15

Thermodynamics

IN THIS CHAPTER ....

The branch of science which deals with transformation of heat energy into other forms of energy and *vice-versa* is known as *thermodynamics*.

Thermodynamic Terms

In order to understand these transformation we need to understand the terms given below.

Thermodynamical System An assembly of an extremely large number of particles which is capable of exchange of energy with its surroundings is called thermodynamic system.

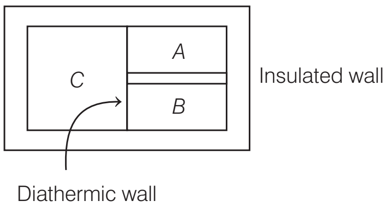
Thermodynamic Parameters The state of thermodynamic system can be described by specifying pressure, volume, temperature, internal energy and number of moles, etc. These are called thermodynamic parameters or coordinates or variables.

The state variables may be extensive (*e.g.* volume, total mass, internal energy) or intensive (*e.g.* pressure, temperature and density.) in nature.

Thermal Equilibrium A thermodynamical system is said to be in thermal equilibrium when macroscopic variables (like pressure, volume, temperature, mass, composition etc) that characterise the system do not change with time

Zeroth Law of Thermodynamics

According to this law, if two systems A and B are each in thermal equilibrium with a third system C, then A and B will also be in thermal equilibrium with each other.



Therefore, there must be a certain scalar physical quantity which is identical for all systems in thermal equilibrium. This quantity (scalar) is the temperature.

Suppose for systems A, B and C are in thermal equilibrium, then $T_A = T_B = T_C$

So for a body, temperature is that physical quantity which decides the degree of hotness or coldness of a body and is responsible for heat flow.

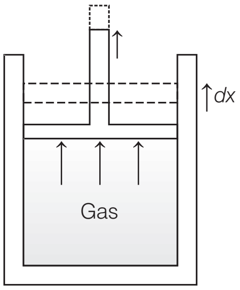
Work

It is defined as the product of force and its displacement in the direction of force. Its unit is joule or N-m, *i.e.*

$$W = \int dW = F\,dx$$

Work Done by a Gas During Expansion

Consider an ideal gas is enclosed in a perfectly insulated cylinder fitted with a non-conducting and frictionless piston. If p is the pressure exerted by the gas, V be the volume of the gas at any particular instant and A be the area of cross-section of the piston, then



Work done, $dW = (pA)dx = p\,dV$

($\because A\,dx = dV$ = infinitesimal change in volume)

During expansion of the gas, *work is done by the gas* and is taken as *positive* while during compression *work is done on the gas* and it is taken as *negative*.

Example 1. *When water is boiled under a pressure of 2 atm, the heat of vaporisation is 2.20×10^6 Jkg^{-1} and the boiling point is $120°$C. At this pressure, 1 kg of water has a volume of 10^{-3} m^3 and 1 kg of steam has a volume of $0.824\,m^3$. What is the work done when 1 kg of steam is formed at this temperature?*

(a) 166.74 kJ (b) 266.74 kJ (c) 366.74 kJ (d) 466.74 kJ

Sol. (a) Work done = $p(\Delta V)$ (at constant pressure)

$\therefore \quad W = 2 \text{ atm} \times (0.824 - 0.001) \text{ m}^3$

$\Rightarrow \quad W = 2 \times 1.013 \times 10^5 \text{ Nm}^{-2} \times 0.823 \text{ m}^3$

$= 166.74$ kJ

Internal Energy

Internal energy of a system is the energy possessed by the system due to molecular motion and molecular configuration. The energy due to molecular motion is called *internal kinetic energy* (U_K) and that due to molecular configuration is called *internal potential energy* (U_P).

i.e. $\quad U = U_K + U_P$

Important points related to internal energy

(i) Change in internal energy is path independent and depends only on the initial and final states of the system.

i.e., $\quad \Delta U = U_f - U_i$

(ii) Change in internal energy in a cyclic process is always zero as for cyclic process, $U_f = U_i$, so that

$$\Delta U = U_f - U_i = 0$$

(iii) In case of ideal gas, as there is no molecular attraction $U_P = 0$, *i.e.* so internal energy of an ideal gas is totally kinetic and is given by

$$U = U_K = \frac{3}{2} nRT$$

with $\quad \Delta U = \frac{3}{2} nR\,\Delta T$

where, n = number of moles

and $\quad R$ = gas constant.

(iv) In case of gases, whatever be the process,

$$\Delta U = nC_V \Delta T = \frac{nR\,\Delta T}{(\gamma - 1)}$$

(v) The change in internal energy (ΔU) of a system in case of gain is taken as positive, while it is taken as negative in case of loss of energy.

First Law of Thermodynamics

When a system changes for a given initial state to a given final state, both the work W and heat Q depend on the nature of the process.

The change in Q and W represent a change in same intrinsic property of the system. This property is the *internal energy* U and we write

$$\Delta U = U_f - U_i = Q - W \quad \ldots\text{(i)}$$

This equation is the *first law of thermodynamics*.

It can be written as $\quad dQ = dU + dW \quad \ldots$(ii)

Thus, we can say that, heat supplied to the system is the sum of external work done dW by the system and increase in its internal energy dU.

In Eq. (ii), dQ is change in heat. So, dQ will be positive when heat is given to the system and dQ will be negative when heat is given by the system.

Note First law of thermodynamics is a direct consequence of law of conservation of energy.

Example 2. *When a system goes from state A to state B, it is supplied with 400 J of heat and it does 100 J of work. For this translation, what will be the change in internal energy of the system?*

(a) 250 J (b) 300 J
(c) 350 J (d) 150 J

Sol. (b) From the first law of thermodynamics,

$$\Delta U_{AB} = Q_{AB} - W_{AB}$$

$$= (400 - 100) \text{ J} = 300 \text{ J}$$

Example 3. *In the above example, if the system moves from B to A, what is the change in internal energy?*

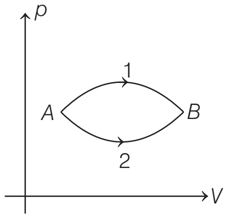
(a) 300 J (b) – 300 J
(c) 400 J (d) – 400 J

Sol. (b) Consider a closed path that passes through the state A and B. Internal energy is a state function, so ΔU is zero for a closed path.

Thus, $\Delta U = \Delta U_{AB} + \Delta U_{BA} = 0$

or $\Delta U_{BA} = -\Delta U_{AB} = -300$ J

Example 4. *A certain amount of an ideal gas passes from state A to B first by means of process 1, then by means of process 2. In which of the process, is the amount of heat absorbed by the gas greater?*



(a) *Process 1* (b) *Process 2*
(c) *Equal in both process* (d) *None of these*

Sol. (a) For process 1, $\Delta Q_1 = \Delta W_1 + \Delta U_1$

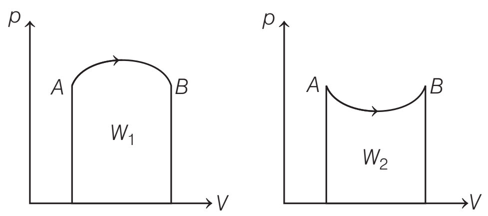
and For process 2, $\Delta Q_2 = \Delta W_2 + \Delta U_2$

U is a state function. Hence, ΔU depends only on the initial and final positions. Therefore,

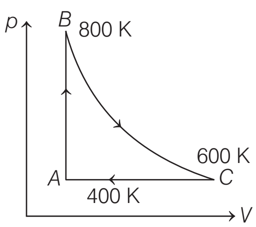
$$\Delta U_1 = \Delta U_2$$

But $W_1 > W_2$

As the area under 1 is greater than area under 2. Hence, $Q_1 > Q_2$



Example 5. *One mole of diatomic ideal gas undergoes a cyclic process ABC as shown in figure. The process BC is adiabatic. The temperatures at A, B and C are 400 K, 800 K and 600 K, respectively.*
Choose the correct statement. **[JEE Main 2014]**



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

Sol. (d) According to first law of thermodynamics, we get

(i) Change in internal energy from A to B, i.e.

$$\Delta U_{AB} = nC_V(T_B - T_A) = 1 \times \frac{5R}{2}(800 - 400) = 1000\,R$$

(ii) Change in internal energy from B to C,

$$\Delta U_{BC} = nC_V(T_C - T_B) = 1 \times \frac{5R}{2}(600 - 800) = -500\,R$$

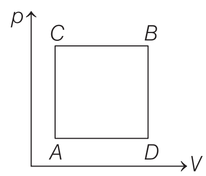
(iii) $\Delta U_{\text{total}} = 0$

(iv) Change in internal energy from C to A,

$$\Delta U_{CA} = nC_v(T_A - T_C) = 1 \times \frac{5\,R}{2}(400 - 600) = -500\,R$$

Hence, option (d) is correct.

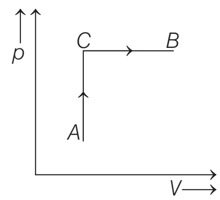
Example 6. *A gas can be taken from A to B via two different processes ACB and ADB.*



When path ACB is used 60 J of heat flows into the system and 30 J of work is done by the system. If path ADB is used, work done by the system is 10 J, the heat flowing into the system in path ADB is **[JEE Main 2019]**

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

Sol. (b) For the ACB as shown in the figure below



According to the first law of thermodynamics,

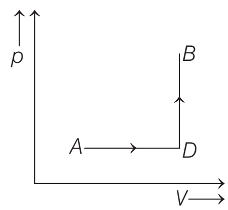
Heat supplied, ΔQ = Work done (ΔW) + Internal energy (ΔU)

$\Rightarrow \Delta Q_{CB} = \Delta W_{ACB} + (U_B - U_A)$ [where, $\Delta U = U_B - U_A$]

Substituting the given values, we get

$$U_B - U_A = 60 - 30 = 30 \text{ J} \quad \text{...(i)}$$

Similarly for the ADB as shown in the figure below



$$\Delta Q_{ADB} = \Delta W_{ADB} + (U_B - U_A)$$

$\Rightarrow \Delta Q_{ADB} = 10 + 30$ [using Eq. (i)]

$= 40$ J

Thermodynamic Process

A thermodynamical process is said to take place when some changes occur in the state of a thermodynamic system *i.e.* the thermodynamic parameters of the system change with time.

Reversible and Irreversible Processes

Reversible Process A process which could be reserved in such a way that the system and its surrounding returns exactly to their initial states with no other changes in the universe is known as reversible process.

Irreversible Process Any process which is not reversible exactly is an irreversible process.

Isothermal Process

In isothermal process, the temperature remains constant. Melting and boiling points are examples of isothermal process. Specific heat in isothermal process is infinity.

Work done in an isothermal process,

$$W = \int p dV = nRT \int_{V_1}^{V_2} \frac{dV}{V}$$

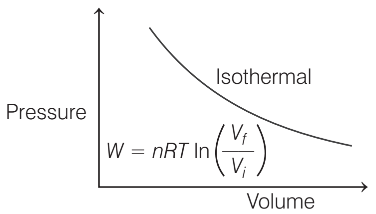
$$= nRT \log_e \frac{V_2}{V_1}$$

$$= 2.303\, nRT \log \frac{V_2}{V_1}$$

$$= 2.303\, nRT \log \frac{p_1}{p_2}$$

Isothermal elasticity = p (Bulk modulus)

The pressure *versus* volume curve for isothermal process is as follows



Since for an ideal gas, the internal energy is proportional to temperature, so it follows that there is no change in the internal energy of the gas during an isothermal process. The first law of thermodynamics then becomes

$$\Delta U = 0 = Q - W$$

$$\therefore \quad Q = W$$

All the heat added to the system is used to do work in an isothermal process.

Example 7. *How much work is done by ideal gas in expanding isothermally from an initial volume of 3 L at 20 atm to a final volume of 24 L?*

(a) 1.36×10^5 J (b) 1.26×10^4 J
(c) 1.36×10^4 J (d) 2.36×10^5 J

Sol. (*b*) In isothermal process at temperature T,

$$W = 2.303\, nRT \log_{10} \frac{V_2}{V_1}$$

$$W = 2.303 (p_1V_1) \log_{10} \frac{V_2}{V_1} \qquad [\text{using } p_1V_1 = nRT]$$

$$= 2.303 (20 \times 3) \log_{10} \frac{24}{3} \text{ L-atm}$$

$$= [2.303 \times 60 \times \log_{10} 8] \times 10^{-3} \times 1.01 \times 10^5$$

$$= 1.26 \times 10^4 \text{ J}$$

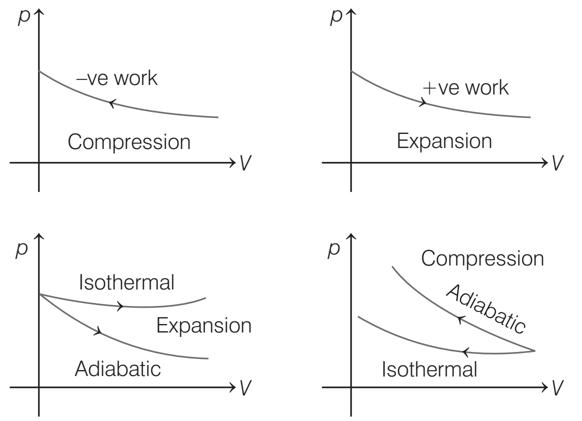
Adiabatic Process

In an adiabatic process, heat is neither allowed to enter nor allowed to escape from the system. Specific heat in an adiabatic process is zero.

Since, $dQ = 0$

$\therefore$ $dU = -p\,dV$

So, let us read through the following graphs of p *versus* V that what happens when adiabatic expansion and compression happens.



In an adiabatic process,

(a) pV^{γ} = constant (b) $p^{1-\gamma}T^{\gamma}$ = constant
(c) $TV^{\gamma-1}$ = constant

Work done in an adiabatic process,

$$W = \frac{p_1V_1 - p_2V_2}{\gamma - 1} = \frac{nR(T_1 - T_2)}{\gamma - 1}$$

where, $\gamma = \frac{C_p}{C_V}$

Adiabatic elasticity (bulk modulus) = γp.

Example 8. *A balloon filled with helium (32°C and 1.7 atm) bursts. Immediately afterwards, the expansion of helium can be considered as* **[JEE Main 2020]**

(a) irreversible, isothermal (b) irreversible, adiabatic
(c) reversible, adiabatic (d) reversible, isothermal

Sol. (*b*) Expansion after bursting of balloon is a fast process in which helium presses the atmosphere. This expansion occurs at the expense of internal energy of helium molecules.

So, this process is irreversible and adiabatic.

Example 9. *During an adiabatic expansion, the increase in volume is associated with which of the following possibilities w.r.t. pressure and temperature?*

Pressure	***Temperature***
(a) Increase	*Increase*
(b) Decrease	*Decrease*
(c) Increase	*Decrease*
(d) Decrease	*Increase*

Sol. (*b*) According to first law of thermodynamics,

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

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

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

In adiabatic process, $\quad p \propto \dfrac{1}{V^{\gamma}}$

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

$\gamma > 1$, because volume increases.

Then, p and T will decrease.

Example 10. *A gasoline engine takes in 5 moles of air at 20°C and 1 atm and compresses it adiabatically to (1/10) th of the original volume. Assume, air to be diatomic. The work done and change in internal energy is*

(*a*) 46 *kJ*, – 46 *kJ* (*b*) 36 *kJ*, – 36 *kJ*
(*c*) –46 *kJ*, 46 *kJ* (*d*) 36 *kJ*, – 46 *kJ*

Sol. (c) Let $p_1 = 1$ atm, $n = 5$ mol, $T_1 = 293$ K

$$V_2 = \frac{V_1}{10}$$

Using, $\quad T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1}$

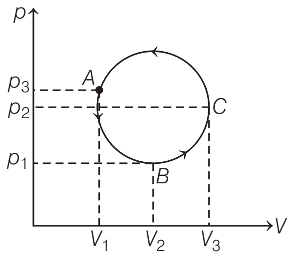
$$\Rightarrow \quad T_2 = T_1\left(\frac{V_1}{V_2}\right)^{\gamma-1} = 293(10)^{0.4} = 736 \text{ K}$$

$$\text{Work done} = \frac{nR(T_1 - T_2)}{\gamma - 1} = \frac{5 \times 8.3 \times (293 - 736)}{0.4} = -46 \text{ kJ}$$

$$\Delta U = \Delta Q - W = 0 - W = 46 \text{ kJ}$$

Cyclic Process

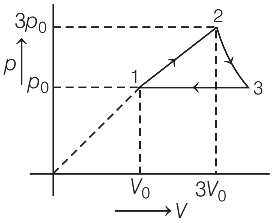
Figure shows a cyclic process *ABC*A, the work done during the cycle can be calculated as



Work done during the process $AB = W_{AB}$.
Work done during the process $BC = W_{BC}$.
Work done during the process $CA = W_{CA}$.
The net work done during the cycle is

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

Example 11. *One mole of an ideal monoatomic gas undergoes thermodynamic cycle $1 \to 2 \to 3 \to 1$ as shown in the figure. Initial temperature of the gas is $T_0 = 300$ K.*



Process $1 \to 2$: $p = \alpha V$
Process $2 \to 3$: pV = *constant*
Process $3 \to 1$: p = *constant* (*Take* $\ln|3| = 1.09$)

The net work done by the cycle is

(*a*) 3.27 RT_0 (*b*) 6.83 RT_0
(*c*) 4.53 RT_0 (*d*) 5.81 RT_0

Sol. (*d*) For process $1 \to 2$,

$$W_{12} = \int_1^2 \alpha V dV = \alpha \int_{V_0}^{3V_0} V dV = \frac{\alpha}{2}(9V_0^2 - V_0^2) = 4\alpha V_0^2$$

Using gas law, $\quad \dfrac{p_1V_1}{T_1} = \dfrac{p_2V_2}{T_2}$

$$\Rightarrow \quad T_2 = \frac{p_2V_2}{p_1V_1}T_1 = \frac{V_2^2}{V_1^2}T_1 = \left(\frac{3V_0}{V_0}\right)^2 T_0 = 9T_0$$

For process $2 \to 3$,

$$W_{23} = RT_2 \log\left|\frac{p_2}{p_3}\right| = R(9T_0)\log\left|\frac{3p_0}{p_0}\right|$$

$$= 9RT_0 \log|3| = 9.81RT_0$$

For isothermal process,

$$p_2V_2 = p_3V_3$$

$$\therefore \quad V_3 = \frac{p_2V_2}{p_3} = \frac{3p_0}{p_0}(3V_0) = 9V_0$$

$$W_{31} = p_0(V_1 - V_3) = p_0(V_0 - 9V_0) = -8p_0V_0$$

$$W_{31} = -8RT_0$$

Applying gas law in process $1 \to 2$,

$$p_0V_0 = RT$$

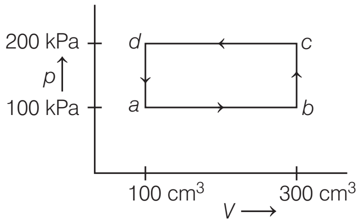
or $\quad \alpha V_0^2 = RT$

The net work,

$$\therefore \quad W_{\text{net}} = W_{12} + W_{23} + W_{31}$$

$$= 4RT_0 + 9.81RT_0 - 8RT_0 = 5.81RT_0$$

Example 12. *A thermodynamic system is taken through the cycle abcda shown in figure. Find the work done by the gas during the parts ab, bc, cd and da.*



(a) (20 *J*, 0, – 40 *J*, 0) (b) (0, 0, – 40 *J*, 20 *J*)
(c) (– 40 *J*, 20 *J*, 0, 0) (d) None of these

Sol. (a) The work done during the part *ab*

$$= \int_a^b p\,dV = (100\text{ kPa}) \int_a^b dV$$
$$= (100\text{ kPa})\,(300\text{ cm}^3 - 100\text{ cm}^3)$$
$$= 20\text{ J}$$

The work during *bc* is zero, as volume does not change.
The work done during *cd*

$$= \int_c^d p\,dV = (200\text{ kPa}) \int_c^d dV$$
$$= (200\text{ kPa})\,(100\text{ cm}^3 - 300\text{ cm}^3)$$
$$= -40\text{ J}$$

The work done during *da* is zero, as the volume does not change.

Isochoric Process

A process taking place in a thermodynamic system at constant volume is called an **isochoric process**.

Process equation is $\dfrac{p}{T}$ = Constant.

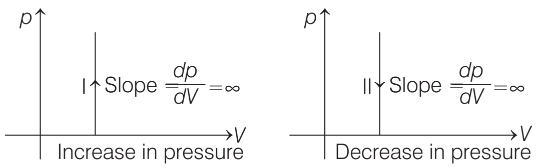
$dQ = nC_V\,dT$, molar heat capacity for isochoric process is C_V.

Volume is constant, so $dW = 0$.

From the first law of thermodynamics,

$$dQ = dU = nC_V\,dT$$

p-V curve is a straight line parallel to pressure axis as shown below.



Isobaric Process

An isobaric process is one in which volume and temperature of system may change but pressure remain constant, *i.e.* $\Delta p = 0$.

- For this process, Charles' law is obeyed.

  Hence, $$V \propto T \Rightarrow \frac{V_1}{T_1} = \frac{V_2}{T_2}$$

- Specific heat of a gas during an isobaric process,

  $$C_p = \left(\frac{f}{2} + 1\right) R = \frac{Q}{n\Delta T}$$

- Work done in an isobaric process,

  $$W = p(V_f - V_i) = nR(T_f - T_i) = nR\Delta T$$

- From first law of thermodynamics,

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

  Here, $$\Delta W = nR\Delta T$$
  $$\Delta U = nC_V\Delta T$$

  $\therefore$ $$\Delta Q = nC_V\Delta T + nR\Delta T = nC_p\Delta T$$

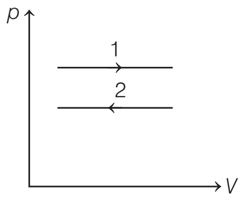
- Bulk modulus of an isobaric process is zero

  $$K_{\text{isobaric}} = \frac{\Delta p}{-\dfrac{\Delta V}{V}} = 0 \qquad (\text{as, } \Delta p = 0)$$

- p-V curve is a straight line parallel to volume axis, slope of p-V curve for an isobaric process, $\dfrac{dp}{dV} = 0$.

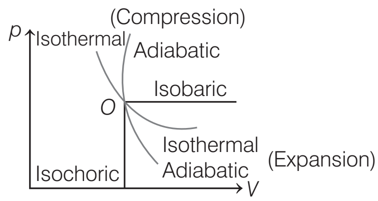
  (a) Graph 1 indicates isobaric expansion. The heat is given to the gas. The volume and temperature of the gas both will rise. The gas expands during positive work.

  (b) Graph 2 indicates isobaric compression. In this process, heat is taken out of the gas. The temperature falls and the gas contracts causing negative work.



Indication Diagram of *p*-*V* Curve

We can determine the work done from area under p-V curve.



For isothermal process, $\dfrac{\Delta p}{\Delta V} = -\dfrac{p}{V}$.

For adiabatic process, $\dfrac{\Delta p}{\Delta V} = -\dfrac{\gamma p}{V}$, *i.e.* it means that at a particular point, slope (value) of adiabatic curve is more than that for isotherm or we can say adiabatic curve is more steep than an isotherm for expansion and just reverse for compression.

It is clear from the figure that, for expansion that occurs within same limits.

$$W_{\text{isobaric}} > W_{\text{isothermal}} > W_{\text{adiabatic}} > W_{\text{isochoric}}$$

Important Points Related to Thermodynamic Process

- For a reversible process, the first law of thermodynamics gives the change in the internal energy of the system.

  $$dU = dQ - dW$$

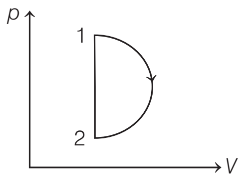
Replacing work with a change in volume gives

$$dU = dQ - pdV$$

Since the process is isochoric, $dV = 0$, therefore the above equation becomes

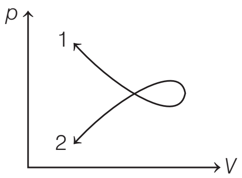
$$dU = dQ$$

- Work done on gas in some process



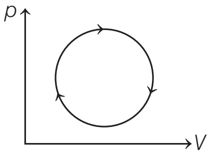
$\Delta V = 0$ but $dV \neq 0$

Work done = + ve



ΔW can be zero

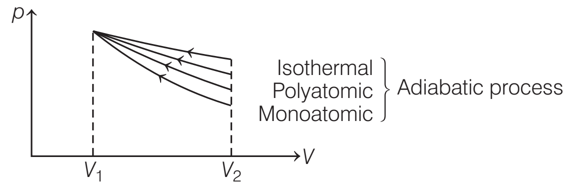
But $dW \neq 0$



For clockwise, $\Delta W = +$ ve

For anti-clockwise, $\Delta W = -$ve

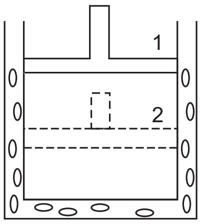
- Work done is least for monoatomic gas expansion.



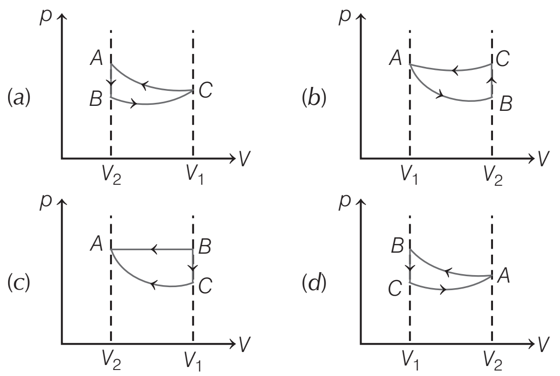
Different Thermodynamic Processes at a Glance

Change or Name of Process	Isobaric	Isochoric	Isothermal	Adiabatic
dQ	(i) For solids, $dQ = mC_p dT$ (ii) For gases, $dQ = mC_p dT = nC_p dT$ (iii) For change in state $dQ = mL$	(i) For solids, $dQ = mC_V dT$ (ii) For gases, $dQ = nC_V dT$	$dQ = dW$	Zero
dU	(i) $dQ - pdV$ (ii) $dQ - nRdT$	dQ	Zero	$-dW$
dW	(i) pdV (ii) $nRdT$	Zero	(i) $2.303\, nRT \log_{10} \frac{V_2}{V_1}$ (ii) $2.303\, p_1V_1 \log_{10} \frac{V_2}{V_1}$ (iii) $2.303\, p_1V_1 \log_{10} \frac{p_1}{p_2}$	(i) $\frac{R(T_2 - T_1)}{(1-\gamma)}$ (ii) $\frac{p_2V_2 - p_1V_1}{(1-\gamma)}$
Equation of state	$\frac{V}{T}$ = constant or $\frac{V_1}{T_1} = \frac{V_2}{T_2}$	$\frac{p}{T}$ = constant or $\frac{p_1}{T_1} = \frac{p_2}{T_2}$	pV = constant or $p_1V_1 = p_2V_2$	(i) pV^γ = constant (ii) $TV^{\gamma-1}$ = constant (iii) $p^{1-\gamma}T^\gamma$ = constant
Slope of p-V curve	Zero	∞	$-\frac{p}{V}$	$-\frac{\gamma p}{V}$
Law	Charles' law	Gay-Lussac's law	Boyle's law	Poisson's law
Form of first law	$dQ = dU + dW$ $= nC_p dT + pd\,V$	$dQ = dU = nC_V dT$	$dQ = dW = pdV$	(i) $dW = -dU$ (ii) $dU = -dW$
Bulk modulus	Zero	Infinity	$-p$	$-\gamma p$
Result of maximum work	Maximum	Zero	Less from isobaric process but greater from adiabatic process	Minimum but not zero

Example 13. *A cylinder containing an ideal gas and closed by a movable piston is submerged in an ice-water mixture. The piston is quickly pushed down from position 1 to position 2 (process AB).*



The piston is held at position 2 until the gas is again at 0°C (process BC). Then the piston is slowly raised back to position 1 (process CA). Which one of the following p-V diagrams correctly represent the processes AB, BC and CA and the cycle ABCA?



Sol. (d) In an adiabatic process, heat is neither allowed to enter nor allowed to escape the system, the process *AB* is adiabatic compression because piston is pushed very quickly from position 1 to position 2.

The process *BC* is isochoric because in this case volume remains constant, whereas process *CA* is an isothermal expansion because temperature remains constant. These are shown on the *p-V* diagram correctly in option (d).

Second Law of Thermodynamics

The second law of thermodynamics gives a fundamental limitation to the efficiency of a heat engine and the coefficient of performance of a refrigerator. It says that efficiency of a heat engine can never be unity (or 100%). This implies that heat released to the cold reservoir can never be made zero.

Kelvin's Statement

It is impossible for an engine operating in a cyclic process to extract heat from a reservoir and convert it completely into work. In other words, whole of heat can never be converted into work. Heat engine works on this principle.

Clausius Statement

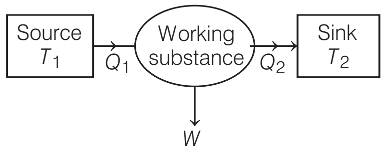
It is impossible for a self-acting machine unaided by any external agency to transfer heat from a colder to a hotter reservoir. In other words, heat by itself can not pass from a colder to a hotter body without an external agency. Refrigerator is based on this statement.

Heat Engine

A heat engine is a device which converts thermal energy into another useful forms of energy and work.

The efficiency of heat engine,

$$\eta = \frac{\text{Work done by working substance}}{\text{Heat given to working substance}}$$



$$\eta = \frac{W}{Q_1} = \frac{Q_1 - Q_2}{Q_1}$$

$$\% \eta = \frac{W}{Q_1} \times 100 = \frac{Q_1 - Q_2}{Q_1} \times 100$$

$$= \left(1 - \frac{Q_2}{Q_1}\right) \times 100 = \left(1 - \frac{T_2}{T_1}\right) \times 100$$

Note If $Q_2 = 0$ or $T_2 = 0$ K, then $\eta = 100\%$, which is impossible.

Example 14. *A heat engine is involved with exchange of heat of 1915 J, – 40 J, + 125 J and – QJ, during one cycle achieving an efficiency of 50.0%. The value of Q is*

[JEE Main 2020]

(a) 640 J *(b)* 40 J *(c)* 980 J *(d)* 400 J

Sol. *(c)* As processes involved in one cycle of a heat engine must be

Expansion ⟶ Compression

Expansion ⟵

⟶ Compression

So, *Q* must be negative.

Now, work done in process = heat supplied – heat rejected

$= (1915 + 125) - (40 + Q)$ J

and heat supplied to cycle = (1915 + 125) J

Given, efficiency = 50% ⇒ $\eta = \frac{\text{Work done}}{\text{Heat supplied}}$

$$\Rightarrow \quad \frac{50}{100} = \frac{(1915 + 125) - (40 + Q)}{1915 + 125}$$

$$\Rightarrow \quad Q = 2000 - 1020 = 980 \text{ J}$$

Types of Heat Engines

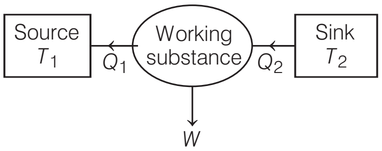
In practice, heat engine are of two types

(i) **External Combustion Engine** In this engine, heat is produced by burning the fuel in a chamber outside the main body (working substance) of the engine. Steam engine is an external combustion engine. The thermal efficiency of a steam engine varies from 10 to 20%.

(ii) **Internal Combustion Engine** In this engine, heat is produced by burning the fuel inside the main body of the engine. Petrol engine and diesel engines are internal combustion engine.

Refrigerator

A refrigerator or heat pump is basically a heat engine running in reverse direction. It takes heat from the colder body (sink) and after doing some work gives the rest heat to the hotter body (source).



The coefficient of performance of refrigerator,

$$\beta = \frac{\text{Heat extracted}}{\text{Work done}} = \frac{Q_2}{W}$$

$$= \frac{Q_2}{Q_1 - Q_2} = \frac{T_2}{T_1 - T_2} = \frac{1-\eta}{\eta}$$

Example 15. *An automobile engine absorbs 1600 J of heat from a hot reservoir and expels 1000 J to a cold reservoir in each cycle. What maximum work is done in each cycle?*

(a) 400 J (b) 500 J (c) 600 J (d) 450 J

Sol. (c) We know that, $W = Q_H - Q_L = 1600 - 1000 = 600$ J

Example 16. *Calculate the least amount of work that must be done to freeze one gram of water at 0°C by means of a refrigerator. Temperature of surrounding is 27°C. How much heat is passed on the surrounding in this process ? (Take, latent heat of fusion, $L = 80\ \text{calg}^{-1}$)*

(a) 87.91 cal (b) 97.91 cal (c) 88.95 cal (d) 89.95 cal

Sol. (a) As, $Q_2 = mL = 1 \times 80 = 80$ cal,

$$T_2 = 0°\text{C} = 273 \text{ K}$$

and $T_1 = 27°\text{C} = 300$ K

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

$$\Rightarrow \quad W = \frac{Q_2(T_1 - T_2)}{T_2} \text{ cal} = \frac{80(300 - 273)}{273} = 7.91$$

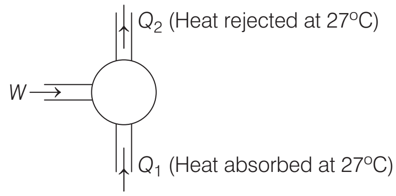
$$\Rightarrow \quad Q_1 = Q_2 + W = (80 + 7.91) = 87.91 \text{ cal}$$

Example 17. *If minimum possible work is done by a refrigerator in converting 100 g of water at 0°C to ice, how much heat (in cal) is released to the surroundings at temperature 27°C to the nearest integer?*
(Take, latent heat of ice = 80 cal/g) **[JEE Main 2020]**

Sol. (8791) To convert 100 g water at 0°C to ice at 0°C, heat absorbed by refrigerator,

$Q_1 = mL = 100 \times 80 = 8000$ cal

W = work done or energy supplied to refrigerator



From figure, we have $W + Q_1 = Q_2 \Rightarrow W = Q_2 - Q_1$

Now, coefficient of performance of refrigerator,

$$\beta = \frac{Q_1}{W} = \frac{Q_1}{Q_2 - Q_1} = \frac{T_1}{T_2 - T_1}$$

Here, $T_1 = 0°\text{C} = 273$ K

$T_2 = 27°\text{C} = 300$ K

So, $$\frac{Q_1}{Q_2 - Q_1} = \frac{273}{300 - 273}$$

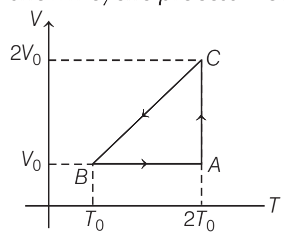
$$\Rightarrow \quad 27Q_1 = (Q_2 - Q_1)273$$

$$\Rightarrow \quad 300\ Q_1 = Q_2 \times 273$$

$$\Rightarrow \quad Q_2 = 300 \times \frac{8000}{273} = \frac{2400000}{273}$$

$$= 8791.2 \text{ cal} \approx 8791 \text{ cal}$$

Example 18. *The efficiency of an ideal gas with adiabatic exponent γ for the shown cyclic process would be*



(a) $\frac{(2\ln 2 - 1)}{\gamma/(\gamma-1)}$ (b) $\frac{(1 - 1\ln 2)}{\gamma/(\gamma-1)}$ (c) $\frac{(2\ln 2 + 1)}{\gamma/(\gamma-1)}$ (d) $\frac{(2\ln 2 - 1)}{\gamma/(\gamma+1)}$

Sol. (a) As, $W_{BC} = p\Delta V = nR\Delta T = -nRT_0$

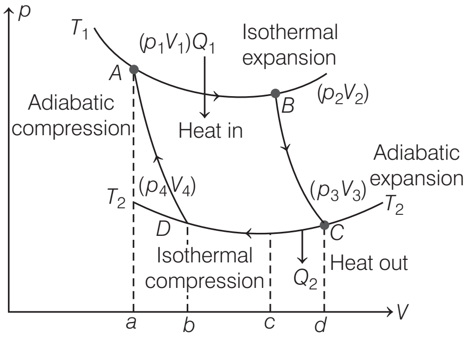
and $W_{CA} = +\ 2nRT_0 \ln 2$

Also, $\Delta Q_{BC} = nC_p\Delta T = \frac{nR_\gamma T_0}{\gamma - 1}$

$$\therefore \quad \text{Efficiency} = \frac{\text{Work}}{\text{Input heat}} = \frac{(2\ln 2 - 1)}{\gamma/(\gamma - 1)}$$

Carnot Cycle

Carnot devised an ideal cycle of operation for a heat engine called Carnot's cycle.



A Carnot's cycle contains the following four processes

(i) Isothermal expansion (AB)

(ii) Adiabatic expansion (BC)

(iii) Isothermal compression (CD)

(iv) Adiabatic compression (DA)

The net work done per cycle by the engine is numerically equal to the area of the loop representing the Carnot's cycle.

After doing the calculations for different processes, we can show that $\frac{Q_2}{Q_1}=\frac{T_2}{T_1}$

Therefore, efficiency of the cycle is $\eta = 1-\frac{T_2}{T_1}$

Efficiency of Carnot engine is maximum (not 100%) for given temperatures T_1 and T_2. But still Carnot engine is not a practical engine because many ideal situations have been assumed while designing this engine which can practically not be obtained.

Carnot Theorem

According to Carnot theorem,

- A heat engine working between the two given temperatures T_1 of hot reservoir *i.e.*, source and T_2 of cold reservoir *i.e.*, sink cannot have efficiency more than that of the Carnot engine.
- The efficiency of the Carnot engine is independent of the nature of working substance.

Carnot's Engine

Carnot engine is an ideal heat engine proposed by *Sadi Carnot* in 1824. The reversible engine which operates between two temperatures of source (T_1) and sink (T_2) is known as *Carnot heat engine*.

The designed engine is a theoretical engine which is free from all the defects of a practical engine. This engine cannot be realised in actual practice, however, this can be taken as a standard against which the performance of an actual engine can be judged.

Example 19. *Carnot's engine takes in a thousand kilo calories of heat from a reservoir at 827°C and exhausts it to a sink at 27°C. How much work does it perform? What is the efficiency of the engine?*

(a) 2.70×10^5 cal, 70.70% (b) 2.70×10^5 cal, 72.72%

(c) 2.70×10^5 cal, 80.70% (d) 3.70×10^5 cal, 70.70%

Sol. (*b*) Given, $Q=10^6$ cal

$$T_1=(827+273)=1100\text{ K}$$

and $$T_2=(27+273)=300\text{ K}$$

As, $$\frac{Q_1}{T_1}=\frac{Q_2}{T_2}$$

$$\therefore \quad Q_2=\frac{T_2}{T_1}Q_1=\left(\frac{300}{1100}\right)(10^6) = 2.720\times10^5\text{ cal}$$

Efficiency of the engine,

$$\eta=\left(1-\frac{T_2}{T_1}\right)\times100 \text{ or } \eta=\left(1-\frac{300}{1100}\right)\times100=72.72\%$$

Example 20. *A Carnot engine has an efficiency of 1/6. When the temperature of the sink is reduced by 62°C, its efficiency is doubled. The temperatures of the source and the sink are respectively,* **[JEE Main 2019]**

(a) 62°C, 124°C (b) 99°C, 37°C

(c) 124°C, 62°C (d) 37°C, 99°C

Sol. (*b*) Efficiency of a Carnot engine working between source of temperature T_1 and sink of temperature T_2 is given by $\eta=1-\frac{T_2}{T_1}$

Here, T_2 and T_1 are absolute temperatures. Initially, $\eta=\frac{1}{6}$

$$\therefore \quad \frac{1}{6}=1-\frac{T_2}{T_1} \Rightarrow \frac{T_2}{T_1}=\frac{5}{6}$$

Finally, efficiency is doubled on reducing sink temperature by 62°C.

$$\therefore \quad \eta=\frac{2}{6},\quad T_{\text{sink}}=T_2'=T_2-62$$

So, $$\eta=1-\frac{T'_2}{T'_1}$$

$$\Rightarrow \quad \frac{2}{6}=1-\frac{T_2-62}{T_1} \Rightarrow \frac{T_2-62}{T_1}=\frac{4}{6}$$

$$\Rightarrow \quad \frac{T_2}{T_1}-\frac{62}{T_1}=\frac{4}{6} \Rightarrow \frac{5}{6}-\frac{62}{T_1}=\frac{4}{6} \quad \left(\because \frac{T_2}{T_1}=\frac{5}{6}\right)$$

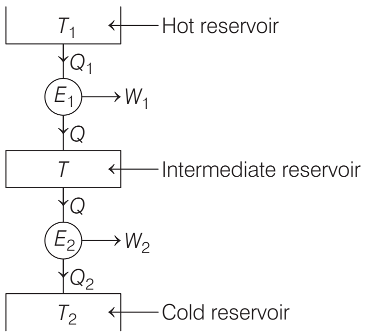
$$\Rightarrow \quad T_1=6\times62=372\text{ K}=372-273=99^\circ\text{ C}$$

$$\Rightarrow \quad T_2=\frac{5}{6}\times T_1\simeq310\text{ K}=310-273=37^\circ\text{ C}$$

Example 21. *Two ideal Carnot engines operate in cascade (all heat given up by one engine is used by the other engine to produce work) between temperatures T_1 and T_2. The temperature of the hot reservoir of the first engine is T_1 and the temperature of the cold reservoir of the second engine is T_2. T is temperature of the sink of first engine which is also the source for the second engine. How is T related to T_1 and T_2, if both the engines perform equal amount of work?* **[JEE Main 2020]**

(a) $T=0$ (b) $T=\frac{2T_1T_2}{T_1+T_2}$ (c) $T=\sqrt{T_1T_2}$ (d) $T=\frac{T_1+T_2}{2}$

Sol. (*d*) Carnot engines given are operating in cascade configuration as shown in the figure.



Work done by engine 1, $W_1 = Q_1 - Q = k(T_1 - T)$

Work done by engine 2, $W_2 = Q - Q_2 = k(T - T_2)$

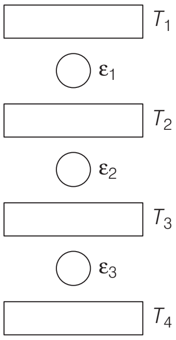
So, $$\frac{W_1}{W_2} = \frac{T_1 - T}{T - T_2}$$

As, $$\frac{W_1}{W_2} = 1 \quad \text{(given)}$$

$\Rightarrow$ $$T - T_2 = T_1 - T$$

$\Rightarrow$ $$T = \frac{T_1 + T_2}{2}$$

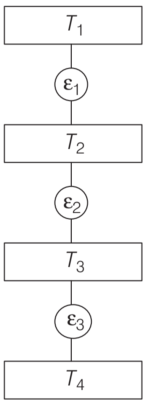
Example 22. *Three Carnot engines operate in series between a heat source at a temperature T_1 and a heat sink at temperature T_4 (see figure). There are two other reservoirs at temperatures T_2 and T_3, as shown with $T_1 > T_2 > T_3 > T_4$. The three engines are equally efficient, if* **[JEE Main 2019]**



(a) $T_2 = (T_1^3 T_4)^{1/4}$; $T_3 = (T_1 T_4^3)^{1/4}$ (b) $T_2 = (T_1^2 T_4)^{1/3}$; $T_3 = (T_1 T_4^2)^{1/3}$

(c) $T_2 = (T_1 T_4)^{1/2}$; $T_3 = (T_1^2 T_4)^{1/3}$ (d) $T_2 = (T_1 T_4^2)^{1/3}$; $T_3 = (T_1^2 T_4)^{1/3}$

Sol. (*b*) Given, Carnot engines operates as,



Efficiency of a Carnot's engine is given by $\eta = 1 - \dfrac{T_{\text{sink}}}{T_{\text{source}}}$

We have, $\eta_1 =$ efficiency of engine $\varepsilon_1 = 1 - \dfrac{T_2}{T_1}$

$\eta_2 =$ efficiency of engine $\varepsilon_2 = 1 - \dfrac{T_3}{T_2}$

$\eta_3 =$ efficiency of engine $\varepsilon_3 = 1 - \dfrac{T_4}{T_3}$

For equal efficiencies, $\eta_1 = \eta_2 = \eta_3$

$\Rightarrow$ $$1 - \frac{T_2}{T_1} = 1 - \frac{T_3}{T_2} = 1 - \frac{T_4}{T_3}$$

$\Rightarrow$ $$\frac{T_2}{T_1} = \frac{T_3}{T_2} = \frac{T_4}{T_3}$$

$\Rightarrow$ $$T_2^2 = T_1 T_3$$

and $$T_3^2 = T_2 T_4$$

$\Rightarrow$ $$T_2^4 = T_1^2 T_3^2$$

$$T_2^4 = T_1^2 T_2 T_4$$

$$T_2^3 = T_4 T_1^2$$

or $$T_2 = (T_1^2 \; T_4)^{\frac{1}{3}}$$

Also, $$T_3^4 = T_2^2 \; T_4^2 = T_1 T_3 T_4^2$$

$$T_3^3 = T_1 T_4^2$$

or $$T_3 = (T_1 T_4^2)^{\frac{1}{3}}$$

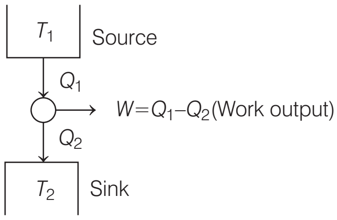
Example 23. *Two Carnot engines A and B are operated in series. The first one, A receives heat at T_1(= 600 K) and rejects to a reservoir at temperature T_2. The second engine B receives heat rejected by the first engine and in turn rejects to a heat reservoir at T_3 (= 400 K).*

Calculate the temperature T_2, if the work outputs of the two engines are equal. **[JEE Main 2019]**

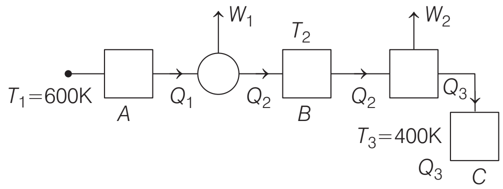
(a) 600 K (b) 500 K

(c) 400 K (d) 300 K

Sol. (*b*) In a Carnot engine, the heat flow from higher temperature source (at T_1) to lower temperature sink (at T_2) and give the work done equal to the $W = Q_1 - Q_2$.



For the given condition, Carnot engines *A* and *B* are operated in series as shown below



where, Q_1 = heat rejected by engine *A* at T_1K,

Q_2 = heat received by engine *B* at T_2K

and Q_3 = heat rejected by engine *B* to source *C* at T_3K.

According to Carnot engine principle,

$W_1 = Q_1 - Q_2$ (work output from source *A* and *B*)

$W_2 = Q_2 - Q_3$ (work output from source *B* and *C*)

As per the given condition, if the work outputs of the two engines are equal, then

$$Q_1 - Q_2 = Q_2 - Q_3$$

$\Rightarrow$ $$Q_1 + Q_3 = 2Q_2$$

$$\frac{Q_1}{Q_2} + \frac{Q_3}{Q_2} = 2$$

Therefore, $$\frac{T_1}{T_2} + \frac{T_3}{T_2} = 2$$

So, $$\frac{T_1 + T_3}{T_2} = 2$$

$\Rightarrow$ $$T_2 = \frac{T_1 + T_3}{2} = \frac{600 + 400}{2}$$

$$T_2 = 500 \text{ K}$$

Practice Exercise

ROUND I Topically Divided Problems

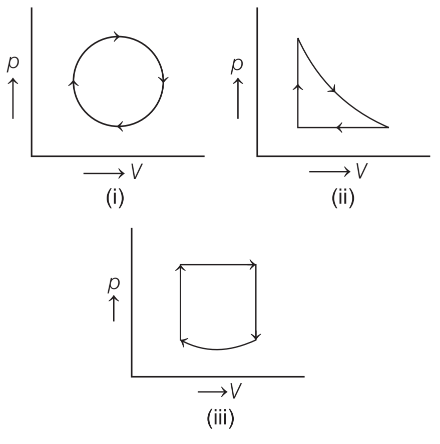
Zeroth Law and First Law of Thermodynamics

1. In a certain process, 400 cal of heat are supplied to a system and at the same time 105 J of mechanical work was done on the system. The increase in its internal energy is
(a) 20 cal (b) 303 cal
(c) 404 cal (d) 425 cal

2. If the heat of 110 J is added to a gaseous system and it acquires internal energy of 40 J, then the amount of internal work done is
(a) 40 J (b) 70 J
(c) 150 J (d) 110 J

3. In a thermodynamic process, pressure of a fixed mass of gas is changed in such a manner that the gas releases 20 J of heat and 8 J of work is done on the gas. If internal energy of the gas was 30 J, then the final internal energy will be
(a) 42 J (b) 18 J
(c) 12 J (d) 60 J

4. What is the nature of change in internal energy in the following three thermodynamic processes shown in figure?

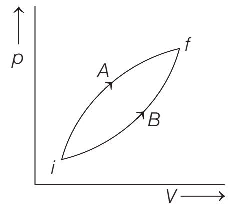


(a) ΔU is positive in all the three cases
(b) ΔU is negative in all the three cases
(c) ΔU is positive for (i), negative for (ii), zero for (iii)
(d) $\Delta U = 0$ in all the cases

5. 1 cm^3 of water at its boiling point absorbs 540 cal of heat to become steam with a volume = 1.013×10^5 Nm^{-2} and the mechanical equivalent of heat = 4.19 $Jcal^{-1}$. The energy spend in this process in overcoming intermolecular forces is
(a) 540 cal (b) 40 cal
(c) 500 cal (d) zero

6. In thermodynamics, heat and work are
(a) path functions **[JEE Main 2021]**
(b) intensive thermodynamic state variables
(c) extensive thermodynamic state variables
(d) point functions

7. Following figure shows two processes A and B for a gas. If ΔQ_A and ΔQ_B are the amount of heat absorbed by the system in two cases and ΔU_A and ΔU_B are changes in internal energies respectively, then **[JEE Main 2019]**



(a) $\Delta Q_A > \Delta Q_B$, $\Delta U_A > \Delta U_B$
(b) $\Delta Q_A < \Delta Q_B$, $\Delta U_A < \Delta U_B$
(c) $\Delta Q_A > \Delta Q_B$, $\Delta U_A = \Delta U_B$
(d) $\Delta Q_A = \Delta Q_B$; $\Delta U_A = \Delta U_B$

8. In a thermodynamic process, pressure of a fixed mass of a gas is changed in such a manner that the gas molecules gives out 20 J of heat and 10 J of work is done on the gas. If the internal energy of gas is 40 J, then the final internal energy will be
(a) 30 J (b) 20 J (c) 60 J (d) 40 J

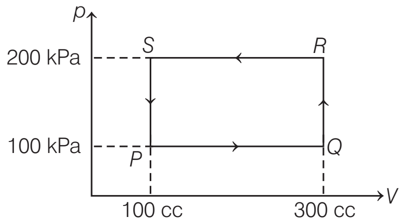
9. In an isothermal change of an ideal gas, $\Delta U = 0$. The change in heat energy ΔQ is equal to
(a) 0.5 W (b) W (c) 1.5 W (d) 2 W

10. 5 mole of an ideal gas with (γ = 7/5) initially at STP are compressed adiabatically, so that its temperature becomes 400°C. The increase in the internal energy of gas (in kJ) is
(a) 21.55 (b) 41.55 (c) 65.55 (d) 50.55

11. When an ideal monoatomic gas is heated at constant pressure, fraction of heat energy supplied which increases the internal energy of gas is

(a) 2/5 (b) 3/5
(c) 3/7 (d) 3/4

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



(a) 20 J (b) –20 J
(c) 400 J (d) –374 J

13. One mole of a monoatomic gas is heated at a constant pressure of 1 atm from 0 K to 100 K. If the gas constant $R = 8.32$ Jmol^{-1} K^{-1}, the change in internal energy of the gas is approximately

(a) 2.3 J (b) 46 J
(c) 8.67×10^3 J (d) 1.25×10^3 J

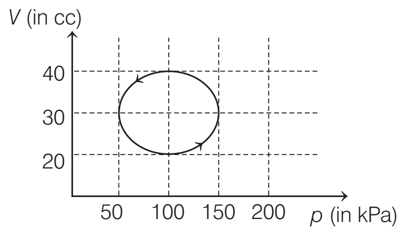
14. For the same rise in temperature of one mole of gas at constant volume, heat required for a non-linear triatomic gas is K times that required for monoatomic gas. The value of K is

(a) 1 (b) 0.5
(c) 2 (d) 2.5

15. A gas expands with temperature according to the relation $V = kT^{2/3}$, calculate work done when the temperature changes by 60 K.

(a) 10 R (b) 30 R (c) 40 R (d) 20 R

16. A system is taken through a cyclic process represented by an ellipse as shown. The heat absorbed by the system is



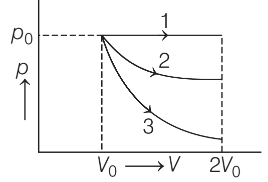
(a) $\pi \times 10^3$ J (b) $\frac{\pi}{2}$ J (c) $4\pi \times 10^2$ J (d) π J

Different Thermodynamic Processes

17. During adiabatic expansion of 10 moles of a gas, the internal energy decreases by 50 J. Work done during the process is

(a) + 50 J (b) – 50 J
(c) zero (d) Cannot say

18. A gas is expanded from volume V_0 to $2V_0$ under three different processes shown in figure.
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) $\Delta U_2 < \Delta U_3 < \Delta U_1$

19. 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

(a) $\frac{3}{2}$ (b) $\frac{4}{3}$ (c) 2 (d) $\frac{5}{3}$

20. The adiabatic elasticity of hydrogen gas ($\gamma = 1.4$) at NTP is

(a) 1×10^5 N/m^2 (b) 1×10^{-8} N/m^2
(c) 1.4 N/m^2 (d) 1.4×10^5 N/m^2

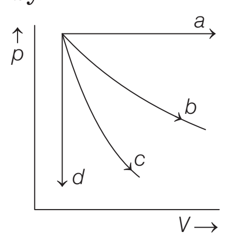
21. Consider two containers A and B containing identical gases at the same pressure, volume and temperature. The gas in container A is compressed to half of its original volume isothermally while the gas in container B is compressed to half of its original value adiabatically. The ratio of final pressure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

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

22. The ratio of the slopes of p-V graphs of adiabatic and isothermal is

(a) $\frac{\gamma - 1}{\gamma}$ (b) $\gamma - 1$ (c) $1/\gamma$ (d) γ

23. The given diagram shows four processes, *i.e.* isochoric, isobaric, isothermal and adiabatic. The correct assignment of the processes, in the same order is given by **[JEE Main 2019]**



(a) $d\ a\ b\ c$ (b) $a\ d\ b\ c$
(c) $d\ a\ c\ b$ (d) $a\ d\ c\ b$

24. Two moles of an ideal monoatomic gas occupies a volume V at 27°C. The gas expands adiabatically to a volume $2\,V$. Calculate (i) the final temperature of the gas and (ii) change in its internal energy.

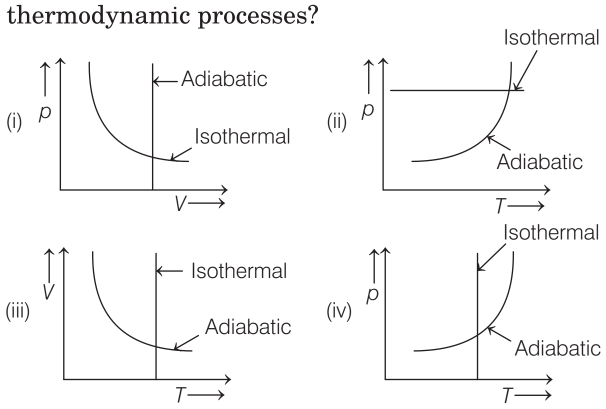
[JEE Main 2018]

(a) (i) 189 K (ii) 2.7 kJ
(b) (i) 195 K (ii) −2.7 kJ
(c) (i) 189 K (ii) −2.7 kJ
(d) (i) 195 K (ii) 2.7 kJ

25. An ideal gas at a pressure 1 atm and temperature of 27°C is compressed adiabatically until its pressure becomes 8 times, the initial pressure. Then, the final temperature is $\left(\gamma = \dfrac{3}{2}\right)$

(a) 627°C (b) 527°C
(c) 427°C (d) 327°C

26. Which one is the correct option for the two different thermodynamic processes?

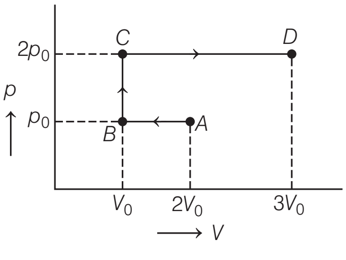


(a) (iii) and (i) (b) (iii) and (iv)
(c) (i) only (d) (ii) and (iii)

27. During an adiabatic process, the pressure p of a fixed mass of an ideal gas changes by Δp and its volume V changes by ΔV. If $\gamma = C_p / C_V$, then $\Delta V/V$ is given by

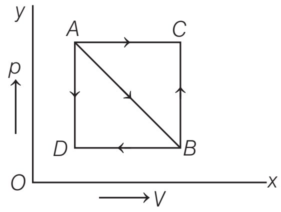
(a) $-\dfrac{\Delta p}{p}$ (b) $-\gamma\dfrac{\Delta p}{p}$
(c) $-\dfrac{\Delta p}{\gamma p}$ (d) $\dfrac{\Delta p}{\gamma^2 p}$

28. p-V diagram of an ideal gas is as shown in figure. Work done by the gas in the process $ABCD$ is



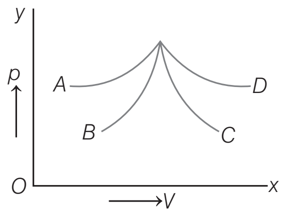
(a) $4pV_0$ (b) $2p_0V_0$
(c) $3p_0V_0$ (d) p_0V_0

29. An ideal gas is taken from state A to state B following three different paths as shown in p-V diagram. Which one of the following is true?



(a) Work done is maximum along AB
(b) Work done is minimum along AB
(c) Work done along ACB = work done along ADB
(d) Work done along ADB is minimum

30. Figure shows four p-V diagrams. Which of these curves represent isothermal and adiabatic process?

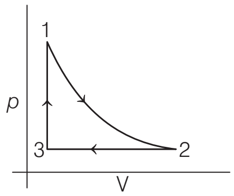


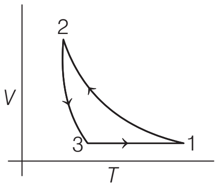
(a) D and C (b) A and C
(c) A and B (d) B and D

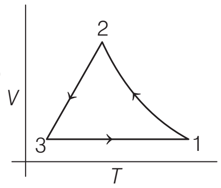
31. Which of the following is an equivalent cyclic process corresponding to the thermodynamic cyclic given in the figure? where, $1 \rightarrow 2$ is adiabatic.

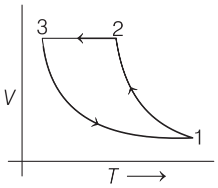
(Graphs are schematic and are not to scale)

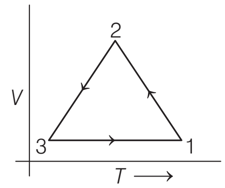
[JEE Main 2020]



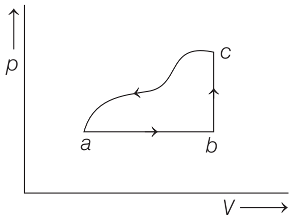
(a)


(b)


(c)


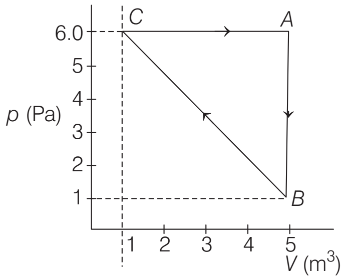
(d)


32. A sample of an ideal gas is taken through the cyclic process $abca$ as shown in the figure. The change in the internal energy of the gas along the path ca is −180 J. The gas absorbs 250 J of heat along the path ab and 60 J along the path bc. The work done by the gas along the path abc is **[JEE Main 2019]**



(a) 120 J (b) 130 J (c) 100 J (d) 140 J

33. For the given cyclic process CAB as shown for a gas, the work done is **[JEE Main 2019]**



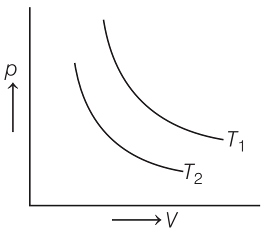
(a) 5 J (b) 10 J (c) 1 J (d) 30 J

34. A gas at pressure p is adiabatically compressed, so that its density becomes twice that of initial value. Given that $\gamma = C_p/C_V = 7/5$, what will be the final pressure of the gas?

(a) $2p$ (b) $\frac{7}{5}p$

(c) $2.63\,p$ (d) p

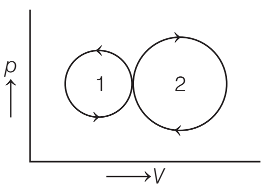
35. Two isothermal curves are shown in figure at temperatures T_1 and T_2. Which of the following relations is correct?



(a) $T_1 > T_2$ (b) $T_1 < T_2$

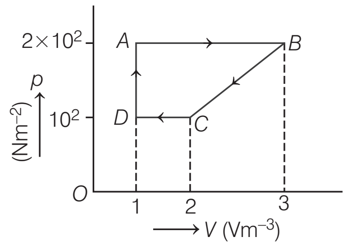
(c) $T_1 = T_2$ (d) $T_1 = \frac{1}{2}T_2$

36. In the indicator diagram, net amount of work done will be



(a) positive (b) zero (c) infinity (d) negative

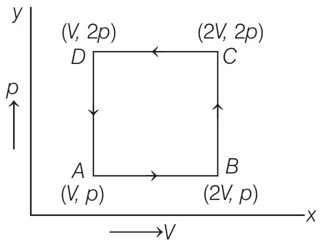
37. A cyclic process is shown in figure. Work done during isobaric expansion is



(a) 1600 J (b) 100 J

(c) 400 J (d) 600 J

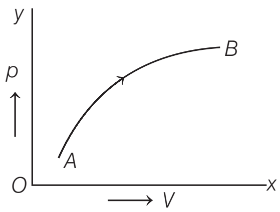
38. An ideal monoatomic gas is taken around the cycle $ABCD$ as shown in p *versus* V diagram. Work done during the cycle is



(a) pV (b) $0.5\,pV$

(c) $2\,pV$ (d) $3\,pV$

39. Figure shows a thermodynamic process on one mole of a gas. How does the work done in the process changes with time?



(a) decreases continuously

(b) increases continuously

(c) remains constant

(d) first increases and then decreases

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

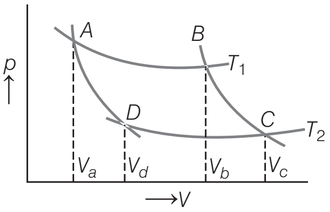
(a) 1.40

(b) 1.60

(c) 2.64

(d) 1.94

41. In the following p-V diagram, two adiabatic curves and two isothermal curves at T_1 and T_2. The value of V_b / V_c is



(a) $= V_a / V_d$ (b) $< V_a / V_d$
(c) $> V_a / V_d$ (d) Cannot say

42. For an adiabatic expansion of an ideal gas, the fractional change in its pressure is equal to (where, γ is the ratio of specific heats) **[JEE Main 2021]**

(a) $-\gamma \frac{dV}{V}$ (b) $-\gamma \frac{V}{dV}$
(c) $-\frac{1}{\gamma}\frac{dV}{V}$ (d) $\frac{dV}{V}$

43. One mole of an ideal gas expands adiabatically from an initial temperature T_1 to a final temperature T_2. The work done by the gas would be

(a) $(C_p - C_V)(T_1 - T_2)$
(b) $C_p(T_1 - T_2)$
(c) $C_V(T_1 - T_2)$
(d) $(C_p - C_V)(T_1 + T_2)$

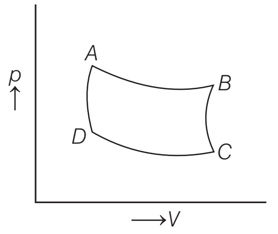
44. A gas at pressure 6×10^5 Nm^{-2} and volume 1 m^3. Its pressure falls to 4×10^5 Nm^{-2} when its volume is 3m^3.Given that the indicator diagram is a straight line, work done by the system is

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

45. A thermodynamic system goes from state (i) (p, V) to $(2p, V)$ and (ii) (p, V) to $(p, 2V)$. Work done in the two cases is

(a) zero, zero (b) zero, pV
(c) pV, zero (d) pV, pV

46. In the indicator diagram, T_a, T_b, T_c, T_d represent temperatures of gas at A, B, C, D, respectively. Which of the following is correct relation?



(a) $T_a = T_b = T_c = T_d$ (b) $T_a \neq T_b \neq T_c \neq T_d$
(c) $T_a = T_b$ and $T_c = T_d$ (d) None of these

47. The pressure inside a tyre is 4 atm at 27°C. If the tyre bursts suddenly, new temperature will be ($\gamma = 7/5$)

(a) $300\,(4)^{7/2}$ (b) $300\,(4)^{2/7}$
(c) $300\,(2)^{7/2}$ (d) $300\,(4)^{-2/7}$

48. A monoatomic ideal gas, initially at temperature T_1 is enclosed in a cylinder fitted with a frictionless piston. The gas is allowed to expand adiabatically to a temperature T_2 by releasing the piston suddenly. If L_1, L_2 are the lengths of the gas column before and after expansion respectively, then T_1 / T_2 is given by

(a) $(L_1 / L_2)^{2/3}$ (b) (L_1 / L_2)
(c) L_1 / L_2 (d) $(L_2 / L_1)^{2/3}$

49. For adiabatic expansion of a perfect monoatomic gas, when volume increases by 24%. What is the percentage decrease in pressure?

(a) 24% (b) 30%
(c) 48% (d) 71%

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

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

51. One litre of dry air at STP is allowed to expand to a volume of 3 L under adiabatic conditions. If γ = 1.40, the work done is ($3^{1.4} = 4.6555$)

(a) 48 J (b) 60.7 J
(c) 90.5 J (d) 100.8 J

52. An ideal gas is heated at constant pressure and absorbs amount of heat Q. If the adiabatic exponent is γ, then the fraction of heat absorbed in raising the internal energy and performing the work, is

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

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

(a) 15.6 J (b) 11.2 J
(c) 14.9 J (d) 16.9 J

54. During an isothermal expansion, a confined ideal gas does –150 J of work against its surrounding. This implies that
(a) 150 J of heat has been added to the gas
(b) 150 J heat has been removed from the gas
(c) 300 J of heat has been added to the gas
(d) No heat is transferred because the process is isothermal

Second Law of Thermodynamics, Refrigerator and Carnot Engine

55. The efficiency of a Carnot engine working between 800 K and 500 K is
(a) 0.4 (b) 0.625 (c) 0.375 (d) 0.5

56. A Carnot engine whose sink is at 300 K has an efficiency of 40%. By how much should the temperature of source be increased, so as to increase its efficiency by 50% of original efficiency ?
(a) 280 K (b) 275 K (c) 325 K (d) 250 K

57. An engine has an efficiency of 1/3. The amount of work this engine can perform per kilocalorie of heat input is
(a) 1400 cal (b) 700 cal
(c) 700 J (d) 1400 J

58. A Carnot engine whose low temperature reservoir is at 27°C has an efficiency 37.5%. The high temperature reservoir is at
(a) 480°C (b) 327°C
(c) 307°C (d) 207°C

59. The coefficient of performance of a refrigerator working between 10°C and 20°C is
(a) 28.3 (b) 29.3
(c) 2 (d) Cannot be calculated

60. A reversible heat engine converts (1/6)th of heat it absorbs from source into work. When temperature of source is 600 K, temperature at which heat exhausts is
(a) 500 K (b) 100 K
(c) 0 K (d) 600 K

61. A Carnot engine having an efficiency of $\frac{1}{10}$ is being used as a refrigerator. If the work done on the refrigerator is 10 J, then the amount of heat absorbed from the reservoir at lower temperature is: **[JEE Main 2020]**
(a) 99 J (b) 100 J (c) 90 J (d) 1 J

62. An ideal Carnot engine whose efficiency is 40% receives heat at 500 K. If its efficiency were 50%, then in take temperature for same exhaust temperature would be
(a) 700 K (b) 900 K
(c) 800 K (d) 600 K

63. A Carnot's engine works between a source at a temperature of 27°C and a sink at – 123°C. Its efficiency is
(a) 0.5 (b) 0.25 (c) 0.75 (d) 0.4

64. Four engines are working between the given temperatures ranges given below. For which temperature range, the efficiency is maximum?
(a) 100 K, 80 K (b) 40 K, 20 K
(c) 60 K, 40 K (d) 120 K, 100 K

65. In a refrigerator, the low temperature coil of evaporator is at – 23°C and the compressed gas in the condenser has a temperature of 77°C. How much electrical energy is spent in freezing 1 kg of water already at 0°C ?
(a) 134400 J (b) 1344 J
(c) 80000 J (d) 3200 J

66. A refrigerator absorbs 2000 cal of heat from ice trays. If the coefficient of performance is 4, then work done by the motor is
(a) 2100 J (b) 4200 J
(c) 8400 J (d) 500 J

67. A Carnot engine has same efficiency between (i) 100 K and 500 K , (ii) T K and 900 K. The value of T is
(a) 180 K (b) 90 K (c) 270 K (d) 360 K

68. A refrigerator works between temperature of melting ice and room temperatures (17°C). The amount of energy (in kWh) that must be supplied to freeze 1 kg of water at 0°C is
(a) 1.4 (b) 1.8 (c) 0.058 (d) 2.5

69. A Carnot's engine working between 400 K and 800 K has a work output of 1200 J per cycle. The amount of heat energy supplied to the engine from the source in each cycle is **[JEE Main 2021]**
(a) 3200 J (b) 1800 J (c) 1600 J (d) 2400 J

70. A Carnot engine used first ideal monoatomic gas and then an ideal diatomic gas, if the source and sink temperatures are 411°C and 69°C, respectively and the engine extracts 1000 J of heat from the source in each cycle, then
(a) area enclosed by the p-V diagram is 10 J
(b) heat energy rejected by engine is 1st case is 600 J while that in 2nd case in 113 J
(c) area enclosed by the p-V diagram is 500 J
(d) efficiencies of the engine in both the cases are in the ratio 21 : 25

71. An ideal gas heat engine operates in Carnot cycle between 227°C and 127°C. It absorbs 6×10^4 cal of heat at higher temperature. Amount of heat converted into work is
(a) 1.2×10^4 cal (b) 2.4×10^4 cal
(c) 6×10^4 cal (d) 4.8×10^4 cal

72. Two heat engines A and B have their sources at 1000 K and 1100 K and their sinks are at 500 K and 400 K, respectively. What is true about their efficiencies?
(a) $\eta_A = \eta_B$ (b) $\eta_A > \eta_B$
(c) $\eta_A < \eta_B$ (d) Cannot say

73. A Carnot engine has the same efficiency between 800 K to 500 K and x K to 600 K. The value of x is
(a) 100 K (b) 960 K (c) 846 K (d) 754 K

74. What is the temperature of source in Carnot cycle of 10% efficiency, when heat exhausts at 270 K?
(a) 400 K (b) 500 K
(c) 300 K (d) 600 K

75. A Carnot engine take 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
(a) 4.2×10^6 J (b) 8.4×10^6 J
(c) 16.8×10^6 J (d) zero

ROUND II Mixed Bag

Only One Correct Option

1. A given system undergoes a change in which the work done by the system equals the decrease in its internal energy. The system must have undergone an
(a) isothermal change (b) adiabatic change
(c) isobaric change (d) isochoric change

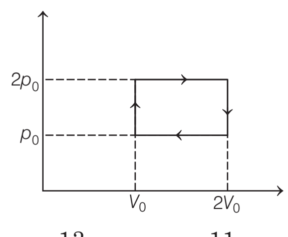
2. One mole of an ideal monoatomic gas is heated at a constant pressure of 1 atm from 0°C to 100°C. Work done by the gas is
(a) 8.31×10^3 J (b) 8.31×10^{-3} J
(c) 8.31×10^{-2} J (d) 8.31×10^2 J

3. The change in internal energy, when a gas is cooled from 927°C to 27°C
(a) 300% (b) 400% (c) 200% (d) 100%

4. A mass of dry air at NTP is compressed to (1/20)th of its original volume suddenly. If $\gamma = 1.4$, the final pressure would be
(a) 20 atm (b) 66.28 atm
(c) 30 atm (d) 150 atm

5. An ideal gas heat engine is operating between 227°C and 127°C. It absorbs 10^4 J of heat at the higher temperature. The amount of heat converted into work is
(a) 2000 J (b) 4000 J (c) 8000 J (d) 5600 J

6. The given p-V diagram represents the thermodynamic cycle of an engine, operating with an ideal monatomic gas. The amount of heat, extracted from the source in a single cycle is **[JEE Main 2013]**

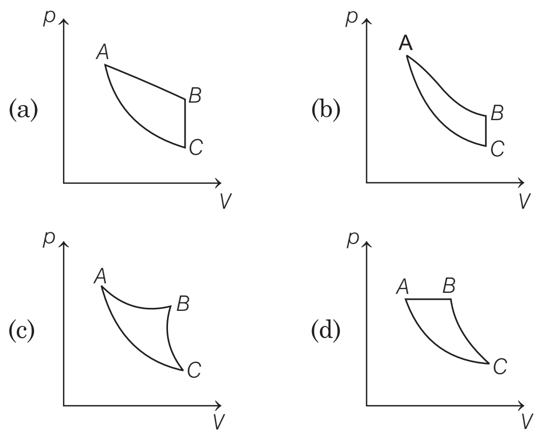


(a) p_0V_0 (b) $\frac{13}{2} p_0V_0$ (c) $\frac{11}{2} p_0V_0$ (d) $4p_0V_0$

7. A solid body of constant heat capacity 1 J/°C is being heated by keeping it in contact with reservoirs in two ways **[JEE Main 2015]**
(i) Sequentially keeping in contact with 2 reservoirs such that each reservoir supplies same amount of heat.
(ii) Sequentially keeping in contact with 8 reservoirs such that each reservoir supplies same amount of heat.

In both the cases, body is brought from initial temperature 100°C to final temperature 200°C. Entropy change of the body in the two cases respectively, is
(a) ln 2, 4 ln 2 (b) ln 2, ln 2
(c) ln 2, 2 ln 2 (d) 2 ln 2, 8 ln 2

8. If AB is an isothermal, BC is an isochoric and AC is an adiabatic curve, which of the graph correctly represents them in figure



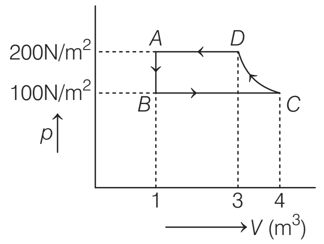
9. In an isothermal reversible expansion, if the volume of 96 g of oxygen at 27°C in increased from 70 L to 140 L, then the work done by the gas will be
(a) $300\, R \log_{10} 2$
(b) $81\, R \log_e 2$
(c) $900\, R \log_{10} 2$
(d) $2.3 \times 900\, R \log_{10} 2$

10. An ideal gas at 27°C is compressed adiabatically to $\frac{8}{27}$ of its original volume. If $\gamma = \frac{5}{3}$, then the rise of temperature is
(a) 450 K (b) 375 K
(c) 225 K (d) 405 K

11. A perfect gas goes from state A to state B by absorbing 8×10^5 J of heat and doing 6.5×10^5 J of external work. It is now transferred between the same two states in another process in which it absorbs 10^5 J of heat. In the second process,
(a) work done on gas is 10^5 J
(b) work done on gas is -0.5×10^5 J
(c) work done by gas is 10^5 J
(d) work done by gas is 0.5×10^5 J

12. At NTP, one mole of diatomic gas is compressed adiabatically to half of its volume and $\gamma = 1.41$. The work done on gas will be
(a) 1280 J (b) 1610 J
(c) 1815 J (d) 2025 J

13. The p-V diagram of a diatomic ideal gas system going under cyclic process as shown in figure. The work done during an adiabatic process CD is (Use, $\gamma = 1.4$) **[JEE Main 2021]**



(a) -500 J (b) -400 J
(c) 400 J (d) 200 J

14. 200 cal of heat is given to a heat engine, so that it reject 150 cal of heat. If source temperature is 400 K, then the sink temperature is
(a) 300 K (b) 200 K (c) 100 K (d) 50 K

15. If the ratio of specific heat of gas at constant pressure to that at constant volume is γ. The change in internal energy of a mass of gas when the volume changes from V to $2V$ at constant pressure p is
(a) $\frac{R}{(\gamma - 1)}$ (b) pV (c) $\frac{pV}{(\gamma - 1)}$ (d) $\frac{\gamma pV}{(\gamma - 1)}$

16. Two moles of an ideal monoatomic gas at 27°C occupies a volume of V. If the gas is expanded adiabatically to the volume $2V$, then the work done by the gas will be $\left(\gamma = \frac{5}{3}, R = 8.31 \text{ J/mol K}\right)$
(a) + 2767.23 J (b) 2627.23 J
(c) 2500 J (d) -2500 J

17. One mole of O_2 gas having a volume equal to 22.4 L at 0°C and 1 atmospheric pressure is compressed isothermally, so that its volume reduces to 11.2 L. The work done in this process is
(a) 1672.5 J (b) 1728 J
(c) -1728 J (d) -1572.5 J

18. The volume of an ideal gas is 1 L and its pressure is equal to 72 cm of mercury column. The volume of gas is made 900 cm^3 by compressing it isothermally. The stress of the gas will be
(a) 8 cm (mercury) (b) 7 cm (mercury)
(c) 6 cm (mercury) (d) 4 m (mercury)

19. The pressure and density of a diatomic gas ($\gamma = 7/5$) change adiabatically from (p, d) to (p', d') if $\frac{d'}{d} = 32$, then $\frac{p'}{p}$ should be
(a) 1/128 (b) 32
(c) 128 (d) None of these

20. Ideal gas undergoes an adiabatic change in its state from $(p_1 V_1 T_1)$ to $(p_2 V_2 T_2)$. The work done in the process is (μ = number of moles, C_p and C_V are molar specific heats of gas)
(a) $W = \mu (T_1 - T_2) C_p$ (b) $W = \mu (T_1 - T_2) C_V$
(c) $W = \mu (T_1 + T_2) C_p$ (d) $W = \mu (T_1 + T_2) C_V$

21. 2 kg of water is converted into steam by boiling at atmospheric pressure. The volume changes from 2×10^{-3} m^3 to 3.34 m^3. The work done by the system is about
(a) -340 kJ (b) -170 kJ
(c) 170 kJ (d) 340 kJ

22. The changes in pressure and volume of a gas when heat content of the gas remains constant are called adiabatic changes. The equation of such changes is pV^γ = constant. The changes must be sudden and the container must be perfectly insulting to disallow any exchange of heat with the surroundings. In such changes, $dQ = 0$, then as per first law of thermodynamics, $dQ = dU + W = 0$
$\Rightarrow dU = -dW$

A gas in a container is compressed suddenly, its temperature would
(a) increase
(b) decrease
(c) stay constant
(d) change depending upon surrounding temperature.

23. In an adiabatic change, the pressure and temperature of a monoatomic gas are related as $p \propto T^{-c}$, where c equals
(a) $\frac{2}{5}$ (b) $\frac{5}{2}$ (c) $\frac{3}{5}$ (d) $\frac{5}{3}$

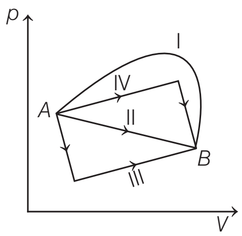
24. The efficiency of a Carnot engine working between source temperature T_1 and sink temperature T_2 is $\eta = 1 - \frac{T_2}{T_1}$. The efficiency cannot be 100%, as we cannot maintain $T_2 = 0$. Coefficient of performance of a refrigerator working between the same two temperature is

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

The efficiency of a Carnot engine is 40%. If temperature of sink is 27°C, what is the source temperature?

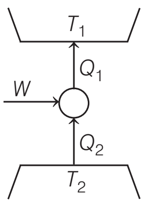
(a) 300 K (b) 400 K
(c) 600 K (d) 500 K

25. Figure shows the p-V diagram of an ideal gas undergoing a change of state from A to B. Four different paths I, II, III and IV as shown in the figure may lead to the same changes of state. **[NCERT Exemplar]**



(a) Change in internal energy is same in IV and III cases, but not in I and II
(b) Change in internal energy is different in all the four cases
(c) Work done is maximum in case I
(d) Work done is minimum in case II

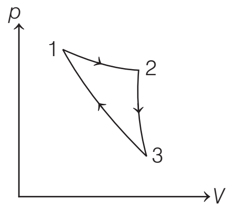
26. Consider a heat engine as shown in figure. Q_1 and Q_2 are heat added to heat bath T_1 and heat T_2 is taken from one cycle of engine. W is the mechanical work done on the engine. If $W > 0$, then possibilities are **[NCERT Exemplar]**



(a) $Q_2 < Q_1 < 0$
(b) $Q_2 > Q_1 > 0$
(c) $Q_1 < Q_2 < 0$
(d) $Q_1 < 0, Q_2 > 0$

27. Consider a cycle followed by an engine (figure)
1 to 2 is isothermal
2 to 3 is adiabatic
3 to 1 is adiabatic

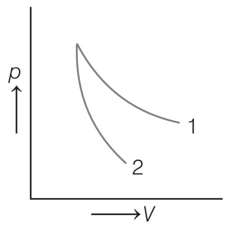
Such a process does not exist because



[NCERT Exemplar]

(a) heat is completely converted to mechanical energy in such a process, which is not possible.
(b) mechanical energy is completely converted to heat in this process, which is not possible.
(c) curves representing two adiabatic processes intersect.
(d) curves representing an adiabatic process and an isothermal process don't intersect.

28. p-V plots for two gases during adiabatic processes are shown in figure. Plots 1 and 2 should correspond respectively to



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

29. Temperature of an ideal gas is 300 K. The change in temperature of the gas when its volume changes from V to $2V$ in the process $p = \alpha V$ (here α is a positive constant) is

(a) 900 K (b) 1200 K
(c) 600 K (d) 300 K

30. A gas under constant pressure of 4.5×10^5 Pa when subjected to 800 kJ of heat changes the volume from 0.5 m^3 to 2.0 m^3. The change in the internal energy of the gas is

(a) 6.75×10^5 J (b) 5.25×10^5 J
(c) 3.25×10^5 J (d) 1.25×10^5 J

31. A Carnot engine is made to work between 200°C and 0°C first and then between 0°C to –200°C. The ratio of efficiencies of the engine in the two cases is

(a) 1 : 2 (b) 1 : 1
(c) 1.73 : 1 (d) 1 : 1.73

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

(a) $3\alpha T_0^2$ (b) $5\alpha T_0^2$ (c) $\frac{3}{2}\alpha T_0^2$ (d) $7\alpha T_0^2$

33. When the ideal monoatomic gas is heated at constant pressure fraction of heat energy supplied which increases the internal energy of gas is

(a) $\frac{2}{5}$ (b) $\frac{3}{5}$

(c) $\frac{3}{7}$ (d) $\frac{3}{4}$

34. If a Carnot engine whose heat sink is at 27°C has an efficiency of 40%. By how many degrees should the temperature of the source be changed to increase the efficiency by 10% of the original efficiency? **[JEE Main 2021]**

(a) 50.5°C (b) 60.2°C

(c) 35.7°C (d) 72.8°C

35. A refrigerator is to remove heat from the eatable kept inside at 9°C. Calculate the coefficient of performance, if the room temperature is 36°C. **[NCERT]**

(a) 10.4 (b) 11.5

(c) 9.8 (d) None of these

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

(a) 10^5 cal (b) 10^4 cal

(c) 10^3 cal (d) 5×10^3 cal

37. In changing the state of a gas adiabatically from an equillibrium state A to another equillibrium state B, an amount of work equal to 22.3 J is done on the system. If the gas is taken from state A to B *via* a process in which the net heat absorbed by the system is 9.35 cal, the net work done by the system in latter case will be

(a) 5.9 J (b) 16.9 J

(c) 9.3 J (d) 4.6 J

38. 540 cal of heat converts 1 cubic centimeter of water at 100°C into 1670 cubic centimeter of steam at 100°C at a pressure of one atmosphere. Then, the work done against the atmospheric pressure is nearly

(a) 540 cal (b) 40 cal

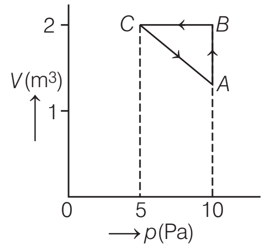
(c) 200 cal (d) 500 cal

39. 5.6 L of helium gas at STP is adiabatically compressed to 0.7 L. Taking the initial temperature to be T_1, the work done in the process is

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

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

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



(a) –5 J (b) –10 J

(c) 15 J (d) –20 J

41. For a monoatomic gas, work done at constant pressure is W. The heat supplied at constant volume for the same rise in temperature of the gas is

(a) $W/2$ (b) $3W/2$

(c) $5W/2$ (d) W

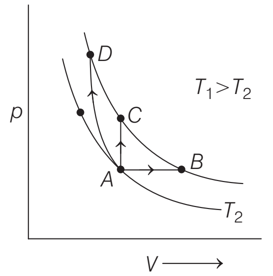
42. How many times a diatomic gas should be expanded adiabatically, so as to reduce the root mean square velocity to half?

(a) 64 (b) 32

(c) 16 (d) 8

43. Three different processes that can occur in an ideal monoatomic gas are shown in the p *versus* V diagram. The paths are labelled as $A \rightarrow B$, $A \rightarrow C$ and $A \rightarrow D$. The change in internal energies during these process are taken as E_{AB}, E_{AC} and E_{AD} and the work done as W_{AB}, W_{AC} and W_{AD}.

The correct relation between these parameters are **[JEE Main 2020]**



(a) $E_{AB} = E_{AC} < E_{AD}$, $W_{AB} > 0$, $W_{AC} = 0$, $W_{AD} < 0$

(b) $E_{AB} = E_{AC} = E_{AD}$, $W_{AB} > 0$, $W_{AC} = 0$, $W_{AD} < 0$

(c) $E_{AB} < E_{AC} < E_{AD}$, $W_{AB} > 0$, $W_{AC} > W_{AD}$

(d) $E_{AB} > E_{AC} > E_{AD}$, $W_{AB} < W_{AC} < W_{AD}$

44. A gas undergoes a process in which its pressure p and volume V are related as Vp^n = constant. The Bulk modulus for the gas in this process is

(a) np (b) $p^{1/n}$

(c) $\frac{p}{n}$ (d) p^n

45. An ideal gas expands isothermally from a volume V_1 to V_2 and then compressed to original volume V_1 adiabatically. Initial pressure is p_1, final pressure is p_3 and total work done is W. Then,

(a) $p_3 > p_1; W > 0$ (b) $p_3 < p_1; W < 0$
(c) $p_3 > p_1; W < 0$ (d) $p_3 = p_1; W = 0$

46. One litre of dry air at STP expands adiabatically to a volume of 3 L. If $\gamma = 1.40$, the work done by air is ($3^{1.4} = 4.6555$)
(Take, air to be an ideal gas) **[JEE Main 2020]**

(a) 100.8 J (b) 90.5 J
(c) 48 J (d) 60.7 J

47. Certain amount of an ideal gas is contained in a closed vessel. The vessel is moving with a constant velocity v. The rise in temperature of the gas when the vessel is suddenly stopped is (M is molecular mass, $\gamma = C_p/C_V$)

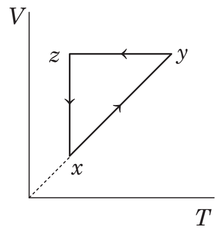
(a) $\dfrac{Mv^2(\gamma-1)}{2R}$ (b) $\dfrac{Mv^2(\gamma+1)}{2R}$

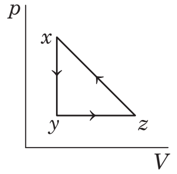
(c) $\dfrac{Mv^2}{2R_y}$ (d) $\dfrac{Mv^2}{2R(\gamma+1)}$

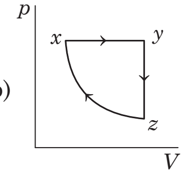
48. An ideal gas is made to go through a cyclic thermodynamical process in four steps. The amount of heat involved are $Q_1 = 600$ J, $Q_2 = -400$ J, $Q_B = -300$ J and $Q_4 = 200$ J, respectively. The corresponding work involved are $W_1 = 300$ J, $W_2 = -200$ J, $W_3 = -150$ J and W_4. What is the value of W_4?

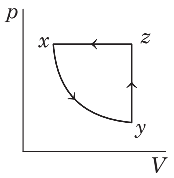
(a) –50 J (b) 100 J (c) 150 J (d) 50 J

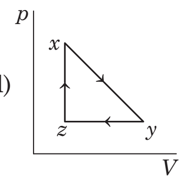
49. A thermodynamic cycle *xyzx* is shown on a V-T diagram. The p-V diagram that best describes this cycle is (diagrams are schematic and not to scale) **[JEE Main 2020]**



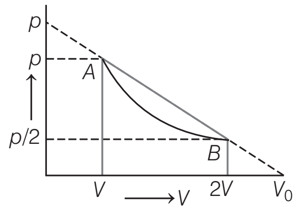
(a)


(b)


(c)


(d)


50. An ideal gas is taken from the state A (p, V) to the state B ($p/2$, 2 V) along a straight line path as shown in figure. Select the correct statement from the following.



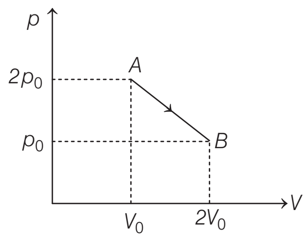
(a) Work done by the gas in going from A to B exceeds the work done in going from A to B under isothermal conditions.
(b) In the T-V diagram, part AB would become a hyperbola.
(c) In the p-T diagram, path AB would be part of hyperbola.
(d) In going from A to B, the temperature T of gas first increases to a maximum value 1 and then decreases.

51. Match the thermodynamic processes taking place in a system with the correct conditions. In the table, ΔQ is heat supplied, ΔW is work done and ΔU is change in internal energy of the system. **[JEE Main 2020]**

Process		Condition
A. Adiabatic	p.	$\Delta W = 0$
B. Isothermal	q.	$\Delta Q = 0$
C. Isochoric	r.	$\Delta U \neq 0$, $\Delta W \neq 0$ and $\Delta Q \neq 0$
D. Isobaric	s.	$\Delta U = 0$

	A	B	C	D
(a)	q	p	s	r
(b)	p	p	q	r
(c)	q	s	p	r
(d)	p	q	s	s

52. 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 **[JEE Main 2016]**



(a) $\dfrac{9}{4}\dfrac{p_0V_0}{nR}$ (b) $\dfrac{3}{2}\dfrac{p_0V_0}{nR}$

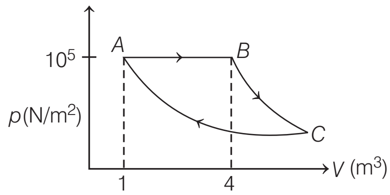
(c) $\dfrac{9}{2}\dfrac{p_0V_0}{nR}$ (d) $\dfrac{9p_0V_0}{nR}$

Numerical Value Questions

53. A Carnot's engine, with its cold body at $17°$ C has 50% efficiency. If the temperature of its hot body is now increased by $145°$ C, then the efficiency of engine (in %) becomes ....

54. A Carnot engine intakes steam at 200°C and after doing work, exhausts it to a sink at 100°C, so the percentage of heat which is utilised for doing work is ....

55. A fixed mass of gas is taken through a process $A \to B \to C \to A$, here $A \to B$ is isobaric $B \to C$ is adiabatic and $C \to A$ is isothermal.



If the pressure at point C is $\frac{10^x}{64}$ N / m^2, then the value of x is .... (Take, $\gamma = 1.5$)

56. An ideal gas is taken through a cyclic thermodynamic process through four steps. The amount of heat involved in these steps are $Q_1 = 5960$ J, $Q_2 = -5585$ J, $Q_3 = -2980$ J and $Q_4 = 3645$ J, respectively. The efficiency (in %) of the cycle is ....

57. An engine takes in 5 moles of air at 20°C and 1 atm and compresses it adiabatically to (1/10)th of the original volume. Assuming air to be a diatomic ideal gas made up of rigid molecules, the change in its internal energy during this process comes out to be XkJ. The value of X to the nearest integer is .... **[JEE Main 2020]**

58. A steam engine delivers 5.4×10^8 J of work per minute and takes 3.6×10^9 J of heat per minute from the boiler. So, the efficiency of the engine (in %) and the amount of heat is wasted (in J/min) will be ...... and ....

59. The volume of system produced by 1g of water at 100°C is 1650 cm^3, so the change in internal energy (in erg) during the change of state is found to be 21.01×10^x erg, then find the value of x. (Take, $J = 4.2 \times 10^7$ erg cal^{-1}, $g = 981$ cms^{-2} and latent heat of steam $= 50$ calg^{-1})

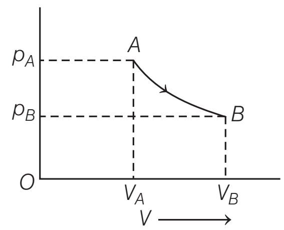
60. A Carnot engine operates between two reservoirs of temperatures 900 K and 300 K. The engine performs 1200 J of work per cycle. The heat energy (in J) delivered by the engine to the low temperature reservoir in a cycle, is .... **[JEE Main 2020]**

61. A gram molecule of a gas at 127°C expands isothermally until its volume is doubled, so the amount of heat energy (in cal) absorbed will be ....

62. Starting at temperature 300 K, one mole of an ideal diatomic gas ($\gamma = 1.4$) is first compressed adiabatically from volume V_1 to $V_2 = \frac{V_1}{16}$. It is then allowed to expand isobarically to volume $2V_2$. If all the processes are the quasi-static, then the final temperature of the gas (in K) is (to the nearest integer) .... **[JEE Main 2020]**

63. A cylinder containing one gram molecule of the gas was compressed adiabatically until its temperature raise from 27°C to 97°C. The heat (in cal) produced in the gas is .... (Take, $\gamma = 1.5$)

64. 5 moles of an ideal gas is carried by a quasi-static isothermal process at 500 K to twice its volume as shown in figure.

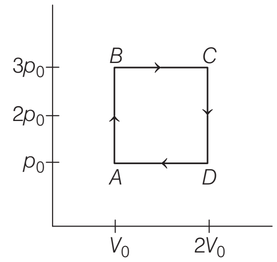


The work done (in J) by the gas along the path AB is .... (Given, $R = 8.31$ J mol^{-1} K^{-1})

65. A Carnot engine absorbs 6×10^5 cal at 227°C. The work done per cycle by the engine, if its sink is maintained at 127°C is found to be 5.04×10^x J, then the value of x is ....

66. If the density of air at NTP = 1.29×10^{-3} gcm^{-3} and $\gamma = 1.4$, then the work (in J) required to compress adiabatically 1 g of air initially at NTP to half of its volume will be ....

67. An engine operates by taking a monatomic ideal gas through the cycle shown in the figure. The efficiency (in %) of the engine is close to .... **[JEE Main 2020]**



Answers

Round I

1. (d)	**2.** (b)	**3.** (b)	**4.** (d)	**5.** (c)	**6.** (a)	**7.** (c)	**8.** (a)	**9.** (b)	**10.** (b)
11. (b)	**12.** (b)	**13.** (d)	**14.** (c)	**15.** (c)	**16.** (b)	**17.** (a)	**18.** (a)	**19.** (a)	**20.** (d)
21. (a)	**22.** (d)	**23.** (a)	**24.** (c)	**25.** (d)	**26.** (b)	**27.** (c)	**28.** (c)	**29.** (d)	**30.** (a)
31. (b)	**32.** (b)	**33.** (b)	**34.** (c)	**35.** (a)	**36.** (a)	**37.** (c)	**38.** (a)	**39.** (b)	**40.** (c)
41. (a)	**42.** (a)	**43.** (c)	**44.** (d)	**45.** (b)	**46.** (c)	**47.** (d)	**48.** (d)	**49.** (b)	**50.** (a)
51. (c)	**52.** (a)	**53.** (d)	**54.** (b)	**55.** (c)	**56.** (d)	**57.** (d)	**58.** (d)	**59.** (a)	**60.** (a)
61. (c)	**62.** (d)	**63.** (a)	**64.** (b)	**65.** (a)	**66.** (a)	**67.** (a)	**68.** (c)	**69.** (d)	**70.** (c)
71. (a)	**72.** (c)	**73.** (b)	**74.** (c)	**75.** (b)					

Round II

1. (b)	**2.** (d)	**3.** (a)	**4.** (b)	**5.** (a)	**6.** (b)	**7.** (b)	**8.** (b)	**9.** (d)	**10.** (b)
11. (b)	**12.** (c)	**13.** (a)	**14.** (a)	**15.** (c)	**16.** (a)	**17.** (d)	**18.** (a)	**19.** (c)	**20.** (b)
21. (d)	**22.** (a)	**23.** (a)	**24.** (d)	**25.** (c)	**26.** (a)	**27.** (a)	**28.** (a)	**29.** (b)	**30.** (d)
31. (d)	**32.** (a)	**33.** (b)	**34.** (c)	**35.** (a)	**36.** (b)	**37.** (b)	**38.** (b)	**39.** (a)	**40.** (a)
41. (b)	**42.** (b)	**43.** (b)	**44.** (c)	**45.** (c)	**46.** (b)	**47.** (a)	**48.** (c)	**49.** (b)	**50.** (a)
51. (c)	**52.** (a)	**53.** 60	**54.** 21.14	**55.** 5	**56.** 10.82	**57** 4	**58.** 15, 3.1×10^{19}		**59.** 9
60. 600	**61.** 548	**62.** 1819	**63.** 276.7	**64.** 14401.3	**65.** 5	**66.** – 62.7	**67.** 19		

Solutions

Round I

1. Here, $dQ = 400$ cal, $dW = -105$ J

$$= -105/4.2 \text{ cal}$$
$$= -25 \text{ cal}; \; dU = ?$$

Now, $dU = dQ - dW$

$$dU = 400 - (-25) = 425 \text{ cal}$$

Note *dW* is negative because work is done on the system.

2. Here, $dQ = 110$ J, $dU = 40$ J, $dW = ?$

From $dQ = dU + dW$

$$dW = dQ - dU = 110 - 40 = 70 \text{ J}$$

3. As, $\Delta U = \Delta Q - \Delta W$

$$\therefore \quad \Delta U = (-20) - (-8) = -12 \text{ J}$$
$$\Delta U = U_f - U_i = -12$$
$$\therefore \quad U_f = -12 + U_i$$
$$= -12 + 30 = 18 \text{ J}$$

4. As indicator diagrams in all the three cases are closed curves, representing cyclic changes, therefore $U =$ constant and $\Delta U = 0$ in all the cases.

5. As, $dU = dQ - dW$

$$= mL - p(dV)$$
$$= 1 \times 540 - \frac{1.013 \times 10^5 (1671 - 1) 10^{-6}}{4.2}$$
$$= 540 - 40 = 500 \text{ cal}$$

6. Heat and work are treated as path functions in thermodynamics.

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

Since work done by gas depends on type of process, i.e. path and ΔU depends just on initial and final states, so ΔQ i.e. heat, also has to depend on process is path.

7. According to the first law of thermodynamics,

Heat supplied (ΔQ) = Work done (W)

+ Change in internal energy of the system (ΔU)

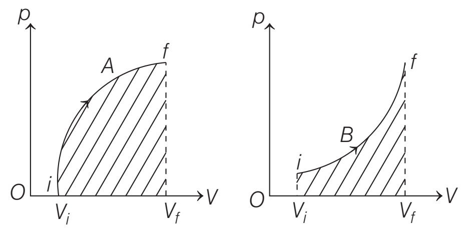
$$\Delta Q_A = \Delta U_A + W_A$$

Similarly, for process B,

$$\Delta Q_B = \Delta U_B + W_B$$

Now, we know that,

Work done for a process = Area under its p-V curve



Thus, it is clear from the above graphs,

$$W_A > W_B \quad \text{...(i)}$$

Also, since the initial and final state are same in both process, so

$$\Delta U_A = \Delta U_B \quad \text{...(ii)}$$

So, from Eqs. (i) and (ii), we can conclude that

$$\Delta Q_A > \Delta Q_B$$

8. Given, $\Delta Q = -20$ J ; $\Delta W = -10$ J

Now, $\Delta Q = (U_f - U_i) + \Delta W$

$\Rightarrow$ $-20 = (U_f - 40) - 10$

$\Rightarrow$ $U_f = -10 + 40 = 30$ J

9. According to the first law of thermodynamics,

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

$\Rightarrow$ $\Delta Q = 0 + W = W$

10. Here, $n = 5, \gamma = \frac{7}{5}, T_1 = 0°$ C, $T_2 = 400°$ C

$\therefore$ $dU = \frac{nRdT}{\frac{7}{5} - 1}$ $\left(\because dU = \frac{nRdT}{\gamma - 1}\right)$

$$dU = \frac{5 \times 8.31 \times (400 - 0)}{\frac{7}{5} - 1} = 41550 \text{ J}$$

$$dU = 41.55 \text{ kJ}$$

11. As, $\frac{dU}{dQ} = \frac{C_V dT}{C_p dT} = \frac{C_V}{C_p} = \frac{(3/2)R}{(5/2)R} = \frac{3}{5}$

(Here, number of moles of gas is constant)

12. Work done by the system = Area of shaded portion on the p-V diagram

$= (300 - 100)10^{-6} \times (100 - 200)10^3$

$= -20$ J

13. As, $dU = C_V\, dT$

$= \left(\frac{3}{2}R\right)dT = \frac{3}{2} \times 8.32 \times 100 = 1.25 \times 10^3$ J

14. For a non-linear triatomic gas, $C_V = 3R$

and for monoatomic gas, $C_V' = \frac{3}{2}R$

$\therefore$ $\frac{Q}{Q'} = \frac{C_V}{C_V'} = K = \frac{3R}{\frac{3}{2}R} = 2$

15. As $V = kT^{2/3}$

$\therefore$ $dV = k\frac{2}{3}T^{-1/3}dT$ (after differentiating)

$\therefore$ $\frac{dV}{V} = \frac{\frac{2}{3}kT^{-1/3}dT}{kT^{2/3}} = \frac{2}{3}\frac{dT}{T}$

Work done, $W = \int_{T_1}^{T_2} RT\frac{dV}{V} = \int_{T_1}^{T_2} RT\frac{2}{3}\frac{dT}{T}$

$$W = \frac{2}{3}R(T_2 - T_1) = \frac{2}{3}R \times 60 = 40R$$

16. In cyclic process, ΔQ = Work done = Area inside the closed curve treat as an ellipse

$= \frac{\pi}{4}(p_2 - p_1)(V_2 - V_1)$

$\Rightarrow$ $\Delta Q = \frac{\pi}{4}\{(180 - 50) \times 10^3 \times (40 - 20) \times 10^{-6}\} = \frac{\pi}{2}$ J

17. In adiabatic expansion, $dQ = 0$.

$\therefore$ $dW = -dU$

$= -(-50 \text{ J})$

$= 50$ J

18. Process 1 is isobaric (p = constant) expansion.

Hence, temperature of gas will increase.

$\therefore$ ΔU_1 = positive

Process 2 is an isothermal process

$\therefore$ $\Delta U_2 = 0$

Process 3 is an adiabatic expansion.

Hence, temperature of gas will fall.

$\therefore$ ΔU_3 = negative

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

19. Given, $p \propto T^3$ but we know that, for an adiabatic process the pressure, $p \propto T^{\gamma/\gamma - 1}$

So, $\frac{\gamma}{\gamma - 1} = 3$

$\Rightarrow$ $\gamma = \frac{3}{2} \Rightarrow \frac{C_p}{C_V} = \frac{3}{2}$

20. We know that, $E_\phi = \gamma p = 1.4 \times (1 \times 10^5) = 1.4 \times 10^5 \text{ N/m}^2$

21. When the compression is isothermal for gas in container A,

$$p_2V_2 = p_1V_1$$

$$p_2 = \frac{p_1V_1}{V_2} = p_1\frac{V_1}{V_1/2} = 2p_1$$

For gas in container B, when compression is adiabatic,

$$p_2' V_2^{\gamma}{}' = p_1V_1^{\gamma}$$

$$p_2' = p_1\left(\frac{V_1}{V_2'}\right)^{\gamma}$$

$$= p_1\left(\frac{V_1}{V_1/2}\right)^{\gamma} = 2^{\gamma}p_1$$

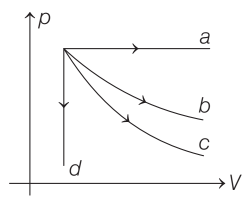
$\therefore$ $\frac{p_2'}{p_2} = \frac{2^{\gamma}p_1}{2p_1} = 2^{\gamma - 1}$

22. Slope of p-V graph of adiabatics = $\gamma\, p/V$

Slope of p-V graph of isothermal = p/V

Required ratio = γ

23. Given processes are



For process a, pressure is constant.

$\therefore a$ is isobaric.

For process d, volume is constant.

$\therefore d$ is isochoric.

Also, as we know that, slope of adiabatic curve in p-V diagram is more than that of isothermal curve.

$\therefore b$ is isothermal and c is adiabatic.

24. For adiabatic process, relation of temperature and volume is

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

$$\Rightarrow \quad T_2(2V)^{2/3} = 300(V)^{2/3}$$

$$\left[\gamma = \frac{5}{3} \text{ for monoatomic gases}\right]$$

$$\Rightarrow \quad T_2 = \frac{300}{2^{2/3}} \approx 189 \text{ K}$$

Also, in adiabatic process,

$$\Delta Q = 0, \Delta U = -\Delta W$$

or $$\Delta U = \frac{-nR(\Delta T)}{\gamma - 1}$$

$$= -2 \times \frac{3}{2} \times \frac{25}{3}(300 - 189)$$

$$\approx -2.7 \text{ kJ}$$

$$T_2 \approx 189 \text{ K}, \ \Delta U \approx -2.7 \text{kJ}$$

25. Here, $p_1 = 1$ atm, $T_1 = 27° \text{ C} = 27 + 273 = 300$ K

$$p_2 = 8 \text{ atm}, T_2 = ?, \gamma = 3/2$$

As change are adiabatic,

$$\therefore \quad p_1^{\gamma-1}T_1^{-\gamma} = p_2^{\gamma-1}T_2^{-\gamma}$$

$$\left(\frac{T_2}{T_1}\right)^{-\gamma} = \left(\frac{p_1}{p_2}\right)^{\gamma-1}$$

$$T_2 = T_1\left(\frac{p_2}{p_1}\right)^{(\gamma-1)/\gamma} = 300 \times (8)^{(1.5-1)/1.5} = 300 \times (8)^{1/3}$$

$$\Rightarrow \quad T_2 = 600 \text{ K} = (600 - 273)° \text{ C} = 327° \text{ C}$$

26. (i) is incorrect ; since in adiabatic process $V \neq$ constant.

(ii) is incorrect, since in isothermal process $T =$ constant.

(iii) and (iv) match isotherms and adiabatic formula

$$TV^{\gamma-1} = \text{constant and } \frac{T^\gamma}{p^{\gamma-1}} = \text{constant}$$

27. In adiabatic process, $pV^\gamma =$ constant

$$\Rightarrow \quad \frac{dp}{dV} \cdot V^\gamma + p \cdot \gamma V^{\gamma-1} = 0$$

$$\Rightarrow \quad \frac{dp}{dV} = -\frac{p\gamma V^{\gamma-1}}{V^\gamma} = \frac{-p\gamma}{V}$$

$$\Rightarrow \quad -\frac{dp}{p\gamma} = \frac{dV}{V}$$

$$\Rightarrow \quad -\frac{\Delta p}{p\gamma} = \frac{\Delta V}{V}$$

28. As, $W_{AB} = -p_0V_0$,

$$W_{BC} = 0 \text{ and } W_{CD} = 4p_0V_0$$

$$\therefore \quad W_{ABCD} = W_{AB} + W_{BC} + W_{CD}$$

$$= -p_0V_0 + 0 + 4p_0V_0 = 3p_0V_0$$

29. As, $W = \int p\,dV =$ area under the p-V curve

$$= \text{minimum along } ADB$$

30. During an adiabatic process, slope of pV curve is

$$\frac{dp}{dV} = -\gamma\frac{p}{V}$$

During an isothermal process, slope of pV curve is

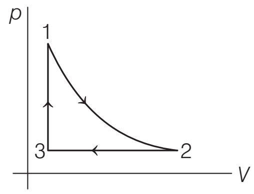
$$\frac{dp}{dV} = \frac{-p}{V}$$

Both slopes are negative, hence A and B are not possible.

Slope of adiabatic curve is more than the slope of isothermal curve, so D is isothermal and C is adiabatic.

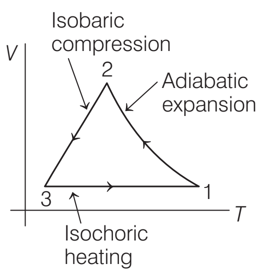
31. In given p-V diagram,

1 to 2 is adiabatic expansion in which temperature reduces.



2 to 3 is isobaric compression, so volume decreases and temperature increases in this process.

3 to 1 is isochoric process in which pressure increases. So, it must be isochoric heating in which temperature increases. So, resultant V-T graph will be



Thus, option (b) is correct.

32. In p-V curve, work done dW, change in internal energy ΔU and heat absorbed ΔQ are connected with first law of thermodynamics, *i.e.*

$$\Delta Q = \Delta U + dW \quad \text{...(i)}$$

and total change in internal energy in complete cycle is always zero. Using this equation in different part of the curve, we can solve the given problem.

In Process $a \rightarrow b$

Given, $\Delta Q_{ab} = 250$ J

$$\therefore \quad 250 \text{ J} = \Delta U_{ab} + dW_{ab} \quad \text{...(ii)}$$

In Process $b \rightarrow c$

Given, $\Delta Q_{bc} = 60$ J

Also, V is constant, so $dV = 0$.

$$\Rightarrow \quad dW_{bc} = p(dV)_{bc} = 0$$

$\therefore \qquad 60\,\text{J} = \Delta U_{bc} + 0$

$\Rightarrow \qquad \Delta U_{bc} = 60\,\text{J} \qquad \ldots\text{(iii)}$

In Process $c \to a$

Given, $\qquad \Delta U_{ca} = -180\,\text{J} \qquad \ldots\text{(iv)}$

Now, for complete cycle,

$$\Delta U_{abca} = \Delta U_{ab} + \Delta U_{bc} + \Delta U_{ca} = 0 \qquad \ldots\text{(v)}$$

From Eqs. (iii), (iv) and (v), we get

$$\Delta U_{ab} = -\Delta U_{bc} - \Delta U_{ca}$$

$$\Delta U_{ab} = -60 + 180 = 120\ \text{J} \qquad \ldots\text{(vi)}$$

From Eq. (ii), we get

$$250\,\text{J} = 120\,\text{J} + dW_{ab}$$

$\Rightarrow \qquad dW_{ab} = 130\,\text{J} \qquad \ldots\text{(vii)}$

From Eqs. (i) and (vii), we get

Work done by the gas along the path abc,

$$dW_{abc} = dW_{ab} + dW_{bc}$$

$$= 130\ \text{J} + 0\ \ \text{K}$$

$\Rightarrow \qquad dW_{abc} = 130\ \text{J}$

33. In a cyclic thermodynamic process, work done = area under p-V diagram

Also in clockwise cycle, work done is positive.

In the given cyclic process,

work done = $\oint pdV$ = area enclosed by the cycle

$= \frac{1}{2} \times$ base $\times$ height of triangle (CAB) made by cycle

$= \frac{1}{2}(V_2 - V_1)(p_2 - p_1)$

From graph, given

$$V_2 = 5\ \text{m}^3,\ V_1 = 1\ \text{m}^3,$$

$$p_2 = 6\ \text{Pa},\ \ p_1 = 1\ \text{Pa}$$

$$= \frac{1}{2}(5-1)(6-1)$$

$$= \frac{1}{2} \times 4 \times 5\ = 10\ \text{J}$$

34. As, $p_2V_2^\gamma = p_1V_1^\gamma$

$$\therefore \qquad p_2 = p_1\left(\frac{V_1}{V_2}\right)^\gamma = p_1\left(\frac{\rho_2}{\rho_1}\right)^\gamma = p\left(\frac{2}{1}\right)^{7/5} = 2.63p$$

35. Using, $pV = nRT$, we see the higher value of pV, higher will be T. Since, pV is higher for T_1.
Thus, $T_1 > T_2$.

36. Figure shows that loop 1 is anti-clockwise, therefore W_1 is negative and loop 2 is clockwise, therefore W_2 is positive.

Also, loop 2 is bigger.

$$W_2 > W_1$$

Hence, net work done, $W = -W_1 + W_2 = W_2 - W_1 = (+)$ ve

37. Isobaric expansion is represented by curve AB.

Work done = Area under AB

$$= 2 \times 10^2 \times (3-1) = 4 \times 10^2 = 400\ \text{J}$$

38. Work done during the complete cycle

$$= \text{Area } ABCDA = AD \times AB = p \times V = pV$$

39. As work done in a process = area under the curve, which increases continuously.

40. Let initial volume of the gas in the cylinder be V.

$\therefore \qquad V_1 = V$

and $\qquad V_2 = V/2$

$$\frac{p_2}{p_1} = ?$$

As, hydrogen is a diatomic gas.

$\therefore \qquad \gamma = \frac{7}{5} = 1.4$

For an adiabatic change, $p_1V_1^\gamma = p_2V_2^\gamma$

$$\therefore \qquad \frac{p_2}{p_1} = \left(\frac{V_1}{V_2}\right)^\gamma$$

$$= \left(\frac{V}{V/2}\right)^{1.4}$$

$$= (2)^{1.4} = 2.64$$

41. From symmetry considerations and also from theory,

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

42. pV^γ = constant

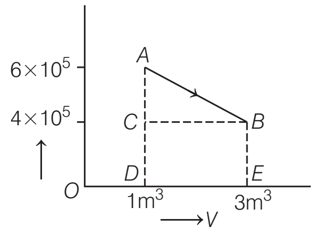
Differentiating, we get $\frac{dp}{dV} = \frac{\gamma p}{V}$

$$\frac{dp}{p} = -\frac{\gamma dV}{V}$$

43. As, $dW = dU = \mu C_V \Delta T = -C_V(T_2 - T_1) = C_V(T_1 - T_2)$

$(\because \mu = 1)$

44. According to question, the figure can be drawn as below



Now, work done by the system

= area under p-V diagram

= area of rectangle $BCDE$ + area of ΔABC

$$= 4 \times 10^5 \times 2 + \frac{2 \times 10^5 \times 2}{2}$$

$\Rightarrow \qquad W = 10 \times 10^5\ \text{J}$

45. As $dW = pdV$

$\therefore \qquad$ (i) $dW = p \times 0 = 0 \qquad (\because$ change in volume $= 0)$

and $\quad$ (ii) $dW = p(2V - V) = pV$

46. AB and CD are isothermal curves, therefore $T_a = T_b$ and $T_c = T_d$ but all the four temperatures are not equal.

47. In adiabatic operation (*e.g.* bursting of tyre),

$$p_2^{1-\gamma}T_2^{\gamma} = p_1^{1-\gamma}T_1^{\gamma}$$

or $$T_2 = T_1\left(\frac{p_1}{p_2}\right)^{1-\gamma/\gamma}$$

$$= 300\left(\frac{4}{1}\right)^{\left(\frac{1-7/5}{7/5}\right)} = 300(4)^{-2/7}$$

($\because$ atmospheric pressure = 1 atm)

48. During adiabatic expansion.

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

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

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

For monoatomic gas, $\gamma = 5/3$

$$\frac{T_1}{T_2} = \left(\frac{AL_2}{AL_1}\right)^{5/3-1} = \left(\frac{L_2}{L_1}\right)^{2/3}$$

49. From, $p_2V_2^{\gamma} = p_1V_1^{\gamma}$

$$\Rightarrow \quad p_2 = p_1\left(\frac{V_1}{V_2}\right)^{\gamma}$$

$$p_2 = \left(\frac{100}{124}\right)^{5/3} p_1$$

$$p_2 = 0.7088p_1$$

$\therefore$ % decrease in pressure

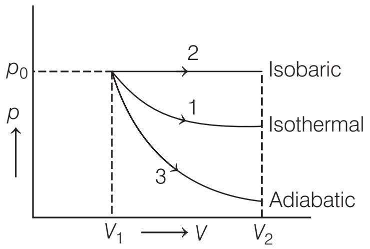
$$= \frac{p_1 - p_2}{p_1} \times 100\%$$

$$= \frac{p_1 - 0.6985p_1}{p_1} \times 100$$

$$= \frac{0.2911p_1}{p_1} \times 100\%$$

$$= 29.11\% \approx 30\%$$

50. The p-V graphs for three given processes are shown in figure.



As, work done by the gas = area under the p-V graph (between the curve and V axis)

$$\Rightarrow \quad (\text{Area})_2 > (\text{Area})_1 > (\text{Area})_3$$

$$\therefore \quad W_2 > W_1 > W_3$$

51. Here, $V_1 = 1\text{ L} = 10^{-3}\text{m}^3$, $V_2 = 3\text{L} = 3 \times 10^{-3}\text{m}^3$

$$p_1 = 1\text{ atm} = 1.013 \times 10^5 \text{ Nm}^{-2}, \gamma = 1.40, W = ?$$

As changes are adiabatic, $p_1V_1^{\gamma} = p_2V_2^{\gamma}$

$$\frac{p_1}{p_2} = \left(\frac{V_2}{V_1}\right)^{\gamma} = (3)^{1.4} = 4.6555$$

$$\therefore \quad p_2 = \frac{p_1}{4.6555} = \frac{1.013 \times 10^5}{4.6555}$$

$$= 0.217 \times 10^5 \text{ Nm}^{-2}$$

Now, work done $= \dfrac{p_1V_1 - p_2V_2}{\gamma - 1}$

$$= \frac{1.013 \times 10^5 \times 10^{-3} - 0.217 \times 10^5 \times 3 \times 10^{-3}}{1.4 - 1}$$

$$= 90.5 \text{ J}$$

52. Heat absorbed by the system at constant pressure, $Q = nC_p\Delta T$

Change in internal energy, $\Delta U = nC_V\Delta t$

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

(first law of thermodynamics)

$$\therefore \quad \frac{W}{Q} = \frac{Q - \Delta U}{Q} = 1 - \frac{\Delta U}{Q}$$

$$= 1 - \frac{RC_{\gamma}\Delta T}{RC_{\gamma}\Delta T} = 1 - \frac{C_V}{C_p} = \left(1 - \frac{1}{\gamma}\right)$$

53. Given, work done, $W = -22.3$ J

Work done is taken negative as work is done on the system.

In an adiabatic change, $\Delta Q = 0$

Using first law of thermodynamics,

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

$$= 0 - (-22.3)$$

$$= 22.3 \text{ J}$$

For another process between state A and state B,

Heat absorbed $(\Delta Q) = +9.35$ cal

$$= +(9.35 \times 4.19) \text{ J}$$

$$= +39.18 \text{ J}$$

Change in internal energy between two states *via* different paths are equal.

$$\therefore \quad \Delta U = 22.3 \text{ J}$$

$\therefore$ From first law of thermodynamics

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

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

$$= 39.18 - 22.3 = 16.88 \text{ J}$$

$$\approx 16.9 \text{ J}$$

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

$$\Delta Q = 0 - 150 \text{ J} = -150 \text{ J}$$

So, heat has been given by the system.

i.e. Heat has been removed from gas.

55. As, $\eta = 1 - \dfrac{T_2}{T_1} = 1 - \dfrac{500}{800} = \dfrac{3}{8} = 0.375$

56. As, $\dfrac{T_2}{T_1} = 1 - \eta = 1 - \dfrac{40}{100} = \dfrac{3}{5}$

$$\therefore \quad T_1 = \frac{5}{3}T_2 = \frac{5}{3} \times 300 = 500 \text{ K}$$

Increase in efficiency = 50% of 40% = 20%

$\therefore$ New efficiency, $\eta' = 40 + 20 = 60\%$

$$\therefore \quad \frac{T_2}{T_1'} = 1 - \eta' = 1 - \frac{60}{100} = \frac{2}{5}$$

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

Increase in temperature of source $= T_1' - T_1$

$= 750 - 500 = 250$ K

57. We have, $\eta = \dfrac{W}{Q_1}$

$$\Rightarrow \quad W = \eta Q_1 = \frac{1}{3} \times 1000 \text{ cal}$$

$$= \frac{1000}{3} \times 4.2 = 1400 \text{ J}$$

58. Given, $T_2 = 27 + 273 = 300$ K and $\eta = 37.5\%$

As, $\quad \eta = 1 - \dfrac{T_2}{T_1}$

$$\therefore \quad \frac{37.5}{100} = 1 - \frac{300}{T_1}$$

or $\quad \dfrac{300}{T_1} = \dfrac{62.5}{100} = \dfrac{5}{8}$

$$T_1 = \frac{2400}{5} = 480 \text{ K}$$

$= 480 - 273 = 207°\text{C}$

59. Given, $T_1 = 273 + 20 = 293$ K, $T_2 = 273 + 10 = 283$ K

$\therefore$ Coefficient of performance

$$= \frac{T_2}{T_1 - T_2} = \frac{283}{293 - 283}$$

$$= \frac{283}{10} = 28.3$$

60. As, $\eta = 1 - \dfrac{T_2}{T_1}$

or $\quad \dfrac{T_2}{T_1} = 1 - \eta = 1 - \dfrac{1}{6} = \dfrac{5}{6}$

$$T_2 = \frac{5}{6} T_1 = \frac{5}{6} \times 600 = 500 \text{ K}$$

61. Relation of coefficient of performance β of refrigerator and efficiency η of engine,

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

In given case, $\eta = \dfrac{1}{10}$

So, $\quad \beta = \dfrac{1 - \dfrac{1}{10}}{\dfrac{1}{10}} = \dfrac{\dfrac{9}{10}}{\dfrac{1}{10}} = 9$

Now, for a Carnot refrigerator, we have

$$\beta = \frac{\text{heat extracted from cold reservoir}}{\text{work done}}$$

$$\Rightarrow \quad 9 = \frac{Q}{10} \Rightarrow Q = 90 \text{J}$$

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

$$\Rightarrow \quad \frac{T_2}{T_1} = 1 - \eta = 1 - \frac{40}{100} = \frac{3}{5}$$

$$\therefore \quad T_2 = \frac{3}{5} T_1 = \frac{3}{5} \times 500 = 300 \text{ K}$$

Again $\quad \dfrac{T_2}{T_1'} = 1 - \eta$

or $\quad \dfrac{300}{T_1'} = 1 - \dfrac{50}{100} = \dfrac{1}{2}$

or $\quad T_1' = 600$ K

63. Given, $T_1 = 27°\text{ C} = (27 + 273)\text{ K} = 300$ K,

and $\quad T_2 = -123 + 273 = 150$ K

$$\therefore \quad \eta = 1 - \frac{T_2}{T_1} = 1 - \frac{150}{300} = 0.5$$

64. As, $\eta = 1 - \dfrac{T_2}{T_1} = \dfrac{T_1 - T_2}{T_1}$

In all the four cases, $T_1 - T_2 = 20$ K. Therefore, η is highest, when T_1 is lowest.

i.e. $T_1 = 40$ K

65. $\text{COP} = \dfrac{T_2}{T_1 - T_2} = \dfrac{273 - 23}{(273 + 77) - (273 - 23)} = \dfrac{250}{100} = 2.5$

As, $\quad \text{COP} = \dfrac{Q_2}{W}$

$$\therefore \quad 2.5 = \frac{1000 \times 80 \times 4.2}{W}$$

or $\quad W = \dfrac{1000 \times 80 \times 4.2}{2.5} = 134400$ J

66. Here, $Q_2 = 2000$ cal

As, $\text{COP} = \dfrac{Q_2}{W}$

$\therefore \quad 4 = 2000 / W$

$W = 500 \text{ cal} = 500 \times 4.2 = 2100$ J

67. As, $\eta = 1 - \dfrac{T_2}{T_1}$

$$\Rightarrow \quad 1 - \frac{100}{500} = 1 - \frac{T}{900}$$

$$\therefore \quad \frac{T}{900} = \frac{1}{5}$$

or $\quad T = 180$ K

68. Given, $T_2 = 0°\text{C} = 273$ K, $T_1 = 17°\text{C} = 17 + 273 = 290$ K

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

$$\Rightarrow \frac{80 \times 1000 \times 4.2}{W} = \frac{273}{290 - 273} = \frac{273}{17}$$

$$W = \frac{80 \times 1000 \times 4.2 \times 17}{273} \text{ J}$$

$$W = \frac{33.6 \times 17 \times 10^4}{273 \times 3.6 \times 10^5} = 0.058 \text{ kWh}$$

69. $\eta = \frac{T_2}{T_1} = \frac{Q_2}{Q_1} = \frac{Q_1 - W}{Q_1}$ $\quad (\because W = Q_1 - Q_2)$

$$\frac{400}{800} = 1 - \frac{W}{Q_1}$$
$$\frac{W}{Q_1} = 1 - \frac{1}{2} = \frac{1}{2}$$
$$Q_1 = 2W = 2400 \text{ J}$$

70. Here, $T_1 = 411° \text{ C} = (411 + 273) \text{ K} = 684 \text{ K}$

$$T_2 = 69°\text{C} = (69 + 273) \text{ K} = 342 \text{ K}$$

and $\quad Q_1 = 1000 \text{ J}$

$\because \quad \eta = \frac{W}{Q_1} = 1 - \frac{T_2}{T_1} = 1 - \frac{342}{684} = \frac{1}{2}$

$\Rightarrow \quad W = \eta Q_1 = \frac{1000}{2} = 500 \text{ J}$

71. As, $\quad \frac{Q_2}{Q_1} = \frac{T_2}{T_1}$

$\therefore \quad \frac{Q_2}{6 \times 10^4} = \frac{127 + 273}{227 + 273} = \frac{400}{500}$

$$Q_2 = \frac{4}{5} \times 6 \times 10^4 = 4.8 \times 10^4 \text{ cal}$$

$\therefore \quad W = Q_1 - Q_2 = 6 \times 10^4 - 4.8 \times 10^4$

$$= 1.2 \times 10^4 \text{ cal}$$

72. The efficiency of two engines are

$$\eta_A = 1 - \frac{T_2}{T_1} = 1 - \frac{500}{1000} = \frac{1}{2}$$

and $\quad \eta_B = 1 - \frac{T_2}{T_1} = 1 - \frac{400}{1100} = \frac{7}{11}$

Clearly, $\quad \eta_A < \eta_B$

73. As, $\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{500}{800} = 1 - \frac{600}{x}$

$\therefore \quad \frac{3}{8} = 1 - \frac{600}{x}$

$$\frac{600}{x} = 1 - \frac{3}{8} = \frac{5}{8}$$
$$5x = 4800$$
$$x = \frac{4800}{5} = 960 \text{ K}$$

74. As, $\quad \eta = 1 - \frac{T_2}{T_1}$

$\therefore \quad \frac{T_2}{T_1} = 1 - \eta = 1 - \frac{10}{100} = \frac{90}{100}$

or $\quad T_1 = \frac{100 T_2}{90} = \frac{100}{90} \times 270 = 300 \text{ K}$

75. As, $\eta = 1 - \frac{T_2}{T_1} = \frac{W}{Q}$

$\Rightarrow \quad W = \left(1 - \frac{T_2}{T_1}\right) Q = \left\{1 - \frac{(273 + 27)}{(273 + 627)}\right\} \times Q$

$\Rightarrow \quad W = \left(1 - \frac{300}{900}\right) \times 3 \times 10^6$

$$= 2 \times 10^6 \times 4.2 \text{ J} = 8.4 \times 10^6 \text{ J}$$

Round II

1. According to first law of thermodynamics,

$$dQ = dU + dW \quad \text{...(i)}$$

As, $\quad dW = -dU \quad$ ...(ii)

So from Eqs. (i) and (ii), we get

$\Rightarrow \quad dQ = dU - dU = 0$

The change must be adiabatic.

2. As, $dW = dQ - dU$

$$= C_p (T_2 - T_1) - C_V (T_2 - T_1)$$
$$= R (T_2 - T_1) \quad (\because C_p - C_V = R)$$
$$= 8.31 \times 100$$
$$= 8.31 \times 10^2 \text{ J}$$

3. Here, $T_1 = 927° \text{ C} = (927 + 273) \text{ K} = 1200 \text{ K}$

and $\quad T_2 = 27° \text{ C} = (27 + 273) \text{ K} = 300 \text{ K}$

As $\quad U \propto T$

$\therefore \quad \frac{\Delta U}{U_2} = \frac{U_1 - U_2}{U_2}$

$$= \frac{1200 - 300}{300} \times 100$$
$$= 300\%$$

4. From $\quad p_2 V_2^\gamma = p_1 V_1^\gamma$

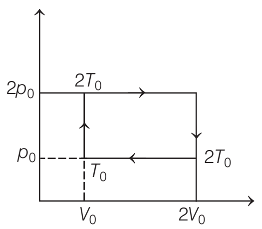
$\Rightarrow \quad p_2 = p_1 \left(\frac{V_1}{V_2}\right)^\gamma = 1 \left(\frac{V_1}{1/20 V_1}\right)^{1.4}$

$$= 66.28 \text{ atm}$$

5. As, $\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{(127 + 273)}{(227 + 273)} = \frac{1}{5}$

$$W = \eta Q_1 = \frac{1}{5} \times 10^4 \text{ J} = 2000 \text{ J}$$

6. Heat supplied $= nC_V \ (2T_0 - T_0) + nC_p \ (2T_0 - T_0)$



$$= \frac{n3RT_0}{2} + \frac{n5R}{2} 2T_0$$
$$= \frac{13}{2} nRT_0 = \frac{13}{2} p_0 V_0$$

7. Since, entropy is a state function, therefore change in entropy in both the processes must be same. Therefore, correct option should be (b).

8. As slope of adiabatic AC is more than the slope of isothermal AB and isochoric BC (*i.e.* at constant volume), therefore Fig. (b) represents the curves correctly.

9. As work done in an isothermal process is

$$W = \mu RT \log_e \frac{V_2}{V_1}$$

$$= \left(\frac{m}{M}\right) RT \log_e \frac{V_2}{V_1}$$

$$= 2.3 \times \frac{m}{M} RT \log_{10} \frac{V_2}{V_1}$$

$$= 2.3 \times \frac{96}{32} R(273 + 27) \log_{10} \frac{140}{70}$$

$$= 2.3 \times 900 R \log_{10} 2$$

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

$$\Rightarrow \quad T_2 = 300\left(\frac{27}{8}\right)^{\frac{5}{3}-1} = 300\left(\frac{27}{8}\right)^{\frac{2}{3}} = 300\left(\frac{3}{2}\right)^2 = 675 \text{ K}$$

$$\Rightarrow \quad \Delta T = 576 - 300 = 375 \text{ K}$$

11. As, $dU = dQ - dW = 8 \times 10^5 - 6.5 \times 10^5 = 1.5 \times 10^5$ J

In the second process, dU remains the same.

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

$$= -0.5 \times 10^5 \text{ J}$$

12. As, $T_2 = T_1\left(\frac{V_1}{V_2}\right)^{\gamma - 1} = 273(2)^{0.41} = 273 \times 1.328 = 363$ K

Now, for one mole of the gas, the work done,

$$|W| = \frac{R(T_1 - T_2)}{\gamma - 1} = \frac{8.31(273 - 363)}{1.41 - 1} = -1815$$

$$\Rightarrow \quad |W| = 1815 \text{ J}$$

13. Adiabatic process is from C to D,

$$\text{Work done} = \frac{p_2V_2 - p_1V_1}{1 - \gamma}$$

$$= \frac{p_DV_D - p_CV_C}{1 - \gamma}$$

$$= \frac{200(3) - (100)(4)}{1 - 1.4}$$

$$= -500 \text{ J}$$

14. Here $Q_1 = 200$ cal, $Q_2 = 150$ cal, $T_1 = 400$ K

As, $\frac{Q_1}{Q_2} = \frac{T_1}{T_2}$

$$T_2 = \frac{Q_2}{Q_1} \times T_1 = \frac{150}{200} \times 400 = 300 \text{ K}$$

15. As, $\Delta U = \mu C_V \Delta T = \mu\left(\frac{R}{\gamma - 1}\right)\Delta T$

$$\therefore \quad \Delta U = \frac{p\Delta V}{(\gamma - 1)} = \frac{p(2V - V)}{(\gamma - 1)} = \frac{pV}{(\gamma - 1)}$$

16. As, $W = \frac{\mu R(T_1 - T_2)}{(\gamma - 1)} = \frac{\mu RT_1}{(\gamma - 1)}\left[1 - \frac{T_2}{T_1}\right]$

$$= \frac{\mu RT_1}{(\gamma - 1)}\left[1 - \left(\frac{V_1}{V_2}\right)^{\gamma - 1}\right]$$

$$= \frac{2 \times 8.31 \times 300}{\left(\frac{5}{3} - 1\right)}\left[1 - \left(\frac{1}{2}\right)^{\frac{5}{3}-1}\right]$$

$$= +\ 2767.23 \text{ J}$$

17. As, $W = -\mu RT \log_e \frac{V_2}{V_1} = -1 \times 8.31 \times (273 + 0) \log_e\left(\frac{22.4}{11.2}\right)$

(–ve sign shows compression)

$$= -8.31 \times 273 \times \log_e 2$$

$$= -1572.5 \text{ J} \qquad [\because \log_e 2 = 0.693]$$

18. For isothermal process, $p_1V_1 = p_2V_2$

$$\Rightarrow \quad p_2 = \frac{p_1V_1}{V_2} = \frac{72 \times 1000}{900} = 80 \text{ cm of mercury}$$

$\therefore$ Stress, $\Delta p = p_2 - p_{12} = 80 - 72 = 8$ cm of mercury

19. As, volume of the gas, $V = \frac{M}{d}$

Now, using $pV^\gamma =$ constant, we get

$$\frac{p'}{p} = \left(\frac{V}{V'}\right)^\gamma = (32)^{7/5} = 128$$

20. Work done during an adiabatic change,

$$W = \frac{\mu R(T_1 - T_2)}{(\gamma - 1)}$$

Now, $\gamma = \frac{C_p}{C_V}$

$$\therefore \quad \gamma - 1 = \frac{C_p - C_V}{C_V} = \frac{R}{C_V}$$

$$\therefore \quad W = \frac{\mu R(T_1 - T_2)C_V}{R}$$

$$= \mu(T_1 - T_2)C_V$$

21. As, $W = p\Delta V = 1.01 \times 10^5 (3.34 - 2 \times 10^{-3})$

$$= 337 \times 10^3 \text{ J} = 340 \text{ kJ}$$

22. As compression is sudden, changes are adiabatic, $dQ = 0$. Therefore, work done on the gas increases the temperature.

23. In an adiabatic change,

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

or $pT^{\gamma/1-\gamma} = \text{constant}$

or $p \propto T^{-(1-\gamma)/\gamma}$

Thus, $c = -\frac{1 - \gamma}{\gamma}$

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

$$\therefore \quad -c = \frac{1 - 5/3}{5/3} = -\frac{2}{5}$$

$$\Rightarrow \quad c = \frac{2}{5}$$

24. From $\eta = 1 - \frac{T_2}{T_1}$

$$\frac{40}{100} = 1 - \frac{(27 + 273)}{T_1}$$

$$\frac{300}{T_1} = 1 - \frac{40}{100} = \frac{3}{5}$$

$$T_1 = \frac{300 \times 5}{3} = 500 \text{ K}$$

25. From the given initial state A to final state B, change in internal energy is same in all the four cases, as it is independent of the path from A to B.
As work done = area under p-V curve, therefore work done is maximum in case I.

26. Figure represents the working of a refrigerator, where

$$Q_1 = Q_2 + W$$

According to problem, $W > 0$, then

$$W = Q_1 - Q_2 > 0$$

So, there are two possibilities
(i) If both Q_1 and Q_2 are positive,

$\Rightarrow$ $Q_1 > Q_2 > 0$

(ii) If both Q_1 and Q_2 are negative,

$$Q_2 < Q_1 < 0$$

27. In the given work, one complete cycle, $1 \to 2 \to 3 \to 1$, the system returns to its initial state.
$\therefore dU = 0$ and $dQ = dW$, *i.e.* heat is completely converted into mechanical energy, which is not possible in such a process. Further, the two adiabatic curves $(2 \to 3)$ and $(3 \to 1)$ cannot intersect each other.

28. As it is clear from figure,
Slope of curve 2 > Slope of curve 1

$$(\gamma p)_2 > (\gamma p)_1$$

$$\gamma_2 > \gamma_1$$

We know that, for monoatomic gas, $\gamma = 1.67$
and for diatomic gas, $\gamma = 1.4$
$\therefore$ Adiabatic curve 2 corresponds to helium (monoatomic) and adiabatic curve 1 corresponds to oxygen (diatomic).

29. The given relation is $p = \alpha V$
Therefore, $p \propto V$
When V changes from V to $2V$, pressure p is also doubled.
For an ideal gas, $\frac{pV}{T}$ = constant

$\therefore$ $T \propto pV$

Hence, T becomes $2 \times 2 = 4$ times
i.e. $4 \times 300 \text{ K} = 1200 \text{ K}$

30. Here, $p = 4.5 \times 10^5$ Pa,

$dV = (2.0 - 0.5) \text{ m}^3 = 1.5 \text{ m}^3$

and $dQ = 800 \text{ kJ} = 8 \times 10^5 \text{ J}, dU = ?$

$$dW = pdV = 4.5 \times 10^5 \times 1.5 = 6.75 \times 10^5 \text{ J}$$

$$dU = dQ - dW$$
$$= 8 \times 10^5 - 6.75 \times 10^5$$
$$= 1.25 \times 10^5 \text{ J}$$

31. Given, $T_1 = 200° \text{ C} = 200 + 273 = 473 \text{ K}$

$T_2 = 0° \text{ C} = 0 + 273 = 273 \text{ K}$

$\therefore$ $\eta_1 = 1 - \frac{T_2}{T_1} = 1 - \frac{273}{473} = \frac{200}{473}$

Again, $T_1' = 0° \text{ C} = (0 + 273) \text{ K} = 273 \text{ K}$
and $T_2' = -200° \text{ C} = (-200 + 273) \text{ K} = 73 \text{ K}$

$\therefore$ $\eta_2 = 1 - \frac{T_2}{T_1'} = 1 - \frac{73}{273} = \frac{200}{273}$

Now, $\frac{\eta_1}{\eta_2} = \frac{200}{473} \times \frac{273}{200} = \frac{273}{473} = \frac{1}{1.732}$

32. The given relation is $p = \frac{\alpha T^2}{V}$

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

As, pressure is kept constant.

$\therefore$ $dV = \left(\frac{2\alpha T}{p}\right) dT$ (after differentiating)

Now, $W = \int p\, dV = \int_{T_0}^{2T_0} p \left(\frac{2\alpha T}{p}\right) dT$

$$= -2\alpha \left[\frac{T^2}{2}\right]_{T_0}^{2T_0} = 3\alpha T_0^2$$

33. For monoatomic gas, $\gamma = \frac{C_p}{C_V} = \frac{5}{3}$

We know that, $\Delta Q = \mu C_p \Delta T$
and $\Delta U = \mu C_V \Delta T$

$\Rightarrow$ $\frac{\Delta U}{\Delta Q} = \frac{C_V}{C_p} = \frac{3}{5}$

i.e. Fraction of heat energy required to increases the internal energy will be $\frac{3}{5}$.

34. Given, $T_2 = 27 + 273 = 300 \text{ K}, \eta = 40\%$

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

$\therefore$ $\frac{T_2}{T_1} = 1 - \eta = 1 - \frac{40}{100} = \frac{60}{100} = \frac{3}{5}$

$\Rightarrow$ $T_1 = \frac{5}{3} \times T_2 = \frac{5}{3} \times 300 = 500 \text{ K}$

$\therefore$ New efficiency, $\eta' = 40 + 4 = 44\%$

($\because$ Increase in efficiency = 10% of 40 = 4%)

Let the new temperature of the source be T_1' K, then

$$\eta' = 1 - \frac{T_2}{T_1'} \Rightarrow \frac{44}{100} = \frac{1 - 300}{T_1'}$$

$\Rightarrow$ $\frac{300}{T_1'} = 1 - \frac{44}{100} = \frac{56}{100}$

$\Rightarrow$ $T_1' = \frac{100 \times 300}{56} = 535.7 \text{ K}$

$\therefore$ Increase in the temperature of the source,

$$= 535.7 - 500 = 35.7 \text{ K or } 35.7° \text{ C}$$

35. Given, temperature of source, $T_1 = (36 + 273)$ K

$= 309$ K

Temperature of sink, $T_2 = (9 + 273) \text{ K} = 282 \text{ K}$

Coefficient of performance of a refrigerator

$$\beta = \frac{T_2}{T_1 - T_2} = \frac{282}{309 - 282} = \frac{282}{27} = 10.4$$

36. From first law of thermodynamics, $\Delta Q = \Delta U + W$

Work done at constant pressure $(\Delta W)_p = (\Delta Q)_p - \Delta U$

$= (\Delta Q)_p - (\Delta Q)_V$ (as we know, $\Delta Q_V = \Delta U$)

Also $(\Delta Q)_p = MC_p \Delta T$

and $(\Delta Q)_V = MC_V \Delta T$

$\Rightarrow$ $(\Delta W_p) = M(C_p - C_V)\Delta T$

$= 1 \times (3.4 \times 10^3 - 2.4 \times 10^3) \times 10 = 10^4$ cal

37. According to first law of thermodynamics,

$\Delta Q = \Delta U + \Delta W$, in adiabatic process, $\Delta Q = 0$

$0 = \Delta U - \Delta W$ (work done on the system negative

$\Delta U = + \Delta W = + 22.3$ J

In second process, $\Delta Q = \Delta U + \Delta W$

$9.35 \times 4.18 = 22.3 + \Delta W$

Work done by system, $\Delta W = 16.95 \text{ J} \simeq 16.9 \text{ J}$

38. Amount of heat given = 540 cal

Change in volume, $\Delta V = 1670$ cc

and atmospheric pressure, $p = 1.01 \times 10^6$ dyne/cm^2

$\therefore$ Work done against atmospheric pressure,

$$W = p\Delta V = \frac{1.01 \times 10^6 \times 1670}{4.2 \times 10^7} = 40 \text{ cal}$$

39. Number of moles of He $= \frac{1}{4}$

Now, $T_1(5.6)^{\gamma - 1} = T_2(0.7)^{\gamma - 1}$

$$T_1 = T_2\left(\frac{1}{8}\right)^{2/3}$$

$$4T_1 = T_2$$

$\therefore$ Work done, $W = \dfrac{-nR[T_2 - T_1]}{\gamma - 1}$

$$= \frac{-\frac{1}{4}R[3T_1]}{\frac{2}{3}} = \frac{-9}{8}RT_1$$

$\Rightarrow$ $|W| = \dfrac{9}{8}RT_1$

40. As, $\Delta W_{AB} = p\Delta V = 10(2 - 1) = 10$ J

and $\Delta W_{BC} = 0$, because V is constant

From first law of thermodynamics,

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

As $ABCA$ is a cyclic process, therefore

$$\Delta U = 0$$

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

$= \Delta W_{AB} + \Delta W_{CA}$

or $\Delta W_{CA} = \Delta Q - \Delta W_{AB} = 5 - 10 = -5$ J

41. For the process at constant pressure,

$$dQ = C_p dT + dW$$

$\therefore$ $dT = \dfrac{dQ - dW}{C_p}$

For the process at constant volume,

$$dQ = C_V dT \qquad (\because dW = 0)$$

$$= C_V\left(\frac{dQ - dW}{C_p}\right)$$

$$= \frac{dQ - dW}{C_p / C_V} = \frac{dQ - dW}{\gamma}$$

or $(\gamma - 1)dQ = dW$

$$\left(\frac{5}{3} - 1\right)dQ = W$$

$\therefore$ $dQ = \dfrac{3}{2}W$

42. As, $v_{\text{rms}} = \sqrt{\dfrac{3RT}{M}} \Rightarrow \dfrac{(v_{\text{rms}})_1}{(v_{\text{rms}})_2} = \sqrt{\dfrac{T_1}{T_2}}$

Now, $T_1V_\gamma^{\gamma - 1} = T_2V_2^{\gamma - 1}$

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

Thus, $\dfrac{(V_{\text{rms}})_1}{(V_{\text{rms}})_2} = \left(\dfrac{V_2}{V_1}\right)^{\frac{\gamma - 1}{2}}$

$$= \frac{V}{V/2} = \left(\frac{V_2}{V_1}\right)^{\frac{\frac{7}{5} - 1}{2}} = 2$$

$$= \left(\frac{V_2}{V_1}\right)^{\frac{2}{5} \times \frac{1}{2}} = \left(\frac{V_1}{V_1}\right)^{\frac{1}{5}}$$

$$= \left(\frac{V_2}{V_1}\right)^5 = 2^5 = 32$$

43. As, initial and final temperatures for each process are same.

$\therefore$ Change in internal energy for each process will be equal, *i.e.*

$$\Delta U = nC_V\Delta T = \text{same}$$

Thus, $E_{AB} = E_{AC} = E_{AD}$

Now, work done, $W = pdV$

For process AB, volume is increasing

$\Rightarrow$ $W_{AB} > 0$

For process AD, volume is decreasing

$\Rightarrow$ $W_{AD} < 0$

For process AC, volume is constant

$\Rightarrow$ $W_{AC} = 0$

Hence, correct option is (b).

44. Given that, Vp^n = constant

$\therefore$ $Vp^n = (V + \Delta V)(p + \Delta p)^n$

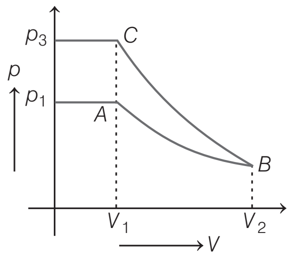
$$= Vp^n\left(1 + \frac{\Delta V}{V}\right)\left(1 + n\frac{\Delta p}{p}\right)$$

$$1 = 1 + \frac{\Delta V}{V} + n\frac{\Delta p}{p} + n\frac{\Delta V}{V}\frac{\Delta p}{p}$$

or $\quad \dfrac{\Delta V}{V} = -n\dfrac{\Delta p}{p}$ (neglecting the product)

$\Rightarrow$ Bulk modulus, $\quad K = \dfrac{-\Delta p}{\Delta V/V} = \dfrac{p}{n}$

45. As, slope of adiabatic process at a given state is more than the slope of isothermal process, therefore in figure, AB is isothermal and BC is an adiabatic.



In going from A to B, volume is increasing

$\therefore \quad W_{AB}$ = positive

In going from B to C, volume is decreasing

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

As work done is area under p-V graph, therefore

$$|W_{BC}| > |W_{AB}|$$

$\therefore \quad W = W_{AB} + W_{BC}$ = Negative, *i.e.* $W < 0$.

From the graph, it is clear that $p_3 > p_1$.

46. The given expansion process is adiabatic in nature and we have the following data

Initial volume, $V_1 = 1\text{ L} = 10^{-3}\text{ m}^3$

Final volume, $V_2 = 3\text{ L} = 3 \times 10^{-3}\text{ m}^3$

Initial pressure, $p_1 = 1\text{ atm} = 1.01 \times 10^5\text{ Pa}$

Final pressure, $p_2 = ?$

Using $p_1V_1^\gamma = p_2V_2^\gamma$, we have

$$1 \times 1^\gamma = p_2 \times (3)^\gamma$$

Here, $\quad \gamma = 1.40$ and $(3)^{1.4} = 4.6555$

So, $\quad p_2 = \dfrac{1}{4.6555} \approx 0.22\text{ atm}$

$$= 0.22 \times 1.01 \times 10^5\text{ Pa}$$

Work done in an adiabatic expansion is given by

$$W = \frac{(p_1V_1 - p_2V_2)}{\gamma - 1}$$

$$= \frac{(1.01 \times 10^5 \times 1 \times 10^3 - 0.22 \times 1.01 \times 10^5 \times 3 \times 10^{-3})}{(1.40 - 1)}$$

$$= 0.85 \times 1.01 \times 10^5 \times 10^{-3}$$

$$= 85.85\text{ J}$$

Closest value of work done, $W \approx 90.5$ J

47. KE of the vessel $= \dfrac{1}{2}Mv^2$

When the vessel is suddenly stopped, the ordered motion of the gas molecules is converted into disordered motion of the molecules, thereby increasing the internal energy of the gas. Thus,

$$\Delta U = nC_V\Delta T = \frac{1}{2}mv^2 = \frac{1}{2}(nM)v^2$$

where, n is number of moles of the gas in the vessel and M is molecular weight of the gas.

$\therefore \quad \Delta T = \dfrac{Mv^2}{2C_V}$

As, $\quad C_V = \dfrac{R}{\gamma - 1}$

$\therefore \quad \Delta T = \dfrac{Mv^2(\gamma - 1)}{2R}$

48. From the first law of thermodynamics,

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

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

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

Now, $\quad \Delta Q = Q_1 + Q_2 + Q_3 + Q_4$

$= 600\text{ J} - 400\text{ J} - 300\text{ J} + 200\text{ J} = 100\text{ J}$

and $\quad \Delta W = W_1 + W_2 + W_3 + W_4$

$\Rightarrow \quad \Delta W = 300\text{ J} - 200\text{ J} - 150\text{ J} + W_4$

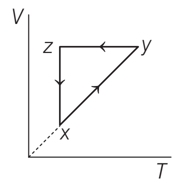
$= -50\text{ J} + W_4$

Substitute the value of ΔQ and ΔW in Eq. (i), we get

$$100\text{ J} = -50\text{ J} + W_4$$

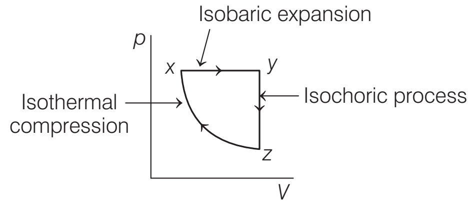
$$W_4 = 150\text{ J}$$

49. For the given V-T graph of thermodynamic cycle $xyzx$,



In process xy, $V \propto T \Rightarrow$ pressure is constant.

Process zx is a isothermal compression process, so pressure increases in this process. Process yz is a isochoric process in which temperature decreases, so pressure must decrease in this process. Hence, the p-V graph is as shown in the figure



50. Isothermal curve from A to B will be parabolic with lesser area under the curve than the area under straight line AB. Therefore, work done by the gas in going straight from A to B is more.

If p_0, V_0 be the intercepts of curve on p and V axes, then its equation is obtained from $y = mx + c$

i.e. $\quad p = \dfrac{p_0}{V_0}V + p_0$ or $\dfrac{RT}{V} = \dfrac{p_0V}{V_0} + p_0$

or $\quad T = \dfrac{p_0}{V_0R}V^2 + \dfrac{p_0V}{R}$

which is the equation of a parabola. Hence T-V curve is parabolic. Therefore (b) is incorrect.

Also $(p/2) \times (2V) = pV =$ constant, *i.e.* process is isothermal.

Hence, option (a) is correct.

51. **I. Adiabatic process**

No heat is transferred between system and surroundings, therefore

$$\Delta Q = 0$$

II. Isothermal process

Temperature of the system remains constant.

i.e. $T =$ constant $\Rightarrow \Delta T = 0$

So, change in internal energy,

$$\Delta U = nC_V \Delta T = nC_V (0) = 0$$

III. Isochoric process

Volume of system remains constant.

i.e. $V =$ constant $\Rightarrow \Delta V = 0$

So, work done,

$$\Delta W = \int p\, dV = \int p\,(0) = 0$$

IV. Isobaric process

Pressure of system remains constant.

i.e. $p =$ constant (C)

$\Rightarrow$ $\Delta p = 0$

So, change in internal energy,

$$\Delta U = nC_V \Delta T = n\left(\frac{fR}{2}\right)\Delta T$$

$$= \frac{f}{2}(nR\Delta T) = \frac{f}{2}(p\Delta V)$$

$$= \frac{f}{2}(C\Delta V) \neq 0$$

and work done,

$$\Delta W = \int p\, dV = \int C\, dV$$

$$= C\int dV = C\,\Delta V \neq 0$$

and heat transferred,

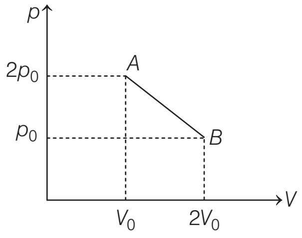
$$\Delta Q = n\,C_p \Delta T = n\left[\frac{(f+2)R}{2}\right]\Delta T$$

$$= \left(\frac{f+2}{2}\right)(nR\Delta T) = \left(\frac{f+2}{2}\right)(p\Delta V)$$

$$= \left(\frac{f+2}{2}\right)(C\,\Delta V) \neq 0$$

So, A $\rightarrow$ q, B $\rightarrow$ s, C $\rightarrow$ p, D $\rightarrow$ r

52. As, T will be maximum temperature where product of pV is maximum.



Equation of line AB, we have

$$y - y_1 = \frac{y_2 - y_1}{x_2 - x_1}(x - x_1)$$

$$\Rightarrow \quad p - p_0 = \frac{2p_0 - p_0}{V_0 - 2V_0}(V - 2V_0)$$

$$\Rightarrow \quad p - p_0 = \frac{-p_0}{V_0}(V - 2V_0)$$

$$\Rightarrow \quad p = \frac{-p_0}{V_0}V + 3p_0$$

$$pV = \frac{-p_0}{V_0}V^2 + 3p_0 V$$

$$nRT = \frac{-p_0}{V_0}V^2 + 3p_0 V$$

$$T = \frac{1}{nR}\left(\frac{-p_0}{V_0}V^2 + 3p_0 V\right)$$

For maximum temperature,

$$\frac{\partial T}{\partial V} = 0$$

$$\frac{-p_0}{V_0}(2V) + 3p_0 = 0$$

$$\frac{-p_0}{V_0}(2V) = -3p_0 \Rightarrow V = \frac{3}{2}V_0$$

(condition for maximum temperature)

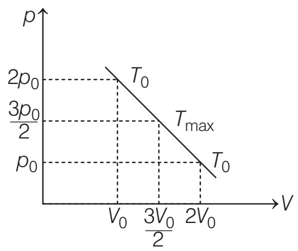
Thus, the maximum temperature of the gas during the process will be

$$T_{\max} = \frac{1}{nR}\left(\frac{-p_0}{V_0} \times \frac{9}{4}V_0^2 + 3p_0 \times \frac{3}{2}V_0\right)$$

$$= \frac{1}{nR}\left(-\frac{9}{4}p_0V_0 + \frac{9}{2}p_0V_0\right) = \frac{9}{4}\frac{p_0V_0}{nR}$$

Alternate solution

Since, initial and final temperatures are equal, hence maximum temperature is at the middle of line.



i.e. $pV = nRT$

$$\Rightarrow \quad \frac{\left(\frac{3}{2}p_0\right)\left(\frac{3V_0}{2}\right)}{nR} = T_{\max}$$

$$\frac{9}{4}\frac{p_0V_0}{nR} = T_{\max}$$

53. $1 - \dfrac{T_2}{T_1} = 0.5$ or $T_1 = 2T_2 = 2\,(17 + 273) = 580\text{ K}$

Temperature of hot body is increased by 145°C or 145 K,

$\therefore$ $T_1' = (580 + 145) = 725\text{ K}$

and $T_2 = (17 + 273) = 290\text{ K}$

$\therefore$ $\eta = \left(1 - \dfrac{290}{725}\right) \times 100 = 60\%$

54. Here, $T_1 = 200°\text{C} = 200 + 273 = 473\text{ K}$

$$T_2 = 100°\text{C} = 100 + 273 = 373\text{ K}$$

$$\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{373}{473} = \frac{100}{473}$$

$$\eta = \frac{100}{473} \times 100\% = 21.14\%$$

This is the percentage of heat which is utilised for doing work.

55. For adiabatic process BC (pressure constant),

$$p_B = p_C \quad \text{...(i)}$$

For isothermal process CA,

$$p_A V_A = p_C V_C \quad \text{...(ii)}$$

From Eqs. (i) and (ii), we get

$$V_C = \left[\frac{V_B^\gamma}{V_A}\right]^{\frac{1}{\gamma-1}} = \left[\frac{4^\gamma}{1}\right]^{\frac{1}{\gamma-1}}$$

For $\quad \gamma = 1.5,\ V_C = 4^3 = 64\text{ m}^3$

$\therefore \quad p_C = \dfrac{p_A V_A}{V_C} = \dfrac{10^5}{64}\text{ N/m}^2$

$$= \frac{10^x}{64}\text{ N/m}^2 \quad \text{(given)}$$

$\therefore \quad x = 5$

56. From the given problem,

$$\Delta Q = Q_1 + Q_2 + Q_3 + Q_4$$
$$= 5960 - 5585 - 2980 + 3645$$
$$\Delta Q = 9605 - 8565 = 1040\text{ J}$$

Efficiency of a cycle is defined as

$$\eta = \frac{\text{Net work}}{\text{Input heat}} = \frac{\Delta W}{Q_1 + Q_4} = \frac{\Delta Q}{Q_1 + Q_4}$$

Putting $\quad \Delta Q = 1040\text{ J}$

and $\quad Q_1 + Q_4 = 5960 + 3645 = 9605\text{ J}$

$\therefore \quad \eta = \dfrac{1040}{9605} = 0.1082 = 10.82\%$

57. Given, air is diatomic gas

$\therefore$ Degrees of freedom, $f = 5$

So, ratio of specific heats of gas, $\gamma = 1 + \dfrac{2}{f} = \dfrac{7}{5}$

Also, given that $V_i = V$ and $V_f = \dfrac{V}{10}$

$$T_i = 20°\text{ C} = 273 + 20 = 293\text{ K}$$

As for adibatic change,

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

$\Rightarrow \quad T_i V_i^{\gamma-1} = T_f V_f^{\gamma-1}$

$\Rightarrow \quad 293 \cdot V^{\frac{7}{5}-1} = T_f \cdot \left(\dfrac{V}{10}\right)^{\frac{7}{5}-1}$

$\Rightarrow \quad T_f = 293 \times 10^{2/5}\text{ K}$

Change in internal energy,

$$\Delta U = \frac{n \cdot f \cdot R(T_f - T_i)}{2}$$

$$= \frac{5 \times 5 \times \frac{25}{3}(293 \times 10^{2/5} - 293)}{2}$$

$$= 4.195 \times 10^3\text{ J} \approx 4\text{kJ}$$

58. Here, $Q_1 =$ heat absorbed per minute

and $\quad Q_2 =$ heat rejected per minute.

We know that, $\eta\,\% = \dfrac{W}{Q_1} \times 100$

$\therefore \quad \eta\,\% = \dfrac{5.4 \times 10^8\text{ J}}{3.6 \times 10^9\text{ J}} \times 100$

$$= \frac{3}{20} \times 100 = 15\%$$

Also using the relation $Q_1 = W + Q_2$, we get

$$Q_2 = Q_1 - W$$
$$= 36 \times 10^8 - 5.4 \times 10^8$$
$$= 30.6 \times 10^8\text{ J/min}$$
$$= 3.06 \times 10^9\text{ J/min}$$
$$= 3.1 \times 10^9\text{ J/min}$$

59. Here, mass of water = 1 g

$\therefore \quad$ Initial volume of water, $V_1 = 1\text{ cm}^3$

Volume of steam, $V_2 = 1650\text{ cm}^3$

Change of internal energy, $dU = ?$

As the state of water is changing,

$\therefore \quad dQ = mL = 1 \times 540\text{ cal}$

$$= 540 \times 4.2 \times 10^7\text{ erg}$$
$$= 22.68 \times 10^9\text{ erg}$$

Taking $p = 1$ atm,

$$= 76 \times 13.6 \times 981\text{ dyne cm}^{-2}$$

$$dW = pdV = p(V_2 - V_1)$$
$$= 76 \times 13.6 \times 981\,(1650 - 1)$$
$$= 76 \times 13.6 \times 981 \times 1649\text{ erg}$$
$$= 1.67 \times 10^9\text{ erg}$$

As, $\quad dQ = dU + dW$

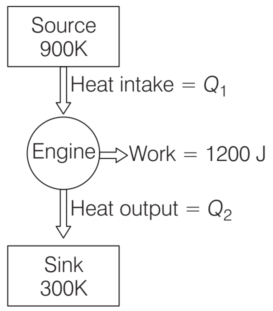
$\therefore \quad dU = dQ - dW = 22.68 \times 10^9 - 1.67 \times 10^9$

$dU = 21.01 \times 10^9$ erg

$= 21.01 \times 10^x$ erg $\quad$ (given)

$\therefore \quad x = 9$

60. According to the question,



For the given Carnot engine, we have work output, $W = Q_1 - Q_2$ and ratio of heat taken and rejected is

$$\frac{Q_1}{Q_2} = \frac{T_1}{T_2}$$

So, we have

$$1200 = Q_1 - Q_2$$

and $$\frac{Q_1}{Q_2} = \frac{900}{300} = 3$$

On solving these, we get

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

61. Here, temperature of the gas,

$$T = 273 + 127 = 400 \text{ K}$$

Let initial volume of the gas, $V_1 = V$

$\therefore$ Final volume of the gas, $V_2 = 2V$

In an isothermal expansion,

Work done $(W) = 2.3026\, RT \log_{10} \dfrac{V_2}{V_1}$

$$= 2.3026 \times 8.3 \times 400 \times \log_{10} \frac{2V}{V}$$

$$= 2.3026 \times 8.3 \times 400 \times 0.3010$$

or $$W = 2.30 \times 10^3 \text{ J}$$

The amount of heat absorbed,

$$H = \frac{W}{J} = \frac{2.30 \times 10^3}{4.2}\ 547.6 = 548 \text{ cal}$$

62. Initially gas is compressed adiabatically.

Initial temperature, $T_1 = 300$ K

Number of moles = 1, $\gamma = 1.4$

Initial volume = V_1

Final volume = $\dfrac{V_1}{16}$

Process equation is

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

$$\Rightarrow \quad 300 V_1^{1.4 - 1} = T_2 \left(\frac{V_1}{16}\right)^{1.4 - 1}$$

$$\Rightarrow \quad T_2 = 300 \times 2^{\frac{8}{5}} \quad \text{...(i)}$$

In next process, gas is expanded isobarically. Initial volume, $V_2 = \dfrac{V_1}{16}$

Final volume, $V_3 = 2\left(\dfrac{V_1}{16}\right) = \dfrac{V_1}{8}$

Now, for isobaric expansion,

$$\frac{V_2}{T_2} = \frac{V_3}{T_3}$$

$$\Rightarrow \quad \frac{V_2}{300 \times 2^{\frac{8}{5}}} = \frac{2V_2}{T_3}$$

$$\Rightarrow \quad T_3 = 2 \times 300 \times 2^{\frac{8}{5}}$$

$$= 300 \times 2^{\frac{13}{5}} = 1818.85$$

or $$T_3 = 1819 \text{ K}$$

63. Here, initial temperature,

$$T_1 = 27^\circ \text{C} = 273 + 27 = 300 \text{ K}$$

Final temperature, $T_2 = 97^\circ$ C $= 273 + 97 = 370$ K

When a gas is compressed adiabatically, work done on the gas is given by

$$W = \frac{R}{(1 - \gamma)} (T_2 - T_1)$$

$$= \frac{8.3 \times (370 - 300)}{1 - 1.5}$$

or $$W = -\ 11.62 \times 10^2 \text{J}$$

$\therefore$ Heat produced,

$$H = \frac{W}{J} = \frac{11.62 \times 10^2}{4.2} = 276.7 \text{ cal}$$

64. Here, $n = 5$, $T = 500$K, $V_B = 2\, V_A$,

$$R = 8.31 \text{ mol}^{-1} \text{ K}^{-1}$$

Now, $$W_{\text{iso}} = n \times 2.303 \times RT \log \frac{V_B}{V_A}$$

$$= 5 \times 2.303 \times 8.31 \times 500 \log \frac{2V_A}{V_A}$$

$$= 5 \times 2.303 \times 8.31 \times 500 \log 2$$

$$= 5 \times 2.303 \times 8.31 \times 500 \times 0.3010$$

$$= 14401.3 \text{ J}$$

65. Here, $Q_1 = 6 \times 10^5$ cal

$$T_1 = 227^\circ \text{C} = 227 + 273 = 500 \text{ K}$$

$$T_2 = 127^\circ \text{C} = 127 + 273 = 400 \text{ K}$$

Work done/cycle, $W = ?$

As, $$\frac{Q_2}{Q_1} = \frac{T_2}{T_1}$$

$$\therefore \quad Q_2 = \frac{T_2}{T_1} \times Q_1 = \frac{400}{500} \times 6 \times 10^5$$

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

As, $$W = Q_1 - Q_2 = 6 \times 10^5 - 4.8 \times 10^5$$

$$W = 1.2 \times 10^5 \text{ cal}$$

$$= 1.2 \times 10^5 \times 4.2 \text{ J}$$

$$W = 5.04 \times 10^5 \text{ J}$$

$$= 5.04 \times 10^x \text{J} \quad \text{(given)}$$

$$\therefore \quad x = 5$$

66. Here, $T_1 = 0 + 273 = 273$ K;

$$p_1 = 1.013 \times 10^6 \text{ dyne cm}^{-2};\ \gamma = 1.4$$

and density of air at NTP, $\rho = 1.29 \times 10^{-3}$ gcm^{-3}

$$\therefore \quad V_1 = \frac{\text{Mass}}{\text{Density}} = \frac{1}{1.29 \times 10^{-3}} = 775.2 \text{ cm}^3$$

and $$V_2 = \frac{V_1}{2} = \frac{775.2}{2} = 387.6 \text{ cm}^3$$

Now, $$p_1 V_1^\gamma = p_2 V_2^\gamma \text{ or } p_2 = p_1 \times \left(\frac{V_1}{V_2}\right)^\gamma$$

or $$p_2 = 1.013 \times 10^6 \times \left(\frac{V_1}{V_1/2}\right)^{1.4} = 1.013 \times 10^6 \times (2)^{1.4}$$

$$= 1.013 \times 10^6 \times 2.639 = 2.673 \times 10^6 \text{ dyne cm}^{-2}$$

Work done during adiabatic change,

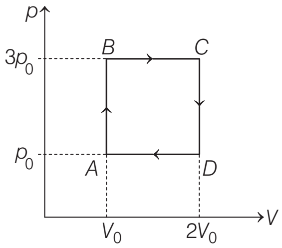
$$W = \frac{p_1V_1 - p_2V_2}{\gamma - 1}$$

$$= \frac{1.013\times 10^6 \times 775.2 - 2.673\times 10^6 \times 387.6}{1.4-1}$$

$$= \frac{7.853\times 10^8 - 10.36\times 10^8}{0.4} = -6.27\times 10^8 \text{ erg}$$

$$= -62.7 \text{ J}$$

67. From given p-V diagram,



Work done by gas in close loop, W = Area of loop

$$= (3p_0 - p_0) \times (2V_0 - V_0)$$

$$W = 2p_0V_0$$

During the cycle $ABCDA$, processes AB and BC absorb the heat.

Heat absorption during process AB,

$$Q_{AB} = \mu C_V \Delta T \qquad \text{(as } AB = \text{isochoric process)}$$

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

$$\left(\because C_V \text{ for monatomic gas is } \frac{3}{2}R\right)$$

$$= \frac{3}{2}(\mu R T_B - \mu R T_A)$$

$$= \frac{3}{2}(p_BV_B - p_AV_A) \qquad (\because pV = \mu RT)$$

$$= \frac{3}{2}(3p_0V_0 - p_0V_0)$$

$$= 3p_0V_0$$

Heat absorption during process BC,

$$Q_{BC} = \mu C_p \Delta T \qquad \text{(as } BC = \text{isobaric process)}$$

$$= \mu\left(\frac{5}{2}R\right)(T_C - T_B) \qquad (\because C_p = C_V + R)$$

$$= \frac{5}{2}(\mu R T_C - \mu R T_B)$$

$$= \frac{5}{2}(p_CV_C - p_BV_B)$$

$$= \frac{5}{2}(6p_0V_0 - 3p_0V_0)$$

$$= \frac{15}{2}p_0V_0$$

Total heat absorption, $Q = Q_{AB} + Q_{BC}$

$$= 3p_0V_0 + \frac{15}{2}p_0V_0$$

$$= \frac{21}{2}p_0V_0$$

$\therefore$ Efficiency of engine,

$$\eta\% = \frac{W}{Q}\times 100 = \frac{2p_0V_0}{\frac{21}{2}p_0V_0}\times 100 = 19\%$$