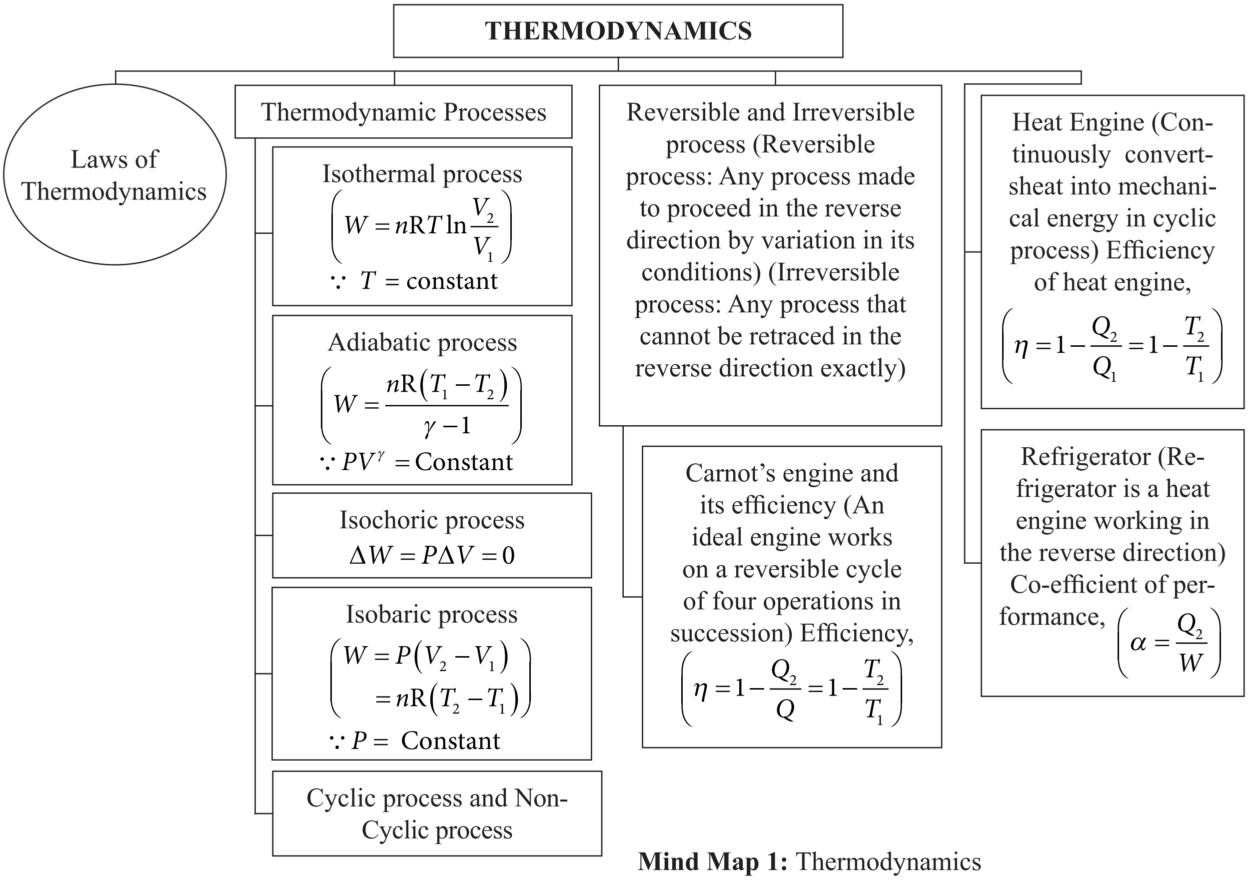
# CHAPTER 12

# Thermodynamics

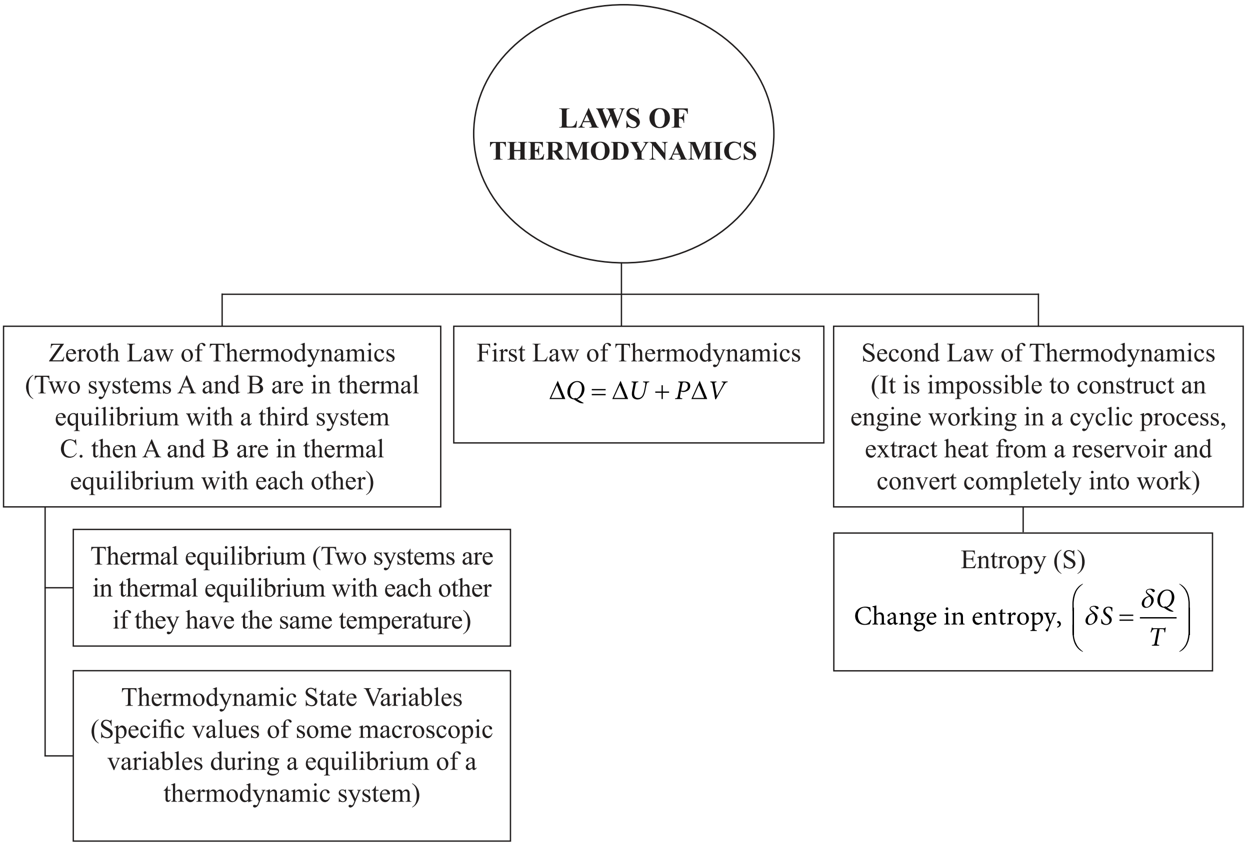
## Syllabus

- **Thermal equilibrium**
- **Zeroth law of thermodynamics:** Thermodynamic state variables.
- **Heat, internal energy, and work**
- **First law of thermodynamics**
- **Thermodynamic process:** Quasi-static process; In quasi-static process; Isothermal process; Adiabatic process; Isobaric process; Cyclic process; Non-cyclic process.
- **Second law of thermodynamics:** Kelvin-Planck statement; Clausius statement; Entropy.
- **Reversible and irreversible processes**
- **Heat engines and refrigerators:** The efficiency (η) of a heat engine; Refrigerator.
- **Carnot engine and its efficiency:** Efficiency (η) of a Carnot engine.

## MIND MAP



**Mind Map 1:** Thermodynamics



**LAWS OF THERMODYNAMICS**

- Zeroth Law of Thermodynamics (Two systems A and B are in thermal equilibrium with a third system C. then A and B are in thermal equilibrium with each other)
  - Thermal equilibrium (Two systems are in thermal equilibrium with each other if they have the same temperature)
  - Thermodynamic State Variables (Specific values of some macroscopic variables during a equilibrium of a thermodynamic system)
- First Law of Thermodynamics $\Delta Q = \Delta U + P\Delta V$
- Second Law of Thermodynamics (It is impossible to construct an engine working in a cyclic process, extract heat from a reservoir and convert completely into work)
  - Entropy (S) Change in entropy, $\left(\delta S = \dfrac{\delta Q}{T}\right)$

**Mind Map 2:** Laws of Thermodynamics

# RECAP

## Thermal Equilibrium

### Thermodynamics

- It is a branch of Physics which deals with the study of transformation of heat into other forms of energy and vice-versa.
- The state of a gas in thermodynamics is specified by macroscopic variables like pressure, volume, temperature, mass and composition.
- No microscopic description of a gas is involved in thermodynamics.

### Thermodynamic system

- It is a collection of an extremely large number of atoms or molecules.
- It is confined within certain boundaries.
- A boundary is a closed surface surrounding a system through which energy and mass may enter or leave the system.
- Everything external to the system is the surroundings.
- Thermodynamic system may be classified into three types:
  - **Open system:** It exchanges both energy on heat and matter with the surroundings.
  - **Closed system:** It exchanges only energy on heat (not matter) with the surroundings.
  - **Isolated system:** It exchanges neither energy on heat nor matter with the surroundings.
- A thermodynamic system is said to be in thermal equilibrium, when macroscopic variables (pressure, volume, temperature, mass composition etc.) that characterise the system do not change with time.
- **Adiabatic wall:** An insulating wall (can be movable) that does not allow flow of energy (heat) from one system to anolter. The systems are insulated from the rest of the surroundings also by similar adiabatic walls.
- **Diathermic wall:** A conducting wall that allows energy flow (heat).

## Zeroth Law of Thermodynamics

- According to Zeroth law, if two systems A and B are separately in thermal equilibrium with a third system C, then the systems A and B when brought into thermal contact will also be in thermal equilibrium.
- All bodies in thermal equilibrium must have a common property which remains the same for all of them. This property is the "temperature". Thus zeroth law defines temperature.

### Thermodynamic State Variables

- Every equilibrium state of a thermodynamic system is completely described by specific values of some macroscopic variables, also called state variables.
- For example, an equilibrium state of a gas is completely specified by the values of pressure and volume. Thermodynamic state variables describe equilibrium states of systems. The various state variables are not necessarily independent. The connection between the state variables is called the equation of state. For example, for an ideal gas, the equation of state is the ideal gas relation.

$$PV = n\mathrm{R}T$$

- For a fixed amount of the gas, i.e., given $n$, there are, only two independent variables, say $P$ and $V$ or $T$ and $V$.
- The pressure-volume curve for a fixed temperature is called an isotherm. Real gases may have more complicated equations of state.
- Thermodynamic variables are of two types:
  - **Extensive variables:** These change with size of the system.
    - Internal energy U, volume V, and total mass M are extensive variables.
  - **Intensive variables:** These do not change with size of the system.
    - Pressure $P$, temperature $T$, and density $\rho$ are intensive variables.

## Heat, Internal Energy, and Work

- Temperature is a measure of the 'hotness' of a body. It determines the direction of flow of heat when two bodies are placed in thermal contact. Heat flows from the body at a higher temperature to the one at lower temperature.

- The internal energy of a system is the energy possessed by the system due to molecular motion and molecular configuration. We denote the internal energy of a system by $U$.
- Change in internal energy does not depend on the path of the process. So it is called a state function i.e. it depends only on the initial and final states of the system, i.e., $\Delta U = U_f - U_i$.
- The internal energy of a given mass of gas depends on its state described by specific values of pressure, volume, and temperature.
- Heat and work in thermodynamics are not state variables. They are modes of energy transfer to a system.

## First Law of Thermodynamics

- Heat given to a system ($\Delta Q$) is equal to the sum of increase in its internal energy ($\Delta U$) and the work done by the system ($\Delta W$) against the surroundings.

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

$$(\Delta W = P\Delta V)$$

- It is a statement of conservation of energy in thermodynamical process.
- The system may go from an initial state to the final state in a number of ways. For example, to change the state of a gas from $(P_1, V_1)$ to $(P_2, V_2)$, we can first change the volume of the gas from $V_1$ to $V_2$, keeping its pressure constant, i.e., we can first go the state $(P_1, V_2)$ and then change the pressure of the gas from $P_1$ to $P_2$, keeping volume constant, to take the gas to $(P_2, V_2)$. Alternatively, we can first keep the volume constant and then keep the pressure constant.
- Work done by the system against a constant pressure $P$ is-

$$\Delta W = P\Delta V$$

$$Q = \Delta U + P\Delta V$$

Where, $\Delta V$ is the change in volume of gas.

## Illustration 1

What will be the change in internal energy for 1 g of water when its phase changes from liquid phase to vapour phase? At atmospheric pressure, 1g of water has a volume 1cm$^3$ in liquid phase and 1671 cm$^3$ in vapour phase. (Latent heat of water is 2256 J/g.)

**Soln.**

As we know,

$$\Delta W = P\left(V_g - V_l\right) = 1.013 \times 10^5 \times \left(1671 \times 10^{-6}\right) = 169.2 \text{ J}$$

$$\Delta U = \Delta Q - \Delta W = 2256 - 169.2 = 2086.8 \text{ J}$$

## Thermodynamic Processes

- The process of change of state of a system involves change of thermodynamic variables such as pressure $P$, volume $V$, and temperature $T$ of the system, such process is known as thermodynamic process.
- Some important processes are as follows:

### Quasi-static Process

- In this process all parameters remain in equilibrium at any instant. It is ideal, infinitely slow process.
- In quasi-static process the pressure *(P)* and temperature *(T)* of the environment can differ from those of the system only infinitesimally.

### Isothermal Process

- For an isothermal process ($T$ fixed), the ideal gas equation gives

  $PV$ = constant

  i.e., pressure of a given mass of gas varies inversely as its volume. This is nothing but **Boyle's Law.**

- Suppose an ideal gas goes isothermally (at temperature $T$) from its initial state ($P_1$, $V_1$) to the final state ($P_2$, $V_2$). At any intermediate stage with pressure P and volume change from $V$ to $V+\Delta V$ ($\Delta V$ small)

  $\Delta W = P\Delta V$
- Taking ($\Delta V \to 0$) and summing the quantity $\Delta W$ over the entire process,

$$W = \int_{V_1}^{V_2} PdV = n\mathrm{R}T\int_{V_1}^{V_2}\frac{dV}{V} = n\mathrm{R}T\ln\frac{V_2}{V_1}$$

- If the system is an ideal gas whose internal energy $U$ depends on temperature 'T', the internal energy remains constant. The first law of thermodynamics then implies that heat supplied in an isothermal process is used entirely to do work against the external surroundings:

  Q = W

  Note from above equation that $V_2 > V_1$, $W > 0$ and for $V_2 < V_1$, $W < 0$. That is, in an isothermal expansion, the gas absorbs heat and does work while in an is thermal compression, work is done on the gas by the environment and heat is released.

## Illustration 2

2 g moles of a gas are compressed isothermally at 298 K from 10 m$^3$ to 1 m$^3$. Calculate the work done during compression.

**Soln.**

Work done in isothermal process,

$$= n\mathrm{R}T\ln\frac{V_2}{V_1} = 2\times 8.314\times 298\times\ln\frac{1}{10} = -11410\text{ J}$$

Here work is done on the gas.

### Adiabatic Process

- A change in pressure and volume of a gas when no heat is allowed to enter into or escape from the gas is called an adiabatic process. For an adiabatic process of an ideal gas.

  $PV^{\gamma} = \text{Constant}$

  Where, $\gamma$ is the ratio of specific heats (ordinary or molar) at constant pressure and at constant volume.

$$\gamma = \frac{C_p}{C_v}$$

- Thus, if an ideal gas undergoes a change in its state adiabatically from ($P_1$, $V_1$) to ($P_2$, $V_2$):

  $P_1V_1^{\gamma} = P_2V_2^{\gamma}$
- We can calculate, as before, the work done in an adiabatic change of an ideal gas from the state ($P_1$, $V_1$, $T_1$) to the state ($P_2$, $V_2$, $T_2$).

$$W = \frac{1}{1-\gamma}\left(\frac{P_2V_2^{\gamma}}{V_2^{\gamma-1}} - \frac{P_1V_1^{\gamma}}{V_1^{\gamma-1}}\right) = \frac{1}{1-\gamma}\left(P_2V_2 - P_1V_1\right) = \frac{n\mathrm{R}\left(T_1 - T_2\right)}{\gamma - 1}$$

### Isobaric Process

- In an isobaric process pressure remains constant. Work done by the gas is

$$W = P\left(V_2 - V_1\right) = n\mathrm{R}\left(T_2 - T_1\right)...(\because PV = n\mathrm{R}T)$$

Since temperature changes, so internal energy also changes.

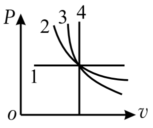
- The heat absorbed goes partly to increase internal energy and partly to do work. The change in temperature for a given amount of heat is determined by the specific heat of the gas at constant pressure.

### Cyclic Process

- In cyclic process, system returns to its initial state after any number of changes. Since internal energy is a state variable, $\Delta U = 0$ for a cyclic process, i.e., net work done in cyclic process is exactly equal to amount of heat energy transferred.

### Non-cyclic Process

- In non-cyclic process, final and initial states are different.
- Work done = Area covered between the curve and volume axis on *PV* diagram
  - *PV, PT*, and *VT*-graph for different processes.
    - *PV* graphs
    - *PT* graphs
    - *VT* graphs



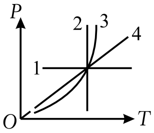
1 → Isobaric (*P*-constant)

2 → Isothermal (Because $P \propto \frac{1}{V}$

3 → Adiabatic (Because $P \propto \frac{1}{V^{\gamma}}$

4 → Isochoric (*V*-constant)

**Figure:** *PV* graphs for different process



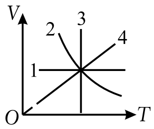
1 → Isobaric (*P*-constant)

2 → Isothermal (*T*-constant),

3 → Adiabatic (Because $P \propto T^{\frac{\gamma}{\gamma-1}}$

4 → Isochoric (In isochoric $P \propto T$)

**Figure:** *PT* graphs for different process



1 → Isoschoric (*V*-constant)

2 → Adiabatic (Because $V \propto T^{\frac{\gamma}{\gamma-1}}$)

3 → Isothermal (*T*-constant)

4 → Isobaric (In isobaric $V \propto T$)

**Figure:** *VT* graphs for different process

## Second Law of Thermodynamics

- The principle which disallows certain phenomena consistent with the first law of thermodynamics is known as second law of thermodynamics.

### Kelvin-Planck Statement

- It is impossible to make an engine which convert heat energy completely into mechanical energy.

### Clausius Statement

- It is impossible for a self-acting machine, unaided by any external agency, to transfer heat from a body at a lower temperature to a body at a higher temperature.

### Entropy

- Entropy is a thermodynamic state quantity (variable) which is a measure of randomness or disorder of the molecules of the system.
  Change in entropy,
  $$\delta S = \frac{\delta Q}{T}$$

## Reversible and Irreversible Processes

- In thermodynamics, a reversible process is a process whose direction can be reversed by inducing infinitesimal changes to some property of the system via its surroundings. Throughout the entire reversible process, the system is in thermodynamic equilibrium with its surroundings.
- All isothermal and adiabatic changes are reversible if they are performed very slowly.
- Following conditions are necessary for reversible process.
  - There must be complete absence of forces such as friction, viscosity, electric resistance, etc.
  - The direct and reverse processes must take place infinitesimally slow.
  - The temperature of the system must not differ appreciably from its surroundings.
- Any process which is not reversible exactly is an irreversible process.
- All natural processes such as conduction, radiation, radioactive decay, etc. are irreversible processes.

## Heat Engines and Refrigerator

- Heat engine is a device which converts heat energy into work continuously through a cyclic process.
- The essential parts of a heat engine are as follows:

  - A hot reservoir called source
  - A working substance
  - A cold reservoir called sink

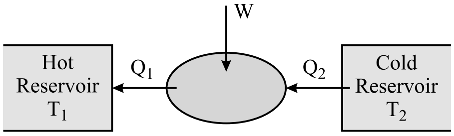


**Figure:** Schematic representation of a heat engine

### The Efficiency ($\eta$) of a Heat Engine

$$\eta = \frac{W}{Q_1}$$

$$W = Q_1 - Q_2$$

$$\text{i.e.,}\quad \eta = 1 - \frac{Q_2}{Q_1} = 1 - \frac{T_2}{T_1}$$

Where, $Q_1$ is the heat input, i.e., the heat absorbed by the system in one complete cycle and $W$ is the work done on the environment in a cycle. In a cycle, a certain amount of heat ($Q_2$) may also be rejected to the environment.

### Refrigerator

- A refrigerator or heat pump is basically a heat engine run in reverse direction. Here the working substance extracts heat $Q_2$ from the cold reservoir at temperature $T_2$, some external work $W$ is done on it and heat $Q_1$ is released to the hot reservoir at temperature $T_1$.
  - The co-efficient of performance ($\alpha$) of a refrigerator

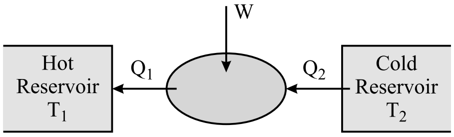


**Figure:** Schematic representation of a refrigerator

$$\alpha = \frac{Q_2}{W}$$

Where, $Q_2$ is the heat extracted from the cold reservoir and $W$ is the work done on the system.

- By energy conservation, the heat released to the hot reservoir is

$$Q_1 = W + Q_2$$

$$\text{i.e.,}\quad \alpha = \frac{Q_2}{Q_1 - Q_2}$$

## Carnot Engine and its Efficiency

- Carnot engine is a theoretical engine which is free from all the drawbacks of a practical engine. This engine cannot be realised in practice.
- Its working consists of four steps:
  - Isothermal expansion
  - Adiabatic expansion
  - Isothermal compression
  - Adiabatic compression

### Efficiency ($\eta$) of a Carnot Engine

- Efficiency is defined as the ratio of useful work obtained from the engine per cycle to the heat supplied to it.

$$\eta = 1 - \frac{T_2}{T_1}$$

## PRACTICE TIME

### Thermal Equilibrium

**1.** When a body A is in thermal equilibrium with a body B, and also separately with a body C, then B and C will be in thermal equilibrium with each other.

(a) True
(b) False
(c) Data is insufficient
(d) None of these

## Zeroth Law of Thermodynamics

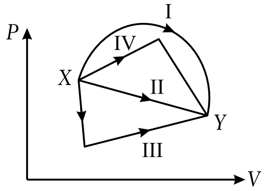
**2.** The zeroth law of thermodynamics states about:
(a) temperature.
(b) Heat content.
(c) pressure.
(d) Internal energy.

**3.** Two systems in thermal equilibrium with a third system separately are in thermal equilibrium with each other.
(a) First law of thermodynamics
(b) Second law of thermodynamics
(c) Third law of thermodynamics
(d) Zeroth law of thermodynamics

## Heat, Internal Energy and Work

**4.** Internal energy of an ideal gas depends upon:
(a) Temperature and volume.
(b) Only volume.
(c) Only pressure.
(d) Only temperature.

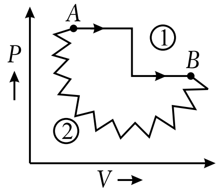
**5.** An ideal gas undergoing a change of state from X to Y through four different paths I, II, III, and IV are as shown in the *P*-*V* diagram that leads to the same change of state, then the change in internal energy is:



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

**6.** Which of the following is true with regards to the energy of an isolated system?
(a) $Q \neq 0$
(b) $dW \neq 0$
(c) $E = \text{constant}$
(d) All the mentioned above

**7.** In the given *P*-*V* diagram, the path (2) from A to B is zig-zag path, but path (1) is a simple path. Then,



(a) $\Delta U_1 = \Delta U_2$ (b) $\Delta U_1 > \Delta U_2$
(c) $\Delta U_1 < \Delta U_2$ (d) $\Delta U_1 = \Delta U_2 = 0$

## First Law of Thermodynamics

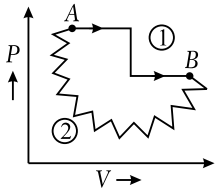
**8.** Which of the following is a path function?
(a) Temperature (b) Internal energy
(c) Work done (d) All of the above

**9.** Air is expanded from 100 L to 150 L at two atmospheric pressures. The external work done is: (Given, $1\text{atm} = 10^5\ \text{Nm}^{-2}$)
(a) $1 \times 10^4$ J (b) $5 \times 10^4$ J
(c) $1 \times 10^6$ J (d) $2 \times 10^4$ J

**10.** An electric heater supplies heat to a system at a rate of 120 W. If system performs work at a rate of 90 $\text{Js}^{-1}$, the rate of increase in internal energy is:
(a) 210 $\text{Js}^{-1}$ (b) 30 $\text{Js}^{-1}$
(c) 60 $\text{Js}^{-1}$ (d) 90 $\text{Js}^{-1}$

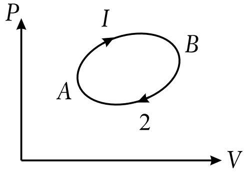
**11.** 2 kg of water is heated from 40°C to 70°C. If its volume remains constant, then the change in internal energy is: (Specific heat of water = 4148 $\text{Jkg}^{-1}\text{K}^{-1}$)
(a) $1.24\times10^5$ J (b) $2.48\times10^5$ J
(c) $1\times10^5$ J (d) $2\times10^5$ J

**12.** In the given *P*-*V* diagram, the path (2) from A to B is zig-zag path, but path (1) is a simple path. Then,



(a) $W_1=W_2$ (b) $W_1<W_2$
(c) $W_1>W_2$ (d) $W_1+W_2=0$

**13.** 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 1300 J, the work done by the system along path (1) is more than path (2) by 350 J. The heat exchanged by the system in path:



(a) 950 J (b) 1650 J
(c) 800 J (d) 350 J

**14.** 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) Change in internal energy $(\Delta U)$
(d) None of these

**15.** Which of the following is not a thermodynamic coordinate?

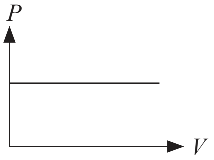
(a) Volume *(V)* (b) Pressure *(P)*
(c) Temperature *(T)* (d) Gas constant *(R)*

**16.** Which is an intensive property?
(a) Density (b) Work done
(c) Mass (d) Volume

**17.** Which is an extensive property?
(a) Temperature (b) Work done
(c) Internal energy (d) Both (b) and (c)

## Thermodynamic Processes

**18.** Which of the following process is correct for given *P-V* diagram?



(a) Isothermal process
(b) Adiabatic process
(c) Isochoric process
(d) Isobaric process

**19.** Match the following with correct one.

| Column I | | Column II | |
|---|---|---|---|
| A | Isobaric | (i) | $\Delta U = \Delta W$ |
| B | Isochoric | (ii) | Pressure constant |
| C | Adiabatic | (iii) | Temperature constant |
| D | Isothermal | (iv) | $\Delta Q = 0$ |

(a) A-(ii), B-(i), C-(iv), D-(iii)
(b) A-(ii), B-(iii), C-(i), D-(iv)
(c) A-(iii), B-(iv), C-(ii), D-(i)
(d) A-(iv), B-(iii), C-(ii), D-(i)

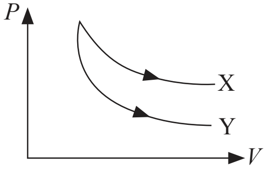
**20.** In a thermodynamic process with 2 moles of gas, 30 J of heat is released and 22 J of work is done on the gas. Given that initial internal energy of the sample was 20 J, what will be the final internal energy?
(a) 72 J (b) 32 J
(c) 28 J (d) 12 J

**21.** One mole of oxygen is expanded from a volume 1 L to 5 L at a constant temperature *T* = 280 K. The change in internal energy is:
(a) 0.22 kJ (b) 22 kJ
(c) 0 kJ (d) 11 kJ

**22.** A sample of perfect gas is compressed isothermally to half its volume. If it is compressed adiabatically to the same volume, the final pressure of the gas will be:
(a) more.
(b) less.
(c) same.
(d) more or less depending upon the initial temperature of the gas.

**23.** Which of the following statements is true about the indicator diagram of adiabatic and isothermal processes?
(a) The slope of isothermal is more than that of adiabatic.
(b) The slope of adiabatic is more than that of isothermal.
(c) Both are parallel curves.
(d) Data is insufficient.

**24.** The given *P-V* diagram is an expansion of a gas. Which one of the following statement is true?



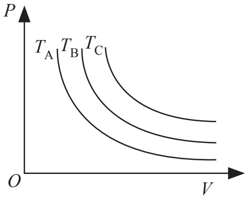
(a) *X* is isothermal and *Y* is isobaric process.
(b) *X* is isothermal and *Y* is isochoric process.
(c) *X* is isothermal and *Y* is adiabatic process.
(d) Both are adiabatic process.

**25.** The possibility of increase in the temperature of a gas without adding heat to it happens in:
(a) adiabatic expansion.
(b) adiabatic compression.
(c) isothermal compression.
(d) isothermal expansion.

**26.** The ideal gas equation for an adiabatic process is:
(a) $PV^{\gamma} = \text{constant}$ (b) $PV^{\gamma+1} = \text{constant}$
(c) $PV^{\gamma} = 0$ (d) $PV^{\gamma-1} = \text{constant}$

**27.** If an ideal gas undergoes isothermal process from some initial state *A* to the final state *B*, then the change in internal energy during this process is:
(a) $dU = dW$ (b) $dU = dQ$
(c) $dW = dQ$ (d) $dW = -dQ$

**28.** The isothermal diagram of a gas at three different temperatures $T_A$, $T_B$, and $T_C$ is shown in the given figure. Then,



(a) $T_A > T_B > T_C$. (b) $T_A < T_B > T_C$.
(c) $T_A < T_B < T_C$. (d) $T_A > T_B < T_C$.

**29.** The relation between the slope of isothermal curve and slope of adiabatic curve:

(a) slope of isothermal curve = $\gamma$ times slope of adiabatic curve.

(b) slope of adiabatic curve = $\gamma$ times slope of isothermal curve.

(c) slope of isothermal curve = $\gamma^2$ times slope of adiabatic curve.

(d) slope of adiabatic curve = $\gamma^{-1}$ times slope of isothermal curve.

**30.** An ideal gas at 27°C is compressed adiabatically to 8/27 of its original volume. The rise in temperature is: (Take, $\gamma = 5/3$)

(a) 475°C (b) 150°C

(c) 275°C (d) 402°C

**31.** A monoatomic gas ($\gamma = 5/3$) at pressure P is suddenly compressed to 1/64th of its volume adiabatically. Then, pressure of gas is:

(a) $8p$ (b) $14p$

(c) $256p$ (d) $1024p$

**32.** A gas is compressed adiabatically till its temperature is doubled. The ratio of its final volume to initial volume will be:

(a) Equal to 0.5 (b) More than 0.5

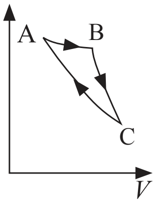
(c) Less than 0.5 (d) Between 1 and 2

**33.** One mole of an ideal gas at an initial temperature of $T$ K does 6 R J of work adiabatically. If the ratio of specific heats of this gas at constant pressure and at constant volume is 5/3, the final temperature of gas will be:

(a) $(T + 2.4)$ K (b) $(T - 2.4)$ K

(c) $(T + 4)$ K (d) $(T - 4)$ K

**34.** Consider a cycle followed by an engine as shown in figure.



A to B is isothermal, B to C is adiabatic, and C to A is adiabatic. Such a process does not exist because:

(a) heat is completely converted to mechanical energy in such a process, which is not possible.

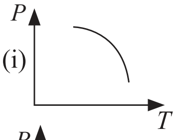
(b) curves representing an adiabatic process and an isothermal process don't intersect.

(c) mechanical energy is completely converted to heat in this process, which is not possible.

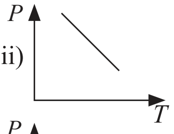
(d) curves representing two adiabatic processes can intersect.

**35.** Which of the following $P$-$V$ diagram represents the graph of isobaric process?

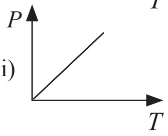
(i)



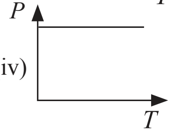
(ii)



(iii)



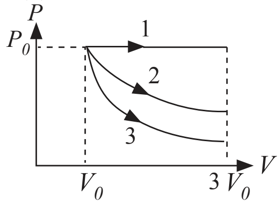
(iv)



(a) (i) (b) (ii), (iii)

(c) (iii) (d) (iv)

**36.** Helium gas expanded from volume to $V_0$ to $3V_0$ under three different processes, as shown in the figure. Process (1) is isobaric process, process (2) is isothermal, and process (3) is adiabatic.



Let $\Delta U_1$, $\Delta U_2$, and $\Delta U_3$ be the change in internal energy of the gas in these three processes, then

(a) $\Delta U_1 < \Delta U_2 < \Delta U_3$

(b) $\Delta U_1 < \Delta U_2 > \Delta U_3$

(c) $\Delta U_1 > \Delta U_2 > \Delta U_3$

(d) $\Delta U_1 > \Delta U_2 < \Delta U_3$

**37.** Two identical cylinders A and B with frictionless pistons contain the same ideal gas at the same temperature and the same volume $V$. The mass of gas A is $m_A$ and that of B is $m_B$. The gas in each cylinder is now allowed to expand isothermally to the same final volume $2V$. The change in the pressure in A and B are found to be $\Delta P$ and $2\Delta P$ respectively. Then,

(a) $4m_A = 9m_B$ (b) $3m_A = 5m_B$

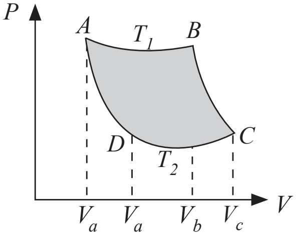
(c) $2m_A = m_B$ (d) $3m_A = 2m_B$

**38.** A heat insulating cylinder with a movable piston contains 5 moles of hydrogen at standard temperature and pressure of the gas is compressed to quarter of its original volume then the pressure of the gas is increased by ($\gamma = 1.5$):

(a) $2^{1.5}$ (b) $4^{1.5}$

(c) $5^{1.5}$ (d) $6^{1.5}$

**39.** Two different adiabatic parts for the same gas intersect two isothermals at $T_1$ and $T_2$ as shown in $P$-$V$ diagram. Then the ratio of $V_a$ and $V_b$ will be:

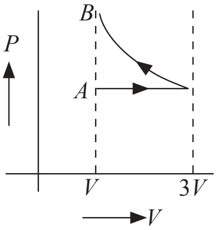


(a) $\gamma \dfrac{V_d}{V_c}$ (b) $2\gamma \dfrac{V_d}{V_c}$

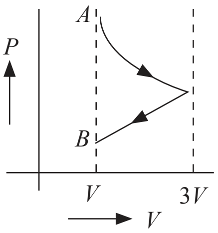
(c) $\dfrac{V_d}{V_c}$ (d) $\dfrac{V_c}{V_d}$

**40.** 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:

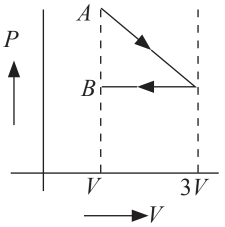
(i)



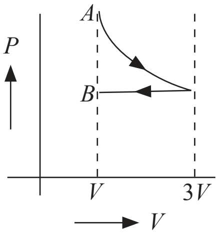
(ii)



(iii)



(iv)



(a) (i) (b) (ii)

(c) (iii) (d) (iv)

**41.** An ideal gas at pressure $P$ is adiabatically compressed so that its density becomes five times the initial value. The final pressure of the gas will be:

(a) $5(\gamma + 1)P$ (b) $5(\gamma - 1)P$

(c) $5^{\gamma}P$ (d) $2.5\gamma P$

**42.** The work done in adiabatic process is given by:

(a) $\dfrac{nR(T_1 - T_2)}{\gamma}$ (b) $\dfrac{nR(T_1 - T_2)}{\gamma - 2}$

(c) $\dfrac{nR(T_1 - T_2)}{\gamma - 1}$ (d) $nR(T_1 - T_2)$

**43.** A gas is compressed at a constant pressure of 50 $Nm^{-2}$ from a volume of 10 $m^3$ to a volume of 4 $m^3$. Energy of 100 J is then added to the gas by heating. Its internal energy is:

(a) increased by 400 J

(b) increased by 200 J

(c) increased by 100 J

(d) decreased by 200 J

**44.** A gas is expanded at a constant pressure of 50 $Nm^{-2}$ from a volume of 5 $m^3$ to a volume of 10 $m^3$. Energy of 100 J is then added to the gas by heating. Its internal energy is:

(a) increased by 150 J

(b) decreased by 150 J

(c) increased by 350 J

(d) decreased by 350 J

**45.** A gas is compressed at a constant pressure of 30 $Nm^{-2}$ from a volume of 20 $m^3$ to a volume of 10 $m^3$. Energy of 300 J is then added to the gas by heating. Its internal energy is:

(a) decreased by 600 J (b) decreased by −100 J

(c) increased by 600 J (d) increased by 100 J

**46.** A sample of gas expands from volume $V_1$ to $V_2$. The amount of work done by the gas is greatest when the expansion is

(a) adiabatic.

(b) isobaric.

(c) isothermal.

(d) equal in all the three cases.

**47.** A sample of gas expands from volume $V_1$ to $V_2$. The amount of work done by the gas is minimum when the expansion is

(a) adiabatic.

(b) isobaric.

(c) isothermal.

(d) equal in all the three cases.

**48.** The relation between internal energy $U$, pressure $P$ and volume $V$ of a gas in an adiabatic process is $U = a + b\,PV$, where $a$ and $b$ are positive constants. What is the value of $\gamma$ ?

(a) $\dfrac{a}{b}$ (b) $\dfrac{a+1}{b}$

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

**49.** Three samples of the same gas $X$, $Y$, and $Z$ ($\gamma = 1.5$) have equal volume initially. Now, the volume of each sample is doubled. For $X$, the process is adiabatic, for $Y$, it is isobaric and for $Z$, the process is isothermal. If the final pressures are equal for all the three samples, the ratio of their initial pressures is:

(a) $2:1:\sqrt{2}$ (b) $1:2:\sqrt{2}$

(c) $2\sqrt{2}:1:2$ (d) $2\sqrt{2}:2:1$

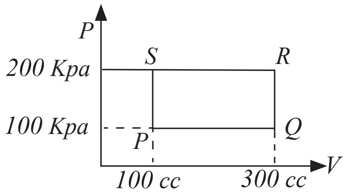
**50.** Two mole of an ideal gas expands adiabatically at constant pressure such that its temperature $T \propto \dfrac{1}{\sqrt{V}}$,

The value of $\gamma$ for the gas is:

(a) 1.2 (b) 1.3

(c) 1.4 (d) 1.5

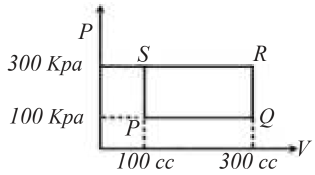
**51.** A thermodynamic system is taken through the cycle PQRSP process. The net work done by the system is:



(a) 20 J (b) 40 J

(c) −200 J (d) 400 J

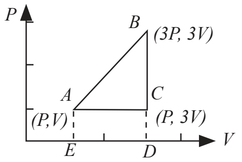
**52.** A thermodynamic system is taken through the cycle PQRSP process. The net work done on the system is:



(a) −20 J (b) −40 J

(c) 20 J (d) 40 J

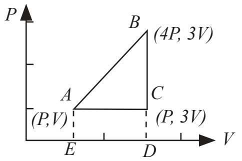
**53.** An ideal gas is taken around ABCA as shown in the above *P-V* diagram. The work done during a cycle is:



(a) 2 *PV* (b) 3 *PV*

(c) 4 *PV* (d) 2.5 *PV*

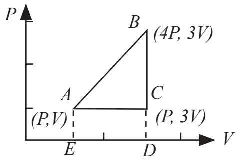
**54.** An ideal gas is taken around ABCA as shown in the above *P-V* diagram. The amount of heat given to the system during a cycle is:



(a) 2 *PV* (b) 3 *PV*

(c) 4 *PV* (d) 5 *PV*

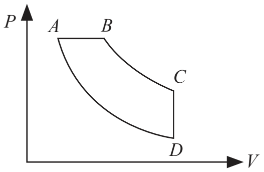
**55.** An ideal gas is taken around ABCA as shown in the above *P-V* diagram. The change in its internal energy:



(a) −3 *PV* (b) 3 *PV*

(c) 0*PV* (d) 2 *PV*

**56.** In pressure-volume diagram given below, the isochoric, isothermal, and isobaric parts respectively, are:



(a) BA, AD, DC (b) DC, CB, BA

(c) AB, BC, CD (d) CD, DA, AB

**57.** Pressure *P*, volume *V* and temperature *T* of a certain material are related by $P = \alpha T^2/V$ where α is constant. Work done by the material when temperature changes from $T_0$ to $3T_0$ and pressure remains constant is:

(a) $2\alpha T_0^2$ (b) $4\alpha T_0^2$

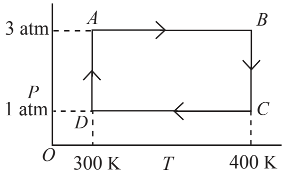
(c) $4\alpha T_0^2$ (d) $8\alpha T_0^2$

**58.** The relation between internal energy *U*, pressure *P* and volume *V* of a gas in an adiabatic process is *U*=*x* + *y PV*, where, *x* and *y* are positive constants. What is the value of γ?

(a) $\frac{x}{y}$ (b) $\frac{x+1}{x}$

(c) $\frac{y+1}{y}$ (d) $\frac{y}{x}$

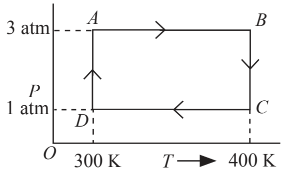
**59.** Two moles of helium gas undergo a cyclic process as shown in figure. Assuming the gas to be ideal. The net work done by the gas is:



(a) $200R\ln 3$ (b) $300R\ln 2$

(c) $-300R\ln 3$ (d) $600R\ln 3$

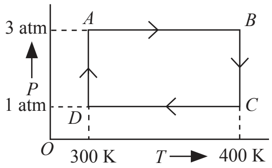
**60.** 20 moles of helium gas undergo a cyclic process as shown in figure. Assuming the gas to be ideal. The net work done by the gas for path *AB* and *CD* is:



(a) 1662 J (b) 3326 J

(c) 0 (d) −3326 J

**61.** 20 moles of helium gas undergo a cyclic process as shown in figure. Assuming the gas to be ideal. The net work done by the gas for path *BC* and *DA* is:



(a) $2000R\ln 3$ (b) $300R\ln 2$

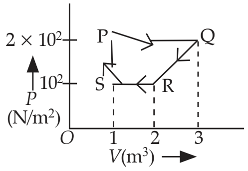
(c) $14000R\ln 3$ (d) $8000R\ln 3$

**62.** Two identical containers $X$ and $Y$ with friction less pistons contain the same ideal gas at the same temperature and the same volume $V$. The mass of gas $X$ is $m_x$ and that of $Y$ is $m_y$. The gas in each cylinder is now allowed to expand isothermally to the same final volume $2V$. The change in the pressure in $X$ and $Y$ are found to be $\Delta P$ and $3\Delta P$ respectively. Then,

(a) $4m_x = 9m_y$ (b) $4m_x = m_y$

(c) $3m_x = m_y$ (d) $3m_x = 2m_y$

**63.** A cyclic process is shown in the figure. Work done during the cyclic process PQRSP is:



(a) 100 J (b) 120 J

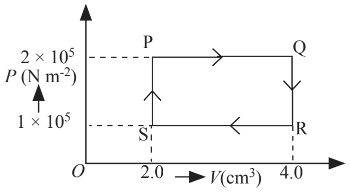
(c) 150 J (d) 170 J

**64.** One mole of an ideal monatomic gas at temperature $T_0$ expands slowly according to the law $P/V$ = constant. If the final temperature is $3T_0$, heat supplied to the gas is:

(a) $\frac{3}{2}RT_0$ (b) $3RT_0$

(c) $4RT_0$ (d) $1.5RT_0$

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



(a) 0.4 J of work is done by the gas from P to Q.

(b) 0.2 J of work is done on the gas from R to S.

(c) No work is done by the gas from Q to R.

(d) Work is done by the gas from Q to R and on the gas from S to P.

**66.** 800 cc volume of a gas having $\gamma = 5/2$ is suddenly compressed to 200 cc. If the initial pressure is $P$, then the final pressure will be:

(a) $3.2\,P$ (b) $32\,P$

(c) $16\,P$ (d) $1.6\,P$

[***Hint:*** *Sudden compression is adiabatic.*]

**67.** A monatomic gas initially at 315 K is suddenly compressed to one-eighth of its original volume. The temperature after compression is:

(a) 560 K (b) 1260 K

(c) 1160 K (d) 880 K

[***Hint:*** *Sudden compression is adiabatic.*]

**68.** When an ideal gas with pressure $P$ and volume $V$ is compressed isothermally to one-fourth of its volume, the pressure is $P_1$. When the same gas is compressed polytropically according to the equation $PV^{1.5}$ = constant, to one-fourth of its initial volume, the pressure is $P_2$. The ratio $P_2{:}P_1$ is:

(a) 1:2 (b) 3:2

(c) 2:1 (d) 2:3

**69.** An ideal gas at pressure $P$ and volume $V$ is expanded to volume $3V$. Column I represents the thermodynamic processes used during expansion. Column II represents the work done during these processes in the random order.

| | Column I | | Column II |
|---|---|---|---|
| A | Isobaric | (i) | $PV\ln 3$ |
| B | Adiabatic | (ii) | $2PV$ |
| C | Isothermal | (iii) | $PV\left(\frac{1-3^{1-\gamma}}{\gamma-1}\right)$ |

(a) A-(i), B-(ii), C-(iii)

(b) A-(ii), B-(iii), C-(i)

(c) A-(ii), B-(i), C-(iii)

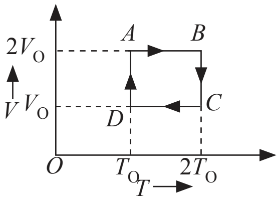
(d) A-(iii), B-(i), C-(ii)

**70.** A gas expands with temperature according to the relation $V = KT^{2/3}$ where $K$ is a constant. The work done by the gas when the temperature changes by 60 $K$ is:

(a) 4 R (b) 40 R

(c) 0.4 R (d) 0.04 R

**71.** 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 correct?



(a) The magnitude of work done by the gas is $4\,RT_0\ln 2$.

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

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

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

**72.** Pressure $P$, volume $V$ and temperature $T$ for a certain gas are related by $P = \dfrac{XT - YT^2}{V}$, where $X$ and $Y$ are constants. The work done by the gas as its temperature change from $T_1$ to $T_2$ with pressure remaining constant is:

(a) $X - Y(T_2 - T_1)$

(b) $X(T_2^2 - T_1^2) - Y(T_2 - T_1)$

(c) $X(T_2 - T_1) - Y(T_2^2 - T_1^2)$

(d) $(X - Y)(T_2^2 - T_1^2)$

**73.** When the state of a gas adiabatically changed from an equilibrium state $X$ to another equilibrium state $Y$, an amount of work done on the system is 35 J. If the gas is taken from state $X$ to $Y$ via process in which the net heat absorbed by the system is 12 calorie, then the net work done by the system is: (1 calorie = 4.2 J)

(a) 13.6 J (b) 15.4 J

(c) 14.6 J (d) 1.26 J

**74.** If a gas is compressed adiabatically by doing work of 250 J, the change in internal energy of the gas is:

(a) 150 J (b) 250 J

(c) 0 (d) 2500 J

**75.** In changing the state of a gas adiabatically from equilibrium state $X$ to another equilibrium state $Y$ an amount of work equal to 19.3 J is done on the system. If the gas is taken from state $X$ to $Y$ via a process in which the net heat absorbed by the system is 9.35 calorie then the net work done by the system in latter case is: (Take 1calorie = 4.2 J)

(a) 20 J (b) 58.6 J

(c) 40 J (d) 80 J

**76.** A monatomic gas is compressed adiabatically to one-third of its original volume, the final pressure of gas in terms of initial pressure $P$ is:

(a) 6.24 $PJ$ (b) 108 $PJ$

(c) 9.08 $PJ$ (d) 62.4 $PJ$

**77.** If at 60°C and 70 cm of mercury pressure, a definite mass of a gas is compressed slowly, then the final pressure of the gas if the final volume is half of the initial volume ($\gamma = 3/2$) is:

(a) 120 cm of Hg (b) 140 cm of Hg

(c) 160 cm of Hg (d) 180 cm of Hg

**78.** During an isothermal expansion, a confined ideal gas does –350 J of work against its surroundings. This implies that

(a) 350 J of heat has been removed from the gas.

(b) 350 J of heat has been added to the gas.

(c) no heat is transferred because the process is isothermal.

(d) 700 J of heat has been added to the gas.

## Second Law of Thermodynamics

**79.** According to Kelvin–Planck's statement of second law of thermodynamics:

(a) it is impossible to construct an engine working on a non-cyclic process, whose sole purpose is to convert heat energy into work.

(b) it is possible to construct an engine working on a cyclic process, whose sole purpose is to convert the heat energy into work.

(c) it is impossible to construct a device which while working in a cyclic process produces no effect other than the transfer of heat from a colder body to a hotter body.

(d) None of the above

**80.** Second law of efficiency is defined as:

(a) actual energy intake/minimum energy intake.

(b) minimum energy intake/actual energy intake.

(c) actual energy intake/maximum energy intake.

(d) maximum energy intake/minimum energy intake.

**81.** The change of entropy, when heat is absorbed by the gas is:

(a) positive.

(b) negative.

(c) positive or negative.

(d) Data is insufficient.

## Reversible and Irreversible Processes

**82.** A process is said to be reversible if

(a) the surroundings return to their original states.

(b) both the system as well as the surroundings return to their original states.

(c) the system returns to their original states.

(d) neither systems nor surroundings return to their original states.

**83.** Which of the following processes described below is irreversible?

(a) Work done against friction

(b) Joule's heating effect

(c) Diffusion of gases into another

(d) All of the above

## Heat Engines and Refrigerator

**84.** A heat engine has an efficiency, $\eta$. Temperatures of source and sink are each decreased by 200 K. The efficiency of the engine:

(a) Decreases (b) Increases

(c) No change (d) Data is insufficient.

**85.** An engine has an efficiency of 0.25 when temperature of sink is reduced by 48°C, if its efficiency is doubled then the temperature of the source is:

(a) 192°C (b) 292°C
(c) 96°C (d) 100°C

**86.** If a steam engine delivers $8.0 \times 10^8$ J of work per minute and absorbs $7 \times 10^9$ J of heat per minute from its boiler then the efficiency of the engine is:

(a) 11.4% (b) 12.4%
(c) 15.4% (d) 116.4%

**87.** In a heat engine, the temperature of the source and sink are 500 K and 375 K. If the engine consumes $5\times10^5$ J per cycle, the work done per cycle is:

(a) $5 \times 10^5$ J (b) $5 \times 10^6$ J
(c) $1.25 \times 10^5$ J (d) $1.25 \times 10^6$ J

**88.** When the door of a refrigerator is kept open, then the room temperature starts

(a) first hot up then cool down.
(b) first cool down then hot up.
(c) hot up.
(d) neither cool down nor hot up.

**89.** A refrigerator is to maintain eatables kept inside at 9°C. The coefficient of performance of refrigerator if room temperature is 28°C is:

(a) 15.2 (b) 14.8
(c) 13.8 (d) 12.8

**90.** The co-efficient of performance of refrigerator, whose efficiency is 20% is:

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

**91.** If the co-efficient of performance of a refrigerator is 5 and operates at the room temperature 25°C, the temperature inside the refrigerator is:

(a) 240 K (b) 248 K
(c) 250 K (d) 252 K

**92.** The temperature inside a refrigerator is $t_B$°C and the room temperature is $t_A$°C. The amount of heat delivered to the room for each joule of electrical energy consumed ideally will be:

(a) $\frac{t_A - 273}{t_A - t_B}$ (b) $\frac{t_B + 273}{t_A - t_B}$

(c) $\frac{t_A + 273}{t_A - t_B}$ (d) $\frac{t_B - 273}{t_A - t_B}$

**93.** The freezer in a refrigerator is located at the top section so that:

(a) the entire chamber of the refrigerator is cooled quickly due to convection.
(b) the motor is not heated.
(c) the heat gained from the environment is high.
(d) the heat gained from the environment is low.

## Carnot Engine and Its Efficiency

**94.** Carnot engine is:

(a) operating between two temperatures $T_1$ (source) and $T_2$(sink) have maximum efficiency.
(b) consisting of two isothermal processes connected by two adiabatic processes.
(c) irreversible engine.
(d) Both (a) and (b) options are correct

# HIGH-ORDER THINKING SKILL

## Thermal Equilibrium

**1.** 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

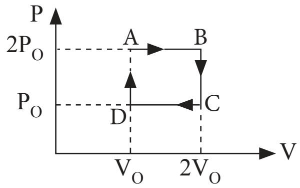
## Zeroth Law of Thermodynamics

**2.** A perfect gas goes from a state A to another state B by absorbing $8 \times 10^5$ J of heat and doing $6.5 \times 10^5$ J of external work. It is now transferred between the same two states in another process in which it absorbs $10^5$ J of heat. In the second process:

(a) work done by gas is $10^5$ J
(b) work done on gas is $10^5$ J
(c) work done by gas is $0.5 \times 10^5$ J
(d) work done on the gas is $0.5 \times 10^5$ J

## Heat, Internal Energy, and Work

**3.** The P-V diagram represents the thermodynamic cycle of an engine operating with an ideal mono atomic gas. The amount of heat extracted from the source in a single cycle is:

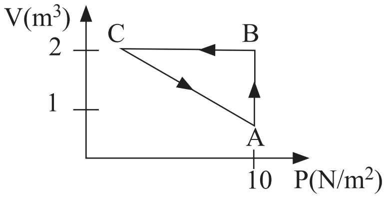


(a) $P_0V_0$ (b) $\left(\frac{13}{2}\right)P_0V_0$

(c) $\left(\frac{11}{2}\right)P_0V_0$ (d) $4P_0V_0$

## First Law of Thermodynamics

**4.** An ideal gas is taken through the cycle ABCA, as shown in the figure. If the net heat supplied to the gas in the cycle is 5 J, the work done by the gas in the process CA is:



(a) $-5$ J
(b) $-10$ J
(c) $-15$ J
(d) $-20$ J

## Thermodynamic Process

**5.** Helium gas is compressed adiabatically in a closed container of $10^3$ L. Find the pressure and change in volume produced if the compression is produced due to pressure change of $5\times10^4$ Pa. Compressibility of He $=3.7\times10^{-8}$ m$^2$/N)

(a) $P=2.22\times10^{-8}$ Pa, $\Delta V=1.85$ mL
(b) $P=16.2\times10^{6}$ Pa, $\Delta V=1.85$ L
(c) $P=2.22\times10^{8}$ Pa, $\Delta V=18.5$ mL
(d) $P=1.62\times10^{7}$ Pa, $\Delta V=18.5$ L

## Heat Engines and Refrigerators

**6.** A refrigerator works between 4°C and 30°C. It is required to remove 600 calories of heat every second in order to keep the temperature of the: refrigerated space constant. The power required is: [Take 1 cal = 4.2 joules]

(a) 236.5 W
(b) 2365 W
(c) 2.365 W
(d) 23.65 W

## Reversible and Irreversible Processes

**7.** Which of the following process is reversible?

(a) Transfer of heat by conduction
(b) Transfer of heat by radiation
(c) Electrical heating of nichrome wire
(d) None of these

## NCERT EXEMPLAR PROBLEMS

## Thermal Equilibrium

**1.** Three copper blocks of masses $M_1$, $M_2$, and $M_3$ kg respectively are brought into thermal contact till they reach equilibrium. Before contact, they were at $T_1$, $T_2$, $T_3$ ($T_1 > T_2 > T_3$). Assuming there is no heat loss to the surroundings, the equilibrium temperature $T$ is ($s$ is specific heat of copper):

(a) $T=\dfrac{T_1+T_2+T_3}{3}$

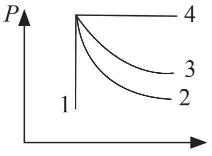
(b) $T=\dfrac{M_1T_1+M_2T_2+M_3T_3}{M_1+M_2+M_3}$

(c) $T=\dfrac{M_1T_1+M_2T_2+M_3T_3}{3(M_1+M_2+M_3)}$

(d) $T=\dfrac{M_1T_1s+M_2T_2s+M_3T_3s}{M_1+M_2+M_3}$

## Thermodynamic Process

**2.** An ideal gas undergoes four different processes from the same initial state as shown in $P$-$V$ diagram. Four processes are adiabatic, isothermal, isobaric, and isochoric.



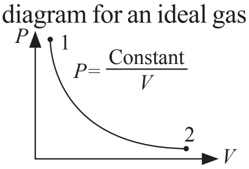
Out of 1,2,3, and 4 which one is adiabatic?

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

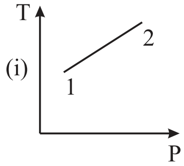
**3.** If an average person jogs, he produces 14.5 × $10^4$ calmin$^{-1}$. This is removed by the evaporation of sweat. The amount of sweat evaporated per minute (assuming 1 kg requires 580 × $10^3$ cal for evaporation) is:

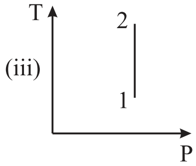
(a) 0.25 kg
(b) 2.25 kg
(c) 0.05 kg
(d) 0.20 kg

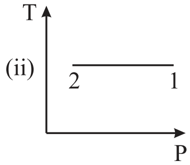
**4.** Consider $P$-$V$ diagram for an ideal gas shown in figure.

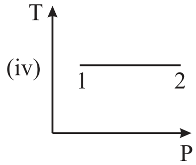


Out of the following diagrams, which represents the $T$-$P$ diagram?





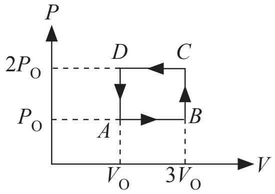




(a) (iv) (b) (ii)

(c) (iii) (d) (i)

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



(a) $6\ P_0V_0$ (b) $-2\ P_0V_0$

(c) $2\ P_0V_0$ (d) $4\ P_0V_0$

**6.** 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) $\left(\frac{1}{\gamma-1}\right)^2$

## ASSERTION AND REASONS

**Directions:** In the following questions, a statement of assertion is followed by a statement of reason. Mark the correct choice as:

(a) If both assertion and reason are true and reason is the correct explanation of assertion.
(b) If both assertion and reason are true but reason is not the correct explanation of assertion.
(c) If assertion is true but reason is false.
(d) If both assertion and reason are false.

### Thermal Equilibrium

**1. Assertion:** When a bullet is fired from a gun, the bullet pierces a wooden block and stops, decreasing the temperature of the bullet and the surrounding layers of wood.

**Reason:** Temperature is related to the energy of motion of the bullet as a whole.

### Zeroth Law of Thermodynamics

**2. Assertion:** The zeroth law said that, when two systems $X$ and $Y$ are in thermal equilibrium, there must be a physical quantity that has the same value for both.

**Reason:** The physical quantity, which is same for both the systems, is temperature.

### Heat, Internal Energy, and Work

**3. Assertion:** The heat supplied to a system is always equal to the increase in its internal energy.

**Reason:** When a system changes from one thermal equilibrium to another, some heat is dissipated by it.

### First Law of Thermodynamics

**4. Assertion:** First law of thermodynamics does not forbid flow of heat from lower temperature to higher temperature.

**Reason:** Heat supplied to a system is not equal to the increase in its internal energy.

### Thermodynamic Process

**5. Assertion:** The entropy of the solids is the highest.
**Reason:** Atoms of the solids are arranged in orderly manner.

### Heat Engines and Refrigerators

**6. Assertion:** A heat engine is the reverse of a refrigerator.
**Reason:** A refrigerator cannot work without some external work done on the system.

**7. Assertion:** The efficiency of a heat engine can be unity.
**Reason:** Efficiency of heat engine is fundamental limitation given by first law of thermodynamics.

**8.** **Assertion:** A refrigerator transfers heat from a higher temperature to a lower temperature.

**Reason:** Heat cannot flow from a higher temperature to a lower temperature.

## Second Law of Thermodynamics

**9.** **Assertion:** In an isolated system, the entropy increases.
**Reason:** The processes in an isolated system are isobaric.

## Reversible and Irreversible Processes

**10.** **Assertion:** A quasi-static isothermal expansion of an ideal gas in a cylinder fitted with a frictionless movable piston is an irreversible process.

**Reason:** A process is irreversible only if system remains in equilibrium with the surroundings at every stage.

## Cornot Engine and its Efficiency

**11.** **Assertion:** Efficiency of a Carnot engine increases on reducing the temperature of sink.

**Reason:** The efficiency of a Carnot engine is defined as ratio of net mechanical work done per cycle by the gas to the amount of heat energy absorbed per cycle from the source.

# ANSWER KEYS

## Practice Time

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | (a) | 2 | (a) | 3 | (d) | 4 | (d) | 5 | (d) | 6 | (c) | 7 | (a) | 8 | (c) | 9 | (a) | 10 | (b) |
| 11 | (b) | 12 | (c) | 13 | (a) | 14 | (c) | 15 | (d) | 16 | (a) | 17 | (d) | 18 | (d) | 19 | (a) | 20 | (d) |
| 21 | (c) | 22 | (a) | 23 | (b) | 24 | (c) | 25 | (b) | 26 | (a) | 27 | (c) | 28 | (c) | 29 | (b) | 30 | (d) |
| 31 | (d) | 32 | (b) | 33 | (d) | 34 | (a) | 35 | (d) | 36 | (c) | 37 | (c) | 38 | (b) | 39 | (c) | 40 | (d) |
| 41 | (b) | 42 | (c) | 43 | (a) | 44 | (b) | 45 | (c) | 46 | (b) | 47 | (a) | 48 | (b) | 49 | (c) | 50 | (d) |
| 51 | (c) | 52 | (b) | 53 | (a) | 54 | (b) | 55 | (c) | 56 | (d) | 57 | (d) | 58 | (c) | 59 | (a) | 60 | (c) |
| 61 | (a) | 62 | (c) | 63 | (c) | 64 | (c) | 65 | (d) | 66 | (b) | 67 | (b) | 68 | (c) | 69 | (b) | 70 | (b) |
| 71 | (b) | 72 | (c) | 73 | (b) | 74 | (b) | 75 | (a) | 76 | (a) | 77 | (b) | 78 | (b) | 79 | (d) | 80 | (b) |
| 81 | (a) | 82 | (b) | 83 | (d) | 84 | (b) | 85 | (a) | 86 | (a) | 87 | (d) | 88 | (c) | 89 | (b) | 90 | (d) |
| 91 | (b) | 92 | (c) | 93 | (a) | 94 | (d) | | | | | | | | | | | | |

## High-Order Thinking Skill

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | (d) | 2 | (d) | 3 | (b) | 4 | (a) | 5 | (b) | 6 | (a) | 7 | (d) |

## NCERT Exemplar Problems

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | (b) | 2 | (b) | 3 | (a) | 4 | (c) | 5 | (b) | 6 | (a) |

## Assertion and Reasons

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | (d) | 2 | (a) | 3 | (d) | 4 | (c) | 5 | (a) | 6 | (a) | 7 | (d) | 8 | (d) | 9 | (c) | 10 | (d) |
| 11 | (c) | | | | | | | | | | | | | | | | | | |

# HINTS AND EXPLANATIONS

## Practice Time

**1 (a)** Zeroth law of thermodynamics.

**2 (a)** The Zeroth law of thermodynamics leads to the concept of temperature.

**3 (d)** Zeroth law of thermodynamics.

**4 (d)** The internal energy of ideal gas depends only on temperature of gas, not on other factors.

**5 (d)** From the given initial state X to final state Y, change in internal energy is same in all the four cases, as it is independent of the path from X to Y.

**6 (c)** For an isolated system, $dQ = dW = 0$ and hence, $dU = 0$ by the first law.

**7 (a)** Internal energy does not depend on the path.

**8 (c)** Temperature and internal energy are path independent.

**9 (a)** Work done

$$\begin{aligned} W &= P\Delta V \\ &= 2\times10^5(150-100)\times10^{-3} \\ &= 1\times10^4\ \text{J} \end{aligned}$$

**10 (b)** According to the first law of thermodynamics,

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

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

$$\because \quad \frac{\Delta Q}{\Delta t} = 120\ \text{W},$$

$$\frac{\Delta W}{\Delta t} = 90\ \text{Js}^{-1}$$

$$\therefore \quad \frac{\Delta U}{\Delta t} = 120-90$$

$$= 30\ \text{Js}^{-1}$$

**11 (b)** Since volume of water remains constant, then work done

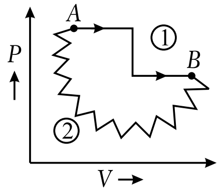
$$\begin{aligned} \Delta W &= PdV \\ &= 0 \end{aligned}$$

According to first pair of thermodynamics,

$$dQ = dU + dW,$$

$$\begin{aligned} dU &= dQ \\ &= ms\Delta T \\ &= 2\times4148\times(70-40) \\ &= 4148\times30\times2 \\ &= 248880\ \text{J} \\ &= 2.488\times10^5\ \text{J} \end{aligned}$$

**12 (c)** The area under *P-V* diagram gives the work done by the gas. Here, path (1) is greater than path (2), so $W_1 > W_2$.



**13 (a)** The change in internal energy of system will be same for both paths (1) and (2).

Along path (1),

$$\Delta Q_1 = \Delta U + \Delta W_1 \quad ...(i)$$

Along path (2),

$$\Delta Q_2 = \Delta U + \Delta W_2 \quad ...(ii)$$

Subtract (ii) from (i), we get,

$$\begin{aligned} \Delta Q_1 - \Delta Q_2 &= \Delta W_1 - \Delta W_2 \\ 1300 - \Delta Q_2 &= 350 \\ \Delta Q_2 &= 1300-350 \\ &= 950\ \text{J} \end{aligned}$$

**14 (c)** The only quantity *(Q-W)* which itself is the internal energy of the system is independent of the path.

**15 (d)** Pressure (*P*), volume (*V*) and temperature (*T*) are the thermodynamic co-ordinates used to describe the states of the system whereas gas constant (R) is a universal gas constant whose value is 8.314 J $\text{mol}^{-1}\ \text{K}^{-1}$.

**16 (a)** An intensive property is that which does not depend on the quantity of matter or mass of the system. Density is an intensive property.

**17 (d)** An extensive property is that which depend on the quantity of matter or mass of the system.

**18 (d)** In the given *P-V* diagram pressure remains constant although volume increases, hence the process is an isobaric process.

**19 (a)** Type of processes:

Isothermal - Temperature constant
Isobaric - Pressure constant
Isochoric - Volume constant
Adiabatic - $\Delta Q = 0$

**20 (d)** As we know that,

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

$$\therefore \quad \Delta Q = U_2 - U_1 + \Delta W$$

$$\because \quad \Delta Q = -30\ \text{J},$$

$$\Delta W = -22\ \text{J}$$

$$U_1 = 20\ \text{J}$$

$$\begin{aligned} \therefore \quad U_2 &= \Delta Q - \Delta W + U_1 \\ &= -30-(-22)+20 \\ &= 12\ \text{J} \end{aligned}$$

**21 (c)** In an isothermal process, the value of $\Delta T = 0$ and therefore the change in internal energy, $\Delta U = 0$.

**22 (a)** For isothermal compression,

$$P_2 = \frac{P_1V_1}{V_2}$$

For adiabatic compression,

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

$$\text{Since,} \quad \gamma = \frac{C_P}{C_V} > 1,$$

Hence $P_2$ will be more in adiabatic compression as compared to that of isothermal compression.

**23 (b)** As we know that,

$$\left(\frac{dP}{dt}\right)_{\text{adiabatic}} = -\gamma\frac{P}{V}$$

$$\text{and } \left(\frac{dP}{dt}\right)_{\text{isothermal}} = -\frac{P}{V}$$

Slope of adiabatic is more than isothermal.

**24 (c)** As slope of curve $Y$ is more than slope of $X$. Therefore, curve $X$ is showing isothermal process and curve $Y$ is showing adiabatic process.

**25 (b)** In adiabatic process,

$$dQ = 0$$

$$\Rightarrow \quad dU + dW = 0$$

$$\text{or } dU = -dW$$

In the process of compression, work is done on the gas therefore $dW$ is negative. Hence $dU$ is positive, i.e., internal energy of gas increases and therefore temperature of the gas also increases.

**26 (a)** Since for adiabatic process, $PV^{\gamma}$ = constant, this is the ideal gas equation.

**27 (c)** During isothermal process, internal energy of system always remains constant; hence change in it will be zero every where during the process.

**28 (c)** The given diagram shows that the curves move away from the origin, at the higher temperature.

**29 (b)** For isothermal process, $PV$ = constant

Differentiating both sides, we have

$$PdV + VdP = 0$$

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

Again for adiabatic process, $PV^{\gamma}$ = constant

Again, differentiating both sides we have-

$$dPV^{\gamma} + \gamma V^{\gamma-1}dVP = 0$$

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

$\therefore$ Slope of adiabatic cuve = $\gamma$ × Slope of isothermal curve

**30 (d)** We know that, for adiabatic process

$$PV^{\gamma} = \text{constant}$$

$$V^{x-1} = \text{constant}$$

$$300 = \left(\frac{8}{27}\right)^{\frac{2}{3}} T_2$$

$$T_2 = 675\text{ K}$$

$$= 402°\text{C}$$

**31 (d)** Since,

$$PV^{\gamma} = \text{constant}$$

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

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

$$\frac{P_2}{P_1} = \left(\frac{V_1}{\frac{V_1}{64}}\right)^{\gamma}$$

$$\frac{P_2}{P_1} = (64)^{\frac{5}{3}}$$

$$P_2 = 1024P_1$$

**32 (b)** As we know that,

$$PV^{\gamma} = \text{constant}$$

$$TV^{\gamma-1} = \text{constant}$$

$$T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1}$$

$$\left(\frac{V_2}{V_1}\right)^{\gamma-1} = \frac{T_1}{T_2}$$

$$\frac{V_2}{V_1} = \left(\frac{T_1}{2T_1}\right)^{\frac{1}{\gamma-1}} \qquad [\because\ T_2 = 2T_1]$$

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

Hence ratio will be more than 1/2.

**33 (d)** Since, for adiabatic process,

$$W = \frac{n\text{R}}{\gamma-1}\left(T_i - T_f\right)$$

After putting values, we have

$$6\text{R} = \frac{1\times\text{R}}{\left(\frac{5}{3}-1\right)}\left(T_i - T_f\right)$$

$$6 = \frac{3}{2}\left(T_i - T_f\right)$$

$$T_f = (T-4)\text{ K} \qquad (\because T_i = T\text{ K})$$

**34 (a)** In one complete cycle, ABCA, the system returns to its initial state so $dU = 0$ and $dQ = dW$, i.e., heat is completely converted into mechanical energy in the given process. It is not possible further two adiabatic curve BC and CA cannot intersect each other.

**35 (d)** In isobaric process, Pressure is constant.

$$\therefore\ V \propto T$$

**36 (c)** Process (1) is isobaric expansion ($P$ = constant).

Hence temperature of gas will increase.

$$\therefore\ \Delta U_1 = \text{Positive}$$

Process (2) is an isothermal process.

$\therefore\ \Delta U_2 = 0$

Process (3) is an adiabatic expansion.

Hence temperature of gas will fall.

$\therefore\ \Delta U_3 = \text{Negative}$

$\therefore\ \Delta U_1 > \Delta U_2 > \Delta U_3$

**37 (c)** For gas $A$,

$$P_1 = \left(\frac{RT}{M}\right)\frac{m_A}{V_1}$$

$$P_2 = \left(\frac{RT}{M}\right)\frac{m_A}{V_2}$$

$$\therefore \quad \Delta P = P_1 - P_2$$

$$= \frac{RT}{M} m_A \left(\frac{1}{V_1} - \frac{1}{V_2}\right)$$

Putting $V_1 = V$ and $V_2 = 2V$, we get

$$\Delta P = \left(\frac{RT}{M}\right)\frac{m_A}{2V} \qquad \text{...(i)}$$

Similarly, for gas $B$

$$2\Delta P = \left(\frac{RT}{M}\right)\frac{m_B}{2V} \qquad \text{...(ii)}$$

From equation (i) and (ii)

$$2m_A = m_B$$

**38 (b)** As the cylinder is a heat insulating, i.e., no heat is allowed to be exchanged. Hence the process is adiabatic.

$$\therefore \quad P_1V_1^\gamma = P_2V_2^\gamma$$

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

After putting values,

$$\therefore \quad \frac{P_2}{P} = \left(\frac{V}{V/4}\right)^{1.5}$$

$$\frac{P_2}{P} = (4)^{1.5}$$

$$P_2 = (4)^{1.5} P$$

**39 (c)** As we know,

For adiabatic curve BC,

$$T_1V_b^{\gamma-1} = T_2V_c^{\gamma-1} \qquad \text{...(i)}$$

Again, for adiabatic curve AD,

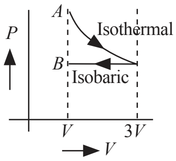
$$T_1V_a^{\gamma-1} = T_2V_d\gamma^{-1} \qquad \text{...(ii)}$$

Dividing (i) by (ii),

$$\left(\frac{V_b}{V_a}\right)^{\gamma-1} = \left(\frac{V_c}{V_d}\right)^{\gamma-1}$$

$$\Rightarrow \qquad \frac{V_a}{V_b} = \frac{V_d}{V_c}$$

**40 (d)**



**41 (c)** For an adiabatic process, $PV^\gamma$ = constant

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

$$= \left(\frac{\rho_2}{\rho_1}\right)^\gamma \quad \left(\because V = \frac{m}{\rho}\right)$$

$$= \left(\frac{5\rho_1}{\rho_1}\right)^\gamma \quad (\because \rho_2 = 5\rho_1)$$

$$\therefore \quad P_2 = P_1 5^\gamma$$

$$= 5^\gamma P \qquad (\because P_1 = P)$$

**42 (c)** In the adiabatic process, $PV^\gamma$ = constant ($K$).

If an ideal gas is changed from state ($P_1$, $V_1$, $T_1$) to state ($P_2$, $V_2$, $T_2$) adiabatically, then work done:

$$W = \int_{V_1}^{V_2} PdV$$

$$= K\int_{V_1}^{V_2} \frac{dV}{V^\gamma}$$

$$= K\left[\frac{V^{-\gamma+1}}{-\gamma+1}\right]_{V_1}^{V_2}$$

$$= \frac{K}{1-\gamma}\left[\frac{1}{V_2^{\gamma-1}} - \frac{1}{V_1^{\gamma-1}}\right]$$

$$W = \frac{1}{1-\gamma}\left[\frac{P_2V_2^\gamma}{V_2^{\gamma-1}} - \frac{P_1V_1^\gamma}{V_1^{\gamma-1}}\right]$$

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

$$= \frac{nR}{1-\gamma}\left(T_2 - T_1\right)$$

$$= \frac{nR\left(T_1 - T_2\right)}{(\gamma - 1)}$$

$$(\because P_1V_1 = nRT_1 \text{ and } P_2V_2 = nRT_2)$$

**43 (a)** As we know that,

$$\because \quad W = PdV$$

$$= 50(4 - 10)$$

$$= -300 \text{ J}$$

$$\because \quad dQ = dU + dW$$

$$\therefore \quad dU = dQ - dW$$

$$= 100 - (-300)$$

$$= 400 \text{ J}$$

**44 (b)** As we know that,

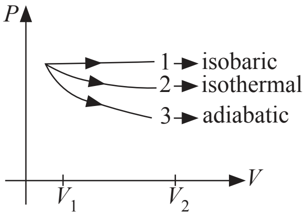
$$\because \; dW = PdV$$
$$= 50(10-5)$$
$$= 250 \text{ J}$$
$$\because \; dQ = dU + dW$$
$$\therefore \; dU = dQ - dW$$
$$= 100 - (250)$$
$$= -150 \text{ J}$$

**45 (c)** As we know that,

$$\because \; W = PdV$$
$$= 30(10-20)$$
$$= -300 \text{ J}$$
$$\because \; dQ = dU + dW$$
$$\therefore \; dU = dQ - dW$$
$$= 300 - (-300)$$
$$= 600 \text{ J}$$

**46 (b)** The *P*-*V* diagram for isobaric, isothermal, and adiabatic process of an ideal gas is shown in graph below.

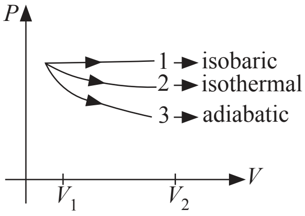
For same change in *V*, the *W* is maximum for the curve having maximum area enclosed with the volume axis.



In isobaric process, area enclosed is maximum.

**47 (a)** The *P*-*V* diagram for isobaric, isothermal, and adiabatic process of an ideal gas is shown in graph below.

For same change in *V*, the *W* is minimum for the curve having minimum area enclosed with the volume axis.



In adiabatic process, area enclosed is minimum.

**48 (b)** For an adiabatic process, $dQ = 0$

From the first law of thermodynamics, we get

$$0 = dU + PdV$$

or $d(a + bPV) + PdV = 0$

or $(b+1)PdV + bVdP = 0$

$$(b+1)\frac{dV}{V} = -b\frac{dP}{P}$$

Integrating both sides, we get

$$\ln(V^{b+1}P^{b}) = \text{constant}$$
$$PV^{\frac{b+1}{b}} = \text{another constant}$$

After comparing,

$$PV^{\gamma} = PV^{\frac{b+1}{b}}$$
$$\Rightarrow \quad \gamma = \frac{b+1}{b}$$

**49 (c)** Let $P_X$, $P_Y$, and $P_Z$ be the initial pressures of the three samples and *P* be the final pressure of each.

For *X*, the process is adiabatic ($PV^{\gamma}$= constant).

$$\therefore \quad P_X(V)^{3/2} = P(2V)^{3/2}$$
$$P_X = 2^{3/2}P$$

For *Y*, the process is isobaric.

$$\therefore \quad P_Y = P$$

For *Z*, the process is isothermal.

$$\therefore \quad PV = \text{constant}$$
$$\therefore \quad P_Z(V) = P(2V)$$
$$P_Z = 2P$$
$$P_X : P_Y : P_Z = 2^{3/2} : 1 : 2$$
$$= 2\sqrt{2} : 1 : 2$$

**50 (d)** By using,

$$PV = \text{constant}$$
$$\Rightarrow \quad TV^{\gamma-1} = \text{constant}$$

or $\quad T \propto V^{1-\gamma}$

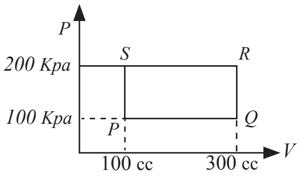
As $\quad T \propto \frac{1}{\sqrt{V}}$

$$\therefore \quad 1 - \gamma = -\frac{1}{2}$$

or $\quad \gamma = 1 + \frac{1}{2}$

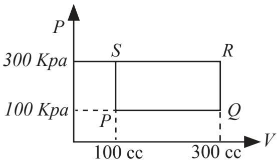
$$= \frac{3}{2}$$

**51 (c)** Work done = Area enclosed in the diagram



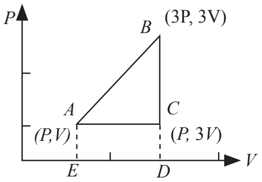
$$= \Delta P \Delta V$$
$$= (P_P - P_S)(V_Q - V_P)$$
$$= (1\times10^{5} - 2\times10^{5})(3\times10^{-4} - 1\times10^{-4})$$
$$= -20 \text{ J}$$

**52 (b)** Work done = Area enclosed in the diagram



$$= \Delta P \Delta V$$
$$= \left(P_P - P_S\right)(V_Q - V_P)$$
$$= \left(1\times10^5 - 3\times10^5\right)\left(3\times10^{-4} - 1\times10^{-4}\right)$$
$$= -40 \text{ J}$$

**53 (a)** Work done = Area enclosed in the diagram



$$P\Delta V = \text{Area of } \Delta\text{ABC},$$
$$= \frac{1}{2}\times \text{AC}\times\text{CB}$$
$$= \frac{1}{2}\times(3V - V)(3P - P)$$
$$= 2\,PV$$

**54 (b)** Work done = Area enclosed in the diagram

$$P\Delta V = \text{Area of } \Delta\text{ABC},$$
$$= \frac{1}{2}\times \text{AC}\times\text{CB}$$
$$= \frac{1}{2}\times(3V - V)(4P - P)$$
$$= 3PV$$

**55 (c)** In a cyclic process, the system returns to its initial state and so the internal energy is not changed.

**56 (d)** In isochoric process volume is constant, so CD part is isochoric process.

In isobaric process pressure is constant, so AB part is isobaric process.

In isothermal process, Temperature is constant $P \propto \frac{1}{V}$. DA part is isothermal process.

**57 (d)** The given relation is expressed as,

$$P = \frac{\alpha T^2}{V}$$
$$\therefore \quad V = \frac{\alpha T^2}{P}$$

As pressure is kept constant, so

$$dV = \left(\frac{2\alpha T}{P}\right)dT$$
$$W = \int P dV$$
$$= \int_{T_0}^{3T_0} P\left(\frac{2\alpha T}{P}\right)dT$$
$$= 2\alpha\left[\frac{T^2}{2}\right]_{T_0}^{3T_0}$$

**58 (c)** For an adiabatic process, $dQ = 0$

From the first law of thermodynamics, we get

$$0 = dU + PdV$$

or $\quad d(x + yPV) + PdV = 0$

or $\quad (y+1)PdV + yVdP = 0$

$$(y+1)\frac{dV}{V} = -y\frac{dP}{P}$$

Integrating both sides, we get

$$\ln(V^{y+1}P^{y}) = \text{constant}$$
$$PV^{\frac{y+1}{y}} = \text{another constant}$$

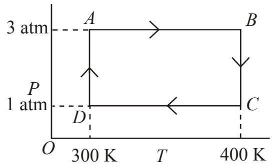
After comparing, we get

$$PV^{\gamma} = PV^{\frac{y+1}{y}}$$
$$\Rightarrow \quad \gamma = \frac{y+1}{y}$$

**59 (a)** At constant pressure, $W = P(V_f - V_i) = n\text{R}(T_f - T_i)$

At constant temperature,

$$W = n\text{R}T\ln\frac{V_f}{V_i}$$
$$= n\text{R}T\ln\left(\frac{P_i}{P_f}\right)$$



So work done for paths AB, BC, CD, and DA respectively will be:

$$W_{AB} = 2\times\text{R}(400 - 300)$$
$$= 200\text{ R}$$
$$W_{BC} = 2\times\text{R}\times 400\ln\left(\frac{3}{1}\right)$$
$$= 800\text{ R}\ln 3$$
$$W_{CD} = 2\times\text{R}(300 - 400)$$
$$= -200\text{ R}$$
$$W_{DA} = 2\times\text{R}\times 300\ln\left(\frac{1}{3}\right)$$
$$= -600\text{ R}\ln 3$$

The net work done by the gas is:

$$W = W_{AB} + W_{BC} + W_{CD} + W_{DA}$$
$$= 200\text{ R} + 800\text{ R}\ln 3 - 200\text{ R} - 600\text{ R}\ln 3$$
$$= 200\text{ R}\ln 3$$

**60 (c)** At constant pressure, $W = P(V_f - V_i) = n\text{R}(T_f - T_i)$

So, net work done for path AB and CD,

$$W = W_{AB} + W_{CD}$$
$$W_{\mathrm{AB}} = 20 \times \mathrm{R}(400 - 300)$$
$$= 2000\mathrm{R}$$
$$W_{\mathrm{CD}} = 20 \times \mathrm{R}(300 - 400)$$
$$= -2000\ \mathrm{R}$$
$$\therefore W_{\mathrm{net}} = 2000\ \mathrm{R} + (-2000\ \mathrm{R})$$
$$= 0\ \mathrm{R}$$

**61 (a)** At constant temperature,

$$W = n\mathrm{R}T \ln \frac{V_f}{V_i}$$
$$= n\mathrm{R}T \ln\left(\frac{P_i}{P_f}\right)$$
$$W_{BC} = 20 \times \mathrm{R} \times 400 \ln\left(\frac{3}{1}\right)$$
$$= 8000\ \mathrm{R} \ln 3$$
$$W_{DA} = 20 \times \mathrm{R} \times 300 \ln\left(\frac{1}{3}\right)$$
$$= -6000\ \mathrm{R} \ln 3$$
$$\therefore \quad W_{\mathrm{net}} = W_{BC} + W_{DA}$$
$$= 8000\ \mathrm{R} \ln 3 + (-6000\ \mathrm{R} \ln 3)$$
$$= 2000\ \mathrm{R} \ln 3$$

**62 (c)** For gas *X*,

$$P_1 = \left(\frac{\mathrm{R}T}{M}\right)\frac{m_X}{V_1}$$
$$P_2 = \left(\frac{\mathrm{R}T}{M}\right)\frac{m_X}{V_2}$$
$$\therefore \quad \Delta P = P_1 - P_2$$
$$= \frac{\mathrm{R}T}{M} m_X \left[\frac{1}{V_1} - \frac{1}{V_2}\right]$$

Putting $V_1 = V$ and $V_2 = 2V$, we get

$$\Delta P = \left(\frac{\mathrm{R}T}{M}\right)\frac{m_X}{2V} \quad \text{...(i)}$$

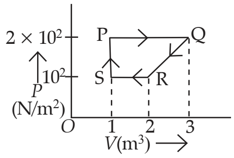
Similarly for gas *Y*,

$$3\Delta P = \left(\frac{\mathrm{R}T}{M}\right)\frac{m_Y}{2V} \quad \text{...(ii)}$$

From equation (i) and (ii), we get

$$3m_X = m_Y$$

**63 (c)** We know that,



Work done during cyclic process PQRSP = Area enclosed by PQRSP

$$= \left(\frac{PQ + RS}{2}\right) \times PS$$
$$= \frac{(2 + 1)}{2} \times 10^2$$
$$= 1.5 \times 10^2\ \mathrm{J}$$
$$= 150\ \mathrm{J}$$

**64 (c)** In a process $PV^x$=constant, molar heat capacity is given by,

$$C = \frac{R}{\gamma - 1} + \frac{R}{1 - x}$$

As the process is $P/V$ = constant,

i.e., $PV^{-1}$ = constant, therefore, $x = -1$

For monotonic gas,

$$\gamma = \frac{5}{3}$$
$$\therefore \quad C = \frac{\mathrm{R}}{\frac{5}{3} - 1} + \frac{\mathrm{R}}{1 - (-1)}$$
$$= \frac{3}{2}\mathrm{R} + \frac{\mathrm{R}}{2}$$
$$= 2\ \mathrm{R}$$

Heat supplied to gas,

$$\Delta Q = nC(\Delta T)$$
$$= 1(2\mathrm{R})\left(3T_0 - T_0\right)$$
$$= 4\ \mathrm{R}T_0$$

**65 (d)** In going from *Q* to *R* and from *S* to *P*, *V* = constant.

$$\text{So,} \quad \Delta V = 0$$
$$\therefore \quad W = P\Delta V$$
$$= 0$$

**66 (b)** For an adiabatic process, $PV^{\gamma}$ = constant.

$$\therefore \quad P_1 V_1^{\gamma} = P_2 V_2^{\gamma}$$
$$P_2 = P_1 \left(\frac{V_1}{V_2}\right)^{\gamma}$$
$$= P\left(\frac{800}{200}\right)^{5/2} \qquad (\because P_1 = P)$$
$$= \left(2^2\right)^{5/2} P$$
$$= 32\ P$$

**67 (b)** Sudden compression is adiabatic for which,

$$T_1 V_1^{\gamma - 1} = T_2 V_2^{\gamma - 1}$$
$$\therefore \quad T_2 = T_1 \left(\frac{V_1}{V_2}\right)^{\gamma - 1}$$
$$= 315 \times 8^{2/3}$$

$$= 315 \times 4$$
$$= 1260 \text{ K}$$

**68 (c)** For an isothermal process, $PV =$ constant

$$\therefore \quad PV = P_1 \frac{V}{4}$$
$$\text{or} \quad P_1 = 4P$$

For polytrophic process,

$$PV^{1.5} = \text{constant}$$
$$\therefore \quad PV^{1.5} = P_2 \left(\frac{V}{4}\right)^{1.5}$$
$$\text{or} \quad P_2 = \left(2^2\right)^{3/2} P$$
$$= 8P$$
$$\therefore \quad \frac{P_2}{P_1} = \frac{2}{1}$$

**69 (b)** For an isobaric process,

$$W = PV$$
$$= P\left(3V - V\right)$$
$$= 2PV$$

For an isothermal process,

$$\text{Work done} = \text{R}T \ln\left(\frac{3V}{V}\right)$$
$$= PV \ln 3$$

For an adiabatic process,

$$PV^{\gamma} = P_1 (3V)^{\gamma}$$
$$P_1 = \left(\frac{1}{3}\right)^{\gamma} P$$
$$= P3^{-\gamma}$$
$$\text{Work done} = \frac{PV - P_1(3V)}{\gamma - 1}$$
$$= \frac{PV\left(1 - 3^{1-\gamma}\right)}{\gamma - 1}$$

**70 (b)** As we know,

$$dW = PdV$$
$$= \frac{\text{R}T}{V} dV \quad \text{...(i)}$$
$$\text{As,} \quad V = KT^{\frac{2}{3}}$$
$$\therefore \quad dV = K\frac{2}{3}T^{\frac{-1}{3}} dT$$
$$\therefore \quad \frac{dV}{V} = \frac{K\frac{2}{3}T^{\frac{-1}{3}} dT}{KT^{\frac{2}{3}}}$$
$$= \frac{2}{3}\frac{dT}{T} \quad \text{...(ii)}$$

From equation (i), we get

$$W = \int_{T_1}^{T_2} \text{R}T \frac{dV}{V} \quad \text{...[By using eq. (ii)]}$$
$$= \int_{T_1}^{T_2} \text{R}T \frac{2}{3}\frac{dT}{T}$$
$$= \frac{2}{3}\text{R}[T]_{T_1}^{T_2}$$
$$= \frac{2}{3}\text{R}\left(T_2 - T_1\right)$$
$$= \frac{2}{3}\text{R} \times 60$$
$$= 40 \text{ R}$$

**71 (b)** As we know that,

$$W_{AB} = W_{CO}$$
$$= 0$$
$$W_{DA} = \text{R}T_0 \ln\left(\frac{2V_0}{V_0}\right)$$
$$= \text{R}T_0 \ln 2$$
$$W_{BC} = \text{R}\left(2T_0\right)\ln\left(\frac{V_0}{2V_0}\right)$$
$$= -2\,\text{R}T_0 \ln 2$$
$$\therefore \quad W = W_{AB} + W_{BC} + W_{CD} + W_{DA}$$
$$= 0 - 2\text{R}T_0 \ln 2 + 0 + \text{R}T_0 \ln 2$$
$$= -\text{R}T_0 \ln 2$$
$$\text{or} \quad |W| = \text{R}T_0 \ln 2$$

**72 (c)** As we know that,

$$P = \frac{XT - YT^2}{V}$$
$$PV = XT - YT^2$$

Since $P$ is constant, we have

$$\therefore \quad PdV = (\text{X} - 2YT)dT$$
$$\text{As,} \quad dW = PdV$$
$$= (\text{X} - 2YT)dT$$
$$\therefore \quad W = \int_{T_1}^{T_2} (\text{X} - 2YT)dT$$
$$= \left[XT - YT^2\right]_{T_1}^{T_2}$$
$$= X\left(T_2 - T_1\right) - Y\left(T_2^2 - T_1^2\right)$$

**73 (b)** In the first case, adiabatic change,

$$\Delta Q = 0,$$
$$\Delta W = -35 \text{ J}$$

From the first law of thermodynamics, we have

$$\Delta Q = \Delta U + \Delta W$$
$$0 = \Delta U - 35$$
$$\therefore \quad \Delta U = 35 \text{ J}$$

In second case,

$$\Delta Q = 12 \text{ cal}$$
$$= 12 \times 4.2 \text{ J}$$
$$= 50.4 \text{ J}$$
$$\Delta W = \Delta Q - \Delta U$$
$$= 50.4 - 35$$
$$= 15.4 \text{ J}$$

**74 (b)** Since the gas is compressed adiabatically, then $dQ = 0$ and $dW = -250$ J

From first law of thermodynamics,

$$dQ = dU + dW$$
$$\therefore \quad dU = -dW$$
$$= -(-250)$$
$$= 250 \text{ J}$$

**75 (a)** In the first case:

For adiabatic change, $\Delta Q = 0$

The work is done on the system.

$\Delta W = -19.3$ J

According to first law of thermodynamics,

$$\Delta Q = \Delta U + \Delta W$$
$$0 = \Delta U - 19.3$$
$$\Delta U = 19.3 \text{ J}$$

In second case,

$$\Delta Q = 9.35 \text{ cal}$$
$$= 9.35 \times 4.2$$
$$= 39.3 \text{ J}$$
$$\therefore \quad \Delta W = 39.3 - 19.3$$
$$= 20 \text{ J}$$

**76 (a)** As we know that,

$$P_1 V_1^{\gamma} = P_2 V_2^{\gamma}$$
$$PV^{\gamma} = P_2 \left(\frac{V}{3}\right)^{\gamma}$$
$$= \frac{P_2 V^{\gamma}}{3^{\gamma}}$$
$$P_2 = 3^{\gamma} P$$
$$\gamma = \frac{5}{3}$$

For monoatomic gases,

$$P_2 = 3^{\frac{5}{3}} P$$
$$= 6.24 \ P$$

**77 (b)** If the gas is compressed slowly, then the process is isothermal.

In this case,

$$P_1 V_1 = P_1 V_1$$

$$\therefore \quad P_2 = \frac{P_1 V_1}{V_2}$$
$$= \frac{70 \times V_1}{V_1 / 2} \quad \left(\because V_2 = \frac{V_1}{2}\right)$$
$$= 140 \text{ cm of Hg}$$

**78 (b)** Since for isothermal, temperature is constant, so $\Delta U = 0$

Therefore, $\Delta W = \Delta Q$ (from first law of thermodynamics)

$\Delta Q = -350$ J, i.e., heat is removed from the system.

**79 (d)** According to Kelvin–Planck's statement it is impossible to devise a cyclically operating thermal engine, the sole effect of which is to absorb energy in the form of heat from a single thermal reservoir and to deliver an equivalent amount of work.

**80 (b)** It is the ratio of minimum energy, which must be consumed to do a task, divided by the actual amount of energy consumed in performing the task.

**81 (a)** The entropy change is positive because when gas absorbs heat, the disorder increases as the molecules tend to move away from each other.

**82 (b)** A reversible process is a process whose direction can be reversed by inducing infinitesimal changes to some property of the system via its surroundings, with no increase in entropy.

**83 (d)** The following processes described below is irreversible:

(i) Some part of the work is lost in friction, sound and other unwanted processes.

(ii) The joule effect absorbs kinetic energy from the whole of the conductor's mass from the drift velocity (through collisions of the free electrons with the ion-grid, collision is irreversible) and turns it into heat.

(iii) Every process that occurs naturally is irreversible. Diffusion is a natural process.

**84 (b)** As we know,

$$\eta = 1 - \frac{T_2}{T_1}$$
$$= \frac{T_1 - T_2}{T_1}$$

When $T_1$ and $T_2$ both are decreased by 200 K each, $(T_1 - T_2)$ stays constant.

Therefore, η increase.

**85 (a)** As we know that,

$$\eta_1 = 1 - \frac{T_2}{T_1}$$
$$0.25 = 1 - \frac{T_2}{T_1}$$

$$\Rightarrow \quad \frac{1}{4} = 1 - \frac{T_2}{T_1}$$

$$\frac{T_2}{T_1} = \frac{3}{4}$$

According to question,

$$\eta_2 = 2\eta_1 \text{ and } T_2 = T_2 - 48$$

$$2 \times \frac{1}{4} = 1 - \frac{(T_2 - 48)}{T_1}$$

$$\frac{1}{2} = \frac{T_2}{T_1} - \frac{48}{T_1}$$

$$\Rightarrow \quad \frac{3}{4} - \frac{1}{2} = \frac{48}{T_1} \quad \left( \because \frac{T_2}{T_1} = \frac{3}{4} \right)$$

$$\Rightarrow \quad T_1 = 192°\text{C}$$

**86 (a)** Efficiency of engine,

$$\eta = \frac{W}{Q}$$

$$= \frac{8 \times 10^8}{7 \times 10^9}$$

$$= 0.114$$

$$= 11.4\%$$

**87 (d)** As we know,

$$\because \quad \eta = 1 - \frac{T_2}{T_1}$$

$$= 1 - \frac{375}{500}$$

$$= 0.25$$

$$= 25\%$$

$$\because \quad W = \eta Q$$

$$\therefore \quad W = 0.25 \times 5 \times 10^5$$

$$= 1.25 \times 10^5 \text{ J}$$

**88 (c)** Room may become hotter as in that event amount of heat removed would be less than the amount of heat released in the room.

**89 (b)** As we know,

$$\text{T}_1 = 28°\text{C} = 301 \text{ K}$$

$$T_2 = 9°\text{C} = 282 \text{ K}$$

∴ Coefficient of performance of refrigerator,

$$\beta = \frac{T_2}{T_1 - T_2} = \frac{282}{301 - 282} = 14.84$$

**90 (d)** Coefficient of performance,

$$\beta = \frac{1 - \eta}{\eta}$$

$$= \frac{1 - 0.20}{0.20} \quad [\because \eta = 20\% = 0.20]$$

$$= \frac{0.80}{0.20} = 4$$

**91 (b)** As we know that,

$$\because \quad \beta = \frac{T_2}{T_1 - T_2}$$

After putting values,

$$5 = \frac{T_2}{298 - T_2}$$

$$1490 - 5T_2 = T_2$$

$$\Rightarrow \quad T_2 = \frac{1490}{6} = 248 \text{ K}$$

**92 (c)** As we know,

Temperature inside refrigerator = $t_B$ ϒC

Room temperature = $t_A$ ϒC

For refrigerator,

$$\frac{\text{Heat given to high temperature } (Q_1)}{\text{Heat taken from lower temperature } (Q_2)} = \frac{T_A}{T_B}$$

$$\frac{Q_1}{Q_2} = \frac{t_A + 273}{t_B + 273}$$

$$1 - \frac{W}{Q_1} = \frac{t_B + 273}{t_A + 273}$$

$$\frac{W}{Q_1} = \frac{t_A - t_B}{t_A + 273}$$

The amount of heat delivered to room for each joule of electrical energy,

$(W = 1 \text{ J})$

$$Q_1 = \frac{t_A + 273}{t_A - t_B}$$

**93 (a)** The entire chamber of the refrigerator is cooled quickly due to convection.

**94 (d)** Operating between two temperatures: $T_1$ (source) and $T_2$ (sink) have maximum efficiency and consisting of two isothermal processes connected.

## High-Order Thinking Skill

**1 (d)** As we know that

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

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

$$\Delta Q = 35 \text{ J}$$

$$\Delta W = -15 \text{ J}$$

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

**2 (d)** As we know that,

$$dU = dQ - dW$$

$$=\left(8\times10^5-6.5\times10^5\right)=1.5\times10^5\text{ J}$$

$$\therefore\ dW=dQ-dU=10^5-1.5\times10^5$$

$$=-0.5\times10^5\text{ J}$$

Negative sign indicates that work done on the gas is $0.5\times10^5$ J.

**3 (b)** In process AB and DA, heat is absorbed from source. In AB, $Q_1=nC_P\Delta T$

For monoatomic ideal gas, $C_P=\frac{5}{2}R$

$$\therefore\ Q_1=\frac{5}{2}(nR\,\Delta T)$$

$$\therefore\ Q_1=\frac{5}{2}\left(4P_0V_0-2P_0V_0\right)=5P_0V_0$$

In DA,

$$Q_2=nC_V\Delta T$$

For monoatomic ideal gas, $C_V=\frac{3}{2}R$

$$\therefore\ Q_2=\frac{3}{2}\,nR\Delta T=\frac{3}{2}\left(2P_0V_0-P_0V_0\right)$$

$$=\frac{3}{2}P_0V_0$$

$$\therefore\ \text{Total } Q=Q_1+Q_2$$

$$=\frac{3}{2}P_0V_0+5P_0V_0=\frac{13}{2}P_0V_0$$

**4 (a)** For cyclic process, total work done,

$$=W_{AB}+W_{BC}+W_{CA}$$

$$\Delta W_{AB}=P\Delta V$$

$$=10(2-1)$$

$$=10\text{ J}$$

$$\text{and } \Delta W_{BC}=0\qquad ...(\because V=\text{ constant })$$

From first law of thermodynamics,

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

$$\Delta U=0\qquad ...(\because \text{Process ABCA is cyclic})$$

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

$$\therefore\quad 5=10+0+\Delta W_{CA}$$

$$\therefore\ \Delta W_{CA}=-5\text{ J}$$

**5 (b)** As we know that,

$$\text{compressibility}=\frac{1}{\text{Bulk modulus}}$$

$$\Rightarrow\qquad B=\frac{1}{K}$$

For adiabatic change,

$$K_{adi}=\gamma P$$

$$P=\frac{K_{adi}}{\gamma}$$

$$=\frac{1}{B_{adi}\gamma}$$

$$=\frac{1\times3}{3.7\times10^{-8}\times5}\qquad ...\left(\because\ \gamma_{He}=\frac{5}{3}\right)$$

$$\therefore\ P=1.62\times10^7\text{ Pa}=16.2\times10^6\text{ Pa}$$

Also, for adiabatic change,

$$PV^\gamma=\text{ constant}$$

$$\Rightarrow\frac{dP}{P}+\gamma\frac{dV}{V}=0$$

$$\therefore\qquad \frac{dP}{P}=-\gamma\frac{dV}{V}$$

Negative indicates volume decreases,

$$\text{i.e }\frac{dP}{dV}=\gamma\frac{P}{V}$$

$$\Rightarrow dV=\frac{dP}{P}\times\frac{V}{\gamma}=\frac{5\times10^4}{1.62\times10^7}\times\frac{10^3\times3}{5}$$

$$\Delta V=1.85\text{ L}$$

**6 (a)** As we know that,

$$\frac{Q_2}{W}=\frac{T_2}{T_1-T_2}$$

Given that,

$$T_2=4°\text{C}=277\text{ K}$$

$$T_1=303\text{ K}$$

$$Q_2=600\text{ cal}$$

Now putting value in above equation, we get,

$$\therefore\frac{600}{W}=\frac{277}{303-277}$$

$$\therefore\ W=\frac{600}{10.65}$$

$$\approx 56\text{ cal}$$

$$\therefore\ P=\frac{W}{t}=\frac{56}{1\,s}\times4.2$$

$$\therefore\ P=236.5\text{ W}$$

**7 (d)** Every process that occurs naturally is irreversible. Here, transfer of heat is a natural process.

## NCERT Exemplar Problems

**1 (b)** According to the question, since there is no net loss to the surroundings and the equilibrium temperature of the system is $T$.
Let us assume that $T_1, T_2 < T < T_3$.
Heat lost by $M_3$ = Heat gained by $M_1$ + Heat gained by $M_2$

$$\Rightarrow \quad M_3 s(T_3 - T) = M_1 s(T - T_1) + M_2 s(T - T_2)$$

where s is the specific heat of copper material.

$$\Rightarrow \quad T[M_1 + M_2 + M_3] = M_3 T_3 + M_1 T_1 + M_2 T_2$$

$$\Rightarrow \quad T = \frac{M_1 T_1 + M_2 T_2 + M_3 T_3}{M_1 + M_2 + M_3}$$

**2 (b)** 1 is isochoric (constant volume), 4 is isobaric (constant pressure). Out of curves 2 and 3, since curve 2 is steeper than curve 3, it represents an adiabatic change, whereas curve 3 represents an isothermal change.

**3 (a)** Amount of sweat evaporated per minute

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

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

**4 (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 $T$.

**5 (b)** Work done = change in pressure × change in volume = $(2P_0 - P_0)(3V_0 - V_0) = 2P_0 V_0$
Since the cyclic process is anticlockwise, work done by the gas is negative, i.e., $-2P_0 V_0$.

**6 (a)** The gas in container $A$ is compressed isothermally,

$$\therefore \quad P_1 V_1 = P_2 V_2$$

$$P_2 = \frac{P_1 V_1}{V_2}$$

$$\text{or} \quad = P_1 \frac{V_1}{V_1/2}$$

$$P_2 = 2P_1 \quad (\because V_2 = V_1/2)$$

Again gas in container B is compressed adiabatically,

$$\therefore \quad P_1 V_1^\gamma = P'_2 (V'_2)^\gamma$$

$$P'_2 = P_1 \frac{V_1^\gamma}{(V'_2)^\gamma} = P_1 \left(\frac{V_1}{V_1/2}\right)^\gamma$$

$$P'_2 = 2^\gamma P_1$$

$$\frac{P'_2}{P_2} = \frac{2^\gamma P_1}{2P_1} = 2^{\gamma - 1}$$

## Assertion and Reasons

**1 (d)** When the bullet pierces a wooden block and stops, kinetic energy of the bullet gets converted into heat. Due to this, the temperature of the wood and the surrounding layers of wood increases. Temperature is related to the energy of the internal motion of the bullet not to the motion of the bullet as a whole.

**2 (a)** If $X$ and $Y$ are separately in equilibrium with $Z$, $T_X = T_Y$ and $T_Y = T_Z$. It means $T_X = T_Y$, i.e., the systems $X$ and $Y$ are also in thermal equilibrium.

**3 (d)** Heat supplied to a system not always increases the internal energy, it also depend on the work done and when a system change from one thermal equilibrium to another, some heat is absorbed by it, so both assertion and reason are false.

**4 (c)** First law of thermodynamics tells only about the conversion of mechanical energy into the heat energy and vice versa.

**5 (a)** Entropy is a measure of the disorder or randomness of the system; greater the randomness, greater the entropy.

**6 (a)** In a heat engine, heat cannot be fully converted to work and a refrigerator cannot work without some external work done on the system.

**7 (d)** In a heat engine, heat cannot be fully converted to work and a refrigerator cannot work without some external work done on the system.

**8 (d)** Refrigerator uses the electric energy to transfer heat from a lower temperature to a higher temperature.

**9 (c)** The entropy of an isolated system increases. In an isolated system, there is no exchange of heat, therefore, process is adiabatic.

**10 (d)** Irreversible process (like a free expansion or an explosive chemical reaction) takes the system to non-equilibrium states.

**11 (c)** Efficiency of Carnot cycle,

$$\eta = \frac{W}{Q_1} = 1 - \frac{T_2}{T_1}$$

For Carnot engine when $T_2$ decrease η increases.

# UNIT 8

# Assessment: Thermodynamics

**Chapter**

- **12** - Thermodynamics

## UNIT ASSESSMENT TIME

**1.** Internal energy of an ideal gas does not depend upon:
(a) Pressure and volume (b) Only volume
(c) Only pressure (d) All of the above

**2.** An electric heater supplies heat to a system at a rate of 140 W. If system performs work at a rate of 100 J $s^{-1}$, the rate of increase in internal energy is:
(a) 240 $Js^{-1}$ (b) 140 $Js^{-1}$
(c) 40 $Js^{-1}$ (d) 100 $Js^{-1}$

**3.** 1 kg of water is heated from 30°C to 60°C, if its volume remains constant, then the change in internal energy is: (specific heat of water = 4148 $Jkg^{-1}K^{-1}$)
(a) $1.24 \times 10^5$ J (b) $2.48 \times 10^5$ J
(c) $1 \times 10^5$ J (d) $2 \times 10^5$ J

**4.** Which of the following is/are thermodynamic coordinate?
(a) Volume *(V)* (b) Pressure *(P)*
(c) Temperature *(T)* (d) All of the above

**5.** Which is/are an intensive property?
(a) Density (b) Temperature
(c) Both (a) and (b) (d) Volume

**6.** Which is/are path dependent?
(a) Work done and internal energy
(b) Work done
(c) Heat
(d) Both (b) and (c)

**7.** An ideal gas at 27°C is compressed adiabatically to 1/8th of its original volume. The rise in temperature is: (take, $\gamma = 2/3$)
(a) 475°C (b) 827°C
(c) 927°C (d) 1200°C

**8.** If a steam engine delivers $5.0 \times 10^8$ J of work per minute and absorbs $4 \times 10^9$ J of heat per minute from its boiler then the efficiency of the engine is:
(a) 11.4% (b) 12.5%
(c) 15.4% (d) 116.4%

**9.** The efficiency of a Carnot engine working between 107°C and 47°C is:
(a) 15.8% (b) 15.5%
(c) 15.4% (d) 15.3%

## ANSWER KEY

| 1 | (d) | 2 | (c) | 3 | (a) | 4 | (d) | 5 | (c) | 6 | (d) | 7 | (c) | 8 | (b) | 9 | (a) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

## HINTS AND EXPLANATIONS

**1 (d)** The internal energy of ideal gas depends only upon temperature of gas not on other factors.

**2 (c)** According to first law of thermodynamics

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

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

$$\because \frac{\Delta Q}{\Delta t} = 140 \text{ W},$$

$$\frac{\Delta W}{\Delta t} = 100 \text{ Js}^{-1}$$

$$\therefore \frac{\Delta U}{\Delta t} = 140 - 100$$

$$= 40 \text{ Js}^{-1}$$

**3 (a)** Since volume of water remains constant, then work done

$$\Delta W = PdV$$
$$= 0$$

According to first pair of thermodynamics

$$dQ = dU + dW$$
$$dU = dQ$$
$$= ms\Delta T$$
$$= 1 \times 4148 \times (60 - 30)$$
$$= 4148 \times 30$$
$$= 124440\text{J} = 1.24 \times 10^5 \text{ J}$$

**4 (d)** Pressure (*P*), volume (*V*) and temperature (*T*) are the thermodynamic co-ordinates used to describe the state of the system.

**5 (c)** An intensive property is that which does not depend on the quantity of matter or mass of the system. refractive index, density, temperature, and, pressure are intensive property.

**6 (d)** Path function's magnitudes depend on the path followed during a process as well as the end states. Work (W), and heat (*Q*) are path functions. Internal energy is state function, it depends on the states not on the path followed during a process.

**7 (c)** We know that, for adiabatic process

$$PV^{\gamma} = \text{constant}$$
$$TV^{\gamma} = \text{constant}$$
$$300 = \left(\frac{1}{8}\right)^{2/3} T_2$$
$$T_2 = 1200 \text{ K}$$
$$= 927°\text{C}$$

**8 (b)** Efficiency of engine,

$$\eta = \frac{W}{Q} = \frac{5 \times 10^8}{4 \times 10^9}$$
$$= 0.125 = 12.5\%$$

**9 (a)** Here, $T_2 = 47°\text{C} = 47 + 273 = 320$ K
and $T_1 = 107°\text{C} = 107 + 273 = 380$ K
Efficiency of Carnot's engine,

$$\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{320}{380}$$
$$= \frac{3}{19} \times 100\% = 15.79\%$$