CHAPTER
12
Thermodynamics

Chapter Highlights

Thermal equilibrium, Zeroth law of thermodynamics, Concept of temperature, Heat, work and internal energy, First law of thermodynamics, Second law of thermodynamics, Reversible and irreversible process, Carnot engine and its efficiency.

Thermodynamics is mainly the study of exchange of heat energy between bodies and conversion of the same into mechanical energy and vice versa.

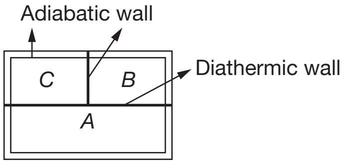
THERMODYNAMIC SYSTEM

Collection of an extremely large number of atoms or molecules confined within certain boundaries such that it has a certain value of pressure (P), volume (V), and temperature (T) is known as a **thermodynamic system**. Anything outside the thermodynamic system to which energy or matter is exchanged is known as its surroundings. Taking into consideration the interaction between a system and its surroundings, thermodynamic system is divided into three classes:

1. **Open system:** A system is said to be an open system if it can exchange both energy and matter with its surroundings.
2. **Closed system:** A system is said to be closed system if it can exchange only energy (not matter with its surroundings).
3. **Isolated system:** A system is said to be isolated if it can neither exchange nor matter with its surroundings.

Zeroth Law of Thermodynamics

If two systems (B and C) are separated in thermal equilibrium with a third one (A), then they themselves are in thermal equilibrium with each other.



Equation of State (for ideal gases)

The relation between the thermodynamic variables (P, V, T) of the system is called equation of state. The equation of state for an ideal gas of n moles is given by

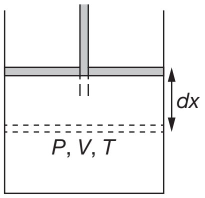
$$PV = nRT.$$

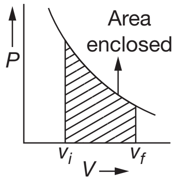
Work Done By a Gas

Let P and V be the pressure and volume of the gas. If A be the area of the piston, then force exerted by gas on the piston is $F = P \times A$.

Let the piston move through a small distance dx during the expansion of the gas. Work done for a small displacement dx is $dW = F\,dx = PA\,dx$.

Since $A\,dx = dV$, increase in volume of the gas is dV
$\Rightarrow\ dW = P\,dV$





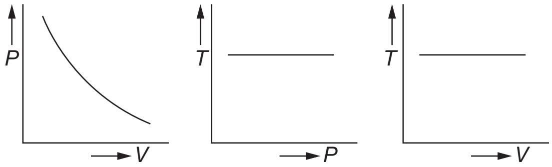
or $$W = \int dW = \int P\,dV$$

Area enclosed under *P*-*V* curve gives work done during process.

Different Types of Processes

(a) Isothermal Process

T = constant [Boyle's law applicable] PV = constant



There is exchange of heat between system and surroundings. System should be compressed or expanded very slowly so that there is sufficient time for exchange of heat to keep the temperature constant.
Slope of *P*-*V* curve in isothermal process

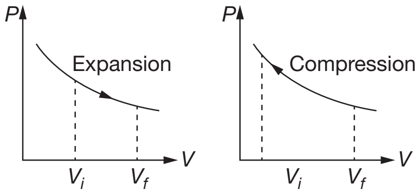
$$PV = \text{constant} = C$$

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

Work done in isothermal process

$$W = nRT\,\ell n\,\frac{V_f}{V_i} \qquad \begin{bmatrix} \text{If } v_f > v_i \text{ then } W \text{ is positive} \\ \text{If } v_f < v_i \text{ then } W \text{ is negative} \end{bmatrix}$$

$$W = \left[2.303\, nRT\, \log_{10}\frac{V_f}{V_i}\right]$$



Internal energy in isothermal process

$$U = f(T) \Rightarrow \Delta U = 0$$

(b) Isochoric Process (Isometric Process)

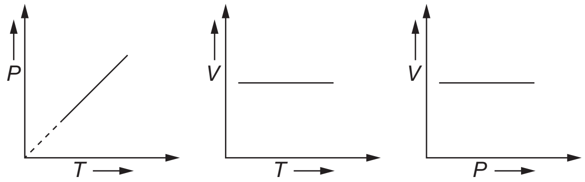
$$V = \text{constant}$$

$\Rightarrow$ change in volume is zero

$$\Rightarrow \qquad \frac{P}{T} \text{ is constant}$$

$$\frac{P}{T} = \text{constant (Gay-Lussac Law)}$$

Work done in isochoric process
Since change in volume is zero, $dW = p\,dV = 0$
Indicator diagram of isochoric process



Change in internal energy in isochoric process

$$\Delta U = n\,\frac{f}{2}R\,\Delta T$$

Heat given in isochoric process

$$\Delta Q = \Delta U = n\,\frac{f}{2}R\,\Delta T$$

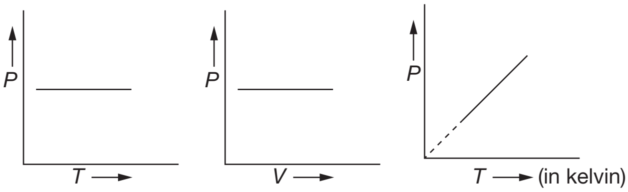
(c) Isobaric Process

Pressure remains constant in isobaric process

$$\therefore \qquad P = \text{constant}$$

$$\Rightarrow \qquad \frac{V}{T} = \text{constant}$$

Indicator diagram of isobaric process



Work done in isobaric process

$$\Delta W = P\,\Delta V = P\,(V_{\text{final}} - V_{\text{initial}}) = nR\,(T_{\text{final}} - T_{\text{initial}})$$

Change in internal energy in isobaric process

$$\Delta U = n\,C_V\,\Delta T$$

Heat given in isobaric process:

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

$$\Delta Q = n\,\frac{f}{2}R\;\Delta T + P\,[V_f - V_i] = n\frac{f}{2}R\,\Delta T + nR\,\Delta T$$

Above expression gives an idea that to increase temperature by ΔT in isobaric process heat required is more than in isochoric process.

(d) Cyclic Process

In the cyclic process, initial and final states are same therefore initial state = final state

Work done = Area enclosed under P-V diagram.

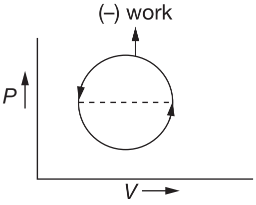
Change in internal Energy $\Delta U = 0$

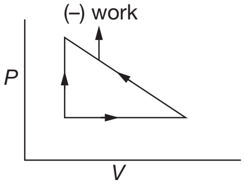
$$\Delta Q = \Delta U + \Delta W$$

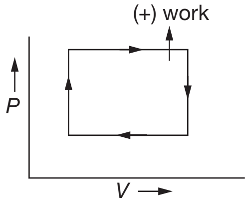
$$\therefore \qquad \Delta Q = \Delta W$$

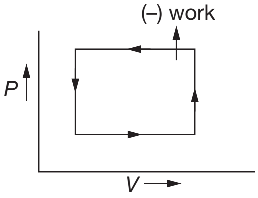
If the process on P-V curve is clockwise, then net work done is +ve and vice-versa.

The graphs shows when work is positive and when it is negative.









SOLVED EXAMPLES

1. The cylinder shown in the Fig. 12.1 has conducting walls, and temperature of the surrounding is T, the piston is initially in equilibrium, the cylinder contains n moles of a gas. Now the piston is displaced slowly by an external agent to make the volume double of the initial. Find work done by external agent in terms of n, R, T

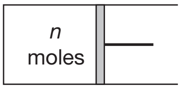
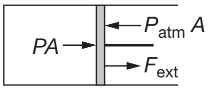


Fig. 12.1

Solution:

First method: Work done by external agent is positive, because F_{ext} and displacement are in the same direction. Since walls are conducting, temperature remains constant.



Applying equilibrium condition when pressure of the gas is P

$$PA + F_{\text{ext}} = P_{\text{atm}} A$$

$$F_{\text{ext}} = P_{\text{atm}} A - PA$$

$$W_{\text{ext}} = \int_0^d F_{\text{ext}}\, dx$$

$$= \int_0^d P_{\text{atm}}\, A dx - \int_0^d PA\, dx$$

$$= P_{\text{atm}}\, \text{A} \int_0^d dx - \int_V^{2V} \frac{nRT}{V}\, dV$$

$$= P_{\text{atm}}\, Ad - nRT \ln 2$$

$$= P_{\text{atm}}\, V_0 - nRT \ln 2 = nRT\,(1 - \ln 2)$$

Second method:
Applying work energy theorem on the piston,

$$\Delta k = 0$$

$$W_{\text{all}} = \Delta k$$

$$W_{\text{gas}} + W_{\text{atm}} + W_{\text{ext}} = 0$$

$$nRT \ln \frac{V_f}{V_i} - nRT + W_{\text{ext}} = 0$$

$$W_{\text{ext}} = nRT\,(1 - \ln 2)$$

2. A non-conducting piston of mass m and area of cross-section A is placed on a non-conducting cylinder as shown in Fig. 12.2. Temperature, spring constant, and height of the piston are given by T, K, h, respectively. Initially, spring is relaxed and piston is at rest. Find
   (A) Number of moles
   (B) Work done by gas to displace the piston by distanced when the gas is heated slowly.
   (C) Find the final temperature

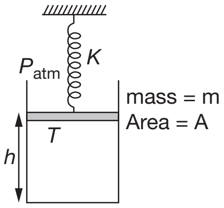


Fig. 12.2

Solution:

(A) $PV = nRT \Rightarrow \left(P_{\text{atm}} + \dfrac{mg}{A}\right) Ah = nRT$

$$\Rightarrow \qquad n = \frac{\left(P_{\text{atm}} + \dfrac{mg}{A}\right) Ah}{RT}$$

(B) *First method:*

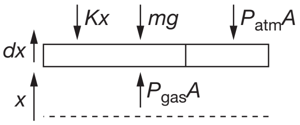
Applying Newton's law on the piston,

$mg + P_{atm}A + Kx = P_{gas}A$

$$W_{gas} = \int_0^d P_g A\, dx$$

$$= \int_0^d (mg + P_{atm}A + Kx)\, dx.$$

$$\Rightarrow \quad W_{gas} = mgd + P_{atm}dA + \frac{1}{2}Kd^2$$



(C) *Second method:*

Applying work energy theorem on the piston

$W_{all} = \Delta KE$

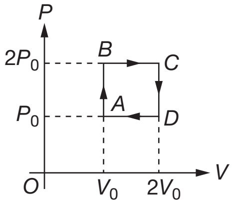
Since piston moves slowly, $\Delta KE = 0$

$W_{gravity} + W_{gas} + W_{atm} + W_{spring} = 0$

$- mgd + W_{gas} + (-P_{atm}Ad) + [-(\frac{1}{2}Kd^2 - 0)] = 0$

$$\Rightarrow \quad W_{gas} = mgd + P_{atm}dA + \frac{1}{2}Kd^2$$

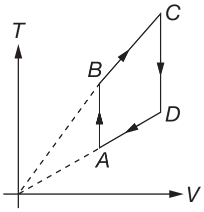
3. Find out the work done in the given graph. Also draw the corresponding *T*-*V* curve and *P*-*T* curve.

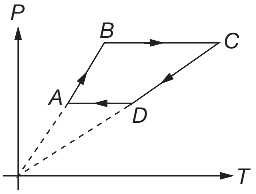


Solution:

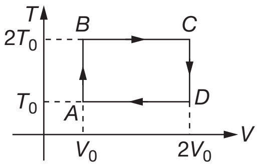
Since in *P*-*V* curves area under the cycle is equal to work done, work done by the gas is equal to $P_0 V_0$. Line *AB* and *CD* are isochoric line, line *BC* and *DA* are isobaric line.

∴ the *T*-*V* and *P*-*T* curves are drawn as shown.





4. *T*-*V* curve of cyclic process is shown below. Number of moles of the gas are *n*. Find the total work done during the cycle.



Solution:

Since path *AB* and *CD* are isochoric, work done is zero during path *AB* and *CD*. Process *BC* and *DA* are isothermal, therefore

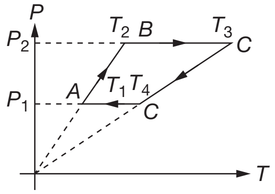
$$W_{BC} = nR2T_0 \ln \frac{V_C}{V_B} = 2nRT_0 \ln 2$$

$$W_{DA} = nRT_0 \ln \frac{V_A}{V_D} = -nRT_0 \ln 2$$

Total work done $= W_{BC} + W_{DA} = 2nRT_0 \ln 2 - nRT_0 \ln 2$

$= nRT_0 \ln 2$

5. *P*-*T* curve of a cyclic process is shown. Find out the work done by the gas in the given process if number of moles of the gas are *n*.



Solution:

Since path *AB* and *CD* are isochoric, work done during *AB* and *CD* is zero. Path *BC* and *DA* are isobaric.

Hence, $W_{BC} = nR\Delta T = nR(T_3 - T_2)$

$W_{DA} = nR(T_1 - T_4)$

Total work done $= W_{BC} + W_{DA} = nR(T_1 + T_3 - T_4 - T_2)$

6. Consider the cyclic process *ABCA* on a sample of 2.0 mol of an ideal gas as shown in Fig. 12.3. The temperatures of the gas at *A* and *B* are 300 K and 500 K, respectively. A total of 1200 J heat is withdrawn from the sample in the process. Find the work done by the gas in part *BC*. Take $R = 8.3$ J/mol–K.

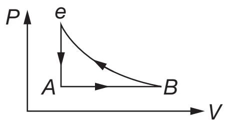


Fig. 12.3

Solution:

The change in internal energy during the cyclic process is zero. Hence, the heat supplied to the gas is equal to the work done by it. Hence,

$$W_{AB} + W_{BC} + W_{CA} = -1200 \text{ J.} \qquad (1)$$

The work done during the process *AB* is

$$W_{AB} = P_A (V_B - V_A)$$

$$= nR(T_B - T_A)$$

$$= (2.0 \text{ mol}) (8.3 \text{ J/mol–K}) (200 \text{ K})$$

$$= 3320 \text{ J}$$

The work done by the gas during the process *CA* is zero as the volume remains constant. From (1),

$$3320 \text{ J} + W_{BC} = -1200 \text{ J}$$

or $$W_{BC} = -4520 \text{ J}$$

$$= -4520 \text{ J}$$

FIRST LAW OF THERMODYNAMICS

The first law of thermodynamics is the law of conservation of energy. It states that if a system absorbs heat dQ; as a result, the internal energy of the system changes by dU and the system does a work dW, then $dQ = dU + dW$.

But, $$dW = P\,dV\,dQ = dU + P\,dV$$

which is the mathematical statement of first law of thermodynamics.

Heat gained by a system, work done by a system, and increase in internal energy are taken as positive.

Heat lost by a system, work done on a system, and decrease in internal energy are taken as negative.

SOLVED EXAMPLES

7. 1 gm water at 100°C is heated to convert into steam at 100°C at 1 atm. Find out change in internal energy of water. It is given that volume of 1 gm water at 100°C = 1 cc. volume of 1 gm steam at 100°C = 1671 cc. Latent heat of vaporization = 540 cal/g. (Mechanical equivalent of heat $J = 4.2$J/cal.)

Solution:

From first law of thermodynamic $\Delta Q = \Delta u + \Delta w$

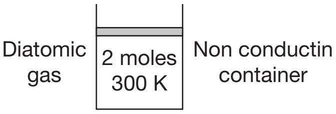
$$\Delta Q = mL = 1 \times 540 \text{ cal.} = 540 \text{ cal.}$$

$$\Delta W = P\Delta V = \frac{10^5(1671-1)\times 10^{-6}}{4.2}$$

$$= \frac{10^5 \times 1670)\times 10^{-6}}{4.2} = 40 \text{ cal.}$$

$$\Delta u = 540 - 40 = 500 \text{ cal.}$$

8. Two moles of a diatomic gas at 300 K are kept in a non-conducting container enclosed by a piston. Gas is now compressed to increase the temperature from 300 K to 400 K. Find work done by the gas



Solution:

$$\Delta Q = \Delta u + \Delta w$$

Since container is non-conducting,

$$\Delta Q = 0 = \Delta u + \Delta w$$

$$\Rightarrow \ \Delta W = -\Delta u = -n\frac{f}{2}R\,\Delta T = -2\times\frac{5}{2}R\,(400-300)$$

$$= -5 \times 8.314 \times 100 \text{ J}$$

$$= -5 \times 831.4 \text{ J}$$

$$= -4157 \text{ J}$$

9. A sample of an ideal gas is taken through the cyclic process abca (Fig. 12.4). It absorbs 50 J of heat during the part *ab*, no heat during *bc,* and rejects 70 J of heat during *ca*. 40 J of work is done on the gas during the part *bc*.

(A) Find the internal energy of the gas at *b* and *c* if it is 1500 J at *a*.

(B) Calculate the work done by the gas during the part *ca*.

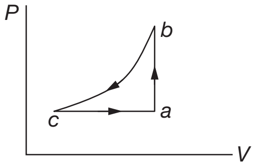


Fig. 12.4

Solution:

(A) In the part *ab*, the volume remains constant. Thus, the work done by the gas is zero. The heat absorbed by the gas is 50 J. The increase in internal energy from a to b is

$$\Delta U = \Delta Q = 50\text{J}.$$

As the internal energy is 1500 J at *a*, it will be 1550 J at *b*. In the part *bc*, the work done by the gas is $\Delta W = -40$J and no heat is given to the system. The increase in internal energy from *b* to *c* is

$$\Delta U = -\Delta W = 40 \text{ J}.$$

As the internal energy is 1550 J at *b*, it will be 1590 J at *c*.

(B) The change in internal energy from *c* to a is

$$\Delta U = 1500 \text{ J} - 1590 \text{ J} = -90 \text{ J}.$$

The heat given to the system is $\Delta Q = -70$ J.

Using $\quad \Delta Q = \Delta U + \Delta W,$

$$\Delta W_{ca} = \Delta Q - \Delta U$$

$$= -70 \text{ J} + 90 \text{ J} = 20 \text{ J}.$$

10. The internal energy of a monatomic ideal gas is 1.5 nRT. One mole of helium is kept in a cylinder of cross-section 8.5 cm^2. The cylinder is closed by a light frictionless piston. The gas is heated slowly in a process during which a total of 42 J heat is given to the gas. If the temperature rises through 2°C, find the distance moved by the piston. Atmospheric pressure = 100 kPa.

Solution:

The change in internal energy of the gas is

$$\Delta U = 1.5\, nR\, (\Delta T)$$

$$= 1.5 \text{ (1 mol) (8.3 J/mol-K) (2K)}$$

$$= 24.9 \text{ J}.$$

The heat given to the gas = 42 J

The work done by the gas is

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

$$= 42 \text{ J} - 24.9 \text{ J} = 17.1 \text{ J}.$$

If the distance moved by the piston is *x*, the work done is

$$\Delta W = (100 \text{ kPa})\, (8.5 \text{ cm}^2)\, x.$$

Thus, $(10^5 \text{ N/m}^2)\, (8.5 \times 10^{-4} \text{ m}^2)\, x = 17.1$ J

or $\qquad x = 0.2 \text{ m} = 20 \text{ cm}.$

11. A sample of an ideal gas has pressure p_0, volume V_0, and temperature T_0. It is isothermally expanded to twice its original volume. It is then compressed at constant pressure to have the original volume V_0. Finally, the gas is heated at constant volume to get the original temperature.

(A) Show the process in a *V-T* diagram

(B) Calculate the heat absorbed in the process.

Solution:

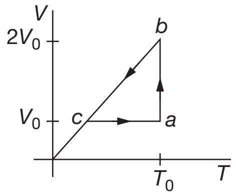


Fig. 12.5

(A) The *V–T* diagram for the process is shown in Fig. 12.5. The initial state is represented by the point a. In the first step, it is isothermally expanded to a volume $2V_0$; this shown by *ab*. Then the pressure is kept constant and the gas is compressed to the volume V_0. From the ideal gas equation, *V*/*T* is constant at constant pressure. Hence, the process is shown by a line *bc* which passes through the origin. At point *c*, the volume is V_0. In the final step, the gas is heated at constant volume to a temperature T_0. This is shown by *ca*. The final state is the same as the initial state.

(B) The process is cyclic so that the change in internal energy is zero. The heat supplied is, therefore, equal to the work done by the gas. The work done during *ab* is

$$W_1 = nRT_0 \text{ In } \frac{2V_0}{V_0} = nRT_0 \text{ In } 2 = p_0\, V_0 \text{ In } 2.$$

Also from the ideal gas equation,

$$p_a V_a = p_b V_b$$

or $$p_b = \frac{p_a V_a}{V_b} = \frac{p_0 V_0}{2V_0} = \frac{p_0}{2}.$$

In the step *bc*, the pressure remains constant. Hence, the work done is

$$W_2 = \frac{p_0}{2}\,(V_0 - 2V_0) = -\frac{p_0 V_0}{2}.$$

In the step *ca*, the volume remains constant and so the work done is zero. The net work done by the gas in the cyclic process is

$$W = W_1 + W_2$$

$$= p_0\, V_0\, [\text{In } 2 - 0.5]$$

$$= 0.193\, p_0 V_0.$$

Hence, the heat supplied to the gas is $0.193\, p_0 V_0$.

12. A sample of ideal gas ($f = 5$) is heated at constant pressure. If an amount 140 J of heat is supplied to the gas, find

(A) the change in internal energy of the gas and

(B) the work done by the gas.

Solution:

Suppose the sample contains n moles. Also suppose the volume changes from V_1 to V_2 and the temperature changes from T_1 to T_2.

The heat supplied is

$$\Delta Q = \Delta U + P\Delta V = \Delta U + nR\Delta T = \Delta U + \frac{2\Delta U}{f}$$

(A) The change in internal energy is

$$\Delta U = n\,\frac{f}{2}R\,(T_2 - T_1) = \frac{f}{2}R\;n\,(T_2 - T_1)$$

$$= \frac{f}{2+f}\,\Delta Q = \frac{140\text{ J}}{1.4} = 100\text{ J.}$$

(B) The work done by the gas is

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

$$= 140\text{ J} - 100\text{ J} = 40\text{ J.}$$

Efficiency of a Cycle (η)

$$\eta = \frac{\text{Total Mechanical work done by the gas in the whole process}}{\text{Heat absorbed by the gas (only +ve)}}$$

$$= \frac{\text{Area under the cycle in P-V curve}}{\text{Heat injected into the system}}$$

$$\eta = \left(1 - \frac{Q_2}{Q_1}\right) \text{ for heat engine}$$

$$\eta = \left(1 - \frac{T_2}{T_1}\right) \text{ for Carnot cycle}$$

SOLVED EXAMPLE

13. n moles of a diatomic gas has undergone a cyclic process ABC as shown in Fig. 12.6. Temperature at a is T. Find

(A) Volume at C
(B) Maximum temperature
(C) Total heat given to gas
(D) Is heat rejected by the gas; if yes, how much?
(E) Find out the efficiency

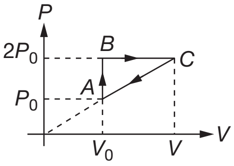


Fig. 12.6

Solution:

(A) Since triangle $O\,A\,V_0$ and $OC\,V$ are similar,

$$\frac{2P_0}{V} = \frac{P_0}{V_0} \Rightarrow V = 2V_0$$

(B) Since process AB is isochoric,

$$\frac{P_A}{T_A} = \frac{P_B}{T_B} \Rightarrow T_B = 2T_0$$

Since process BC is isobaric, $\dfrac{T_B}{V_B} = \dfrac{T_C}{V_C}$

$$\Rightarrow \qquad T_C = 2T_B = 4\,T_0$$

(C) Since process is cyclic,

$$\Delta Q = \Delta W = \text{area under the cycle} = \frac{1}{2}P_0V_0\,.$$

(D) Since Δu and ΔW both are negative in process CA
$\therefore$ ΔQ is negative in process CA and heat is rejected in process CA

$$\Delta Q_{CA} = \Delta w_{CA} + \Delta u_{CA}$$

$$= -\frac{1}{2}\,[P_0 + 2P_0]\,V_0 - \frac{5}{2}nR\,(T_c - T_a)$$

$$= -\frac{1}{2}\,[P_0 + 2P_0]\,V_0 - \frac{5}{2}nR\left(\frac{4P_0V_0}{nR} - \frac{P_0V_0}{nR}\right)$$

$$= -9P_0V_0 = \text{Heat injected.}$$

(E) η = efficiency of the cycle $= \dfrac{\text{Work done by the gas}}{\text{Heat injected}}$

$$= \eta = \frac{P_0V_0/2}{Q_{\text{injected}}} \times 100$$

$$\Delta Q_{\text{inj}} = \Delta Q_{AB} + \Delta Q_{BC}$$

$$= \left[\frac{5}{2}nR(2T_0 - T_0)\right] + \left[\frac{5}{2}nR(2T_0) + 2P_0(2V_0 - V_0)\right]$$

$$= \frac{19}{2}P_0V_0.$$

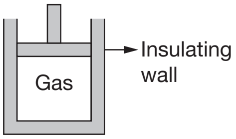
$$\eta = \frac{100}{19}\ \%$$

Adiabatic Process

When no heat is supplied or extracted from the system, the process is called adiabatic. Process is sudden so that there is no time for exchange of heat. If walls of a container are thermally insulated, no heat can cross the boundary of the system, and the process is adiabatic.

Equation of adiabatic process is given by

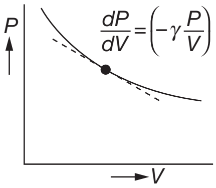
$$PV^{\gamma} = \text{constant} \qquad \text{[Poisson Law]}$$



$$T\gamma P^{1-\gamma} = \text{constant}$$

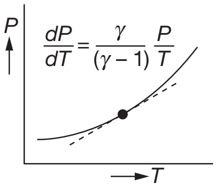
$$TV^{\gamma-1} = \text{constant}$$

Slope of P-V curve in an adiabatic process
Since PV^{γ} is a constant



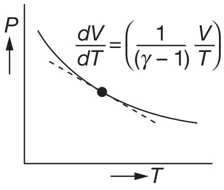
$$\therefore \qquad \frac{dP}{dV} = -\gamma\left(\frac{P}{V}\right)$$

Slope of P-T curve in adiabatic process
Since $T^{\gamma}P^{1-\gamma}$ is a constant



$$\therefore \qquad \frac{dP}{dT} = -\frac{\gamma}{(1-\gamma)}\frac{P}{T} = \frac{(\gamma)}{(\gamma-1)}\frac{P}{T}$$

Slope of T-V curve



$$\frac{dV}{dT} = -\frac{1}{(\gamma-1)}\frac{V}{T}$$

Work done in adiabatic process

$$\Delta W = -\Delta U = nC_v(T_i - T_f) = \frac{P_iV_i - P_fV_f}{(\gamma-1)}$$

$$= \frac{nR(T_i - T_f)}{\gamma - 1}$$

Work done by system is (+ve), if $T_i > T_f$ (hence expansion)

Work done on the system is (–ve), if $T_i < T_f$ (hence compression)

SOLVED EXAMPLES

14. A quantity of air is kept in a container having walls which are slightly conducting. The initial temperature and volume are 27°C (equal to the temperature of the surrounding) and 800 cm^3, respectively. Find the rise in the temperature if the gas is compressed to 200 cm^3

(A) in a short time

(B) in a long time. Take $\gamma = 1.4$.

Solution:

(A) When the gas is compressed in a short time, the process is adiabatic. Thus,

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

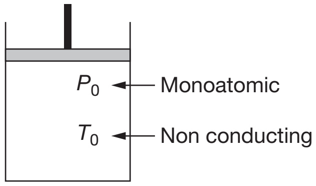
$$\text{or} \qquad T_2 = T_1\left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

$$= (300\text{ K}) \times \left[\frac{800}{200}\right]^{0.4} = 522\text{ K}.$$

Rise in temperature $= T_2 - T_1 = 222$ K.

(B) When the gas is compressed for a long time, the process is isothermal. Thus, the temperature remains equal to the temperature of the surrounding, that is, 27°C. The rise in temperature = 0.

15. A monoatomic gas is enclosed in a non-conducting cylinder having a piston which can move freely. Suddenly, gas is compressed to 1/8 of its initial volume. Find the final pressure and temperature if initial pressure and temperature are P_0 and T_0, respectively.



Solution:

Since process is adiabatic,

$$P_0\, V^{\frac{5}{3}} = P_{\text{final}}\left(\frac{V}{8}\right)^{5/3}$$

$$\Rightarrow \qquad \gamma = \frac{C_P}{C_V} = \frac{5R}{2}\Big/\frac{3R}{2} = \frac{5}{3}$$

$$P_{\text{final}} = 32\, P_0.$$

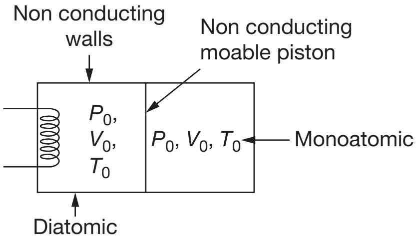
Since process is adiabatic,

$$T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$$

$$\Rightarrow \quad T_0 V_0^{2/3} = T_{\text{final}} \left(\frac{V_0}{8}\right)^{2/3}$$

$$\Rightarrow \quad T = 4T_0$$

16. A cylindrical container having non-conducting walls is partitioned in two equal parts such that the volume of the each parts is equal to V_0. A movable non-conducting piston is kept between the two parts. Gas on left is slowly heated so that the gas on right is compressed up to volume $\frac{V_0}{8}$. Find pressure and temperature on both sides if initial pressure and temperature were P_0 and T_0, respectively. Also find heat given by the heater to the gas. (Number of moles in each part is n.)



Solution:

Since the process on right is adiabatic,

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

$$\Rightarrow \quad P_0 V_0^{\gamma} = P_{\text{final}} (V_0/8)^{\gamma}$$

$$\Rightarrow \quad P_{\text{final}} = 32 P_0$$

$$T_0 V_0^{\gamma-1} = T_{\text{final}} (V_0/8)^{\gamma-1}$$

$$\Rightarrow \quad T_{\text{final}} = 4T_0$$

Let volume of the left part is V_1

$$\Rightarrow \quad 2V_0 = V_1 + \frac{V_0}{8}$$

$$\Rightarrow \quad V_1 = \frac{15V_0}{8}.$$

Since number of moles on the left parts remains constant, for the left part $\frac{PV}{T}$ = constant.

Final pressure on both sides will be same

$$\Rightarrow \quad \frac{P_0 V_0}{T_0} = \frac{P_{\text{final}} V_1}{T_{\text{final}}}$$

$$\Rightarrow \quad T_{\text{final}} = 60\ T_0$$

$$\Delta Q = \Delta u + \Delta w$$

$$\Delta Q = n\frac{5R}{2}(60T_0 - T_0) + n\frac{3R}{2}(4T_0 - T_0)$$

$$\Delta Q = \frac{5nR}{2} \times 59T_0 + \frac{3nR}{2} \times 3T_0$$

FREE EXPANSION

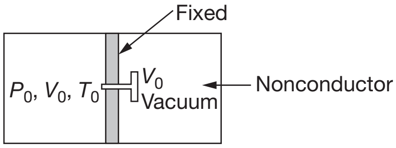
If a system, if a gas expands in such a way that no heat enters or leaves the system and also no work is done by or on the system, then the expansion is called 'free expansion'.

$$\Delta Q = 0,\ \Delta U = 0, \text{ and } \Delta W = 0.$$

Temperature in the free expansion remains constant.

SOLVED EXAMPLE

17. A non-conducting cylinder having volume $2V_0$ is partitioned by a fixed non-conducting wall in two equal part. Partition is attached with a valve. Right side of the partition is a vacuum and left part is filled with a gas having pressure and temperature P_0 and T_0, respectively. If valve is opened find the final pressure and temperature of the two parts.



Solution:

From the first law of thermodynamics, $\Delta Q = \Delta u + \Delta W$

Since gas expands freely, $\Delta W = 0$ and since no heat is given to gas $\Delta Q = 0$

$\Rightarrow$ $\Delta u = 0$ and temperature remains constant.

$$T_{\text{final}} = T_0$$

Since the process is isothermal,

$$P_0 \times V_0 = P_{\text{final}} \times 2V_0$$

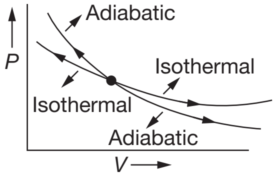
$$\Rightarrow \quad P_{\text{final}} = P_0/2$$

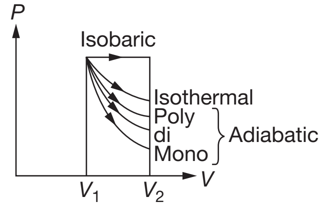
Reversible and Irreversible Process

A process is said to be reversible when the various stages of an operation in which it is subjected can be traversed back in the opposite direction in such a way that the substance passes through exactly the same conditions at every step in the reverse process as in the direct process.

A process in which any one of the condition stated for reversible process are not fulfilled is called an irreversible process.

Comparison Slopes of Isothermal and Adiabatic Curves





$W_{\text{mono}} < W_{\text{di}} < W_{\text{poly}}$
$< W_{\text{isothermal}} < W_{\text{isobaric}}$

$$\left|\frac{dP}{dV}\right|_{\text{adia}} > \left|\frac{dP}{dV}\right|_{\text{isothermal}}$$

In compression, up to same final volume:
$| W_{\text{adia}} | > | W_{\text{isothermal}} |$

In expansion, up to same final volume:
$W_{\text{isothermal}} > W_{\text{adia}}$

Limitations of First Law of Thermodynamics

The first law of thermodynamics says that heat and mechanical work are interconvertible. However, this law fails to explain the following points:

1. It does not explain about the direction of transfer of heat.
2. It does not explain about the conditions under which heat energy is converted into work.
3. It does not explain about the possibility of some processes.

Mixture of Non-reacting Gases

(A) Molecular weight $= \dfrac{n_1 M_1 + n_2 M_2}{n_1 + n_2}$

M_1 and M_2 are molar masses.

(B) Specific heat, $C_V = \dfrac{n_1 C_{V_1} + n_2 C_{V_2}}{n_1 + n_2}$

$$C_P = \frac{n_1 C_{P_1} + n_2 C_{P_2}}{n_1 + n_2}$$

(C) For mixture, $\gamma = \dfrac{C_{p_{\text{mix}}}}{C_{v_{\text{mix}}}} = \dfrac{n_1 C_{p_1} + n_2 C_{p_2} + \ldots\ldots}{n_1 C_{v_1} + n_2 C_{v_2} + \ldots\ldots}$

SOLVED EXAMPLES

18. A vessel of volume 2×10^{-2} m^3 contains a mixture of hydrogen and helium at 47°C temperature and 4.15×10^5 N/m^2 pressure. The mass of the mixture is 10^{-2} kg. Calculate the masses of hydrogen and helium in the given mixture.

Solution:

Let mass of H_2 be m_1 and He be m_2

$$\therefore \quad m_1 + m_2 = 10^{-2} \text{ kg} = 10 \times 10^{-3} \qquad (1)$$

If

P_1 and P_2 are partial pressure of H_2 and He

$$P_1 + P_2 = 4.15 \times 10^5 \text{ N/m}^2$$

For the mixture,

$$(P_1 + P_2)\, V = \left(\frac{m_1}{n_1} + \frac{m_2}{n_2}\right) RT$$

$$\Rightarrow 4.15 \times 10^5 \times 2 \times 10^{-2} = \left(\frac{m_1}{2\times 10^{-3}} + \frac{m_2}{4\times 10^{-3}}\right) 8.31 \times 320$$

$$\Rightarrow \quad \frac{m_1}{2} + \frac{m_2}{4} = \frac{4.15\times 2}{8.31\times 320}$$

$$= 0.00312 = 3.12 \times 10^{-3}$$

$$\Rightarrow \quad 2m_1 + m_2 = 12.48 \times 10^{-3} \text{ kg} \qquad (2)$$

Solving (1) and (2),

$$m_1 = 2.48 \times 10^{-3} \text{ kg} \cong 2.5 \times 10^{-3} \text{ kg}$$

and $\quad m = 7.5 \times 10^{-3}$ kg.

19. The pressure in a monoatomic gas increases linearly from 4×10^5 N m^{-2} to 8×10^5 N m^{-2} when its volume increases from 0.2 m^3 to 0.5 m^3, calculate the following:

(A) Work done by the gas
(B) Increase in the internal energy

Solution:

(A) As here pressure is varying linearly with volume, work done by the gas

$\Delta W = \int PdV$ = area under P-V curve,

which in the light of Fig. 12.7 becomes:

$\Delta W = P_I\,(V_F - V_I)\,(P_F - P_I) \times (V_F - V_I)$

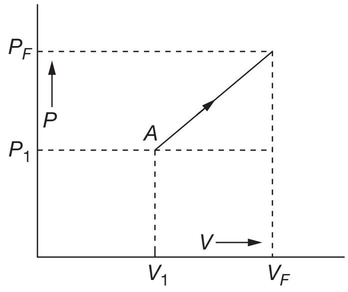


Fig. 12.7

i.e., $\Delta W = P_I\left(V_F - V_I\right) + \frac{1}{2}\left(P_F - P_I\right) \times \left(V_F - V_I\right)$

i.e., $\Delta W = (0.5 - 0.2)\,(8 + 4) \times 10^5$

i.e., $\Delta W = 1.8 \times 10^5$ J

(B) The change in internal energy of a gas is given by

$$\Delta U = \mu C_V\,\Delta T = \frac{\mu R \Delta T}{(\gamma - 1)} = \frac{(P_F V_F - P_I V_I)}{(\gamma - 1)}$$

As the gas is monatomic, $\gamma = (5/3)$

So, $$\Delta U = \frac{10^5(8 \times 0.5 - 4 \times 0.2)}{[(5/3) - 1]}$$

$$= \frac{3}{2} \times 10^5(4 - 0.8).$$

i.e., $\Delta U = 4.8 \times 10^5$ J

20. There are two vessels. Each of them contains one mole of a monoatomic ideal gas. Initial volume of the gas in each vessel is 8.3×10^{-3} m^3 at 27°C. Equal amount of heat is supplied to each vessel. In one of the vessels, the volume of the gas is doubled without change in its internal energy, whereas the volume of the gas is held constant in the second vessel. The vessels are now connected to allow free mixing of the gas. Find the final temperature and pressure of the combined gas system.

Solution:

According to first law of thermodynamics,

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

So for the vessel for which internal energy (and hence, temperature) remains constant

$$\Delta Q_1 = \Delta W = \mu R T \log_e (V_F/V_I)$$

$$\Delta Q_1 = 1 \times R \times 300 \log_e(2)$$

$$= 0.693 \times 300\, R = 207.9\, R$$

and for the vessel for which volume is kept constant,

$$\Delta Q_2 = \Delta U = \mu\, C_V\, \Delta T \qquad [\text{as } \Delta W = 0]$$

i.e., $\Delta Q_1 = 1(3/2) R\, \Delta T$

According to given problem $\Delta Q_1 = \Delta Q_2$,

i.e., $207.9\text{R} = (3/2) R \Delta T,$

i.e. $\Delta T = 138.6$

i.e., $T_F - T_I = 138.6$

with $T_I = 300$ K

So, $T_F = 300 + 138.6 = 438.6$ K

Now, when the free mixing of gases is allowed

$$U_1 + U_2 = U$$

$$\mu_1 (C_V)_1 T_1 + \mu_2\, (C_V)_2 T_2 = \mu C_V T$$

with $\mu = \mu_1 + \mu_2$

Here $\mu_1 = \mu_2 = 1$

and $(C_V)_1 = (C_V)_2 = C_V$

So $1 \times 300 + 1 \times 438.6 = 2\text{T},$

i.e., $T = 369.3$ K

Further for the mixture from $PV = \mu RT$ with $V = V + 2V = 3V$ and $\mu = \mu_1 + \mu_2 = 2$, we have

$$P = \frac{\mu R T}{3V} = \frac{2 \times 8.3 \times 369.3}{3 \times 8.3 \times 10^{-3}} = 2.462 \times 10^5 \text{ N/m}^2$$

21. A gaseous mixture enclosed in a vessel of volume V consists of 1 gram mole of a gas A with $\gamma = \frac{C_p}{C_v} = \frac{5}{3}$ and another gas B with $\gamma = \frac{7}{5}$ at a certain temperature T. The gram molecular weights of the gases A and B are 4 and 32, respectively. The gases A and B do not react with each other and are assumed to be ideal. The gaseous mixture follows the equation: $PV^{19/13}$ = constant in adiabatic processes.

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

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

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

Solution:

(A) As for ideal gas, $C_P - C_V = R$ and $\gamma = (C_P/C_V)$,

So $$\gamma - 1 = \frac{R}{C_V}$$

or $$C_V = \frac{R}{(\gamma - 1)}$$

$$\therefore \quad (C_V)_1 = \frac{R}{(5/3) - 1} = \frac{3}{2} R$$

$$(C_V)_2 = \frac{R}{(7/2) - 1} = \frac{5}{2} R$$

and $$(C_V)_{\text{mix}} = \frac{R}{(19/13) - 1} = \frac{13}{6} R$$

Now from conservation of energy,
i.e., $\Delta U = \Delta U_1 + \Delta U_2$,
$(\mu_1 + \mu_2)\,(C_V)_{\text{mix}}\,\Delta T = [\mu_1(C_V)_1 + \mu_2(C_V)_2]\Delta T$

i.e., $$(C_V)_{\text{mix}} = \frac{\mu_1(C_V)_1 + \mu_2(C_V)_2}{\mu_1 + \mu_2}$$

We have $$\frac{13}{6}R = \frac{1\times\frac{3}{2}R + n\times\frac{5}{2}R}{1+n} = \frac{(3+5n)}{2(1+n)}$$

or $13 + 13n = 9 + 15n$,
$n = 2$ mole.

(B) Molecular weight of the mixture will be given by

$$M = \frac{n_A M_A + n_B M_B}{n_A + n_B} = \frac{(1)(4) + 2(32)}{1+2}$$

$M = 22.67$

Speed of sound in a gas is given by

$$v = \sqrt{\frac{\gamma RT}{M}}$$

Therefore in the mixture of the gas,

$$v = \sqrt{\frac{(19/13)(8.31)(300)}{22.67\times 10^{-3}}}\ \text{m/s}$$

$v \approx 401$ m/s

(C) $v \propto \sqrt{T}$

or $$v = KT^{1/2} \qquad (2)$$

$$\Rightarrow \quad \frac{dv}{dt} = \frac{1}{2}KT^{-1/2}$$

$$\Rightarrow \quad dv = K\left(\frac{dT}{2\sqrt{T}}\right)$$

$$\Rightarrow \quad \frac{dv}{v} = \frac{K}{v}\left(\frac{dT}{2\sqrt{T}}\right)\ \frac{K}{v} = \frac{1}{\sqrt{T}}$$

$$\Rightarrow \quad \frac{dv}{v} = \frac{1}{\sqrt{T}}\left(\frac{dT}{2\sqrt{T}}\right) = \frac{1}{2}\left(\frac{dT}{T}\right)$$

$$\Rightarrow \quad \frac{dv}{v}\times 100 = \frac{1}{2}\left(\frac{dT}{T}\right)\times 100$$

$$= \frac{1}{2}\left(\frac{1}{300}\right)\times 100 = 0.167 = \frac{1}{6}$$

Therefore, percentage change in speed is 0.167%.

BRAIN MAP

THERMODYNAMICS

1. Ideal gas laws
   Boyle's law : PV = Constant
   Charls law: VT^{-1} = Constant
   Equation of state of an ideal gas
   $PV = nRT$
2. Specific heat capacity of gas is process dependent
   $C_P - C_V = R$
   $C_P/C_V = \gamma$
3. Energy of a mole of an ideal gas per degree of freedom = $\frac{1}{2}RT$
   For
   monoatomic gas $\gamma = 1.67$
   diatomic gas $\gamma = 1.40$
   polyatomic gas $\gamma = 1.33$ or 1.4
4. First law of thermodynamics
   $\Delta Q = \Delta U + \Delta W$
   U is state function depends only on temperature.
   Work done by a gas = $\int_{V_1}^{V_2} p\,dV$
5. Equation of isothermal process:
   PV = Constant
   Equation of adiabatic process
   PV^{γ} = Constant
   Slope of adiabatic curve = γ. Slope of isothermal curve.
6. Work done in isothermal process
   $= 2.303\,nRT\log 10\dfrac{V_2}{V_1}$
   Work done in adiabatic process
   $= \dfrac{P_1V_1 - P_2V_2}{\gamma - 1}$

EXERCISES

Single Option Correct Type

1. An ideal gas is taken through the cycle $A \to B \to C \to A$ as shown in Fig. 12.8. If the net heat supplied to the gas in the cycle is 5 J, the work done by the gas in the process $C \to A$ is

(A) –5 J (B) –10 J
(C) –15 J (D) –20 J

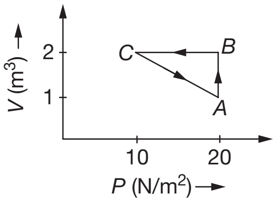


Fig. 12.8

2. For an adiabatic expansion process, the quantity PV

(A) decreases.
(B) increases.
(C) remains constant.
(D) depends on adiabatic exponent of the gas.

3. A gas is confined inside a container having a movable piston. The gas is allowed to expand isobarically. If the initial volume of gas is V_0 and the speed of sound in the gas is C_0, then the speed of sound when the volume of the gas increases to $4V_0$ is

(A) C_0 (B) $2C_0$ (C) $4C_0$ (D) $C_0/2$

4. An ideal gas is taken through cycle $A \to B \to C \to A$ as shown in Fig. 12.9. If the net heat supplied to the gas is 10 J, then the work done by the gas in process $B \to C$ is

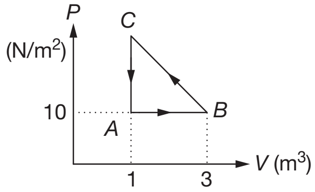


Fig. 12.9

(A) –10 J (B) –30 J (C) –15 J (D) –20 J

5. The work of 146 kJ is performed in order to compress 1 kilo mole of gas adiabatically and in this process, the temperature of the gas increases by 7°C. The gas is ($R = 8.3$ J mol^{-1} K^{-1})

(A) Monoatomic
(B) Diatomic
(C) Triatomic
(D) A mixture of monoatomic and diatomic

6. If amount of heat given to a system is 50 J and work done on the system is 15 J, then change in internal energy of the system is

(A) 35 J (B) 50 J (C) 65 J (D) 15 J

7. Which one of the following statements is incorrect?

(A) If positive work is done by a system in a thermodynamic process, its volume must increase.
(B) If heat is added to a system, its temperature must increase.
(C) A body at 20°C radiates in a room, where room temperature is 30°C.
(D) If pressure vs temperature graph of an ideal gas is a straight line, then work done by the gas is zero.

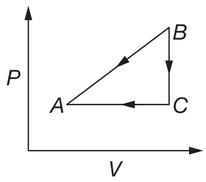
8. When a given quantity of an ideal monoatomic gas is at pressure P and absolute temperature T, then the adiabatic bulk modulus of the gas will be

(A) P (B) $\frac{5}{3}P$ (C) T (D) $\frac{5T}{2}$

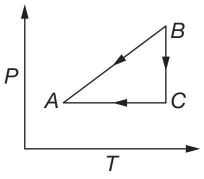
9. Equal amount of same gas in two similar cylinders, A and B, compressed to same final volume from same initial volume one adiabatically and another isothermally, respectively, then

(A) final pressure in A is more than in B.
(B) final pressure in B is greater than in A.
(C) final pressure in both equal.
(D) for the gas, value of $\gamma = \frac{C_p}{C_V}$ is required.

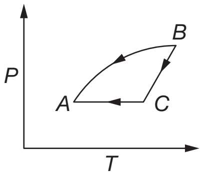
10. P-T curve of the following process will be



(A)



(B)



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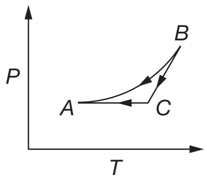

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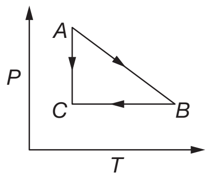
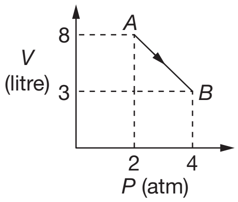


11. Work done in process *AB* will be

(A) 900 J (B) 1500 J
(C) 3300 J (D) 33 J



12. Temperature of source is 330°C. Temperature of sink is changed in order to increase the efficiency of engine from $\frac{1}{5}$ to $\frac{1}{4}$, by

(A) 30°K (B) 303°K
(C) 603°K (D) 60°K

13. Two moles of an ideal gas at 300 K were cooled at constant volume so that the pressure is reduced to half the initial value. As a result of heating at constant pressure, the gas has expanded till it attains the original temperature. The total heat absorbed by gas, if *R* is the gas constant

(A) 150 *R* (B) 300 *R* (C) 75 *R* (D) 100 *R*

14. P-V diagram of an ideal gas is as shown in Fig. 12.10. Work done by the gas in the process *ABCD* is

(A) $4P_0V_0$ (B) $2P_0V_0$
(C) $3P_0V_0$ (D) P_0V_0

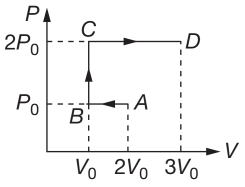


Fig. 12.10

15. The total KE of all the molecules of helium having a volume *V* exerting a pressure *P* is 1500 J. The total KE in joules of all the molecules of N_2 having the same volume *V* and exerting a pressure 2*P* is

(A) 3000 (B) 4000
(C) 5000 (D) 6000

16. One mole of an ideal gas at an initial temperature of *T*K does $6R$ joules 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

17. Two rigid boxes containing different ideal gases are placed on a table. Box *A* contains one mole of nitrogen at temperature T_0, while Box *B* contains one mole of helium at temperature (7/3) T_0. The boxes are then put into thermal contact with each other and heat flows between them until the gases reach a common final temperature. (Ignore the heat capacity of boxes.) Then, the final temperature of the gases, T_f, in terms of T_0 is

(A) $T_f = \frac{5}{2}T_0$ (B) $T_f = \frac{3}{7}T_0$

(C) $T_f = \frac{7}{3}T_0$ (D) $T_f = \frac{3}{2}T_0$

18. Figure 12.11 shows a process on a gas in which pressure and volume both changes. The molar heat capacity for this process is *C*. Then

(A) $C = 0$ (B) $C = C_V$
(C) $C > C_V$ (D) $C < C_V$

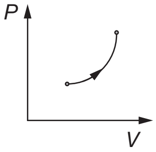


Fig. 12.11

19. Heat energy absorbed by a system in going through a cyclic process shown in Fig. 12.12 is

(A) $10^7\ \pi$J (B) $10^4\ \pi$J
(C) $10^2\ \pi$J (D) $10^{-3}\ \pi$J

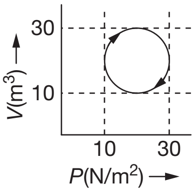


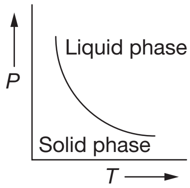
Fig. 12.12

20. The pressure-temperature (*P*-*T*) phase diagram shown below corresponds to the

(A) curve of fusion of solids that expand on solidification.
(B) curve of sublimation of solids that directly go over to the vapour phase.

(C) curve of fusion of solids that contract on solidification.

(D) curve of fusion of solids that do not change in volume upon solidification.



21. Three samples of the same gas *A*, *B,* and *C* ($\gamma = 3/2$) have initial equal volumes. Now the volume of each sample is doubled. The process is adiabatic for *A*, isobaric for *B,* and isothermal for *C*. If the final pressures are equal for all three samples, the ratio of their initial pressures is

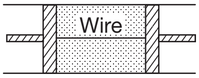
(A) $2\sqrt{2} : 2 : 1$ (B) $2\sqrt{2} : 1 : 2$

(C) $\sqrt{2} : 1 : 2$ (D) $2 : 1 : \sqrt{2}$

22. A cylindrical tube of uniform cross-sectional area *A* is fitted with two air tight frictionless pistons. The pistons are connected to each other by a metallic wire. Initially, the pressure of the gas is P_0 and temperature is T_0. Atmospheric pressure is also P_0. Now the temperature of the gas is increased to $2T_0$, the tension in the wire will be

(A) $2P_0A$ (B) P_0A

(C) $\frac{P_0A}{2}$ (D) $4P_0A$



23. P-V diagram of a diatomic gas is a straight line passing through origin. The molar heat capacity of the gas in the process will be

(A) 4 *R* (B) 2.5 *R* (C) 3 *R* (D) 4*R*/3

24. A system is taken from state *A* to state *B* along two different paths 1 and 2. The heat absorbed and work done by the system along these two paths are Q_1 and Q_2 and W_1 and W_2, respectively.

(A) $Q_1 = Q_2$ (B) $W_1 = W_2$

(C) $Q_1 + W_1 = Q_2 + W_2$ (D) None of these

25. *n* moles of a gas expands from volume V_1 to V_2 at constant temperature *T*. The work done by the gas is

(A) $nRT\left(\frac{v_2}{v_1}\right)$ (B) $nRT\left(\frac{v_2}{v_1} - 1\right)$

(C) $nRT \ln\left(\frac{v_1}{v_2}\right)$ (D) None of these

26. The molar specific heats of an ideal gas at constant pressure and volume are denoted by C_p and C_v, respectively. Further, $\frac{C_p}{C_v} = \gamma$ and *R* is the gas constant for 1 gm mole of a gas. Then C_v is equal to

(A) R (B) γR (C) $\frac{R}{\gamma - 1}$ (D) $\frac{\gamma R}{\gamma - 1}$

27. A gas expands under constant pressure *P* from volume V_1 to V_2. The work done by the gas is

(A) $P(V_2 - V_1)$ (B) $P(V_1 - V_2)$

(C) $P(V_1^{\gamma} - V_2^{\gamma})$ (D) $\frac{PV_1V_2}{V_2 - V_1}$

28. The internal energy *U* is a unique function of any state because of change in *U*

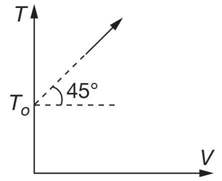
(A) does not depend upon path.

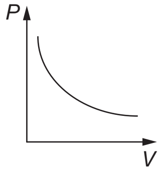
(B) depends upon path.

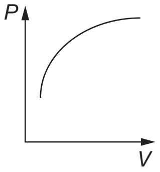
(C) corresponds to an adiabatic process.

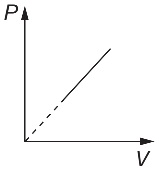
(D) corresponds to an isothermal process.

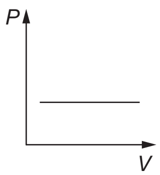
29. The give curve represents the variation of temperature as a function of volume for one mole of an ideal gas. Which of the following curves represents the variation of pressure as a function of volume?



(A) 

(B) 

(C) 

(D) 

30. One mole of an ideal monatomic gas is taken from temperature T_0 to $2T_0$ by the process $PT^{-4} = C$. Considering the following statements, choose the correct alternative.

I. Molar heat capacity of the gas is $-\frac{3R}{2}$

II. Molar heat capacity of the gas is $\frac{3R}{2}$

III. Work done is $-3RT_0$

IV. Work done is $3RT_0$

(A) Statements I and IV are correct.
(B) Statements I and III are correct.
(C) Statements II and IV are correct.
(D) Statements II and III are correct.

31. A vertical cylinder with a massless piston is filled with one mole of an ideal gas. The piston can move freely without friction. The piston is slowly raised so that the gas expands isothermally at temperature 300 K. The amount of work done in increasing the volume two times is $R = \frac{25}{3}$ J/ mol/ K , $\log_e 2 = 0.7$

(A) 1750 J
(B) 2500 J
(C) 750 J
(D) 4250 J

32. Helium gas of 2 g is let through a thermal cycle shown in Fig. 12.13. The lowest temperature of the gas in the cycle is –17°C, the highest is 127°C, and the temperature is equal at points A and B.

[R = Universal gas constant]

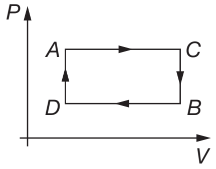


Fig. 12.13

(A) The temperature at A and B is 320 K and net work done by the gas during a cycle is $32R$.
(B) The temperature at A and B is 320 K and net work done by the gas during a cycle is $8R$.
(C) The temperature at A and B is 328 K and net work done by the gas during a cycle is $32R$.
(D) The temperature at A and B is 328 K and net work done by the gas during a cycle is $8R$.

33. One mole of an ideal gas is enclosed in a cylinder fitted with a frictionless piston and occupies a volume of 1.5 litre at a pressure of 1.2 atm. It is subjected to a process given by equation $T = \alpha V^2, \gamma$ (adiabatic constant) for the gas = 1.5. Choose the wrong statement. Given $R\alpha = 80$ J mol^{-1} lit^{-2} (R = gas constant and α is constant)

(A) The P-V diagram of the process is a straight line.
(B) The work done by the gas in increasing the volume of the gas to 9 litre is 3150 J.
(C) The change in the internal energy of the gas is 12600 J.
(D) The heat supplied to the gas in the process is 1575 J.

34. Temperature of 100 gm water in changed from 0°C to 3°C. In this process, heat supplied to water will be (specified heat of water = 1 cal/gm °C)

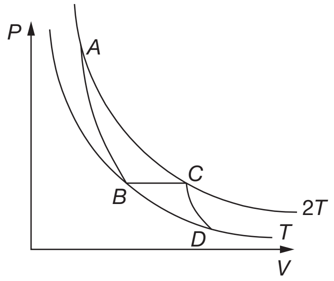
(A) Equal to 300 cal
(B) Greater than 300 cal
(C) Less than 300 cal
(D) Data is insufficient

35. A gas is confined inside a container having a movable piston. The gas is allowed to expand isobarically. If the initial volume of gas is V_0 and the speed of sound in the gas is C_0, then the speed of sound when the volume of the gas increases to $4V_0$ is

(A) C_0
(B) $2C_0$
(C) $4C_0$
(D) $C_0/2$

36. Between two isotherms at temperatures $2T$ and T, a process $ABCD$ is performed with an ideal monatomic gas. AB and CD are adiabatic expansion processes and BC is isobaric expansion process. The average molar specific heat capacity of the overall process will be

(A) $-3R/2$
(B) $5R/2$
(C) $3R/2$
(D) $-5R/2$



37. The pressure of a monatomic gas increases linearly from 4×10^5 N/m^2 to 8×10^5 N/m^2 when its volume increases from 0.2 m^3 to 0.5 m^3. The work done by the gas and increase in its internal energy are given by

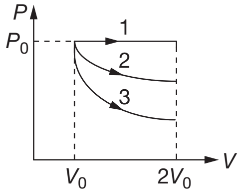
(A) 1.8×10^5 J, 1.8×10^5 J
(B) 4.8×10^5 J, 4.8×10^5 J
(C) 1.8×10^5 J, 4.8×10^5 J
(D) 4.8×10^5 J, 1.8×10^5 J

38. An ideal heat engine working between temperatures T_H and T_L has efficiency η. If both the temperature are raised by 100 K each, the new efficiency of the heat engine will be

(A) equal to η.
(B) greater than η.
(C) less than η.
(D) greater or less than η depending upon the nature of the working substance.

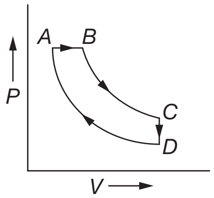
39. A gas is expanded from volume V_0 to $2V_0$ under three different processes. Process 1 is isobaric process, process 2 is isothermal, and process 3 is adiabatic. Let

ΔU_1, ΔU_2, and ΔU_3 be the change in internal energy of the gas in these three processes. Then

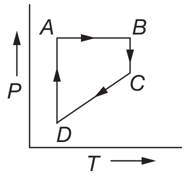


(A) $\Delta U_1 > \Delta U_2 > \Delta U_3$
(B) $\Delta U_1 < \Delta U_2 > \Delta U_3$
(C) $\Delta U_2 < \Delta U_1 < \Delta U_3$
(D) $\Delta U_2 > \Delta U_3 > \Delta U_1$

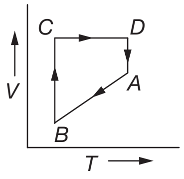
40. A cyclic process *ABCD* is shown in the *P–V* diagram. Which of the following curves represent the same process?



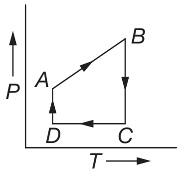
(A)



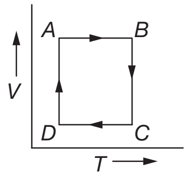
(B)



(C)



(D)



41. An ideal gas undergoes four different processes from the same initial state (Fig. 12.14). Four processes are adiabatic, isothermal, isobaric, and isochoric. Out of 1, 2, 3, and 4 which one is adiabatic?

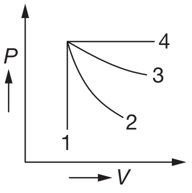


Fig. 12.14

(A) 4 (B) 3
(C) 2 (D) 1

42. If an average person jogs, he produces 14.5×10^3 cal/min. This is evaporated as sweat. The amount of sweat evaporated per min (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

43. Consider *P*-*V* diagram for an ideal gas shown in Fig. 12.15.

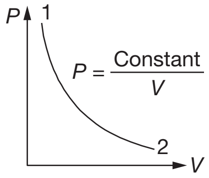
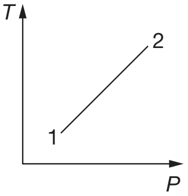


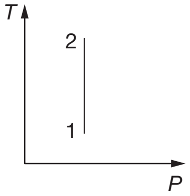
Fig. 12.15

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

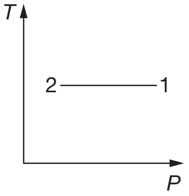
(i)



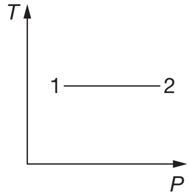
(ii)



(iii)

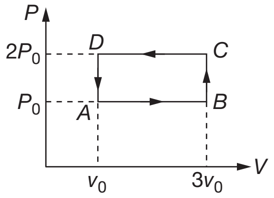


(iv)



(A) (iv) (B) (ii) (C) (iii) (D) (i)

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



(A) $6P_0V_0$ (B) $-2P_0V_0$
(C) $+2P_0V_0$ (D) $+4P_0V_0$

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

46. Three copper blocks of masses M_1, M_2, and M_3 kg, respectively, are brought in to 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) $T = \frac{T_1 + T_2 + T_3}{3}$

(B) $T = \frac{M_1T_1 + M_2T_2 + M_3T_3}{M_1 + M_2 + M_3}$

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

(D) $T = \frac{M_1T_1s + M_2T_2s + M_3T_3s}{M_1 + M_2 + M_3}$

More than One Option Correct Type

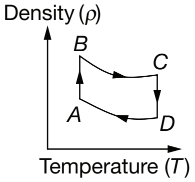
47. Two gases have same initial pressure, volume, and temperature. They expand to same final volume, one adiabatically and the other isothermally.

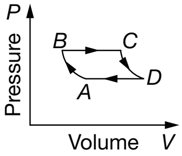
(A) The final temperature is greater for isothermal process.
(B) The final temperature is lesser for isothermal process.
(C) The work done by the gas is greater for isothermal process.
(D) The work done by the gas is greater for adiabatic process.

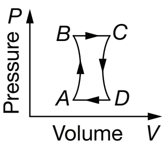
48. Two moles of a monatomic ideal gas undergo a thermodynamic process $\frac{V^3}{T^2} =$ constant, if the temperature is raised by 300K then

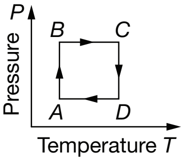
(A) Work done by the gas is 400 R.
(B) Change in internal energy is 900 R.
(C) Molar heat capacity of the gas for the process is 13/6 R.
(D) Molar heat capacity of the gas for the process is 3/2 R.

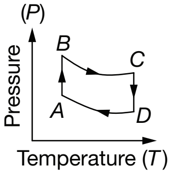
49. Density (ρ) versus temperature (T) graph of a thermodynamic cycle of an ideal gas is as shown. If BC and AD are the part of rectangular hyperbola, then which of the following graphs will represent the same thermodynamic cycle.



(A)


(B)


(C)


(D)


50. In Fig. 12.16, the amount of heat supplied to one mole of an ideal gas is plotted on the horizontal axis, and the amount of work performed by the gas is plotted on vertical axis. The experiment is done on two gases. The initial states for both the gases are same. Two of the straight lines are isobars. Then (Given $\theta_3 = 45°$, $\theta_2 = 30°$, $\theta_1 = 25°$)

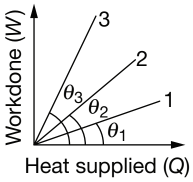


Fig. 12.16

(A) Curve 3 corresponds to isothermal process.
(B) Curves 1 and 2 corresponds to isobaric process.
(C) Curves 3 and 2 corresponds to isobaric process.
(D) Curves 1 and 3 corresponds to isobaric process.

51. In the arrangement shown in Fig. 12.17, gas is thermally insulated. An ideal gas is filled in the cylinder having pressure P greater than atmospheric pressure P_0. The spring of force constant K is initially upstretched. The piston of mass m and area s is frictionless. In equilibrium, the piston rises up a distance x_0, then

(A) Final pressure of the gas is $P_0 + \frac{Kx_0}{s} + \frac{mg}{s}$.

(B) Work done by the gas is $\frac{1}{2}Kx_0^2 + mgx_0$.

(C) Decrease in internal energy of the gas is $\frac{1}{2}Kx_0^2 + mgx_0 + P_0 s x_0$.

(D) All of the above.

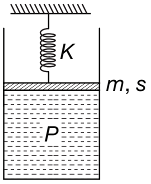
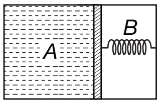


Fig. 12.17

52. A thermally insulated chamber of volume $2V_0$ is divided by a frictionless piston of area S into two equal parts, A and B. Part A has an ideal gas at pressure P_0 and temperature T_0, and in part B is vacuum. A massless spring of force constant k is connected with piston and the wall of the container is as shown. Initially, spring is unstretched. Gas in chamber A is allowed to expand. Let the equilibrium spring be compressed by x_0. Then



(A) Final pressure of the gas is $\frac{kx_0}{S}$.

(B) Work done by the gas is $\frac{1}{2}kx_0^2$.

(C) Change in internal energy of the gas is $\frac{1}{2}kx_0^2$.

(D) Temperature of the gas is decreased.

Passage Based Questions

Passage 1

Two moles of a monatomic gas is taken through a cyclic process starting from A, as shown in Fig. 12.18. The volume ratio are $\frac{v_B}{v_A} = 2$ and $\frac{v_D}{v_A} = 4$. The temperature T_A at A is 27°C. On the basis of this statement, answer the following questions.

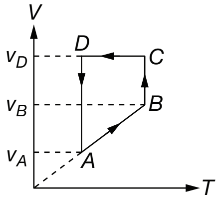


Fig. 12.18

53. The temperature of the gas at point B is

(A) 27°C (B) 235°C
(C) 327°C (D) None of these

54. The heat absorbed by the gas in the process $A \to B$ is

(A) 1500 R (B) 900 R
(C) 0 (D) 600 R

55. The total work done by the gas during the complete cycle is

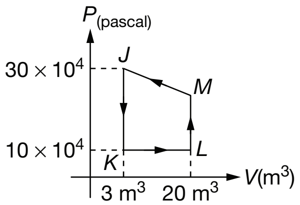
(A) 900 R (B) 1500 R
(C) 0 (D) 600 R

Match the Column Type

56. For n moles of an ideal gas while going through different thermodynamic process

Column-I	Column-II
(A) Isobaric expansion	1. Internal energy increases
(B) Adiabatic expansion	2. Internal energy decreases
(C) Isothermal compression	3. Work done on the gas is positive
(D) Adiabatic compression	4. Heat change for the gas is positive

57. Pressure versus volume graph of a thermodynamic cyclic process of an ideal gas is as shown. When the gas does work, $\Delta W > 0$ and when heat is absorbed by the gas, $\Delta Q > 0$



Column-I	Column-II
(A) In process J-K	1. $\Delta Q > 0$
(B) In process K-L	2. $\Delta Q < 0$
(C) In process L-M	**3.** $\Delta W > 0$
(D) In process M-J	4. $\Delta W < 0$

58. Figure 12.19 given below shows different thermodynamic processes for a given amount of an ideal gas. W is work done by the system and ΔQ is heat absorbed by the system.

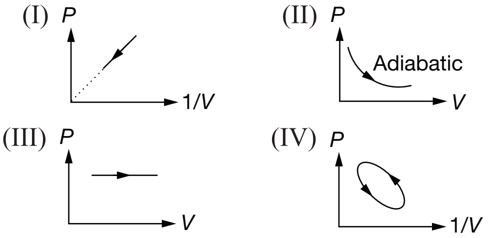


Fig. 12.19

Column-I	Column-II
(A) In Figure (I)	1. $\Delta Q > 0$
(B) In Figure (II)	2. $W < 0$
(C) In Figure (III)	3. $\Delta Q < 0$
(D) In Figure (IV)	4. $W > 0$

59. One mole of an ideal monoatomic gas is taken round the cyclic process ABCA as shown in the Fig. 12.20. Then match the quantities of Column-I with their values in Column-II.

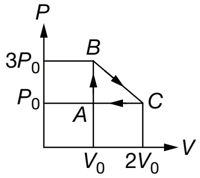


Fig. 12.20

Column-I	Column-II
(A) Heat exchange by the gas in path *CA*	1. $-\frac{5}{2}P_0V_0$
(B) Heat exchange by the gas in path *AB*	2. $3P_0V_0$
(C) Heat exchange by the gas in path *BC*	3. $\frac{P_0V_0}{2}$
(D) Net work done during *ABCA* is	4. P_0V_0

Assertion–Reason Type

60. Assertion: Suppose ΔQ is the heat given to an ice cube to melt it. Magnitude of work done by ice on surroundings is ΔW. Then $\Delta U = \Delta Q - \Delta W$

Reason: First law of thermodynamics cannot be applied in this situation.

(A) A (B) B (C) C (D) D

61. **Assertion:** For an ideal gas, internal energy change is zero if the temperature is constant, irrespective of the process being cyclic or non-cyclic.

Reason: $dU = nC_V dT$ for all processes and is independent of path.

(A) A (B) B (C) C (D) D

62. Assertion: In a complete thermodynamic cycle heat supplied to a system can be completely converted into mechanical work without rejecting any heat to the surrounding.

Reason: Net change in internal energy in a cyclic process is zero.

(A) A (B) B (C) C (D) D

63. Assertion: Adiabatic compressibility of an ideal gas is greater than its isothermal compressibility at same pressure.

Reason: Slope of adiabatic *P*-*V* graph has greater magnitude than the slope of isothermal *P*-*V* graph at same pressure.

(A) A (B) B (C) C (D) D

Integer Type

64. An insulated container is divided into two equal parts. One part contains an ideal gas at pressure P and temperature T, while the other part is a perfect vacuum. If a hole is opened between the two parts, find the change in the temperature of the gas.

65. Water flows at the rate of 0.1500 kg/min through a tube and is heated by a heater dissipating 25.2 W. The inflow and outflow water temperatures are 15.2°C and 17.4°C, respectively. When the rate of flow is increased to 0.2318 kg/min and the rate of heating to 37.8 W, the inflow and outflow temperatures are unaltered. Find:

(A) The specific heat capacity of water.
(B) The rate of loss of heat from the tube.

66. One mole of a gas is enclosed in a cylinder and occupies a volume of 1.5 l at a pressure 1.2 atm. It is subjected to strong heating due to which temperature of the gas increases according to the relation $T = \alpha V^2$, where α is a positive constant and V is volume of the gas.

(A) Find the work done by air in increasing the volume of gas to 9l.
(B) Draw the P-V diagram of the process.
(C) Determine the heat supplied to the gas assuming $\gamma = 1.5$.

67. A cylinder contains He and O_2 of equal volume, separated by a massless freely movable piston as shown in Fig. 12.21. If the gas is adiabatically compressed by moving the upper piston, so that volume of He becomes half, then find the volume occupied by O_2. Cross-section area of cylinder is A.

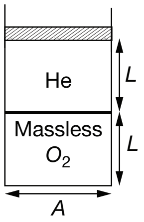


Fig. 12.21

Previous Years' Questions

68. Even Carnot engine cannot give 100% efficiency because we cannot **[2002]**

(A) prevent radiation.
(B) find ideal sources.
(C) reach absolute zero temperature.
(D) eliminate friction.

69. Which statement is incorrect? **[2002]**

(A) All reversible cycles have same efficiency.
(B) Reversible cycle as more efficiency than an irreversible one.
(C) Carnot cycle is a reversible one.
(D) Carnot cycle has the maximum efficiency in all cycles.

70. 'Heat cannot be itself flow from a body at lower temperature to a body at higher temperature' is a statement or consequence of **[2003]**

(A) Second law of thermodynamics.
(B) Conservation of momentum.
(C) Conservation of mass.
(D) First law of thermodynamics.

71. During an adiabatic process, the pressure of a gas is found to be proportional to the cube of its absolute temperature. The ratio C_P/C_V for the gas is **[2003]**

(A) 4/3 (B) 2 (C) 5/3 (D) 3/2

72. Which of the following parameters does not characterize the thermodynamics state of matter? **[2003]**

(A) Temperature (B) Pressure
(C) Work (D) Volume

73. A Carnot engine takes 3×10^6 cal of heat from a reservoir at 627°C and gives it to a sink at 27°C. The work done by the engine is **[2003]**

(A) 4.2×10^6 J (B) 8.4×10^6 J
(C) 16.8×10^6 J (D) Zero

74. Which of the following statements is correct for any thermodynamic system? **[2004]**

(A) The internal energy changes in all processes.
(B) Internal energy and entropy are state functions.
(C) The change in entropy can never be zero.
(D) The work done in an adiabatic process is always zero.

75. A system goes from A to B via two processes I and II as shown in Fig. 12.22. If ΔU_1 and ΔU_2 are the changes in internal energies in the processes I and II, respectively, then **[2005]**

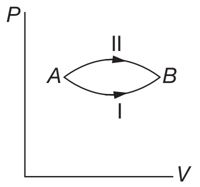


Fig. 12.22

(A) $\Delta U_1 = \Delta U_2$.
(B) relation between ΔU_1 and ΔU_2 cannot be determined.
(C) $\Delta U_2 > \Delta U_1$.
(D) $\Delta U_2 < \Delta U_1$.

76. The temperature-entropy diagram of a reversible engine cycle is given in the Fig. 12.23. Its efficiency is **[2005]**

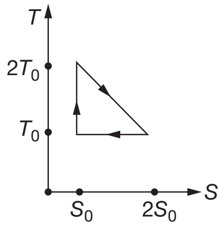


Fig. 12.23

(A) $\frac{1}{2}$ (B) $\frac{1}{4}$
(C) $\frac{1}{3}$ (D) $\frac{2}{3}$

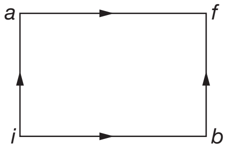
77. Which of the following is incorrect regarding the first law of thermodynamics? **[2005]**

(A) It is not applicable to any cyclic process.
(B) It is a restatement of the principle of conservation of energy.
(C) It introduces the concept of the internal energy.
(D) It introduces the concept of the entropy.

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

(A) diatomic.
(B) triatomic.
(C) a mixture of monoatomic and diatomic.
(D) monatomic.

79. When a system is taken from state i to state f along the path iaf, it is found $Q = 50$ cal and $W = 20$ cal. Along the path ibf, $Q = 36$ cal. W along the path ibf is **[2007]**



(A) 6 cal (B) 16 cal (C) 66 cal (D) 14 cal

80. A Carnot engine, having an efficiency of $\eta = \frac{1}{10}$ as heat engine is used as a refrigerator. If the work done on the system is 10 J, the amount of energy absorbed from the reservoir at lower temperature is **[2007]**

(A) 99 J (B) 90 J (C) 1 J (D) 100 J

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

(A) $\dfrac{T_1T_2(P_1V_1 + P_2V_2)}{P_1V_1T_1 + P_2V_2T_2}$

(B) $\dfrac{T_1T_2(P_1V_1 + P_2V_2)}{P_1V_1T_2 + P_2V_2T_1}$

(C) $\dfrac{P_1V_1T_1 + P_2V_2T_2}{P_1V_1 + P_2V_2}$

(D) $\dfrac{P_1V_1T_2 + P_2V_2T_1}{P_1V_1 + P_2V_2}$

82. The net work done on the gas in the cycle $ABCDA$ is **[2009]**

(A) Zero (B) 276 R
(C) 1076 R (D) 1904 R

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

(A) 0.25 (B) 0.5 (C) 0.75 (D) 0.99

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

(A) $\dfrac{(T_1+T_2+T_3)}{3}$

(B) $\dfrac{n_1T_1+n_2T_2+n_3T_3}{n_1+n_2+n_3}$

(C) $\dfrac{n_1T_1^2+n_2T_2^2+n_3T_3^3}{n_1T_1+n_2T_2+n_3T_3}$

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

85. Helium gas goes through a cycle *ABCDA* (consisting of two isochoric and two isobaric lines) as shown in Fig. 12.23. Efficiency of this cycle is nearly

(Assume the gas to be close to ideal gas) **[2012]**

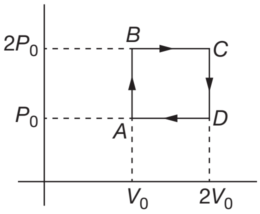


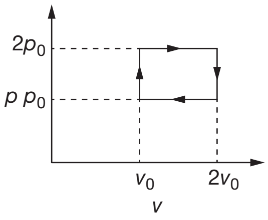
Fig. 12.23

(A) 15.4 % (B) 9.1 %
(C) 10.5 % (D) 12.5 %

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

(A) Efficiency of Carnot engine cannot be made larger than 50%
(B) 1200 K
(C) 750 K
(D) 600 K

87. The above p-v diagram represents the thermodynamic cycle of an engine, operating with an ideal monoatomic gas. The amount of heat extracted from the source in a single cycle is **[2013]**



(A) $\left(\dfrac{13}{2}\right)p_0v_0$ (B) $\left(\dfrac{11}{2}\right)p_0v_0$

(C) $4\,p_0v_0$ (D) p_0v_0

88. One mole of diatomic ideal gas undergoes a cyclic process *ABC* as shown in Fig. 12.24. The process *BC* is adiabatic. The temperatures at *A*, *B*, and *C* are 400 K, 800 K, and 600 K, respectively. Choose the correct statement. **[2014]**

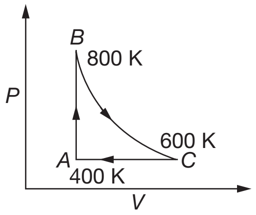


Fig. 12.24

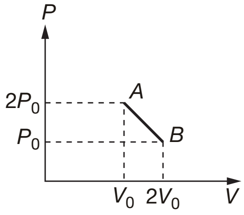
(A) The change in internal energy in whole cyclic process is 250 R.
(B) The change in internal energy in the process *CA* is 700 R.
(C) The change in internal energy in the process *AB* is –350 R.
(D) The change in internal energy in the process *BC* is –500 R.

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

(A) $\dfrac{3\gamma-5}{6}$ (B) $\dfrac{\gamma+1}{2}$

(C) $\dfrac{\gamma-1}{2}$ (D) $\dfrac{3\gamma+5}{6}$

90. n moles of an ideal gas undergoes a process $A \to B$ as shown in the figure. The maximum temperature of the gas during the process will be **[2016]**



(A) $\frac{3P_0V_0}{2nR}$ (B) $\frac{9P_0V_0}{2nR}$

(C) $\frac{9P_0V_0}{nR}$ (D) $\frac{9P_0V_0}{4nR}$

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

(A) $n = \frac{C - C_P}{C - C_V}$ (B) $n = \frac{C_P - C}{C - C_V}$

(C) $n = \frac{C - C_V}{C - C_P}$ (D) $n = \frac{C_P}{C_V}$

ANSWER KEYS

Single Option Correct Type

1. (C) **2.** (A) **3.** (B) **4.** (A) **5.** (B) **6.** (C) **7.** (B) **8.** (B) **9.** (A) **10.** (B)
11. (B) **12.** (A) **13.** (B) **14.** (C) **15.** (C) **16.** (D) **17.** (D) **18.** (C) **19.** (C) **20.** (C)
21. (B) **22.** (B) **23.** (C) **24.** (D) **25.** (D) **26.** (C) **27.** (A) **28.** (A) **29.** (A) **30.** (B)
31. (C) **32.** (B) **33.** (D) **34.** (C) **35.** (B) **36.** (D) **37.** (C) **38.** (C) **39.** (A) **40.** (A)
41. (C) **42.** (A) **43.** (C) **44.** (B) **45.** (A) **46.** (B)

More than One Option Correct Type

47. (A) and (C) **48.** (A), (B) and (C) **49.** (A) and (C) **50.** (A) and (B)
51. (A) and (C) **52.** (A), (B), (C) and (D)

Passage Based Questions

Passage 1

53. (C) **54.** (A) **55.** (D)

Match the Column Type

56. (A) → 1, 4; (B) → 2; (C) → 3; (D) → 1, 3 **57.** (A) –2; (B) → 1,3; (C) → 1; (D) → 2, 4
58. (A) →1,4; (B) → 4; (C) →1, 4; (D) → 2, 3 **59.** (A) → 1, (B) → 2, (C) → 3, (D) → 4

Assertion–Reason Type

60. (C) **61.** (A) **62.** (D) **63.** (D)

Integer Type

64. $\Delta T = 0$ **65.** $P = 2.1\text{W}$ **66.** (A) 3150J (C) 15750J **67.** $= \frac{LA}{(2)^{\frac{25}{21}}}$

Previous Years' Questions

68. (C) **69.** (A) **70.** (A) **71.** (D) **72.** (C) **73.** (B) **74.** (B) **75.** (A) **76.** (C)
77. (A) and (D) **78.** (A) **79.** (A) **80.** (B) **81.** (B) **82.** (B) **83.** (C) **84.** (B) **85.** (A)
86. (C) **87.** (A) **88.** (D) **89.** (B) **90.** (D) **91.** (A)

HINTS AND SOLUTIONS

Single Option Correct Type

1. $W_{AB}+W_{BC}+W_{CA}=5;\ 20+0+W_{CA}=5;\ W_{CA}=-15\text{ J}$

   The correct option is (A)

2. In an adiabatic expansion, $\Delta U=-\text{ve}$

   The correct option is (A)

3. $C=\sqrt{\dfrac{\gamma RT}{M}}$

   For isobaric process, $\dfrac{V_1}{T_1}=\dfrac{V_2}{T_2}$

   Hence, $\dfrac{V_0}{T_1}=\dfrac{4V_0}{T_2}\Rightarrow T_2=4T_1$

   From $\dfrac{C_1}{C_2}=\sqrt{\dfrac{T_1}{T_2}}\Rightarrow\dfrac{C_0}{C_2}=\sqrt{\dfrac{T_0}{4T_0}}\Rightarrow C_2=2C_0$

   The correct option is (B)

4. $\Delta Q=W_{AB}+W_{BC}+W_{CA}+\Delta U$ ($\Delta U=0$ for the complete cycle)

   $\therefore\ 10=10(3-1)+W_{BC}+0$

   $\therefore\ W_{BC}=-10\text{ J}$

   The correct option is (A)

5. $W=\dfrac{nR\Delta T}{\gamma-1}$

   $146\times10^3=\dfrac{10^3\times8.3\times7}{\gamma-1}$

   $\Rightarrow\ \gamma=1.4$

   The correct option is (B)

6. $\Delta U=$ heat given to system + work done on the system = 50 + 15 = 65 J

   The correct option is (C)

7. The correct option is (B)

8. Adiabatic bulk modulus $=\gamma P=\dfrac{5}{3}P$

   The correct option is (A)

9. Adiabatically,

   $$P_1V_1^\gamma=P_2V_2^\gamma$$

   $$P_2=P_1\left(\frac{V_1}{V_2}\right)^\gamma=P_1(\eta)^\gamma \qquad (1)$$

   $$\left[\text{as } \eta=\left(\frac{V_1}{V_2}\right)\right]$$

   Isothermally,

   $$P_1V_1=P_2'V_2$$

   $$P_2'=P_1\eta \qquad (2)$$

   From (1) and (2)

   $P_2>P_2'$

   The correct option is (A)

10. In process AB, $V\propto P$

    $V=kP$

    $PV=nRT$

    $T=\dfrac{k}{nR}p^2$, parabolic

    The correct option is (B)

11. $W=$ Area under curve on volume axis.

    $=\dfrac{1}{2}\times(8-3)(2+4)\times10^5\times10^{-3}=1500\text{ J}$

    The correct option is (B)

12. $\eta=1-\dfrac{T_2}{T_1}$

    $\dfrac{1}{5}=1-\dfrac{T_2}{T_1}$

    $\dfrac{1}{4}=1-\dfrac{T_2'}{T_1}$

    $\dfrac{T_2-T_2'}{T_1}=\dfrac{1}{4}-\dfrac{1}{5}=\dfrac{1}{20}$

    $\Delta T_2=\dfrac{1}{20}\times(330+273)=30.15°\text{K}$

    The correct option is (A)

13. $n=2$ moles, $T_A=T_C=300\text{ K}$

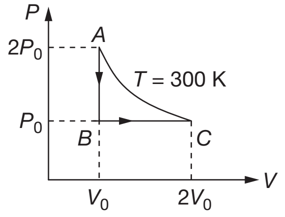
    For isochoric process AB,

    $(\Delta Q)_{AB}=U_B-U_A=nC_V(T_B-T_A)=-300\ C_V$

    For isobaric process BC,

    $(\Delta Q)_{BC}=nC_P(T_C-T_B)=300C_P$

    $\Delta Q=\Delta Q_{AB}+\Delta Q_{BC}=300(C_P-C_V)=300\text{ R}$

    The correct option is (B)

14. $W_{AB} = -P_0V_0$, $W_{BC} = 0$, and $W_{CD} = 4P_0V_0$

$$\therefore \quad W_{ABCD} = -P_0V_0 + 0 + 4P_0V_0$$
$$= 3P_0V_0$$

The correct option is (C)

15. $P = \dfrac{2}{3}\dfrac{E}{V}$ or $E = \dfrac{3}{2}PV$

$\therefore$ Total energy $= \dfrac{3}{2}PV$

For He, $\quad 1500 = \dfrac{3}{2}PV$

For N_2, $\quad E = \dfrac{5}{2} \times 2PV$

Hence, $\quad E = 1500 \times 2 = 5000$ J

The correct option is (C)

16. For adiabatic process,

$$\Delta W = -\Delta U = -nC_V\left(T_f - T_i\right)$$

$$6R = \frac{-1}{\frac{5}{3}-1}R[T_f - T_i] \quad \Rightarrow \quad T_f - T_i = -4$$

$$\therefore \quad T_f = (T-4)\ K$$

The correct option is (D)

17. $\Delta U = 0 \Rightarrow \dfrac{5}{2}R(T_f - T_0) + 1 \times \dfrac{3}{2}R(T_f - \dfrac{7}{3}T_0) = 0$

The correct option is (D)

18. According to graph, pressure is increasing with increase in volume, hence T also increases. It means that energy is used both in increasing internal energy and work done

$$nCdT = nC_vdT + PdV$$

$$\therefore \quad C > C_V$$

The correct option is (C)

19. $\Delta U = 0, \Delta W = \pi(10)^2$

The correct option is (C)

20. The correct option is (C)

21. Let the initial pressure of the three samples be P_A, P_B, and P_C, then

$$P_A(V)^{3/2} = (2V)^{3/2}P, \ P_B = P$$

and $P_C(V) = P(2V)$

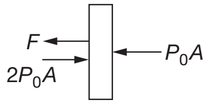
$$\therefore \quad P_A : P_B : P_C = (2)^{3/2} : 1 : 2 = 2\sqrt{2} : 1 : 2$$

The correct option is (B)

22. $P \propto T$

Pressure will be double if temperature is double

$$F = (2P_0 - P_0)A = P_0A$$



The correct option is (B)

23. $P \propto V$

$$PV^{-1} = c$$

$$PV^x = c$$

$$c = \frac{R}{\gamma-1} + \frac{R}{1-x} = \frac{R}{1.4-1} + \frac{R}{1+1} = 3R$$

The correct option is (C)

24. Internal energy is a state function

$$\therefore \quad Q_1 - W_1 = Q_2 - W_2$$

The correct option is (D)

25. $W_{\text{isothermal}} = \int PdV = nRT\displaystyle\int_{V_1}^{V_2}\frac{dV}{V} = nRT\ln\frac{V_2}{V_1}$

The correct option is (D)

26. $C_p - C_v = R \therefore \gamma C_V - C_V = R \therefore C_V = \dfrac{R}{\gamma-1}$

The correct option is (C)

27. Work done $= \displaystyle\int_{V_1}^{V_2} PdV = P(V_2 - V_1)$

The correct option is (A)

28. The correct option is (A)

29. $T = V\tan 45° + T_0$

$$T = V + T_0$$

For one mole of an ideal gas $T = \dfrac{PV}{R}$

$$\therefore \quad \frac{PV}{R} = V + T_0$$

$$\therefore \quad (P-R)V = RT_0$$

Hence, graph is rectangular hyperbola.

The correct option is (A)

30. We know that $PT^{-4} = C$, $PV^{4/3} = C$

$$C = \frac{R}{\gamma-1} - \frac{R}{x-1} = \frac{3R}{2} - \frac{3R}{1} = \frac{-3R}{2}$$

$$W = \frac{\eta R(T_1 - T_2)}{\frac{4}{3}-1} = -3RT_0$$

The correct option is (B)

31. $W_g + W_A + W_{\text{ext}} = 0$

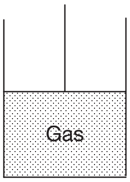
$$W_{\text{ext}} = -[W_g + W_A]$$

$$W_g = nRT\ln\left(\frac{V_2}{V_1}\right) = 1750\ \text{J}$$

$$W_A = -P_0(V_2 - V_1) = \frac{nRT}{(V_2 - V_1)}(V_2 - V_1) = -nRT$$

$$= 1 \times \frac{25}{3} \times 300 = -2500 \text{ J}$$

$\therefore \quad W_{\text{ext}} = 750$ J



The correct option is (C)

32. $T_C = 400$ K, $T_D = 256$ K

$$\frac{V_A}{T_A} = \frac{V_C}{T_C} \quad (1)$$

$$\frac{P_C}{T_C} = \frac{P_B}{T_B} \quad (2)$$

$$\frac{V_B}{T_B} = \frac{V_D}{T_D} \quad (3)$$

also $V_A = V_D, V_C = V_B$ and $T_A = T_B$ from these

$T_A = T_B = 320$ K

$$W_{AC} = \frac{1}{2}R(T_C - T_A) = 40\,R,\ W_{BD} = \frac{1}{2}R(T_D - T_B)$$

$$= -\,32\,R,\ W_{CD} = W_{DA} = 0,\ W_{\text{Net}} = 8R.$$

The correct option is (B)

33. $T = \alpha V^2$

$P = nR\alpha V$

$$dW = \int P dV = \int_{V_1}^{V_2} nR\alpha V\, dV = 3150$$

$[V_1 = 1.5 \text{ litre}, V_2 = 9 \text{ litre}]$

$$dU = nC_v dT = \frac{R}{\gamma - 1}\alpha[V_2^2 - V_1^2] = 12600 \text{ J}$$

$$= \Delta Q = \Delta U + \Delta W = 15750 \text{ J}$$

The correct option is (D)

34. As density of water increases up to 4°C. ⇒ $\Delta V = -$ve ⇒ $\Delta W = -$ve and $\Delta U = 300$ cal. By $\Delta Q = \Delta U + \Delta W < 300$ cal.

The correct option is (C)

35. $C = \sqrt{\frac{\gamma RT}{M}}$

For isobaric process, $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

Hence, $\frac{V_0}{T_1} = \frac{4V_0}{T_2}$

$\Rightarrow \ T_2 = 4T_1$

From $\frac{C_1}{C_2} = \sqrt{\frac{T_1}{T_2}} \Rightarrow \frac{C_0}{C_2} = \sqrt{\frac{T_0}{4T_0}} \Rightarrow C_2 = 2C_0$

The correct option is (B)

36. $\Delta Q_{\text{net}} = \Delta Q_{AB} + \Delta Q_{BC} + \Delta Q_{CD} = 0 + nC_P\left(T_C - T_B\right) + 0$

$$C = \frac{1}{n}\frac{\Delta Q_{\text{net}}}{\left(T_D - T_A\right)}$$

$$= -\frac{5R}{2}$$

The correct option is (D)

37. $w = \frac{1}{2}\left(P_A + P_B\right)\left(v_B - v_A\right) = \frac{1}{2} \times \left(4 + 8\right)10^5\left(0.5 - 0.2\right)$

$$= 6 \times 10^5 \times 0.3 = 1.8 \times 10^5 \text{ J}$$

$$\Delta U = nC_V\Delta T = \frac{3}{2} \times \left(8 \times 10^5 \times 0.5 - 4 \times 10^5 \times 0.2\right)$$

$$= 4.8 \times 10^5 \text{ J}$$

The correct option is (C)

38. $\eta = \frac{T_H - T_L}{T_H}$;

$$\eta' = \frac{(T_H + 100) - (T_L + 100)}{(T_H + 100)} = \frac{T_H - T_L}{T_H + 100}$$

$\eta' < \eta$

The correct option is (C)

39. Process 2 is an isothermal process.

Hence, $\Delta U_2 = 0$.

Process 1 is an isobaric (P = constant) expansion.

Hence, temperature of the gas will increase.

or $\quad \Delta U_1$ = positive

Process 3 is an adiabatic expansion. Hence, temperature will decrease

or $\quad \Delta U_3$ = negative

Therefore, $\Delta U_1 > \Delta U_2 > \Delta U_3$ is the correct option.

The correct option is (A)

40. $AB \rightarrow$ constant P. T will be increasing with increasing V.

$BC \rightarrow$ constant T. P will be decreasing with increasing V.

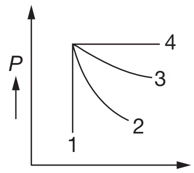
$CD \rightarrow$ constant V, decreasing P, hence decreasing T.

$DA \rightarrow$ constant T, decreasing V, increasing P.

Also, BC is at a higher temperature than AD.

The correct option is (A)

41.



For the curve 4, pressure is constant, so this is an isobaric process.

For the curve 1, volume is constant, so it is isochoric process. Between curves 3 and 2, curve 2 is steeper, so it is adiabatic and 3 is isothermal.

The correct option is (C)

42. Amount of sweat evaporated/minute

$$= \frac{\text{Sweat produced/minute}}{\text{Number of calories required for evaporation/kg}}$$

$$= \frac{\text{Amount of heat produced per minute in jogging}}{\text{Latent heat (in cal/kg)}}$$

$$= \frac{14.5\times10^3}{580\times10^3} = \frac{145}{580} = 0.25 \text{ kg}$$

The correct option is (A)

43. According to the question, given that $pV =$ constant

Hence, we can say that the gas is going through an isothermal process.

Clearly, from the graph, between process 1 and 2 temperature is constant and the gas expands and pressure decreases, i.e., $p_2 < p_1$, which corresponds to diagram (iii).

The correct option is (C)

44. Consider the p-V diagram given in the question.

Work done in the process $ABCD =$ area of rectangle $ABCDA$

$$= (AB)\times BC = (3V_0 - V_0)\times(2\rho_0 - \rho_0)$$

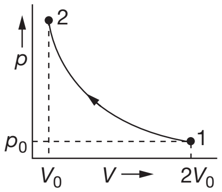
$$= 2V_0 \times \rho_0 = 2\rho_0 V_0$$

As the process is going anti-clockwise, there is a net compression in the gas.

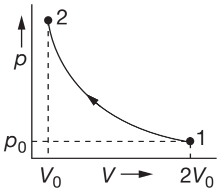
So, work done by the gas $= -2\,\rho_0 V_0$

The correct option is (B)

45. Consider the p-V diagram shown for the container A (isothermal) and for container B (adiabatic).



Container *A*
(Isothermal)



Container *B*
(Adiabatic)

Both the process involves compression of the gas.

For isothermal process, (gas A) (during $1 \to 2$)

$$p_1V_1 = p_2V_2$$

$$\Rightarrow\; p_0(2V_0) = p_2(V_0)$$

$$\Rightarrow\; p_2 = 2p_0$$

For adiabatic process, (gas B) (during $1 \to 2$)

$$p_1V_1^\gamma = p_2V_2^\gamma$$

$$\Rightarrow\; p_0(2V_0)^\gamma = p_2(V_0)^\gamma$$

$$\Rightarrow\; p_2 = \left(\frac{2V_0}{V_0}\right)^\gamma p_0 = (2)^\gamma\, p_0$$

Hence $\dfrac{(p_2)_B}{(p_2)_A} =$ Ratio of final pressure $= \dfrac{(2)^\gamma\, p_0}{2p_0} = 2^{\gamma-1}$

where γ is ratio of specific heat capacities for the gas.

The correct option is (A)

46. Let the equilibrium temperature of the system be T.

Let us assume that $T_1, T_2 < T < T_3$

According to question, there is no loss to the surroundings.

Heat lost by $m_3 =$ Heat gained by M_1 + Heat gained by M_2

$$\Rightarrow\; M_3s(T_3 - T) = M_1s(T - T_1) + M_2s(T - T_2)$$

(where s is specific heat of the copper material)

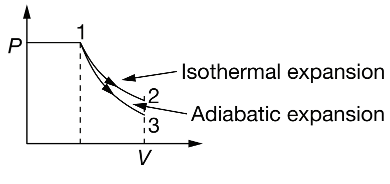
$$\Rightarrow\; T[M_1 + M_2 + M_3] = \mathrm{M}_3T_3 + \mathrm{M}_1T_1 + \mathrm{M}_2T_2$$

$$\Rightarrow\; T = \frac{\mathrm{M}_1T_1 + \mathrm{M}_2T_2 + \mathrm{M}_3T_3}{M_1 + M_2 + M_3}$$

The correct option is (B)

More than One Option Correct Type

47. As slope of PV curve at point 1 is more in adiabatic process work done in isothermal process is more. Also in adiabatic expansion, temperature decreases but remains constant in isothermal process.



The correct option is (A) and (C)

48. $\dfrac{V^3}{T^2} =$ constant, $\quad dV = \dfrac{2}{3}\dfrac{V}{T}dT, \quad P = \dfrac{2RT}{V}, \quad W = \int PdV$

$\Rightarrow 400\,R$

$$\Delta U = nC_V\Delta T = 900R,\; \Delta Q = nC\Delta T$$

and $\Delta Q = \Delta U + W = 1300\,R$

$$C = \frac{\Delta Q}{n\Delta T} = \frac{13}{6}R$$

The correct option is (A), (B) and (C)

49. $A \to B$ is isothermal as per $\rho - T$ graph

$\rho_A < \rho_B \Rightarrow P_A < P_B$

process $B \to C$ is isobaric, process $C \to D$ is isothermal, and process $D \to A$ is isobaric

The correct option is (A) and (C)

50. For isothermal process,

Heat supplied (Q) = work done (W)

The correct option is (A) and (B)

51. Equilibrium of piston gives,

$$Ps = P_0 s + Kx_0 + mg$$

$$P = P_0 + \frac{Kx_0}{s} + \frac{mg}{s}$$

Work done by the gas,

$$W = P_0 \Delta V + \frac{1}{2}Kx_0{}^2 + mgx_0 = P_0 sx_0 + \frac{1}{2}Kx_0^2 + mgx_0$$

Also, $W = -\Delta U$

Decrease in internal energy of the gas

$$= P_0 sx_0 + \frac{1}{2}Kx_0{}^2 + mgx_0$$

The correct option is (A) and (C)

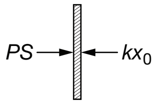
52. Equilibrium of piston gives

$$PS = kx_0$$

or $P = \dfrac{kx_0}{S}$

Since the chamber is thermally insulated, $\Delta Q = 0$

∴ Elastic potential energy of spring = work done by gas



or work done by gas = $\dfrac{1}{2}kx_0^2$

This work is done in the expense of internal energy of the gas.

Therefore, internal energy of the gas is decreased by $\frac{1}{2}kx_0^2$.

Internal energy of an ideal gas depends on its temperature only. Internal energy of the gas is decreasing. Therefore, temperature of the gas will decrease.

The correct option is (A) (B), (C) and (D)

Passage Based Questions

Passage 1

53. **Process $A - B$:** $\dfrac{V}{T}$ = constant

or $\dfrac{V_0}{(273+27)} = \dfrac{2V_0}{T_B}$ or $T_B = 600\text{ K} = 327°\text{C}$

The correct option is (C)

54. **Process $A - B$:**

Heat absorbed in isobaric process, $Q_P = nC_P\Delta T$

$$Q_P = 2 \times \left(\frac{5}{2}R\right)(600 - 300) = 1500\,R$$

The correct option is (A)

55. **Process $B - C$:**

$$Q_2 = W_2 = nRT_B \log_e \frac{V_C}{V_B} = 2 \times R \times 600 \log_e 2 = 831.6\,R$$

Process $C - D$:

$$Q_3 = nC_v \Delta T = 2 \times \frac{3}{2}R(300 - 600) = -900\,R$$

Process $D - A$:

$$Q_4 = nRT_A \log_e \frac{V_A}{V_D} = 2 \times R \times 300 \log_e \frac{1}{4} = -831.6\,R$$

For a cyclic process, $\Delta U = 0$

Hence, $\Sigma Q = \Sigma W$, $W = Q_1 + Q_2 + Q_3 + Q_4 = 600\,R$

The correct option is (D)

Match the Column Type

56. (A) – 1, 4; (B) – 2; (C) – 3; (D) – 1, 3

57. For $J \to K$, $P \propto T \Rightarrow \Delta Q < 0$, $W = 0$

For $K \to L$, $V \propto T \Rightarrow \Delta Q > 0$, $W > 0$

For $L \to M$, $P \propto T \Rightarrow \Delta Q > 0$, $W = 0$

For $M \to J$, $W < 0$, $\Delta Q < 0$

(A) – 2; (B) – 1, 3; (C) – 1; (D) – 2, 4

58. (A) –1, 4; (B) –4; (C) –1, 4; (D) –2, 3.

59. $Q = Q_{AB} + Q_{BC} + Q_{AC} = W$ = area of PV diagram = P_0V_0

$$Q_{CA} = \frac{5}{2}R(T_A - T_C) = -\frac{5}{2}P_0V_0$$

$$Q_{AB} = \frac{3}{2}R(T_B - T_A) = 3P_0V_0$$

$$Q_{BC} = W - (Q_{AB} + Q_{AC}) = \frac{P_0V_0}{2}$$

Net work done = $\dfrac{1}{2}V_0 \times 2P_0 = P_0V_0$

(A) – 1, (B) – 2, (C) – 3, (D) – 4

Integer Type

64. As the system is thermally insulated,

$\Delta Q = 0$

Further as the gas is expanding against vacuum (surroundings), the process is called free expansion and for it

$\Delta W = \int PdV = 0$

So in accordance with first law of thermodynamics,

i.e., $\Delta Q = \Delta U + \Delta W$ we have

$0 = \Delta U + 0,$

$\Delta U = 0$ or $U =$ constant

For an ideal gas,

$U = nC_V T$

or $U \propto T$

$\therefore \quad \Delta T = 0$

65. (A) $\Delta m = \dfrac{0.15}{60}$ kg/s $= 2.5 \times 10^{-3}$ kg/s

Let P be the rate of loss of heat from the tube, and C be the specific heat capacity of water, then

$P + \Delta m \times C \times (17.4 - 15.2) = 25.2$ (1)

Also, $P + \Delta m' \times C \times (17.4 - 15.2) = 37.8$ (2)

Where $\Delta m' = \dfrac{0.2318}{60} = 3.8633 \times 10^{-3}$ kg/s

Equation (2) – Equation (1)

$2.2 \times C\,[3.86 - 2.5] \times 10^{-3} = 12.6$

$C = 4.2 \times 10^3$ J/kg –°C

(B) Putting the value of C in Equation (1)

$P + 23.1 = 25.2$

$P = 2.1$W

66. (A) $W = \displaystyle\int_{V_1}^{V_2} PdV = \int_{V_1}^{V_2} \frac{RT}{V}dV = \int_{V_1}^{V_2} \frac{R(\alpha V)^2}{V}dV$

$$= \alpha R \int_{V_1}^{V_2} VdV = \frac{\alpha R}{2}[V_2^2 - V_1^2]$$

or, $\quad W = \dfrac{R}{2}(T_2 - T_1)$ (1)

Now, $\quad T_1 = \alpha V_1^2$

$T_2 = \alpha V_2^2$

$\therefore \quad T_2 = T_1 \left[\dfrac{V_2}{V_1}\right]^2 = 36\,T_1$

Hence from Equation (1) we have,

$$W = \frac{R}{2}[36T_1 - T_1] = \frac{35RT_1}{2}$$

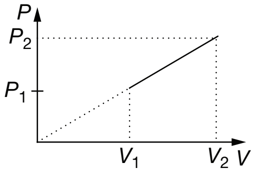
$$= \frac{35}{2}P_1V_1 = \frac{35}{2} \times (1.5 \times 10^{-3}) \times (12 \times 10^5)\text{ J}$$

$= 3150$ J

(B) We know, $PV = RT = R\alpha V^2$

$\Rightarrow \quad P \propto V$

Hence, P-V graph is a straight line.



(C) $\Delta U = nC_V\,\Delta T = n\left(\dfrac{R}{\gamma - 1}\right)(T_2 - T_1) = \dfrac{R}{.5} \times 35T_1 = 70$

$RT_1 = 70\,P_1V_1$

$= 70 \times (1.2 \times 10^5) \times (1.5 \times 10^{-3})$ J $= 12600$ J

$\therefore \quad \Delta Q = \Delta U + W = 12600 + 3150 = 15750$ J

67. $\gamma_{\text{He}} = \dfrac{5}{3},\ \gamma_{O_2} = \dfrac{7}{5}$

For helium,

$$P_{\text{He}}(LA)^{\gamma_{He}} = P'_{\text{He}}\left(\frac{LA}{2}\right)^{\gamma_{He}}$$

$$P'_{\text{He}} = P_{\text{He}}(2)^{\frac{5}{3}} \qquad (1)$$

For oxygen,

$$P_{O_2}(LA)^{\gamma_{O_2}} = P'_{O_2}(L_2A)^{\gamma_{O_2}}$$

$$P'_{O_2} = P_{O_2}\left(\frac{L}{L_2}\right)^{\frac{7}{5}} \qquad (2)$$

Here $P_{O_2} = P_{\text{He}};\ P'_{O_2} = P'_{\text{He}}$

Dividing (1) and (2), $\left(\dfrac{L}{L_2}\right)^{\frac{7}{5}} = (2)^{\frac{5}{3}} \Rightarrow L_2 = \dfrac{L}{(2)^{\frac{25}{21}}}$

$\therefore$ Required volume $= \dfrac{LA}{(2)^{\frac{25}{21}}}$

Previous Years' Questions

68. We cannot reach absolute zero temperature.

The correct option is (C)

69. All reversible cycles do not have same efficiency.

The correct option is (A)

70. Second law of thermodynamics.

The correct option is (A)

71. In an adiabatic process, $T^{\gamma} = (\text{constant})\,P^{\gamma-1}$

or $T^{\gamma/\gamma-1} = (\text{constant})\,P$

Given $T^3 = (\text{constant})\,P$

$$\therefore \quad \frac{\gamma}{\gamma-1} = 3 \Rightarrow 3\gamma - 3 = \gamma$$

or $2\gamma = 3 \Rightarrow \gamma = 3/2$

For monoatomic gas, $\gamma = \frac{5}{3} = 1.67$

For diatomic gas, $\gamma = \frac{7}{5} = 1.4$

when $\gamma = 1.5$, the gas must be a suitable mixture of monoatomic and diatomic gases

$\therefore \quad \gamma = 3/2$

The correct option is (D)

72. The work does not characterize the thermodynamic state of matter.

The correct option is (C)

73. Efficiency $= 1 - \frac{T_2}{T_1} = 1 - \frac{300}{900} = 1 - \frac{1}{3} = \frac{2}{3}$

Heat energy $= 3 \times 10^6 \text{ cal} = 3 \times 10^6 \times 4.2\,\text{J}$

Work done by engine $= (\text{Heat energy}) \times (\text{efficiency})$

$$= (3 \times 10^6 \times 4.2) \times \frac{2}{3}\,\text{J}$$

$$= 8.4 \times 10^6\ \text{J}$$

The correct option is (B)

74. Internal energy and entropy are state functions.

The correct option is (B)

75. $\Delta U_1 = \Delta U_2$, because the change in internal energy depends only upon the initial and final states A and B.

The correct option is (A)

76. Efficiency $\eta = 1 - \frac{Q_2}{Q_1}$

$$Q_2 = T_0\,(2S_0 - S_0) = T_0\,S_0$$

$$Q_1 = T_0 S_0 + \frac{T_0 S_0}{2} = \frac{3}{2} T_0\,S_0$$

$$\therefore \quad \eta = 1 - \frac{T_0 S_0 \times 2}{3 T_0 S_0} = 1 - \frac{2}{3} = \frac{1}{3}$$

The correct option is (C)

77. Statements (b) and (c) are incorrect regarding the first law of thermodynamics.

The correct option is (A) and (D)

78. According to first law of thermodynamics,

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

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

$\therefore \quad 0 = \Delta U + \Delta W$

or $\Delta U = -\Delta W$

or $nC_v \Delta T = -\Delta W$

or $C_v = \frac{-\Delta W}{n\Delta T} = \frac{-(-146) \times 10^3}{(1 \times 10^3) \times 7}$

$$= 20.8\ \text{J mol}^{-1}\ \text{K}^{-1}$$

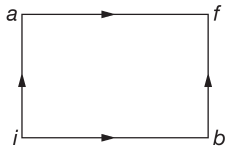
For diatomic gas,

$$C_v = \frac{5}{2} R = \frac{5}{2} \times 8.3 = 20.8\ \text{J mol}^{-1}\,\text{K}^{-1}$$

Hence the gas is diatomic.

The correct option is (A)

79. According to first law of thermodynamics for the path iaf,



$Q_{\text{iaf}} = \Delta U_{\text{iaf}} + W_{\text{iaf}}$ or $\Delta U_{\text{iaf}} = Q_{\text{iaf}} - W_{\text{iaf}}$

$$= 50 - 20 = 30 \text{ cal}$$

For the path ibf,

$$Q_{\text{ibf}} = \Delta U_{\text{iaf}} + W_{\text{ibf}}$$

Since $\Delta U_{\text{iaf}} = \Delta U_{\text{iaf}}$, change in internal energy is path-independent.

$$Q_{\text{ibf}} = \Delta U_{\text{iaf}} = W_{\text{ibf}}$$

$\therefore \quad W_{\text{ibf}} = Q_{\text{ibf}} - \Delta U_{\text{iaf}} = 36 - 30 = 6$ cal.

The correct option is (A)

80. For Carnot engine efficiency $\eta = \frac{Q_H - Q_L}{Q_L}$

Coefficient of performance of a refrigerator $\beta = \frac{1-\eta}{\eta}$

$$\beta = \frac{1 - \frac{1}{10}}{1/10} = 9$$

Also $\beta = \frac{Q_L}{W}$ (where W is the work done)

or $Q_L = \beta \times W = 9 \times 10 = 90\,\text{J}$

The correct option is (B)

81. As this is a simple mixing of gas, even if adiabatic conditions are satisfied, $PV = nRT$ for adiabatic as well as isothermal changes. The total number of molecules is conserved.

$$\therefore \; n_1 = \frac{P_1V_1}{R_1T_1}, n_2 = \frac{P_2V_2}{RT_2}$$

Final state $= (n_1 + n_2)RT$

$$(n_1 + n_2) = \frac{P_1V_1}{RT_1} + \frac{P_2V_2}{RT_2} = \frac{T_2P_1V_1 + T_1P_2V_2}{RT_1T_2}$$

$$T = \frac{T_1n_1 + T_2n_2}{n_1 + n_2}, \; T = \frac{T_1T_2(P_1V_1 + P_2V_2)}{T_2P_1V_1 + T_1P_2V_2}$$

The correct option is (B)

82. Total work done on the gas when taking from A to $B = 400\,R$, from C to D is equal and opposite

Then cancel each other.

For taking from D to A, work done on the gas = +414 R. Work done on the gas in taking it from B to C, pressure is decreased, temperature remain the same, volume increases.

$$\Rightarrow W_{BC} + W_{DA} = 2 \;\; In \;\; 2(500R - 300R)$$

$$\Rightarrow W_{BC+DA} = (2\,In\;2) \times (200R)$$

$$= 400\;R \times 0.693 = 277\,R$$

Work done along AB and CD cancel each other because pressure changes but temperature is the same.

Net work done on the gas of 2 moles of helium through the whole network = 277 R per cycle or nearest to the answer (B).

The correct option is (B)

83. For an adiabatic process,

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

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

$$T_1 = T_2\left(\frac{V_2}{V_1}\right)^{\gamma-1} = T_2\left(\frac{32V}{V}\right)^{\gamma-1} = T_2(32)^{\gamma-1}$$

For diatomic gas, $\gamma = \frac{7}{5}$

$$\therefore \; T_1 = T_2(32)^{\frac{7}{5}-1} = T_2(32)^{2/5} = T_2(2^5)^{2/5} = 4T_2$$

Efficiency of the engine, $\eta = 1 - \frac{T_2}{T_1} = \left(1 - \frac{1}{4}\right)$

$$\eta = \frac{3}{4} = 0.75$$

The correct option is (C)

84. The final temperature of the mixture is

$$T_{\text{mixture}} = \frac{n_1T_1 + n_2T_2 + n_3T_3}{n_1 + n_2 + n_3}$$

The correct option is (B)

85. In case of a cyclic process, work done is equal to the area under the cycle and is taken to be positive if the cycle is clockwise.

Work done by the gas

W = Area of the rectangle $ABCD = P_0V_0$

Helium gas is a monoatomic gas.

$$\therefore \; C_v = \frac{3}{2}R \;\text{ and }\; C_P = \frac{5}{2}R$$

Along the path AB, heat supplied to the gas at constant volume,

$$\therefore \; \Delta Q_{AB} = nC_V\Delta T = n\frac{3}{2}R\Delta T = \frac{3}{2}V_0\Delta P = \frac{3}{2}P_0V_0$$

Along the path BC, heat supplied to the gas at constant pressure,

$$\therefore \; \Delta Q_{BC} = nC_P\Delta T = n\frac{5}{2}R\Delta T = \frac{5}{2}(2P_0)\Delta V = 5\,P_0V_0$$

Along the path CD and DA, heat is rejected by the gas

$$\text{Efficiency, } \eta = \frac{\text{Work done by the gas}}{\text{Heat supplied to the gas}} \times 100$$

$$= \frac{P_0V_0}{\frac{3}{2}P_0V_0 + 5P_0V_0} \times 100 = \frac{200}{13} = 15.4\%$$

The correct option is (A)

86. Efficiency of Carnot engine,

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

where T_1 is the temperature of the source and T_2 is the temperature of the sink.

For first case,

$\eta = 40\%, T_1 = 500\;K$

$$\therefore \; \frac{40}{100} = 1 - \frac{T_2}{500} \Rightarrow \frac{T_2}{500} = 1 - \frac{40}{100} = \frac{3}{5}$$

$$T_2 = \frac{3}{5} \times 500 = 300\,K$$

For second case,

$\eta = 60\%, T_2 = 300\,K$

$$\therefore \; \frac{60}{100} = 1 - \frac{300}{T_1} \Rightarrow \frac{300}{T_1} = 1 - \frac{60}{100} = \frac{2}{5}$$

$$T_1 = \frac{5}{2} \times 300 = 750\;K$$

The correct option is (C)

87. Heat is extracted from the source in path DA and AB.

Along path DA, volume is constant.

Hence,

$$\Delta Q_{DA} = nC_v\Delta T = nC_v(T_A - T_D)$$

According to ideal gas equation,

$$pv = nRT \;\text{ or }\; T = \frac{pv}{nR}$$

For a monoatomic gas, $C_v = \frac{3}{2}R$

$$\therefore\ \Delta Q_{DA} = n\left(\frac{3}{2}R\right)\left[\frac{2p_0v_0}{nR} - \frac{p_0v_0}{nR}\right] = \frac{3}{2}p_0v_0$$

Along the path AB, pressure is constant. Hence,

$$\Delta Q_{AB} = nC_p\Delta T = nC_p(T_B - T_A)$$

For a monoatomic gas, $C_p = \frac{5}{2}R$

$$\therefore\ \Delta Q_{AB} = n\left(\frac{5}{2}R\right)\left[\frac{2p_0 2v_0}{nR} - \frac{2p_0v_0}{nR}\right] = \frac{10}{2}p_0v_0$$

The amount of heat extracted from the source in a single cycle is

$$\Delta Q = \Delta Q_{DA} + \Delta Q_{AB}$$

$$= \frac{3}{2}p_0v_0 + \frac{10}{2}p_0v_0 = \frac{13}{2}p_0v_0$$

The correct option is (A)

88. Change in internal energy $\Delta U = nC_v\Delta T$

$$= 1\times\frac{5R}{2}\Delta T$$

In the process AB, $\Delta u_{AB} = \frac{5R}{2}(400) = 1000\,R$

In the process BC, $\Delta u_{BC} = \frac{5R}{2}(-200) = -500\,R$

In the process CA, $\Delta u_{CA} = \frac{5R}{2}(-200) = -500\,R$

The change in internal energy in cyclic process is zero.

The correct option is (D)

89. Time of collision

$$t = \frac{\lambda}{v}$$

$\lambda =$ mean free path; v = average speed of molecule; N = number of molecules; V = volume;

d = diameter of molecule

$$\lambda = \frac{1}{\pi d^2(N/V)}$$

$$\Rightarrow\ t \propto \frac{\lambda}{v}$$

$$\propto \frac{V}{v\cdot N}$$

$$\propto \frac{V}{\sqrt{T}}$$

$$\propto \frac{V}{\left(\dfrac{1}{V^{\frac{\gamma-1}{2}}}\right)}$$

$$\propto V^{\frac{\gamma+1}{2}}$$

The correct option is (B)

90. $P - 2P_0 = (V - V_0)\cdot\left(-\frac{P_0}{V_0}\right)$

$$P - 2P_0 - \frac{P_0}{V_0}\cdot(V_0 - V_0)$$

$$\text{nRT} = V_0\cdot 2P_0 - \frac{P_0}{V_0}\left(V^2 - V_0V\right)$$

$$\frac{dT}{dV} = 0 \Rightarrow 2P_0 - \frac{P_0}{V_0}(2V - V_0) = 0$$

$$\Rightarrow\ V = \frac{3V_0}{2}$$

$$\therefore\ T_{\max} = \frac{1}{hR}\left[\frac{3V_0}{2}\cdot 2P_0 - \frac{P_0}{V_0}\left(\frac{9}{4}.V_0^2 - V_0.\frac{3}{2}V_0\right)\right]$$

$$= \frac{9}{4}\frac{P_0V_0}{nR}$$

The correct option is (D)

91. We know

$$C = C_v + \frac{R}{1-n}$$

$$C = C_v + \frac{C_p - C_v}{1-n}$$

$$C - C_v = \frac{C_p - C_v}{1-n}$$

$$1 - n = \frac{C_p - C_v}{C - C_v}$$

$$\therefore\ \ n = \frac{C - C_p}{C - C_v}$$

The correct option is (A)