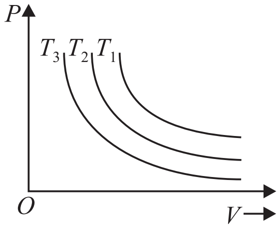
Thermodynamics

OBJECTIVE TYPE QUESTIONS

Multiple Choice Questions (MCQs)

1. The isothermal diagram of a gas at three different temperatures T_1, T_2 and T_3, is shown in the given figure. Then



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

2. The relation between the slope of isothermal curve and slope of adiabatic curve

(a) slope of adiabatic curve = γ times slope of isothermal curve
(b) slope of isothermal curve = γ times slope of adiabatic curve
(c) slope of adiabatic curve = γ^2 times slope of isothermal curve
(d) slope of isothermal curve = γ^2 times slope of adiabatic curve

3. The change in internal energy of a thermodynamical system which has absorbed 2 kcal of heat and done 400 J of work is (1 cal = 4.2 J)

(a) 2 kJ (b) 8 kJ
(c) 3.5 kJ (d) 5.5 kJ

4. If the amount of heat given to a system is 35 J and the amount of work done on the system is 15 J, then the change in internal energy of the system is

(a) –50 J (b) 20 J
(c) 30 J (d) 50 J

5. In a cyclic process, work done by the system is

(a) zero
(b) more than the heat given to the system
(c) equal to heat given to the system
(d) independent of heat given to the system

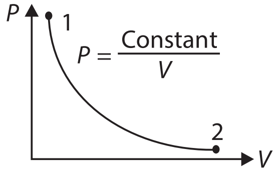
6. In a thermodynamic system working substance is an ideal gas. Its internal energy is in the form of

(a) kinetic energy only
(b) kinetic and potential energy
(c) potential energy
(d) electric energy.

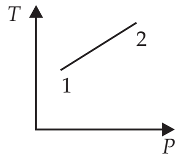
7. If an average person jogs, he produces 14.5×10^4 cal min^{-1}. This is removed by the evaporation of sweat. The amount of sweat evaporated per minute (assuming 1 kg requires 580×10^3 cal for evaporation) is

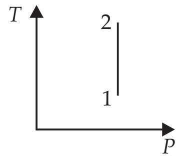
(a) 0.25 kg (b) 2.25 kg
(c) 0.05 kg (d) 0.20 kg

8. Consider P-V diagram for an ideal gas shown in figure.



Out of the following diagrams, which represents the T-P diagram?

(i)


(ii)


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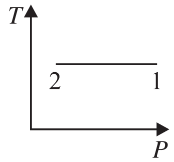
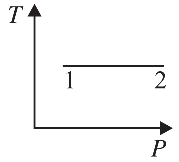
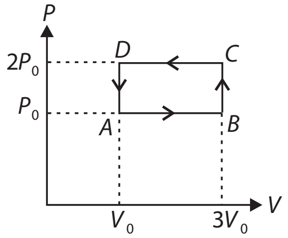


(iv)


(a) (iv) (b) (ii)
(c) (iii) (d) (i)

9. An ideal gas undergoes cyclic process $ABCDA$ as shown in given P-V diagram. The amount of work done by the gas is



(a) $6P_0V_0$ (b) $-2P_0V_0$
(c) $+2P_0V_0$ (d) $+4P_0V_0$

10. Which of the following is not a state function?
(a) Temperature (b) Entropy
(c) Pressure (d) Work

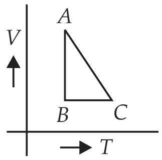
11. Which of the following is not a thermodynamic coordinate?
(a) Gas constant (R) (b) Pressure (P)
(c) Volume (V) (d) Temperature (T)

12. Consider two containers A and B containing identical gases at the same pressure, volume and temperature. The gas in container A is compressed to half of its original volume isothermally while the gas in container B is compressed to half of its original value adiabatically. The ratio of final pressure of gas in B to that of gas in A is

(a) $2^{\gamma-1}$ (b) $\left(\frac{1}{2}\right)^{\gamma-1}$

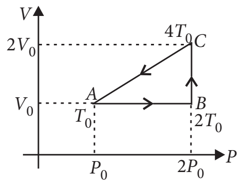
(c) $\left(\frac{1}{1-\gamma}\right)^2$ (d) $\left(\frac{1}{\gamma-1}\right)^2$

13. One mole of an ideal gas is taken from A to B, from B to C and then back to A. The variation of its volume with temperature for that change is as shown. Its pressure at A is P_0, volume is V_0. Then, the internal energy
(a) at A is more than at B
(b) at C is less than at B
(c) at B is more than at A
(d) at A and B are equal



14. A sample of ideal gas ($\gamma = 1.4$) is heated at constant pressure. If 100 J of heat is supplied to the gas the work done by the gas is
(a) 28.57 J (b) 56.54 J
(c) 38.92 J (d) 65.38 J

15. A thermodynamic process of one mole of an monoatomic ideal gas is shown in the figure. The efficiency of cyclic process $ABCA$ will be

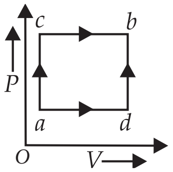


(a) 25% (b) 12.5%
(c) 50% (d) 7.7%.

16. For an ideal gas, the equation of a process for which the heat capacity of the gas varies with temperature as $C = \alpha/T$ (α is a constant) is given by
(a) $V \ln T$ = constant
(b) $VT^{1/(\gamma-1)}e^{\alpha/RT}$ = constant
(c) $V^{\frac{1}{\gamma-1}}T^{\alpha/RT}$ = constant
(d) $V^{\gamma-1}T$ = constant

17. For a diatomic gas change in internal energy for unit change in temperature for constant pressure and constant volume is ΔU_1 and ΔU_2 respectively. The ratio of $\Delta U_1 : \Delta U_2$ is
(a) 5 : 3 (b) 3 : 5
(c) 1 : 1 (d) 5 : 7

18. When a system is taken from state a to state b along the path acb as shown in figure, 60 J of heat flows into the system and 30 J of work is done by the system. Along the path adb, if the work done by the system is 10 J, heat flow into the system is



(a) 100 J (b) 20 J
(c) 80 J (d) 40 J

19. A system is taken from a given initial state to a given final state along various paths represented on a P-V diagram. The quantity that is independent of the path is
(a) amount of heat transferred Q
(b) amount of work done W
(c) Q but not W
(d) $(Q - W)$

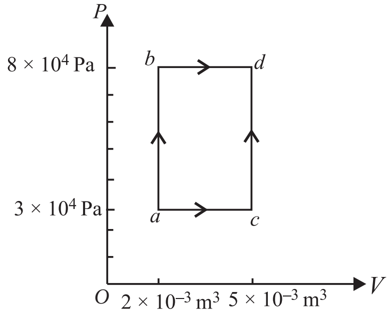
20. In an adiabatic change the specific heat of a gas is
(a) increase with increase in temperature
(b) decrease with increase in temperature
(c) not depend upon change in temperature
(d) always zero.

21. An ideal gas having molar specific heat capacity at constant volume is $\frac{3}{2}R$, the molar specific heat capacities at constant pressure is
(a) $\frac{1}{2}R$ (b) $\frac{5}{2}R$
(c) $\frac{7}{2}R$ (d) $\frac{9}{2}R$

22. 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 gas is

(a) 4/3 (b) 2
(c) 5/3 (d) 3/2

23. A thermodynamic process is shown in figure. In process *ab*, 600 J of heat is added, and in process *bd* 200 J of heat is added. The total heat added in process *acd* is

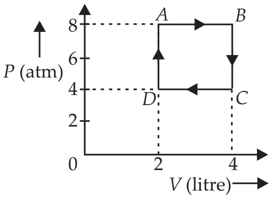


(a) 550 J (b) 650 J
(c) 750 J (d) 850 J

24. The ideal gas equation for an adiabatic process is

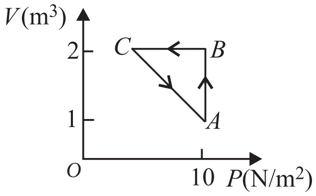
(a) $PV^{\gamma} = \text{constant}$
(b) $TV^{\gamma+1} = \text{constant}$
(c) $P^{(\gamma-1)}T = \text{constant}$
(d) $P^{\gamma+1}T = \text{constant}$

25. One mole of an ideal gas undergoes a cyclic process *ABCD*, *A* as shown in the *P*-*V* diagram,
The net work done in the process is
(1 atm = 10^6 dyne cm^{-2})



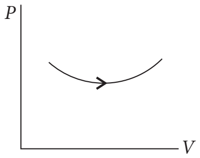
(a) 500 J (b) 700 J
(c) 800 J (d) 900 J

26. An ideal gas is taken through the cycle $A \rightarrow B \rightarrow C \rightarrow A$, as shown in figure. If the net heat supplied to the gas in the cycle is 5 J, the work done by the gas in the process $C \rightarrow A$ is



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

27. Consider the process on a system shown in figure below. During the process, the work done by the system

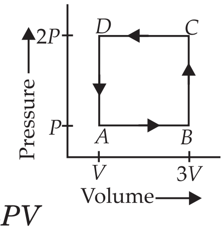


(a) continuously increases
(b) continuously decreases
(c) first increases then decreases
(d) first decreases then increases

28. The internal energy of a gas in an adiabatic process is given by $U = a + bPV$, find γ.

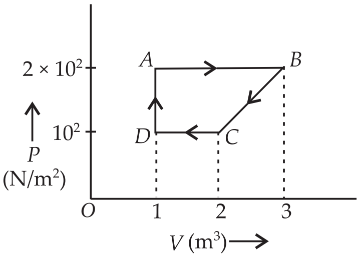
(a) $\frac{a+1}{a}$ (b) $\frac{b+1}{b}$
(c) $\frac{b+1}{a}$ (d) $\frac{a}{b+1}$

29. A thermodynamic system is taken through the cycle *ABCD* as shown in figure. Heat rejected by the gas during the cycle is



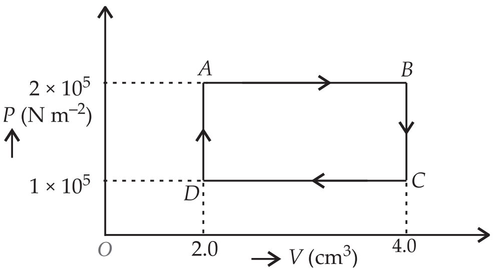
(a) 2*PV* (b) 4*PV*
(c) $\frac{1}{2}PV$ (d) *PV*

30. A cyclic process is shown in the figure. Work done during the cyclic process *ABCDA* is



(a) 160 J (b) 150 J
(c) 600 J (d) 900 J

31. The *P*-*V* diagram of a gas undergoing a cyclic process (*ABCDA*) is shown in the graph, where *P* is in units of N m^{-2} and *V* in cm^3. Identify the incorrect statement.

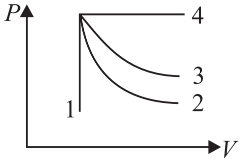


(a) 0.4 J of work is done by the gas from *A* to *B*.
(b) 0.2 J of work is done on the gas from *C* to *D*.

(c) No work is done by the gas from B to C.

(d) Work is done by the gas from B to C and on the gas from D to A.

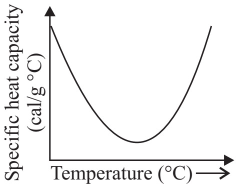
32. An ideal gas undergoes four different processes from the same initial state as shown in P-V diagram. Out of these four processes which one is isothermal process?

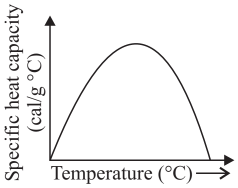


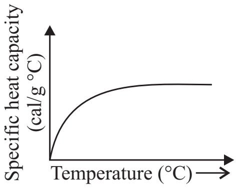
(a) 1 (b) 2

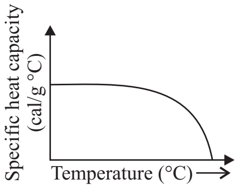
(c) 3 (d) 4

33. Which one of the following graphs represents variation of specific heat capacity of water with temperature?

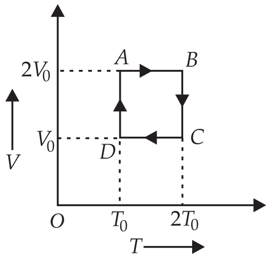
(a)


(b)


(c)


(d)


34. One mole of an ideal gas is taken through a cyclic process as shown in the V-T diagram. Which of the following statements is true?



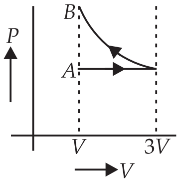
(a) The magnitude of work done by the gas is $RT_0\ln 2$.

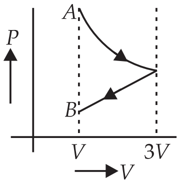
(b) Work done by gas is V_0T_0.

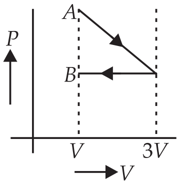
(c) Net work done by the gas is zero.

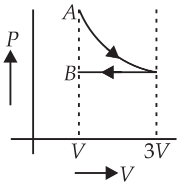
(d) Work done by the gas is $2RT_0\ln 2$.

35. One mole of an ideal gas goes from an initial state A to final state B via two processes : It first undergoes isothermal expansion from volume V to $3V$ and then its volume is reduced from $3V$ to V at constant pressure. The correct P-V diagram representing the two processes is

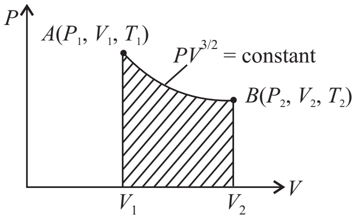
(a)


(b)


(c)


(d)


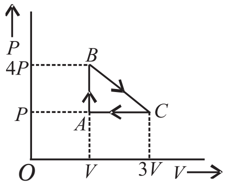
36. The P-V diagram of path followed by one mole of perfect gas in a cylindrical container is shown in figure, the work done when the gas is taken from state A to state B is



(a) $2P_2V_1\left[1-\frac{\sqrt{V_2}}{\sqrt{V_1}}\right]$ (b) $2P_1V_1\left[1-\frac{\sqrt{V_1}}{\sqrt{V_2}}\right]$

(c) $2P_1V_2\left[\frac{\sqrt{V_1}}{\sqrt{V_2}}-1\right]$ (d) $2P_2V_2\left[1-\frac{\sqrt{V_1}}{\sqrt{V_2}}\right]$

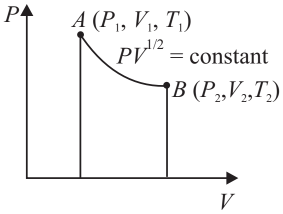
37. An ideal gas is taken around the cycle $ABCA$ as shown in the P-V diagram. The total work done by the gas during the cycle is



(a) PV (b) $2PV$

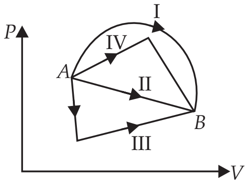
(c) $4PV$ (d) $3PV$

38. 1 mole of an ideal gas in a cylindrical container have the P-V diagram as shown in figure. If $V_2 = 4V_1$, then the ratio of temperatures $\frac{T_1}{T_2}$ will be



(a) $\frac{1}{2}$ (b) $\frac{1}{4}$ (c) $\frac{3}{2}$ (d) $\frac{3}{4}$

39. An ideal gas undergoing a change of state from A to B through four different paths I, II, III and IV as shown in the P-V diagram



that lead to the same change of state, then the change in internal energy is

(a) is same in I and II but not in III and IV
(b) is same in III and IV but not in I and II
(c) is same in I, II and III but not in IV
(d) same in all the four cases

40. The volume of one mole of an ideal gas changes from V to $2V$ at temperature 300 K. If R is universal gas constant, then work done in this process is

(a) $300R\ln 2$
(b) $600R\ln 2$
(c) $300\ln 2$
(d) $600\ln 2$

Case Based MCQs

Case I : Read the passage given below and answer the following questions from 41 to 45.

First Law of Thermodynamics

The first law of thermodynamics is the general law of conservation of energy applied to any system in which energy transfer from or to the surroundings (through heat and work) is taken into account. It states that the energy supplied to the system goes in partly to increase the internal energy of the system and the rest in work on the environment.

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

where ΔQ is the heat supplied to the system, ΔW is the work done by the system and ΔU is the change in internal energy of the system. ΔQ and ΔW depend on the path taken to go from initial to final states, but the combination $\Delta Q - \Delta W$ is path independent.

41. The first law of thermodynamics is concerned with conservation of

(a) number of molecules
(b) number of moles
(c) energy
(d) temperature

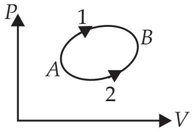
42. Which of the following is not a path function ?

(a) ΔQ
(b) $\Delta Q + \Delta W$
(c) ΔW
(d) $\Delta Q - \Delta W$

43. An electric heater supplies heat to a system at a rate of 120 W. If system performs work at a rate of 80 J s^{-1}, the rate of increase in internal energy is

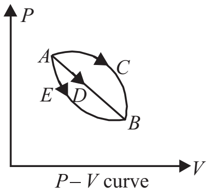
(a) 30 J s^{-1}
(b) 40 J s^{-1}
(c) 50 J s^{-1}
(d) 60 J s^{-1}

44. A system goes from A to B by two different paths in the P-V diagram as shown in figure. Heat given to the system in path 1 is 1100 J, the work done by the system along path 1 is more than path 2 by 150 J. The heat exchanged by the system in path 2 is



(a) 800 J
(b) 750 J
(c) 1050 J
(d) 950 J

45. A certain mass of gas is carried from A to B, along three paths via ACB, ADB and AEB. Which one of the following is correct?



P– V curve

(a) Work done via path ACB is minimum.
(b) Work done via path ADB is maximum.
(c) Work done via path ACB is maximum.
(d) Work done via path AEB is maximum.

Case II : Read the passage given below and answer the following questions from 46 to 50.

Thermodynamic Process

Isothermal process : A thermodynamic process in which the temperature remains constant.

Equation of isothermal process, PV = constant.

Adiabatic process : A thermodynamic process in which no heat flows between the system and the surroundings.

Equation of adiabatic process, PV^{γ} = constant

where $\gamma = C_P/C_V$. If an ideal gas undergoes a change in its state adiabatically from (P_1, V_1) to (P_2, V_2).

$P_1V_1^{\gamma} = P_2V_2^{\gamma}$

46. No heat flows between the system and surrounding. Then the thermodynamic process is

(a) isothermal
(b) isochoric
(c) adiabatic
(d) isobaric

47. A thermoflask made of stainless steel contains several tiny lead shots. If the flask is quickly shaken up and down several times, the temperature of lead shots

(a) increases by adiabatic process

(b) increases by isothermal process

(c) decreases by adiabatic process

(d) remains same

48. If an ideal gas is compressed isothermally, then

(a) no work is done against gas

(b) heat is released by the gas.

(c) the internal energy of gas will increase

(d) pressure does not change.

49. An ideal gas A and a real gas B have their volumes increased from V to $2V$ under isothermal conditions The increase in internal energy

(a) will be same in both A and B

(b) will be zero in both the gases

(c) of B will be more than that of A

(d) of A will be more than that of B

50. For an ideal gas, in an isothermal process,

(a) heat content remains constant.

(b) heat content and temperature remains constant

(c) temperature remains constant

(d) heat energy varies.

Assertion & Reasoning Based MCQs

For question numbers 51-60, two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.

(a) Both A and R are true and R is the correct explanation of A

(b) Both A and R are true but R is NOT the correct explanation of A

(c) A is true but R is false

(d) A is false and R is also false

51. Assertion (A) : We can change the temperature of a body without giving (or taking) heat to (or from) it.

Reason (R) : According to principle of conservation of energy, total energy of a system should remain conserved.

52. Assertion (A) : A gas does not have a unique value of specific heat.

Reason (R) : Specific heat is defined as the amount of heat required to raise the temperature of unit mass of the substance through unit degree.

53. Assertion (A) : The internal energy of an isothermal process does not change.

Reason (R) : The internal energy of a system depends only on pressure of the system.

54. Assertion (A) : An adiabatic process is an isoentropic process.

Reason (R) : Change in entropy is zero in case of adiabatic process.

55. Assertion (A) : Work done by a gas in isothermal expansion is more than the work done by the gas in the same expansion, adiabatically.

Reason (R) : Temperature remains constant in isothermal expansion and not in adiabatic expansion.

56. Assertion (A) : First law of thermodynamics is a restatement of the principle of conservation of energy.

Reason (R) : Energy is a fundamental quantity.

57. Assertion (A) : The internal energy of a real gas is function of both, temperature and volume.

Reason (R) : Internal kinetic energy depends on temperature and internal potential energy depends on volume.

58. Assertion (A) : In an adiabatic compression, the internal energy and temperature of the system get decreased.

Reason (R) : An adiabatic compression is a slow process.

59. Assertion (A) : Two systems in thermal equilibrium with a third system, are in thermal equilibrium with each other.

Reason (R) : Heat flows spontaneously from a system at a higher temperature to a system at a lower temperature.

60. Assertion (A) : In an adiabatic process, change in internal energy of a gas is equal to work done on or by the gas in the process.

Reason (R) : Temperature of gas remains constant in an adiabatic process.

SUBJECTIVE TYPE QUESTIONS

Very Short Answer Type Questions (VSA)

1. What does the zeroth law of thermodynamics tell us about measuring the temperature of an object ?

2. First law of thermodynamics does not forbid flow of heat from lower temperature to higher temperature. Comment.

3. A thermos bottle containing tea is vigorously shaken. What will be the effect on the temperature of tea?

4. Which thermodynamic variable is defined by Zeroth law of thermodynamics?

5. A gas does work during adiabatic expansion. What is the source of mechanical energy so produced ?

6. If hot air rises up, why is it cooler at the top of mountain than near the sea level ? Explain.

7. If no external energy is supplied to an expanding gas, will the gas do any work ? If yes, then what will be the source of energy ?

8. What is the nature of the internal energy of an ideal gas ?

9. Is it possible to increase the temperature of a gas without adding heat to it? Explain.

10. A gas has two specific heats whereas a liquid and a solid have only one. Why?

Short Answer Type Questions (SA-I)

11. Two bodies at different temperatures T_1 and T_2, if brought in thermal contact do not necessarily settle to the mean temperature $(T_1 + T_2)/2$. Explain.

12. Give difference between heat and work.

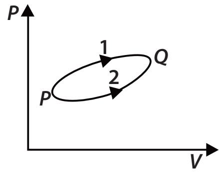
13. An electric heater supplies heat to a system at a rate of 100 W. If system performs work at a rate of 75 joules per second. At what rate is the internal energy increasing?

14. For one mole of gas, work done at constant pressure is W. What is the heat supplied at constant volume for the same rise in temperature of the gas ?

15. What is an isothermal process ? What are the essential conditions for an isothermal process to take place ?

16. A cylinder with a movable piston contains 3 moles of hydrogen at standard temperature and pressure. The walls of the cylinder are made of a heat insulator, and the piston is insulated by having a pile of sand on it. By what factor does the pressure of the gas increase if the gas is compressed to half its original volume?

17. A system goes from P to Q by two different paths in the P-V diagram as shown in figure. Heat given to the system in path 1 is 1000 J. The work done by the system along path 1 is more than path 2 by 100 J. What is the heat exchanged by the system in path 2?



18. Why is it impossible for a ship to use the internal energy of sea water to operate its engine ?

19. What do you mean by extensive and intensive state variables? Explain using suitable example.

20. The specific heat of hydrogen gas of constant pressure is $C_P = 3.4 \times 10^3$ cal/ kg °C and at constant volume is $C_V = 2.4 \times 10^3$ cal/kg °C. If one kilogram hydrogen gas is heated from 10°C to 20°C at constant pressure. What will be the external work done on the gas to maintain it at constant pressure?

Short Answer Type Questions (SA-II)

21. Two cylinders *A* and *B* of equal capacity are connected to each other via a stopcock. The cylinder *A* contains a gas at standard temperature and pressure, while the cylinder *B* is completely evacuated. The entire system is thermally insulated. The stopcock is suddenly opened.

Answer the following :

(a) What is the final pressure of the gas in *A* and *B*?

(b) What is the change in internal energy of the gas?

(c) What is the change in temperature of the gas?

22. Define internal energy of a gas. Explain whether it is an extensive or intensive variable? How internal energy of a gas can be changed ?

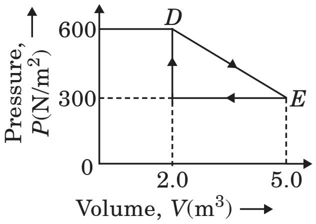
23. An ideal gas has a molar heat capacity C_V at constant volume. Find the molar heat capacity of this gas as a function of its volume *V*, if the gas undergoes the process $T = T_0e^{\alpha V}$.

24. A thermosflask contains coffee. It is vigorously shaken. Consider the coffee as the system. (a) Has any heat been added to it? (b) Has any work been done on it? (c) Has its internal energy changed? (d) Does its temperature rise?

25. An air bubble of volume 1.0 cm^3 rises from the bottom of a lake 40 m deep at a temperature of 12°C. To what volume does it grow when it reaches the surface which is at a temperature of 35°C ?

26. When heat energy of 1500 J is supplied to a gas at constant pressure, 2.1×10^5 N m^{-2}, there was an increase in its volume equal to 2.5×10^{-3} m^3. What is the increase in its internal energy ?

27. Deduce the work done in the following complete cycle :



28. In changing the state of gas adiabatically from state of equilibrium *A* to state of equilibrium *B*. In this process 22.3 J work is done on the system. If the gas is taken from *A* to *B* via a process in which the net heat absorbed by the system is 9.35 cal, how much is the net work done by the system in later case ?

29. Two samples of an ideal gas initially at the same temperature and pressure are allowed to expand from a volume *V* to 2*V*, one isothermally and other adiabatically. In which case, will

(a) the work done be more?

(b) the final pressure be more?

(c) the final temperature be more?

Justify your answers.

30. What do you understand by reversible and irreversible processes ? Give examples. What are the necessary conditions for a process to be reversible ?

Long Answer Type Questions (LA)

31. A mixture of 1.78 kg of water and 262 g of ice at 0°C is, in a reversible process, brought to a final equilibrium state where the water / ice ratio, by mass is 1 : 1 at 0°C.

(a) Calculate the entropy change of the system during this process.

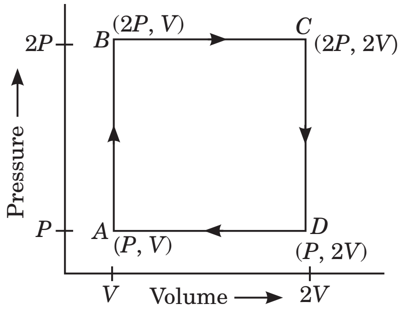
(b) The system is then returned to the first equilibrium state, but in an irreversible way (by using a Bunsen burner, for instance). Calculate the entropy change of the system during this process.

(c) Show that your answer is consistent with the second law of thermodynamics.

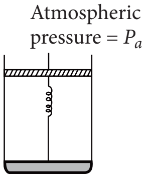
32. (a) State first law of thermodynamics. Establish the relation between two principle molar specific heats of a gas on the basis of this law.

(b) An ideal gas is taken around the cycle *ABCDA* as shown in the *P*-*V* diagram.

What is the work done during the cycle.



33. Consider one mole of perfect gas in a cylinder of unit cross section with a piston attached as shown in figure. A spring (spring constant k) is attached (unstretched length L) to the piston and to the bottom of the cylinder. Initially the spring is unstretched and the gas is in equilibrium. A certain amount of heat Q is supplied to the gas causing an increase of volume from V_o to V

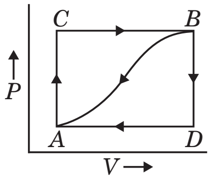


(a) What is the initial pressure of the system?

(b) What is the final pressure of the system?

(c) Using the first law of thermodynamics, write down a relation between Q, P_a, V, V_o and k.

34. When a system is taken from state A to state B along the path ACB, 80 kcal of heat flows into the system and 30 kcal of work is done.



(a) How much heat flows into the system along path ADB if the work done is 10 kcal ?

(b) When the system is returned from B to A along the curved path the work done is 20 kcal. Does the system absorb or librate heat?

(c) If $U_A = 0$ and $U_D = 40$ kcal, find the heat absorbed in the process AD.

35. For the case of an ideal gas, find the equation of the process (in the variables T, V) in which the molar heat capacity varies as :

(a) $C = C_V + \alpha T$

(b) $C = C_V + \beta V$

(c) $C = C_V + aP$

where α, β, a are constants.

ANSWERS

OBJECTIVE TYPE QUESTIONS

1. (c) : The given diagram shows that the curves move away from the origin at higher temperature.

2. (a) : For isothermal process,

PV = constant

Differentiating both side

$$PdV + VdP = 0 \text{ or } \frac{dP}{dV} = \frac{-P}{V} \quad \text{...(i)}$$

Again for adiabatic process

PV^γ = constant

Again differentiating both side

$$dPV^\gamma + \gamma V^{\gamma-1} dV\, P = 0$$

$$\text{or} \quad \frac{dP}{dV} = -\frac{P}{V} \times \gamma$$

∴ slope of adiabatic curve = γ × slope of isothermal curve

3. (b) : Here,

Heat absorbed, $\Delta Q = 2 \text{ kcal} = 2 \times 10^3 \times 4.2 \text{ J}$

($\because$ 1 cal = 4.2 J)

$= 8.4 \times 10^3 \text{ J} = 8400 \text{ J}$

Work done, $\Delta W = 400$ J

According to first law of thermodynamics

Change in internal energy, $\Delta U = \Delta Q - \Delta W$

$\Delta U = 8400 \text{ J} - 400 \text{ J} = 8000 \text{ J} = 8 \times 10^3 \text{ J} = 8 \text{ kJ}$

4. (d) : According to first law of thermodynamics

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

$\Delta U = \Delta Q - \Delta W$

Here $\Delta Q = 35$ J, $\Delta W = -15$ J

$\therefore \quad \Delta U = 35 \text{ J} - (-15 \text{ J}) = 50 \text{ J}$

Note : ΔW is negative because work is done on the system.

5. (c) : The first law of thermodynamics states that heat supplied in a cyclic process, $(\Delta Q) = \Delta U + \Delta W$.

Since in a cyclic process, the system returns to its original state, therefore $\Delta U = 0$. Hence $\Delta Q = \Delta W$.

6. (b)

7. (a) : Amount of sweat evaporated per minute

$$= \frac{\text{calories produced per minute}}{\text{no. of calories required for evaporation per kg}}$$

$$= \frac{14.5 \times 10^4}{580 \times 10^3} = 0.25 \text{ kg}$$

8. **(c) :** In the given diagram T is constant and $P_1 > P_2$. Curve (iii) represents $P_1 > P_2$ and straight line graph, parallel to pressure axis indicates constant T.

9. **(b) :** Work done = change in pressure × change in volume

$= (2P_0 - P_0)\,(3V_0 - V_0) = 2P_0V_0$

Since the cyclic process is anticlockwise, work done by the gas is negative, *i.e.*, $-2P_0V_0$.

10. **(d) :** Work is not a function to describe the state of a system.

11. **(a) :** Pressure (P), volume (V) and temperature (T) are the thermodynamic coordinates used to describe the state of the system whereas gas constant (R) is a universal gas constant whose value is 8.314 J mol^{-1} K^{-1}.

12. **(a) :** The gas in container A is compressed isothermally,

$\therefore \quad P_1V_1 = P_2V_2$

or $\quad P_2 = \dfrac{P_1V_1}{V_2} = P_1\dfrac{V_1}{V_1/2} = 2P_1 \qquad (\because V_2 = V_1/2)$

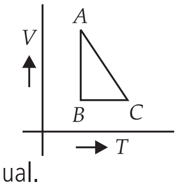
Again the gas in container B is compressed adiabatically,

$\therefore \quad P_1V_1^{\gamma} = P_2'(V_2')^{\gamma}$

$$P_2' = P_1\frac{V_1^{\gamma}}{(V_2')^{\gamma}} = P_1\left(\frac{V_1}{V_1/2}\right)^{\gamma} = 2^{\gamma}P_1$$

Hence $\dfrac{P_2'}{P_2} = \dfrac{2^{\gamma}P_1}{2P_1} = 2^{\gamma-1}$

13. **(d) :** The internal energy of an ideal gas is only dependent upon its temperature.



From the graph,

The ideal gas at same temperature at A and B.

$\therefore$ The internal energy at A and B are equal.

So, $U_A = U_B$

14. **(a) :** At constant pressure,

$\Delta Q = nC_P\,\Delta T$ and $\Delta U = nC_V\Delta T$

From the first law of thermodynamics,

$\Delta W = \Delta Q - \Delta U = n(C_P - C_V)\Delta T$

$$\therefore \quad \frac{\Delta W}{\Delta Q} = \frac{n\,(C_P - C_V)\Delta T}{n\,C_P\,\Delta T} = 1 - \frac{C_V}{C_P} = 1 - \frac{1}{\gamma}$$

$$= 1 - \frac{1}{1.4} = \frac{0.4}{1.4} = \frac{4}{14} = \frac{2}{7}$$

or $\quad \Delta W = \dfrac{2}{7}\Delta Q = \dfrac{2}{7}\times 100\ \text{J} = 28.57\ \text{J}$

15. **(d) :** $W = \dfrac{1}{2}P_0V_0$, $T_A = T_0$, $T_B = 2T_0$, $T_C = 4T_0$

Heat supplied $= Q_{AB} + Q_{BC} = C_VT_0 + C_P2T_0$

$= \dfrac{13}{2}RT_0 = \dfrac{13}{2}P_0V_0$

$\therefore$ Efficiency of the cyclic process

$$= \frac{\frac{1}{2}P_0V_0}{\frac{13}{2}P_0V_0}\times 100 = \frac{1}{13}\times 100 = 7.7\%$$

16. **(b) :** $\Delta Q = dU + PdV$

$$\Rightarrow \quad \frac{\alpha}{T}dT = C_VdT + PdV \Rightarrow \quad \frac{\alpha}{T}dT = C_VdT + \frac{RT}{V}dV$$

$$\alpha\frac{dT}{T} = \frac{R}{(\gamma-1)}dT + RT\frac{dV}{V} \Rightarrow \frac{\alpha}{R}\frac{dT}{T^2} = \frac{1}{(\gamma-1)}\frac{dT}{T} + \frac{dV}{V}$$

On integrating and solving

$VT^{1/(\gamma-1)}e^{\alpha/RT} = \text{constant}$

17. **(c) :** According to first law of thermodynamics,

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

At constant pressure,

$\Delta Q = nC_P\Delta T$, $\Delta U = \Delta U_1$, $\Delta W = P\Delta V = nR\Delta T$

$\therefore \quad nC_P\Delta T = \Delta U + nR\Delta T$ or $n(C_P - R)\Delta T = \Delta U_1$

At constant volume, $\Delta Q = nC_V\Delta T$, $\Delta W = 0$

$\therefore \quad nC_V\Delta T = \Delta U_2$

Thus, $\quad \dfrac{\Delta U_1}{\Delta U_2} = \dfrac{C_P - R}{C_V} = \dfrac{C_V}{C_V} = 1:1$

18. **(d) :** According to first law of thermodynamics,

For the path acb, $Q_{acb} = \Delta U_{acb} + W_{acb}$

$\therefore \quad \Delta U_{acb} = Q_{acb} - W_{acb} = 60\ \text{J} - 30\ \text{J} = 30\ \text{J}$

For the path adb, $Q_{adb} = \Delta U_{adb} + W_{adb}$

As change in internal energy is path independent,

so $\Delta U_{acb} = \Delta U_{adb}$

$\therefore \quad Q_{adb} = 30\ \text{J} + 10\ \text{J} = 40\ \text{J}$

19. **(d) :** The only quantity ($Q - W$) which itself is the internal energy of the system is independent of the path.

20. **(d) :** In adiabatic process Q = constant, then $\Delta Q = 0$ and specific heat $s = \dfrac{\Delta Q}{m\Delta T} = \dfrac{0}{m\Delta T} = 0$

21. **(b) :** Here, $C_V = \dfrac{3}{2}R$

Since $C_P - C_V = R$

$\therefore \quad C_P = C_V + R = \dfrac{3}{2}R + R = \dfrac{5}{2}R$

22. **(d) :** As $P \propto T^3$ or $\dfrac{P}{T^3} = \text{constant}$ or PT^{-3} = constant

For an adiabatic change, $PT^{\frac{\gamma}{1-\gamma}}$ = constant

$$\therefore \quad \frac{\gamma}{1-\gamma} = -3 \text{ or } -3 + 3\gamma = \gamma \text{ or } 2\gamma = 3 \text{ or } \gamma = \frac{3}{2}$$

23. (b) : There is no volume change in process *ab*, so $W = 0$

Process *bd* occurs at constant pressure, so the work done by the system is

$W = P(V_2 - V_1)$

$= (8 \times 10^4\ \text{Pa})\ (5 \times 10^{-3}\ \text{m}^3 - 2 \times 10^{-3}\ \text{m}^3) = 240\ \text{J}$

Thus the total work for *abd* is $W = 240$ J and the total heat for *abd* is $Q = 800$ J.

$\therefore\quad \Delta U = Q - W = 800\ \text{J} - 240\ \text{J} = 560\ \text{J}$

Because ΔU is independent of path, the internal energy change is the same for path *acd* as for *abd*, that is, 560 J. The total work for path *acd* is

$W = (3 \times 10^4\ \text{Pa})\ (5 \times 10^{-3}\ \text{m}^3 - 2 \times 10^{-3}\ \text{m}^3) = 90\ \text{J}$

$\therefore$ Total heat added in the path *acd* is

$Q = \Delta U + W = 560\ \text{J} + 90\ \text{J} = 650\ \text{J}$

24. (a)

25. (c) : As the loop is traced in clockwise direction the work done is positive.

Work done in the process = area of rectangle $ABCD = AB \times AD$

Here, $AB = 4 - 2 = 2$ litre $= 2 \times 10^3\ \text{cm}^3$

$AD = 8 - 4 = 4$ atm $= 4 \times 10^6$ dyne cm^{-2}

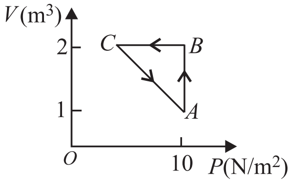
Work done, $W = AB \times AD$

$= 2 \times 10^3 \times 4 \times 10^6 = 8 \times 10^9$ erg $= 800$ J.

26. (a) : Process $A \rightarrow B$ occurs at constant pressure,

$\therefore\quad W_{AB} = P\Delta V = P(V_2 - V_1)$

$= 10 \times (2 - 1) = 10\ \text{J}$



Process $B \rightarrow C$, occurs at constant volume,

$\therefore\quad W_{BC} = 0$

For a cyclic process, $\Delta Q = W$

$\therefore\quad \Delta Q = W_{AB} + W_{BC} + W_{CA}$

or $5 = 10 + 0 + W_{CA}$

or $\quad W_{CA} = -5\ \text{J}$

27. (a) : Work done by the system is area under *P-V* curve. During the process, area under *P-V* curve continuously increases and hence the work done by the system.

28. (b) : $U = a + bPV = a + bnRT$

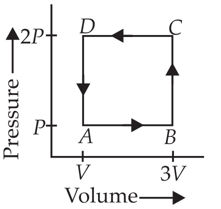
$\Rightarrow\quad \Delta U = bnR\Delta T = nC_V\Delta T \Rightarrow C_V = bR \Rightarrow C_P = bR + R$

$$\Rightarrow\quad \gamma = \frac{C_P}{C_V} = \frac{bR + R}{bR} = \frac{b+1}{b}$$

29. (a) : In a cyclic process work done is equal to the area under the cycle and is positive if the cycle is clockwise and negative if anticlockwise.

$\therefore\quad \Delta W = -$ Area of rectangle $ABCD = -P(2V) = -2PV$

According to first law of thermodynamics $\Delta Q = \Delta U + \Delta W$



But for a cyclic process, $\Delta U = 0$

$\therefore\quad \Delta Q = \Delta W$

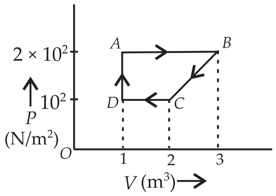
i.e., heat supplied to the system is equal to the work done.

So heat absorbed,

$\Delta Q = \Delta W = -2PV$

$\therefore\quad$ Heat rejected by the gas $= 2PV$

30. (b) : Work done during cyclic process *ABCDA* = area enclosed by *ABCDA*



$$= \left(\frac{AB + CD}{2}\right) \times AD$$

$$= \frac{(2+1)}{2} \times 10^2 = 150\ \text{J}$$

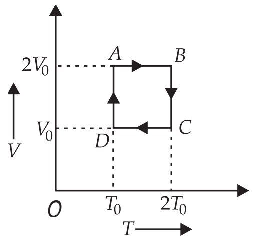
31. (d) : In going from *B* to *C* and from *D* to *A*, $V =$ constant. So, $\Delta V = 0$.

$\therefore\quad W = P\Delta V = 0$

32. (c) : From the given *P-V* diagram it is clear that process 1 is isochoric process, process 4 is isobaric process, the slope of curve 2 has smaller than the slope of curve 3. Hence curve 3 is corresponds to isothermal process and curve 2 corresponds to adiabatic process.

33. (a)

34. (a) : $W_{AB} = W_{CA} = 0$ (as volume is constant)



$$W_{DA} = RT_0 \ln\left(\frac{2V_0}{V_0}\right) = RT_0 \ln 2$$

$$W_{BC} = R(2T_0)\ln\left(\frac{V_0}{2V_0}\right) = -2RT_0 \ln 2$$

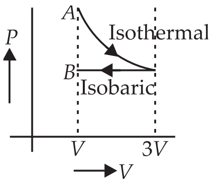
Total work done by the gas is

$W = W_{AB} + W_{BC} + W_{CD} + W_{DA}$

$= 0 - 2RT_0 \ln 2 + 0 + RT_0 \ln 2 = -RT_0 \ln 2$

or $\quad |W| = RT_0 \ln 2$

35. (d) :



36. (b) : For path *A* to *B*

$PV^{3/2} =$ constant $= A$

the work done $W = \int_{V_1}^{V_2} P\,dV = \int_{V_1}^{V_2} \frac{A}{V^{3/2}}\,dV = A\left[\frac{V^{-1/2}}{-1/2}\right]_{V_1}^{V_2}$

$$= -2A\left[V^{-1/2}\right]_{V_1}^{V_2} = -2A\left[\frac{1}{\sqrt{V_2}} - \frac{1}{\sqrt{V_1}}\right]$$

$$= 2A\left[\frac{1}{\sqrt{V_1}} - \frac{1}{\sqrt{V_2}}\right] = 2P_1V_1^{3/2}\left[\frac{\sqrt{V_2}-\sqrt{V_1}}{\sqrt{V_1V_2}}\right] = 2P_1V_1\left[1-\frac{\sqrt{V_1}}{\sqrt{V_2}}\right]$$

$[\because\ P_1V_1^{3/2} = \text{constant}]$

37. (d) : The total work done

= Area of $\Delta ABC = \frac{1}{2} \times 2V \times 3P = 3PV$

38. (a) : Ideal gas equation, $PV = nRT$

or $T = \frac{PV}{nR}$ ... (i)

According to question,

$PV^{1/2}$ = constant (A)

multipling both side by $\sqrt{V}$

or $PV = A\sqrt{V}$ ... (ii)

From eqn's (i) and (ii)

$$\therefore\quad T = \frac{A\sqrt{V}}{nR} \Rightarrow T \propto \sqrt{V}$$

Now $\frac{T_1}{T_2} = \sqrt{\frac{V_1}{V_2}} = \sqrt{\frac{V_1}{4V_1}} = \frac{1}{2}$ $\quad[\because\ V_2 = 4V_1]$

$$\therefore\quad \frac{T_1}{T_2} = \frac{1}{2}$$

39. (d) : From the given initial state A to final state B, change in internal energy is same all the four cases, as it is independent of the path from A to B.

40. (a) : Work done in an isothermal process

$$W = nRT\ln\left(\frac{V_2}{V_1}\right)$$

Here, n = 1 mol, T = 300 K, $V_1 = V$ and $V_2 = 2V$

$$\therefore\quad W = 1 \times R \times 300\ln\left(\frac{2V}{V}\right) = 300R\ln 2$$

41. (c) : The first law of thermodynamics is concerned with conservation of energy.

42. (d) : $\Delta U = \Delta Q - \Delta W$

The internal energy is independent of path.

43. (b) : According to first Law of thermodynamics

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

$$\therefore\quad \frac{\Delta Q}{\Delta t} = \frac{\Delta U}{\Delta t} + \frac{\Delta W}{\Delta t}$$

Here, $\frac{\Delta Q}{\Delta t} = 120\,\text{W},\ \frac{\Delta W}{\Delta t} = 80\,\text{J s}^{-1}$

$$\therefore\quad \frac{\Delta U}{\Delta t} = 120 - 80 = 40\,\text{J s}^{-1}$$

44. (d) : The change in internal energy of system will be same for both paths 1 and 2.

Along path 1, $\Delta Q_1 = \Delta U + \Delta W_1$ ... (i)

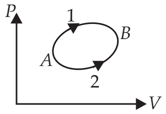
Along path 2, $\Delta Q_2 = \Delta U + \Delta W_2$ ... (ii)

Subtract (ii) from (i), we get

or $\Delta Q_1 - \Delta Q_2 = \Delta W_1 - \Delta W_2$

$1100 - \Delta Q_2 = 150$

$\Delta Q_2 = 1100 - 150 = 950$ J



45. (c) : Work done by a gas depends on the area enclosed between the P-V curve and the volume axis.

The area enclosed by curve ACB is maximum. Hence work done is maximum along path ACB.

The area enclosed by curve AEB is minimum.

Hence work done is minimum along path AEB.

46. (c) : In an adiabatic process, no heat flows between the system and surrounding.

47. (a) : The temperature of lead shots increases because of increase in internal energy by adiabatic process.

48. (b) : In isothermal process, heat is released by the gas to maintain the constant temperature.

49. (b) : Under isothermal condition, $\Delta U = 0$.

50. (c) : In isothermal process, temperature remains constant.

51. (b) : We can change the temperature of a body without giving (or taking) heat to (or from) it. For example in an adiabatic compression temperature rises and in an adiabatic expansion temperature fall, although no heat is given or taken from the system in the respective changes.

52. (b) : According to first law of thermodynamics, the heat supplied to a system is equal to sum of the increase in internal energy of the system and external work done on it. $dQ = dU + dW = dU + PdV$. If heat is supplied in such a manner that volume does not change $dV = 0$ *i.e.*, isochoric process, then whole of the heat energy supplied to the system will increase internal energy only. But, in any other process it is not possible.

53. (c) : The internal energy of a system depends only on its temperature. In isothermal process temperature does not change, therefore, internal energy of the system remains the same.

54. (a) : Change in entropy, $\Delta S = \frac{\Delta Q}{T}$. In an adiabatic change, heat transfer $\Delta Q = 0$.

$\therefore$ $\Delta S = 0$, or $S =$ constant *i.e.*, entropy remains constant in an adiabatic process, or an adiabatic process is an isoentropic process.

55. (b) : The slope of adiabatic curve is γ times the slope of an isothermal curve. As $\gamma > 1$, therefore, adiabatic curve at any point is steeper than isothermal curve at that point. Therefore, area under adiabatic curve is smaller than the area under isothermal curve, *i.e.*, work done by the gas in adiabatic expansion is smaller than the work done by the gas in isothermal expansion.

56. (c) : First law of thermodynamics is restatement of the principle of conservation of energy as applied to heat energy. According to first law of thermodynamics when some quantity of heat is supplied to a system capable of doing external work, then the quantity of heat absorbed by the system is equal to the sum of the increase in the energy of the system due to rise in temperature and the external work done by the system in expansion.

57. (a) : In real gas, intermolecular force do exist. Work has to be done in changing the distance between the molecules. Therefore, internal energy of real gas is sum of internal kinetic and internal potential energy which are function of temperature and volume respectively. Also change in internal energy of a system depends only on initial and final states of the system.

58. (c) : Adiabatic processes are quick.

59. (b)

60. (c) : In an adiabatic process, no exchange of heat is permissible *i.e.*, $dQ = 0$.

As, $dQ = dU + dW = 0 \quad \therefore\ dU = -\,dW$

SUBJECTIVE TYPE QUESTIONS

1. Two objects in thermal equilibrium have the same temperature.

2. First law of thermodynamics simply tells about the conversion of mechanical energy into heat energy and vice-versa. It does not put any condition as to why heat cannot flow from lower temperature to higher temperature.

3. Temperature of tea will rise.

4. Zeroth law of thermodynamics defines temperature.

5. By first law of thermodynamics, $\Delta Q = \Delta U + \Delta W$. But for an adiabatic process, $\Delta Q = 0$, so $\Delta W = -\Delta U$. Thus the source of energy required for doing mechanical work during adiabatic expansion is the internal energy of the gas itself.

6. As a rising hot air moves into regions of low pressure *i.e.*, hill top, it expands. The air has to do work to expand, so its temperature must decrease. The only possible source of energy to do work for expansion is the thermal energy of the gas *i.e.*, internal energy of gas. This is an adiabatic expansion as no thermal energy is transferred from surrounding. As a result, rising hot air become cooler at the top of mountain.

7. Yes, the gas will do work at the expense of its internal energy.

8. Internal energy of an ideal gas is purely kinetic in nature.

9. Temperature of the gas can be increased by compressing the gas adiabatically. In this process, system requires no external heat supply.

According to first law of thermodynamics

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

For an adiabatic process, $\Delta Q = 0$

$\therefore$ $\Delta U = -\Delta W$

When the gas is compressed, ΔW is negative hence ΔU is positive. So, the internal energy and therefore the temperature of the gas increases.

10. When solids and liquids are heated, there is only a slight change in their volume and as such they possess only one specific heat, *i.e.*, specific heat at constant volume. But in case of gases, pressure and volume both change and as such they possess two principal specific heats; one at constant pressure and one at constant volume.

11. Let m_1, m_2 and c_1, c_2 be the masses and specific heats of the two bodies. Let T be their common temperature when these are brought in thermal contact.

From the principle of calorimetry,

$m_1c_1[T_1 - T] = m_2c_2[T - T_2]$ (taking $T_1 > T_2$)

For $T = \dfrac{T_1+T_2}{2}$,

$$m_1c_1\left[T_1 - \frac{T_1+T_2}{2}\right] = m_2c_2\left[\frac{T_1+T_2}{2} - T_2\right]$$

or $$m_1c_1\left[\frac{T_1-T_2}{2}\right] = m_2c_2\left[\frac{T_1-T_2}{2}\right]$$

or $m_1c_1 = m_2c_2$

i.e., heat capacities of the two bodies should be equal.

12. Heat : Heat is the energy transfer arising due to temperature difference between the system and the surroundings.

Work done : Work is energy transfer brought about by other means, such as moving the piston of a cylinder containing the gas, by raising or lowering some weight connected to it.

13. Given that

Heat supplied, $\Delta Q = 100\ \text{W} = 100\ \text{J s}^{-1}$

Useful work done, $\Delta W = 75\ \text{J s}^{-1}$

Change in internal energy, $\Delta U = ?$

According to first law of thermodynamics, change in internal energy is given by

$\Delta U = \Delta Q - \Delta W$

$\Delta U = 100 - 75 = 25\ \text{J s}^{-1} = 25\ \text{W}$

14. For the process at constant pressure

$$W = RdT \qquad \text{...(i)}$$

For the process at constant volume,

$$dQ = C_V\, dT = \frac{R}{\gamma-1}dT = \frac{W}{\gamma-1} \qquad \text{(Using (i))}$$

15. A process in which temperature remains constant is called isothermal process. The essential conditions for an isothermal process to take place are :

(i) The walls of the container must be perfectly conducting to allow free exchange of heat between the gas and the surroundings.

(ii) The process of compression or expansion should be slow, so as to provide sufficient time for the exchange of heat.

16. As the gas is completely insulated, the process is adiabatic.

$$P_1V_1^{\gamma} = P_2V_2^{\gamma}$$

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^{\gamma}$$

$$\frac{P_2}{P_1} = \left(\frac{V_1}{\frac{V_1}{2}}\right)^{1.4} \qquad \left(\begin{array}{l} \because\ V_2 = \frac{1}{2}V_1 \\ \gamma = 1.4 \text{ Given}\end{array}\right)$$

$$\frac{P_2}{P_1} = (2)^{1.4} = 2.64$$

17. For path 2,

$\Delta Q = \Delta U + \Delta W \qquad$ ...(i)

For path 1,

$1000 = \Delta U' + (\Delta W + 100)$

$\Rightarrow \quad \Delta U + \Delta W = 900 \qquad (\because \Delta U = \Delta U')$

$\Rightarrow \quad \Delta Q = 900$ J [Using eqn (i)]

18. According to second law of thermodynamics, a working substance can do work only if its temperature is higher than that of its surroundings. Thus, if a ship is to use the internal energy of water to operate its engine, there should be a suitable sink to absorb the unused heat. The temperature of such a sink should be lower than that of sea water. Since there is no such sink available, the internal energy of sea water cannot be used to run a ship.

19. Let us consider a system at equilibrium, and now it is divided into two equal parts. The variables that remain unchanged for each part are intensive. The variables whose value get halved in each part are extensive.

In other words, mass dependent variables are extensive and mass independent variables are intensive.

For e.g. : Internal energy (U), volume (V) and mass (M) are extensive variables.

Pressure (P), temperature (T) and density (ρ) are intensive variables.

20. From First law of thermodynamics, $\Delta Q = \Delta U + \Delta W$

Work done at constant pressure $(\Delta W)_P = (\Delta Q)_P - \Delta U$ $= (\Delta Q)_P - (\Delta Q)_V$ [As we know $(\Delta Q)_V = \Delta U$]

Also $(\Delta Q)_P = mc_P\Delta T$ and $(\Delta Q)_V = mc_V\Delta T$

$\Rightarrow \quad (\Delta W)_P = m(c_P - c_V)\Delta T$

$\Rightarrow \quad (\Delta W)_P = 1 \times (3.4 \times 10^3 - 2.4 \times 10^3) \times 10 = 10^4$ cal

21. (a) When the stopcock is suddenly opened, the volume available to the gas at 1 atm becomes twice the original volume and hence pressure becomes half the original volume (Boyle's law). Hence the pressure of the gas in each of the cylinders *A* and *B* is 0.5 atm.

(b) As the system is thermally insulated, so $\Delta Q = 0$. Also, the gas expands against zero pressure, so $\Delta W = 0$. Hence by first law of thermodynamics, $\Delta U = 0$ *i.e.*, there is no change in the internal energy of the gas.

(c) As there is no change in the internal energy of the gas, so the temperature of the gas remains unchanged.

22. Internal energy : Internal energy of a system is the sum of kinetic energies and potential energies of the molecular constituents of the system. It does not include the overall kinetic energy of the system.

Internal energy is an extensive variable because it depends upon the mass and size (volume) of the system. Intensive variables like temperature, pressure does not depends upon the mass and size of the system.

Change in internal energy does not depend on the path of the process. It depends only on the initial and final states of the system *i.e.*, $\Delta U = U_f - U_i$.

23. Molar specific heat, $C = \dfrac{dQ}{dT} = \dfrac{dU + PdV}{dT}$

$$C = \frac{dU}{dT} + \frac{PdV}{dT}$$

$$C = C_V + \frac{PdV}{dT} = C_V + \frac{RT}{V}\frac{dV}{dT} \qquad (\because\ PV = RT)$$

Since, $T = T_0e^{\alpha V}$

$$\frac{dT}{dV} = T_0e^{\alpha V} \cdot \alpha = T\alpha \quad \therefore \quad \frac{dV}{dT} = \frac{1}{T\alpha}$$

$$\Rightarrow \quad C = C_V + \frac{RT}{V}\frac{1}{T\alpha} = C_V + \frac{R}{\alpha V}$$

24. (a) No. As the thermos flask is insulated, heat has not been added to the coffee ($\Delta Q = 0$).

(b) Yes. Some work is done by the man in shaking the coffee against the forces of viscosity *i.e.*, ΔW is negative.

(c) By first law of thermodynamics, $\Delta Q = \Delta U + \Delta W$. As $\Delta Q = 0$ and ΔW is negative, so ΔU is positive *i.e.*, internal energy of the coffee increases.

(d) Because of the increase in internal energy of the coffee, the temperature of the coffee will also increase.

25. When the air bubble is at 40 m depth, then

$V_1 = 1\text{ cm}^3 = 10^{-6}\text{ m}^3$, $T_1 = 12°\text{C} = 285\text{ K}$

$P_1 = 1\text{ atm} + h\rho g$

$= (1.01 \times 10^5) + (40 \times 10^3 \times 9.8)$

$= 491 \times 10^3\text{ Pa}$

When the air bubble reaches at the surface of the lake,

$T_2 = 35°\text{C} = 308\text{ K}$

$P_2 = 1\text{ atm} = 1.013 \times 10^5\text{ Pa}$

Now, $\dfrac{P_1V_1}{T_1} = \dfrac{P_2V_2}{T_2} \Rightarrow V_2 = \dfrac{P_1V_1T_2}{T_1P_2}$

$$\Rightarrow \quad V_2 = \frac{491 \times 10^3 \times 10^{-6} \times 308}{285 \times 1.01 \times 10^5}$$

$\Rightarrow \quad V_2 = 5.253 \times 10^{-6}\text{ m}^3$

26. Heat supplied to the gas, $\Delta Q = 1500\text{ J}$

Work done by the gas,

$\Delta W = P\Delta V = (2.1 \times 10^5\text{ N m}^{-2})(2.5 \times 10^{-3}\text{ m}^3)$

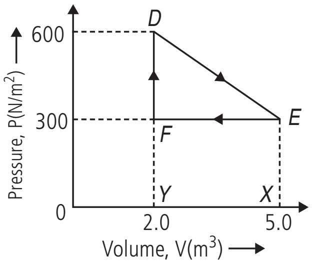
$= 5.25 \times 10^2\text{ N m} = 525\text{ J}$

According to first law of thermodynamics,

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

$\therefore \quad \Delta U = \Delta Q - \Delta W = 1500\text{ J} - 525\text{ J} = 975\text{ J}$

27.



Work done in complete cycle = Area of $\Delta DEF = \dfrac{1}{2} \times EF \times DF$

$= \dfrac{1}{2} \times 3 \times 300 = 450\text{ J}$

28. When the gas changes state under adiabatic condition ($A \to B$)

$\Delta Q = 0 \Rightarrow \Delta U = -\Delta W = -22.3\text{ J}$

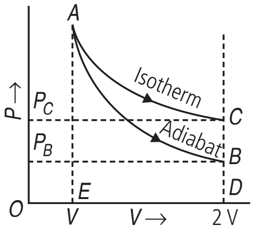
Since internal energy of the system is independent of path followed.

$\therefore \quad$ In second case, $\Delta U = -22.3\text{ J}$

$\Delta Q = 9.35\text{ cal} = (9.35 \times 4.2)\text{ J} = 39.27\text{ J}$

$\Delta W = \Delta Q - \Delta U = 61.57\text{ J}$

29. Figure shows the *P-V* diagrams for two gases expanded from volume *V* to 2*V*. As an adiabatic is steeper than an isotherm, so the adiabatic expansion curve *AB* lies below the isothermal expansion curve *AC*.



(a) Work done in adiabatic expansion = area *ABDE*

Work done in isothermal expansion = area *ACDE*

As area *ACDE* > area *ABDE*

So more work is done in the isothermal expansion.

(b) P_B and P_C are the final pressures for adiabatic and isothermal expansions respectively. Clearly, $P_C > P_B$. Hence the final pressure is greater for the isothermal expansion.

(c) In isothermal expansion, temperature remains constant *T*. In adiabatic expansion temperature decreases below *T*. So the final temperature is greater for the isothermal expansion.

30. Reversible Process : A thermodynamics process is reversible if the process can return back in such a way that both the system and surroundings return to their original states, with no other change anywhere else in the universe. It means both system and surroundings are returned to their initial states at the end of the reverse process.

Examples:

(i) The process of gradual compression and extension of an elastic spring is approximately reversible.

(ii) The process of electrolysis is reversible if the resistance offered by the electrolyte is negligibly small.

Irreversible process : An irreversible process is a thermodynamic process that departs from equilibrium. In this process, the system and surroundings do not return to their original condition once the process is initiated.

Examples :

(i) Diffusion of gases

(ii) Dissolution of salt in water

(iii) Rusting of iron

Necessary conditions for a reversible process :

(i) The process must be quasi-static. For this, the process must be carried out infinitesimally slowly so that the system remains in thermal and mechanical equilibrium with the surroundings throughout.

(ii) The dissipative force such as viscosity, friction, inelasticity, etc. should be absent.

31. (a) Mass of water = 1.78 kg

Mass of ice = 262 g = 0.262 kg

So the total mass of ice and water mixture will be,

Mass of ice-water mixture

= (Mass of water) + (Mass of ice)

= 1.78 kg + 0.262 kg = 2.04 kg

If eventually the ice and water have the same mass, then the final state will have 1.02 kg (2.04 kg/2) of each. Thus the mass of the water that changed into ice m will be the difference of mass of water m_w and mass of final state m_s.

So, $m = m_w - m_s$

To obtain mass of water that changed into ice m, substitute 1.78 kg for mass of water m_w and 1.02 kg for mass of final state m_s in the equation $m = m_w - m_s$

= 1.78 kg – 1.02 kg = 0.76 kg

The change of water at 0°C to ice at 0°C is isothermal.

To obtain the change is entropy ΔS of the system during this process, substitute 0.76 kg for mass m, 333×10^3 J/kg for heat of fusion of water L and 273 K for T in the equation $\Delta S = -mL/T$

$= -(0.76 \text{ kg})\,(333 \times 10^3 \text{ J/kg})/(273 \text{ K}) = -927$ J/K

From the above ,we conclude that, the change in entropy ΔS of the system during this process will be –927 J/K.

(b) Now the system is returned to the first equilibrium state, but in an irreversible way. Thus the change in entropy ΔS of the system during this process is equal to the negative of previous case.

So, $\Delta S = -(-927 \text{ J/K}) = 927$ J/K

From the above observation we conclude that, the change is entropy ΔS of the system would be 927 J/K.

(c) In accordance to second law of thermo-dynamics, entropy change ΔS is always zero.

The total change in entropy will be,

$\Delta S = (-927 \text{ J/K}) + (927 \text{ J/K}) = 0$

From the above observation we conclude that, our answer is consistent with the second law of thermodynamics.

32. (a) The first law of thermodynamics is the general law of conservation of energy applied to any system in which energy transfer from or to the surroundings (through heat and work) is taken into account. It states that

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

where ΔQ is the heat supplied to the system, ΔW is the work done by the system and ΔU is the change in internal energy of the system.

Consider one mole of an ideal gas. Heat the gas to raise its temperature by ΔT. According to the first law of thermodynamics, the heat supplied ΔQ is used partly to increase the internal energy and partly in doing the work of expansion. That is, $\Delta Q = \Delta U + P\Delta V$

If the heat ΔQ is absorbed at constant volume, then $\Delta V = 0$ and we have

$$C_V = \left(\frac{\Delta Q}{\Delta T}\right)_V = \left(\frac{\Delta U}{\Delta T}\right)_V = \left(\frac{\Delta U}{\Delta T}\right)$$

We have dropped the subscript V because the internal energy U of an ideal gas depends only on its temperature T.

If now the heat ΔQ is absorbed at constant pressure, then

$$C_P = \left(\frac{\Delta Q}{\Delta T}\right)_P = \left(\frac{\Delta U}{\Delta T}\right)_P + P\left(\frac{\Delta V}{\Delta T}\right)_P$$

$$= \left(\frac{\Delta U}{\Delta T}\right) + P\left(\frac{\Delta V}{\Delta T}\right)_P$$

Again, we have dropped the subscript P from the first term because U of an ideal gas depends only on T.

$$\therefore \quad C_P - C_V = P\left(\frac{\Delta V}{\Delta T}\right)_P$$

But for one mole of an ideal gas, $PV = RT$.

Differentiating both sides w.r.t. T for constant pressure P,

$$\frac{\Delta(PV)}{\Delta T} = \frac{\Delta(RT)}{\Delta T}$$

or $\quad P\left(\frac{\Delta V}{\Delta T}\right)_P = R$

Hence $C_P - C_V = R$

This is the required relation between C_P and C_V. It is also known as Mayer's formula.

(b) Work done in the cyclic process $ABCDA$

= Area of the loop $ABCD$

$= (2P - P) \times (2V - V) = PV$

33. Given, cross-sectional area of the piston

$A = 1 \text{ m}^2$

Heat supplied = Q.

Initial Volume = V_0, Final volume = V

Atmospheric pressure = P_a

(a) Since system is in equilibrium so, initial pressure of the system, $P_i = P_a$.

(b) When the gas expands from V_0 to V after heat Q is supplied.

Change in volume of the gas = $V - V_0$

Extension in the spring, $x = \dfrac{(V - V_0)}{A} = V - V_0$ $\quad (\because \; A = 1 \text{ m}^2)$

Force applied by the spring on the piston

$F = kx = k(V - V_0)$

So, pressure exerted by the extended spring on the piston of unit cross-section

$P = \dfrac{F}{A} = \dfrac{k}{A}(V - V_0) = k(V - V_0)$ $\quad$ (as $A = 1 \text{ m}^2$)

Hence final pressure of the system,

$P_f = P_a + P = P_a + k(V - V_0)$.

(c) Using the first law of thermodynamics,

$Q = U + W$ ...(i)

Here, $U = C_V(T - T_0)$

$$W = P_a(V - V_0) + \frac{1}{2}kx^2 \quad \text{...(ii)}$$

Also, $T_0 = \frac{P_0V_0}{R} = \frac{P_aV_0}{R}$

$$T = \frac{P_fV}{R} = \frac{[P_a + k(V - V_0)]V}{R}$$

$$\therefore\ U = C_V\left[(P_a + k(V - V_0))\frac{V}{R} - \frac{P_aV_0}{R}\right] \quad \text{...(iii)}$$

From (i), (ii) and (iii)

$$Q = \frac{1}{(\gamma - 1)}[(P_a + k(V - V_0))V - P_aV_0] + P_a(V - V_0) + \frac{1}{2}kx^2 \quad \left(\because\ \frac{C_V}{R} = \frac{1}{(\gamma - 1)}\right)$$

$$= \frac{1}{(\gamma - 1)}[(P_a + k(V - V_0))V - P_aV_0] + P_a(V - V_0) + \frac{1}{2}k(V - V_0)^2 \quad (\because\ x = V - V_0)$$

34. (a) $dW_{ADB} = +10$ kcal

Internal energy is path independent

$dU_{ADB} = dU_{ACB} = 50$ kcal

$dQ_{ADB} = 50 + 10 = 60$ kcal

(b) $dW_{BA} = -20$ kcal

$dU_{BA} = -dU_{ADB}$

$dQ_{BA} = dU_{BA} + dW_{BA}$

$= -50 - 20 = -70$ kcal

Since dQ_{BD} is negative so heat is librated by the system

(c) $U_A = 0$, $U_D = 40$ kcal

$dU_{AD} = 40$ kcal

$dW_{ADB} = 10$ kcal

$dW_{DB} = 0$ since $dV = 0$

$dQ_{AD} = 40 + 10 = 50$ kcal

35. Heat capacity is given by $C = C_V + \frac{RT}{V}\frac{dV}{dT}$

(a) Given $C = C_V + \alpha T$

So, $C_V + \alpha T = C_V + \frac{RT}{V}\frac{dV}{dT}$, or $\alpha T = \frac{RT}{V}\frac{dV}{dT}$,

or $\frac{\alpha}{R}dT = \frac{dV}{V}$

Integrating both sides, we get $\frac{\alpha}{R}T = \ln V + \ln C = \ln VC$

or $V \cdot C = e^{\alpha T/R}$ or $V \cdot e^{\alpha T/R} = \frac{1}{C}$ = constant

(b) Given, $C = C_V + \beta V$

and $C = C_V + \frac{RT}{V}\frac{dV}{dT}$ so, $C_V\frac{RT}{V}\frac{dV}{dT} = C_V + \beta V$

or $\frac{RT}{V}\frac{dV}{dT} = \beta V$ or $\frac{dV}{V^2} = \frac{\beta}{R}\frac{dT}{T}$

or $\frac{R}{\beta}V^{-2} = \frac{dT}{T}$

Integrating both sides, we get

$\frac{R}{\beta}\frac{V^{-1}}{(-1)} = \ln T + \ln C = \ln T \cdot C$

So, $\ln T \cdot C = -\frac{R}{\beta V} \Rightarrow T \cdot C = e^{-R/\beta V}$

or $Te^{-R/\beta V} = \frac{1}{C} = \text{constant}$

(c) $C = C_V + aP$ and $C = C_V + \frac{RT}{V}\frac{dV}{dT}$

So, $C_V + aP = C_V + \frac{RT}{V}\frac{dV}{dT}$ so, $aP = \frac{RT}{V}\frac{dV}{dT}$

or $a\frac{RT}{V} = \frac{RT}{V}\frac{dV}{dT}$ (as $P = \frac{RT}{V}$ for one mole of gas)

or $\frac{dV}{dT} = a$ or $dV = a\,dT$ or $dT = \frac{dV}{a}$

So, $T = \frac{V}{an}$ + constant

As $n = 1$, $T = \frac{V}{a}$ + constant or $V - aT$ = constant