engine

$$\frac{1}{6}=1-\frac{T_2}{T_1}\text{ and }\eta_2=1-\frac{T_2-62}{T_1}=\frac{1}{3}$$

$$\therefore T_1=372\,\text{K and }T_2=\frac{5}{6}\times372=310\,\text{K}$$

46. **(a)** $\Delta U=\Delta Q=mc\Delta T=100\times10^{-3}\times4184\,(50-30)\approx 8.4\,\text{kJ}$

47. **(d)** $Y=\frac{F/S}{\Delta L/L}\Rightarrow \Delta L=\frac{FL}{SY}$

$$\therefore L\alpha\Delta T=\frac{FL}{SY}\qquad[\because \Delta L=L\alpha\Delta T]$$

$\therefore\ F=SY\alpha\Delta T$

$\therefore$ The ring is pressing the wheel from both sides,

$\therefore\ F_{\text{net}}=2F=2YS\alpha\Delta T$

48. **(a)** Heat given to system $=(nC_V\Delta T)_{A\to B}+(nC_p\Delta T)_{B\to C}$

$$=\left[\frac{3}{2}(nR\Delta T)\right]_{A\to B}+\left[\frac{5}{2}(nR\Delta T)\right]_{B\to C}$$

$$=\left[\frac{3}{2}\times V_0\Delta P\right]_{A\to B}+\left[\frac{5}{2}\times2P_0\times V_0\right]$$

$$=\frac{13}{2}P_0V_0$$

and $W_0 = P_0V_0$

$$\eta = \frac{\text{Work}}{\text{heat given}} = \frac{P_0V_0}{\frac{13}{2}P_0V_0} \times 100 = 15.4\%$$

49. (a) Newton's law of cooling

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

Integrating

$\Rightarrow \log(\theta - \theta_0) = -kt + c$

Which represents an equation of straight line.
Thus the option (a) is correct.

50. (c) $0.4 = 1 - \frac{T_2}{500}$ and $0.6 = 1 - \frac{T_2}{T_1}$

on solving we get $T_2 = 750$ K

51. (b) Same as in A -51

52. (c) According to Newton's law of cooling, the temperature goes on decreasing with time non-linearly.

53. (a) Young's modulus $Y = \frac{\text{stress}}{\text{strain}}$

stress = Y × strain

Stress in steel wire = Applied pressure

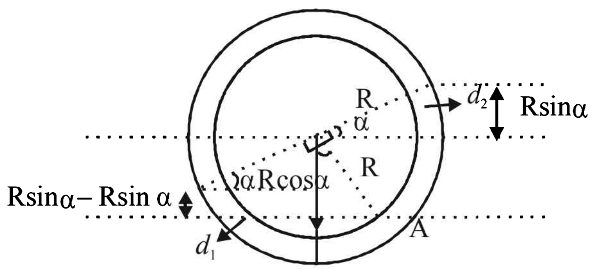
Pressure = stress = Y × strain

Strain $= \frac{\Delta L}{L} = \alpha \Delta T$ (As length is constant)

$= 2 \times 10^{11} \times 1.1 \times 10^{-5} \times 100$

$= 2.2 \times 10^8$ Pa

54. (c) Pressure at interface A must be same from both the sides to be in equilibrium.



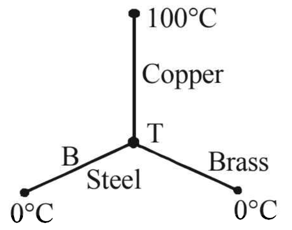
$\therefore \quad (R\cos\alpha + R\sin\alpha)d_2 g = (R\cos\alpha - R\sin\alpha)d_1 g$

$$\Rightarrow \frac{d_1}{d_2} = \frac{\cos\alpha + \sin\alpha}{\cos\alpha - \sin\alpha} = \frac{1+\tan\alpha}{1-\tan\alpha}$$

55. (c) Rate of heat flow is given by,

$$Q = \frac{KA(\theta_1 - \theta_2)}{l}$$

Where, K = coefficient of thermal conductivity
l = length of rod and A = Area of cross-section of rod



If the junction temperature is T, then

$Q_{Copper} = Q_{Brass} + Q_{Steel}$

$$\frac{0.92 \times 4(100 - T)}{46} = \frac{0.26 \times 4 \times (T - 0)}{13} + \frac{0.12 \times 4 \times (T-0)}{12}$$

$\Rightarrow 200 - 2T = 2T + T$

$\Rightarrow T = 40°C$

$$\therefore \quad Q_{Copper} = \frac{0.92 \times 4 \times 60}{46} = 4.8 \text{ cal/s}$$

56. (d) In cyclic process, change in total internal energy is zero.

$\Delta U_{cyclic} = 0$

$$\Delta U_{BC} = nC_v\Delta T = 1 \times \frac{5R}{2}\Delta T$$

Where, C_v = molar specific heat at constant volume.
For BC, ΔT = –200 K

$\therefore \quad \Delta U_{BC} = -500R$

57. (d) The entropy change of the body in the two cases is same as entropy is a state function.

58. (a) As, $P = \frac{1}{3}\left(\frac{U}{V}\right)$

But $\frac{U}{V} = KT^4$

So, $P = \frac{1}{3}KT^4$

or $\frac{uRT}{V} = \frac{1}{3}KT^4$ [As PV = u RT]

$\frac{4}{3}\pi R^3 T^3 = \text{constant}$

Therefore, $T \propto \frac{1}{R}$

59. (a) $$\tau = \frac{1}{\sqrt{2}\pi d^2\left(\frac{N}{V}\right)\sqrt{\frac{3RT}{M}}}$$

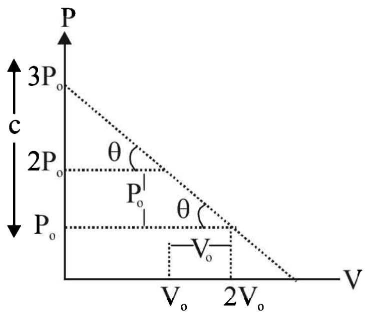
$$\tau \propto \frac{V}{\sqrt{T}}$$

As, $TV^{\gamma-1} = K$

So, $\tau \propto V^{\gamma + 1/2}$

Therefore, $q = \frac{\gamma+1}{2}$

60. (c) The equation for the line is



$$P = \frac{-P_0}{V_0}V + 3P$$

$$[\text{slope} = \frac{-P_0}{V_0}, c = 3P_0]$$

$$PV_0 + P_0V = 3P_0V_0 \quad \text{...(i)}$$

But $pv = nRT$

$$\therefore p = \frac{nRT}{v} \quad \text{...(ii)}$$

From (i) & (ii) $\frac{nRT}{v}V_0 + P_0V = 3P_0V_0$

$\therefore nRT\,V_0 + P_0V^2 = 3P_0V_0$ ...(iii)

For temperature to be maximum $\frac{dT}{dv} = 0$

Differentiating e.q. (iii) by 'v' we get

$$nRV_0\frac{dT}{dv} + P_0(2v) = 3P_0V_0$$

$$\therefore nRV_0\frac{dT}{dv} = 3P_0V_0 - 2P_0V$$

$$\frac{dT}{dv} = \frac{3P_0V_0 - 2P_0V}{nRV_0} = 0$$

$$V = \frac{3V_0}{2} \qquad \therefore p = \frac{3P_0}{2} \qquad \text{[From (i)]}$$

$$\therefore T_{max} = \frac{9P_oV_o}{4nR} \quad \text{[From (iii)]}$$

61. (c) Time lost/gained per day $= \frac{1}{2} \propto \Delta\theta \times 86400$ second

$$12 = \frac{1}{2}\alpha(40-\theta) \times 86400 \quad \text{.... (i)}$$

$$4 = \frac{1}{2}\alpha(\theta-20) \times 86400 \quad \text{....(ii)}$$

On dividing we get, $3 = \frac{40-\theta}{\theta-20}$

$3\theta - 60 = 40 - \theta$

$4\theta = 100 \Rightarrow \theta = 25°C$

62. (d) For a polytropic process

$$C = C_v + \frac{R}{1-n} \qquad \therefore C - C_v = \frac{R}{1-n}$$

$$\therefore 1-n = \frac{R}{C-C_v} \qquad \therefore 1 - \frac{R}{C-C_v} = n$$

$$\therefore n = \frac{C-C_v-R}{C-C_v} = \frac{C-C_v-C_p+C_v}{C-C_v}$$

$$= \frac{C-C_p}{C-C_v} \; (\because C_p - C_{v=R})$$