Chapter 12

Thermodynamics

Chapter Contents

Introduction

The study of heat and its transformation to mechanical energy is called thermodynamics. It comes from a Greek word meaning "Movement of Heat". The science of thermodynamics was developed in the early nineteenth century, before the atomic theory of matter was understood. As earlier no one knew about electrons and other microscopic particles, so the workers in thermodynamics used the microscopic notions in their models such as work, pressure and temperature.

The foundation of thermodynamics is the conservation of energy and the fact that heat flows spontaneously from hot to cold body and not the other way around.

The difference between the mechanics and thermodynamics should always be kept in our mind. In mechanics, our interest is in the motion of particles or bodies under the action of forces and torques. While thermodynamics deal with the internal microscopic state of the body without considering with the motion of the system as a whole.

In this chapter we shall study the laws of thermodynamics, various thermodynamic processes, basic theory of heat engines, refrigerators and Carnot engine.

THERMAL EQUILIBRIUM

In mechanics the term 'Equilibrium' means that the net external force and torque on a system are zero. But in thermodynamics the term 'equilibrium' is quite different. To understand the term thermodynamic equilibrium let us first take few examples, when hot water is mixed with cold water, the final temperature of the mixture is somewhere between the initial hot and cold temperatures. Similarly when a cube of ice is dropped in hot tea, the ice melts and the temperature of tea decreases. In both of these examples when the temperature of the mixture becomes almost stable with the surrounding there is no further exchange of energy. In general, whether or not a system is in a state of equilibrium depends on the surroundings and the nature of the wall that separates the system from the surroundings.

Let's consider two systems *A* and *B*, which are separated by an insulating wall *i.e.* a wall that does not allow the flow of energy also known as **adiabatic wall**.

These system are also insulated from rest of the surroundings by adiabatic walls as shown in the Fig.(a). A thermometer is used to measure the temperature of *A* and *B* and are different initially. Now the adiabatic wall between *A* and *B* is replaced by a conducting wall *i.e.*, a wall that allows energy flow from one to another also known as **diathermic wall** as shown in Fig. (b).

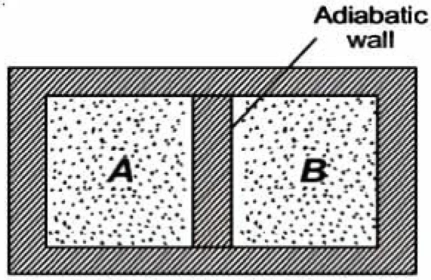


Fig. (a)

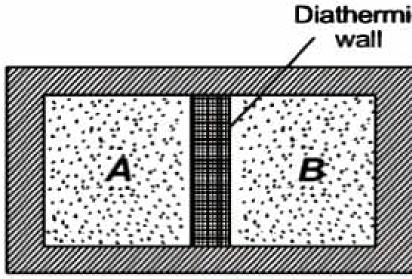


Fig. (b)

Fig.: **(a)** Both the systems separated by an adiabatic wall with each other and with surroundings. **(b)** Both the systems separated by diathermic wall with each other and by adiabatic wall with surroundings.

Now the thermometer records same temperature for both the systems. This concludes that there is no further exchange of heat between them.

This state in thermodynamics is called thermal equilibrium. So we may say in thermal equilibrium, the temperatures of the two systems are equal.

Example 1 : *When are the two bodies in thermal equilibrium?*

Solution : The two bodies are in thermal equilibrium if there is no exchange of heat between them.

Try Yourself

1. What is the essential condition for thermodynamic equilibrium?
2. If a body *A* is in thermal equilibrium with three different bodies *B*, *C* and D then

   (1) *B* is in thermal equilibrium with *C* (2) *C* is in thermal equilibrium with *D*

   (3) *D* is in thermal equilibrium with *B* (4) All of these

ZEROTH LAW OF THERMODYNAMICS

We have seen that through adiabatic wall heat cannot be transferred while through conducting wall heat can be transferred easily. To understand what zeroth law of thermodynamics actually states, let us imagine a situation where two systems *A* and *B* are separated by an adiabatic wall, while both of these systems are further in contact with a third systems *C* by a conducting wall. Now the states of the systems (*i.e.*, their macroscopic variables) will change until both the systems *A* and *B* come in thermal equilibrium with the third system *C*. After the thermal equilibrium is achieved if the adiabatic wall between *A* and *B* is replaced by a conducting wall while the conducting wall between the system *C* and both the systems *A* and *B* are replaced by adiabatic wall. It is found that there is no further change in the states of the system. In simple language we may say that when any two systems are in thermal equilibrium with each other, there must be a physical quantity that has the same value for both. This physical quantity (*i.e.*, a thermodynamic variable) whose value is equal for two systems in thermal equilibrium is called temperature (*T*).

Thus "when two bodies are in thermal equilibrium, their temperatures are equal and vice versa."

***Note :** System in thermal equilibrium must have same temperature. This is a necessary condition for systems to be in thermal equilibrium*

The above discussed experimental facts is concluded in zeroth law of thermodynamics which states that **"If two systems are in thermal equilibrium with a third system separately are in thermal equilibrium with each other."**

***Note :** Two or more systems are said to be in thermal equilibrium, if there is no exchange of heat energy between them when they are brought in thermal contact.*

This law came into light in 1931 by R. H. Fowler long after the first and second law of thermodynamics had been discovered and numbered. As the concept of temperature is fundamental to those two laws, the law that establishes temperature as a valid concept should have the lowest number. Hence the above stated law is numbered as zeroth law of thermodynamics.

HEAT, INTERNAL ENERGY AND WORK

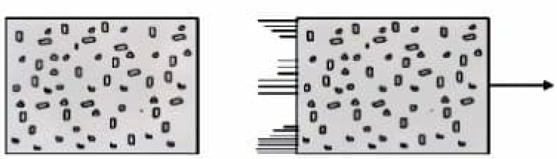
The concept of temperature arised from the zeroth law of thermodynamics. Temperature determines the direction of flow of heat when two bodies are placed in thermal contact. Heat is that form of energy which gets transferred between a system and its surrounding because of temperature difference between them. Heat flows from the body at a higher temperature to the body at lower temperature. The flow stops when the temperature equalises. *i.e.*, the two bodies are then in thermal equilibrium.

We shall now study the concept of internal energy and work

Internal Energy : It is sum of the kinetic energies and potential energies of all the constituent molecules of the system.

It is denoted by '*U*'. *U* depends only on the state of the system. It is a state variable which is independent of the path taken to arrive at that state. If we neglect the small intermolecular forces in a gas, the internal energy of the gas is just the sum of the kinetic energies associated with various random motions of its molecules.

***Note :** Internal energy of a system does not depend on the motion of a system as a whole i.e., the sum of the kinetic energy of only the constituent molecules due to their randomness inside the system is considered.*



(a) (b)

Fig.: (a) Internal energy U of a gas is the sum of the kinetic and potential energy of its molecules when the box is at rest. Kinetic energy due to various types of motion (translational, rotational, vibrational)is to be included in U. **(b)** If the same box is moving as a whole with some velocity, the kinetic energy of the box is not to be included in U.

Work done by gas : When a piston of a cylinder is pushed down, the work done by the gas is taken to be negative. Similarly when the gas expands the work done by the gas is taken to be positive.

Formula for work done is : $W = \int P \cdot dV$

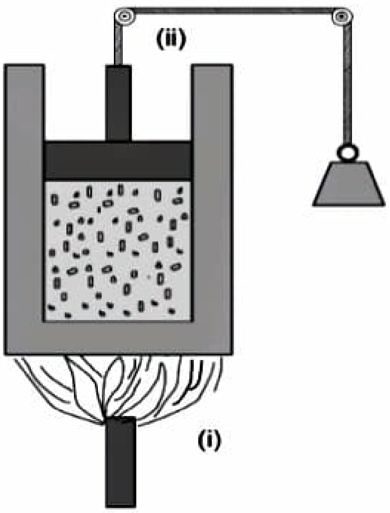
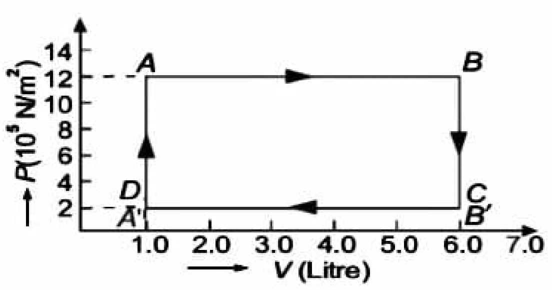


Fig.: Heat and work are two distinct modes of energy transfer to a system that results in change in its internal energy (i) Heat is energy transfer due to temperature difference. (ii) Work is energy transfer brought without the difference in temperature.

***Note :** Both heat and work are two different modes for the alteration of the state of a thermodynamic system and changing its internal energy.*

Remember that heat differs by internal energy as a thermodynamic system is characterised by its internal energy, not heat. A statement like '**a gas in a given state has a certain amount of heat**.' is as meaningless as the statement that '**a gas in a given state has a certain amount of work**'. While a statement that '**a gas in a given state has a certain amount of inernal energy**' is a meaningful statement. Similarly we may say that '**a certain amount of heat is supplied to the system**' or '**a certain amount of work was done by the system**' are meaningful.

Example 2 : *The figure shows a P-V graph of the thermodynamic behaviour of an ideal gas. Find out from this graph (i) work done by the gas in the process $A \rightarrow B$, $B \rightarrow C$, $C \rightarrow D$ and $D \rightarrow A$, (ii) work done by the gas in complete cycle $A \rightarrow B \rightarrow C \rightarrow D \rightarrow A$.*



Solution : (i) The work done in a thermodynamic process is equal to the area enclosed between the P–V curve and the volume-axis.

Work done by the gas in the process $A \rightarrow B$ is

W_1 = area $ABB'A'$ = $AB \times A'A$

$= (6.0 - 1.0)$ litre $\times (12 \times 10^5)$ N/m^2

$= 5.0 \times 10^{-3}$ m$^3 \times (12 \times 10^5)$ N/m^2

= 6000 N-m = 6000 joule.

Work done in the process $B \rightarrow C$ is zero since volume remains constant.

Work done on the gas in the process $C \rightarrow D$ is

W_2 = area $DCB'A'$

$= DC \times A'D = (-5.0 \times 10^{-3}) \times (2 \times 10^5) = -1000$ joule. (Negative sign is taken because volume decreases)

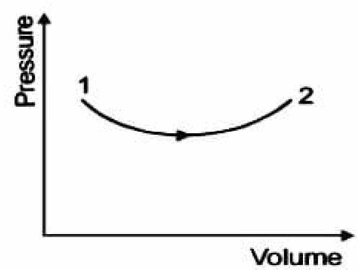
Work done in the process $D \rightarrow A$ is also zero, because volume remains constant.

(ii) Work W_1 is positive, while W_2 is negative. Hence the net work done in the whole cycle is

$W = W_1 - W_2 = 6000 - 1000 = 5000$ joule

This net work is done by the gas.

Example 3 : *Consider the process on a system shown in figure below. During the process, the work done by the system.*



(1) *Continuously increases*

(2) *Continuously decreases*

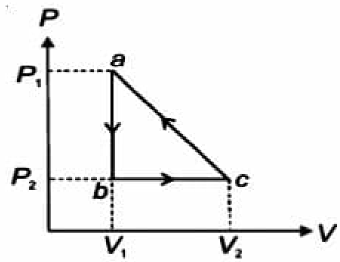
(3) *First increases then decreases*

(4) *First decreases then increases*

Solution : Don't get tempted to mark the answer (3). We said that the area under the p-V diagram is equal to the work done. So, if we move from 1 to 2 the area under the graph is continuously increasing so the correct response will be (1).

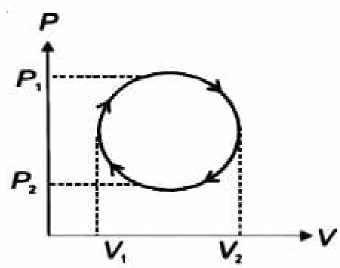
Note : *In this question the rate with which the work is being done by the system is first decreasing then increasing.*

Example 4 : *Find the net work done during the cycle abc.*



Solution : Here the area is $\frac{1}{2} \times \text{perpendicular} \times \text{base}$. Since the cycle is anticlockwise, the work done is negative. So, the final answer is $-\frac{1}{2}(P_1 - P_2)(V_2 - V_1)$

Example 5 : *Find the work done during the perfectly circular cyclic process as shown in the diagram.*



Solution : The area of a circle is πR^2. But here you have two radii. The horizontal radius $R_1 = \frac{(V_2 - V_1)}{2}$ and the vertical radius $R_2 = \frac{(P_1 - P_2)}{2}$. You know that the area of an ellipse is $\pi R_1 R_2$, where R_1 & R_2 are semi-major and semi-minor axis respectively. If $R_1 = R_2$ the ellipse becomes a circle. So, here the work done = area = $\pi R_1 R_2 = \pi \frac{(V_2 - V_1)}{2} \cdot \frac{(P_1 - P_2)}{2}$. The +ve sign is due to the fact that the cycle is clockwise.

Try Yourself

3. An ideal gas is compressed in a closed container its U

(1) Increases (2) Decreases

(3) Remains same (4) Both (1) & (2)

FIRST LAW OF THERMODYNAMICS

First law of thermodynamics is in accordance with law of conservation of energy. According to Clausius statement of first law of thermodynamics, the heat given to the system

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

ΔU = Increase in the internal energy

ΔW = Work done by the system against external pressure

Note : *It should be remembered that*

(1) *The units of dQ, dU and dW should be same while using this equation.*

(2) *If the temperature of an ideal gas rises, then dU should be positive and if the temperature falls, then dU is negative.*

(3) *If heat energy is given to the system, then dQ is positive while if the heat energy is taken away from the system, then dQ will be negative.*

(4) *If the volume of the system increases, then dW is positive while if the volume of the system, decreases, then dW is negative. If the volume is fixed, dW = 0.*

(5) *dQ and dW depend not only on the initial and final states but also on the path (or thermodynamic process).*

(6) *dU depends only on initial and final states, not on the path. For all processes* $\boxed{dU = nC_V dT}$ *for an ideal gas even when volume is not constant. But for non-ideal gas it is true only when volume is constant.*

(7) *During melting change in volume is neglected,* $\therefore$ $\Delta W = 0$, *hence* $\boxed{dQ = dU}$, *But during boiling* $dV \neq 0$, *so* $dQ = dU + PdV > dU$.

Example 6 : *For a gaseous system find change in internal energy if the heat supplied to the system is 50 J and work done by the system is 16 J.*

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

$\therefore \quad \Delta U = 50 - 16$

$\therefore \quad \Delta U = 34$ J

Try Yourself

4. If work is done by the system during expansion then work done is

   (1) Positive

   (2) Negative

   (3) Zero

   (4) Depends upon the thermodynamic process

5. For a gaseous system, change in internal energy and work done on the system are respectively 17 J and 41 J. Find heat supplied / evolved from the system.

SPECIFIC HEAT CAPACITY

We have seen in last chapter that heat capacity of a substance is given by

$$S = \frac{\Delta Q}{\Delta T} \qquad \text{...(i)}$$

If we divide S by mass of the substance m in kg, we get

$$s = \frac{S}{m} = \frac{1}{m}\frac{\Delta Q}{\Delta T} \qquad \text{...(ii)}$$

here s is known as the specific heat capacity of the substance. It depends on the nature of the substance and its temperature. The unit of s is J kg^{-1} K^{-1}.

If the amount of substance is specified in terms of moles μ (instead of mass m in kg), we can define heat capacity per mole of the substance by

$$C = \frac{S}{\mu} = \frac{1}{\mu}\frac{\Delta Q}{\Delta T} \qquad \text{...(iii)}$$

Here C is known as molar specific heat capcity of substance.

Both s and C are independent of the amount of the substance. The unit of C is J mol^{-1} K^{-1}.

Knowledge Cloud

Law of equipartition of energy states that in equilibrium the total energy is equally distributed in all possible energy modes, with each mode having an average energy equal to $\frac{1}{2}k_BT$ per molecule.

[Where, k_B is Boltzmann constant.]

Substance	Specific heat (J kg^{-1}K^{-1})	Molar specific Heat (J mol^{-1}K^{-1})
Aluminum	900.0	24.4
Carbon	506.5	6.1
Copper	386.4	24.5
Lead	127.7	26.5
Silver	236.1	25.5
Tungsten	134.4	24.9

Table : Specific and molar heat capacities of some solids at room temperature and atmospheric pressure

Specific Heat Capacity of Water

Initially heat was measured in calorie only. Earlier it was defined as the amount of heat required to raise the temperature of 1 g of water by 1°C. But with advancement in thermodynamics when more precise measurements were taken, it was observed that the specific heat of water varies slightly with temperature, as shown in the graph below.

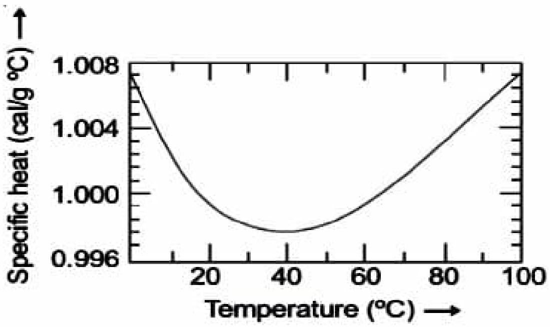


Fig.: Variation of specific heat capacity of water with temperature.

So to define calorie more precisely, it was necessary to specify the unit temperature interval. Then finally we may define one calorie as the amount of heat required to raise the temperature of 1 g of water from 14.5°C to 15.5°C. Since the SI unit of energy is joule and heat is a form of energy, so it is preferable to use the unit joule 'J'. In SI units, the specific heat capacity of water is 4186 J kg^{-1} K^{-1} or 4.186 J g^{-1} K^{-1}.

Specific heat capacity depends on the process or the conditions under which heat transfer takes place. For gases, two types of specific heats are specific heat capacity at constant pressure 'C_p' and specific heat capacity at constant volume 'C_v'.

For an ideal gas,

$$C_p - C_v = R$$

where, R is the universal gas constant. Let us now prove the above relation

Proof : From 1st law

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

At constant volume $\Delta V = 0$ so $\Delta Q = \Delta U$

$$\therefore \quad C_v = \left(\frac{\Delta Q}{\Delta T}\right)_v = \left(\frac{\Delta U}{\Delta T}\right)_v$$

$$\therefore \quad C_v = \frac{\Delta U}{\Delta T} \qquad \text{...(i)}$$

On the other hand, at constant pressure,

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

$$\therefore \quad C_p = \left(\frac{\Delta Q}{\Delta T}\right)_p = \left(\frac{\Delta U}{\Delta T}\right)_p + P\left(\frac{\Delta V}{\Delta T}\right)_p$$

Now, for a mole of an ideal gas

$$PV = RT$$

$$\therefore \quad \frac{\Delta V}{\Delta T} = \frac{R}{P} \qquad \text{(As } P \text{ is constant)}$$

$$\therefore \quad C_p = \left(\frac{\Delta U}{\Delta T}\right)_p + \frac{P \times R}{P}$$

$$\therefore \quad C_p = C_v + R \qquad \text{[From (i)]}$$

$$\therefore \quad \boxed{C_p - C_v = R}$$

***Note :** In above equations the subscript denotes the quantity kept fixed.*

(1) $C_v = \frac{1}{n} \cdot \frac{\Delta U}{\Delta T}$ *is true for all ideal gases for all thermodynamic processes even when volume is not constant. But for non-ideal gases (or any other systems), it is true only when volume is constant.*

(2) *The relation $C_p - C_v = R$ is derived by using ideal-gas model, but it is true within few percent for many real gases at moderate pressure.*

(3) *For a few substances, $C_p < C_v$. There are some substances, the volume of which decreases during heating (one of which is water between 0°C and 4°C). In this case ΔW is negative, so the heat input ΔQ is less than that in constant-volume case. Hence $C_p < C_v$.*

(4) *When n_1 moles of an ideal gas with molar heat capacities C_v' and C_p' is mixed with another ideal gas of n_2 moles with molar heat capacities C_v'' and C_p'', then the molar heat capacities of the mixture are*

$$C_v = \frac{n_1 C_v' + n_2 C_v''}{n_1 + n_2} \text{ and } C_p = \frac{n_1 C_p' + n_2 C_p''}{n_1 + n_2}$$

$$\text{and } \gamma = \frac{C_p}{C_v} = \frac{n_1 C_p' + n_2 C_p''}{n_1 C_v' + n_2 C_v''}$$

If both the gases are monatomic or both are diatomic, then

$$C_v = C_v' = C_v'' \text{ and } C_p = C_p' = C_p'', \therefore \quad \gamma = \gamma' = \gamma''$$

If the first gas is monatomic and the second is diatomic, then

$$C_v = \frac{n_1 \cdot \frac{3R}{2} + n_2 \cdot \frac{5R}{2}}{n_1 + n_2} = \frac{3n_1 + 5n_2}{2(n_1 + n_2)} R$$

$$C_p = \frac{n_1 \cdot \frac{5R}{2} + n_2 \cdot \frac{7R}{2}}{n_1 + n_2} = \frac{5n_1 + 7n_2}{2(n_1 + n_2)} R$$

$$\text{and } \gamma = \frac{5n_1 + 7n_2}{3n_1 + 5n_2}.$$

Example 7 : *Value of C_p for monatomic gas is $\frac{5}{2}R$. Find C_v*

Solution : As $C_p - C_v = R$

$\therefore$ $C_v = C_p - R$

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

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

Try Yourself

6. Find $\frac{C_p}{C_v}$ for monatomic ideal gas.

THERMODYNAMIC STATE VARIABLES AND EQUATION OF STATE

Equilibrium state of a thermodynamic system can be described completely by some parameters or some macroscopic variables. These parameters or variables which describe equilibrium states of the system are called state variables. The various state variables are not necessarily be independent. The relation between the state variables is called the equation of state.

For example, for an ideal gas, the equation of state is

$$PV = \mu RT$$

Thermodynamic state variables are of two kinds

(a) **Intensive Variable :** These are the variables which are independent of the size. *e.g.,* pressure, density and temperature.

(b) **Extensive Variable :** These are the variables which depend on the size of the system. *e.g.,* volume, mass, internal energy.

Isotherm : The pressure – volume curve for a fixed temperature is called an isotherm.

THERMODYNAMIC PROCESSES

Quasi-Static Process

The process in which the system shifts infinitesimally from the equilibrium state is known as quasi-static process. It is a hypothetical concept. Practically the processs that are sufficiently slow and do not involve accelerated motion of the piston, large temperature gradient etc. are nearly approximation to an ideal quasi-static process.

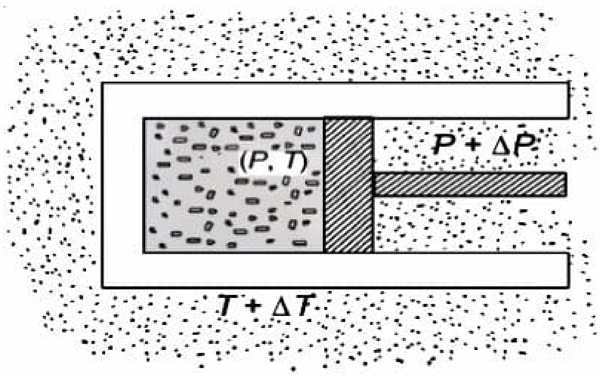


Fig.: In a quasi-static process, the temperature of the surrounding reservoir and the external pressure differ only infinitesimally from the temperature and pressure of the system.

Isothermal Process

A process in which the temperature of the system is kept fixed throughout is called an isothermal process also known as constant-temperature process. For a process to be isothermal, any heat flow into or out of the system must occur very slowly so that it always maintains thermal equilibrium.

In general, for an isothermal process none of the quantities ΔU, W or Q is zero, but in some special cases the internal energy of a system depends only on its temperature, not on its pressure or volume. The most common system following this special case is an ideal gas. For ideal gas if temperature is constant, the internal energy is also constant. *i.e.,* $\Delta U = 0$ and hence the first law of thermodynamics then implies that heat supplied to the gas equals the work done by the gas *i.e.* $Q = W$.

For an isothermal process, the ideal gas equation *i.e.,* $PV = \mu RT$ gives PV = constant, which is just Boyle's law.

Work done in an Isothermal Process

Consider an ideal gas enclosed in a cylinder with perfectly conducting walls and fitted with a perfectly frictionless and conducting piston of area A. Let its initial states be P_1, V_1, T and final states be P_2, V_2, T.

Force exerted by the gas on piston is

$$F = P \times A$$

If we assume that pressure of the gas during an infinitesimally small outward displacement dx of the piston remains constant.

Then the small work done during expansion is given by

$$dW = F \times dx$$

$$= PAdx$$

$\therefore$ $dW = PdV$ (Where $dV = Adx$]

$\therefore$ Total work done will be

$$W = \int dW = \int_{V_1}^{V_2} PdV \quad \text{...(i)}$$

As $PV = \mu RT$

$$\therefore \quad P = \frac{\mu RT}{V}$$

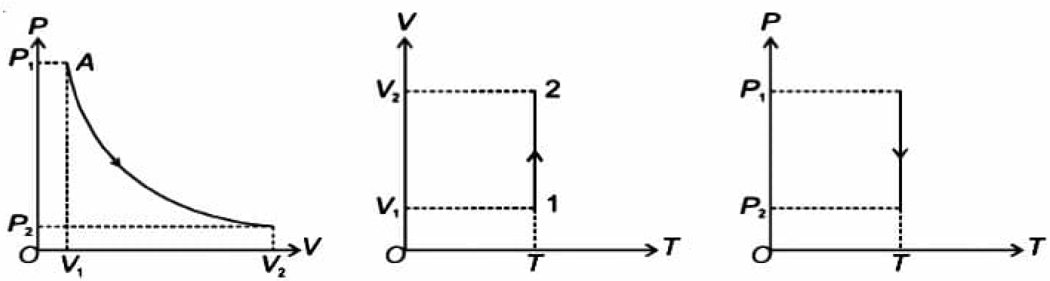
$$\therefore \quad W = \int_{V_1}^{V_2} \frac{\mu RT}{V} dV$$

$$\therefore \quad W = \mu RT \int_{V_1}^{V_2} \frac{dV}{V}$$

$$\therefore \quad W = \mu RT \ln \frac{V_2}{V_1} \quad \text{...(ii)}$$

$$\therefore \quad \boxed{W = 2.303 \mu RT \log \frac{V_2}{V_1}}$$

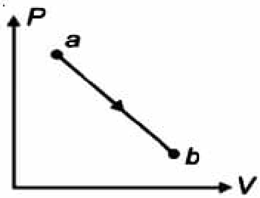
Graphs for isothermal process



Note : *If $V_2 > V_1$ then $W > 0$, hence $Q > 0$ i.e., gas absorbs heat and work is done by the gas on the environment during expansion.*

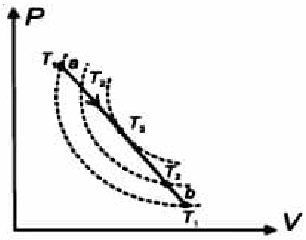
$\Rightarrow$ If $V_2 < V_1$, then $W < 0$, hence $Q < 0$ i.e., during compression, work is done on the gas by the environment and heat is released.

Example 8 : *A gas undergoes expansion in such a manner that its p-V diagram plot is a downward sloping straight line as shown in the figure below. What happens to the temperature during the process?*



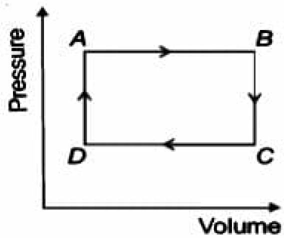
(1) *It increases first then decreases*
(2) *It decreases first then increases*
(3) *It continuously decreases*
(4) *Data insufficient*

Solution : Plot the process *a* to *b* in the background of various dotted isothermal lines.



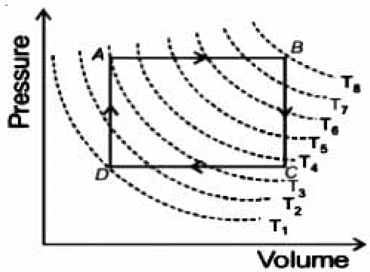
Note here $T_3 > T_2 > T_1$. If you start from a towards b, you are at T_1 then T_2 then T_3 and then to T_2 an back to T_1. So, the temperature first increases then it decreases. Hence, the correct response is (1).

Example 9 : *The pressure and volume of a gas are changed as shown in the p-V diagram in the figure ahead. The temperature of the gas*



(1) *Increases as it goes from A to B*
(2) *Increases as it goes from B to C*
(3) *Remains constant during these changes*
(4) *Decreases as it goes from D to A*

Solution : Once again plot the rectangular cycle against the background of various dotted isothermal lines.



Note here $T_8 > T_7 > T_6 > T_5 > .... > T_1$. So, in the process *D* to *A* the temperature increases. In *A* to *B* it further increases. In *B* to *C* it decreases and in *C* to *D* it decreases. So, the correct response is (1).

Try Yourself

7. In an isothermal expansion change in internal energy and work done by the gas are respectively

(1) (–) ve, (–) ve (2) 0, (+) ve

(3) 0, (–) ve (4) (+) ve, (–) ve

Adiabatic Process

A process in which no heat transfer takes place between a system and its surrounding is called an adiabatic process.

Zero heat transfer is an idealization, but a process is approximately adiabatic if the system is well insulated or if the process takes place so quickly that there is not enough time for appreciable heat flow to occur. In an adiabatic process, $Q = 0$ so from the first law of thermodynamics, $\Delta U = -W$, hence we see that work done by the gas results in decrease in its internal energy. For an adiabatic process of an ideal gas. PV^γ = constant, where γ is the ratio of specific heats (ordinary or molar) at constant pressure and at constant volume *i.e.*,

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

Work done in an Adiabatic Process

Consider an ideal gas enclosed in a cylinder with perfectly insulating walls and fitted with a perectly frictionless, non-conducting pistion of area A. Let its initial states be P_1, V_1 and T_1 and final states be P_2, V_2 and T_2.

As we know, $F = P \times A$

Now, if we assume that pressure of the gas during an infinitesimally small outward displacement dx of the piston remains constant, then the small amount of work done during expansion will be

$$dW = F \times dx = P \times A \times dx$$

$$\therefore \quad dW = PdV \qquad \text{...(i)}$$

As the ideal gas undergoes a change in its states adiabatically from (P_1, V_1) to (P_2, V_2)

$$\therefore \quad P_1V_1^\gamma = P_2V_2^\gamma = k \text{ (say)} \qquad \text{...(ii)}$$

$\therefore$ Total work done will be

$$W = \int_{V_1}^{V_2} P\,dV$$

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

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

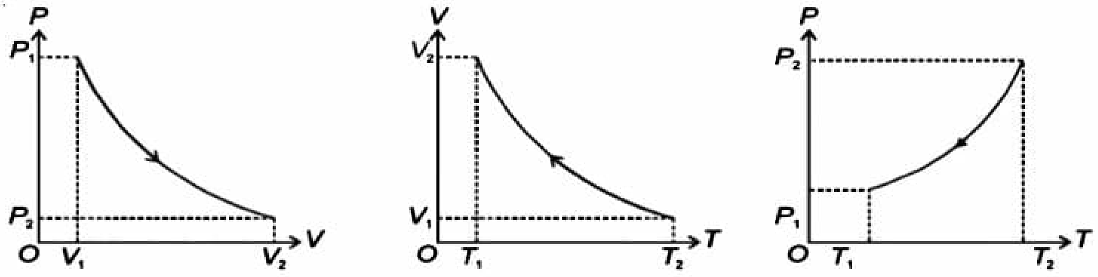
From equation (ii), K is $P_1V_1^\gamma$ or $P_2V_2^\gamma$

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

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

$$= \frac{\mu R(T_1 - T_2)}{\gamma - 1}$$

Graphs for adiabatic process



***Note** : If work is done by the gas in an adiabatic process ($W > 0$) then $T_2 < T_1$.*

⇒ If work is done on the gas ($W < 0$), we get $T_2 > T_1$, i.e., the temperature of the gas rises.

Example 10 : *The pressure (1×10^5 newton/m²) of the air filled in a vessel is decreased adiabatically so much as to increase its volume three times. Calculate the pressure of air. γ for air = 1.4, $\log_{10} 3 = 0.4771$, $\log_{10} 2.148 = 0.33206$.*

Solution : Initial pressure $P = 1 \times 10^5$ N/m², initial volume = V, final volume $V' = 3V$, final pressure = P' (say).

For adiabatic expansion, we have

$$PV^\gamma = P'V'^\gamma$$

Substituting values :

$$(1 \times 10^5)V^\gamma = P'(3V)^\gamma$$

or $\quad 10^5 = P'(3)^{1.4} \quad$ or $\quad P' = 10^5 (1/3)^{1.4}$

Taking log

$\log P' = 5 \log 10 + 1.4 (\log 1 - \log 3)$

$= 5(1) + 1.4(0 - 0.4771) = 5 - 0.66794 = 4.33206$

$\therefore \quad P' = 2.148 \times 10^4$ N/m².

Example 11 : *A tyre pumped to a pressure of 3.375 atmosphere and at 27°C suddenly bursts. What is the final temperature? ($\gamma = 1.5$)*

Solution : Air of the tyre is adiabatically expanded.

Initial pressure $\quad P = 3.375$ atmosphere,

Initial temperature $\quad T = 27°\text{C} + 273 = 300$ K,

Final pressure $\quad P' = 1$ atmosphere,

Final temperature $\quad T' = ?$

$\gamma = 1.5 = 3/2$

For adiabatic expansion

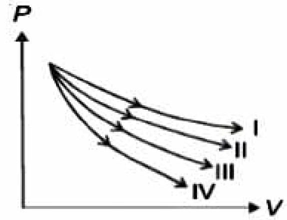
$$\frac{T^{\gamma}}{P^{\gamma-1}} = \frac{T'^{\gamma}}{P'^{\gamma-1}} \quad \text{or} \quad \left(\frac{T}{T'}\right)^{\gamma} = \left(\frac{P}{P'}\right)^{\gamma-1}$$

Putting the values :

$$\left(\frac{300}{T'}\right)^{3/2} = \left(\frac{3.375}{1}\right)^{1/2} \quad \text{or} \quad \frac{300}{T'} = \left(\frac{3.375}{1}\right)^{1/3} = 1.5$$

or $T' = 300/1.5 = 200\text{ K} = -73°\text{C}$.

Example 12 : *In the following plots match I, II, III, IV with (a) Isothermal process and Adiabatic process for (b) monatomic, (c) diatomic and (d) triatomic gases respectively.*



Solution : For Isothermal process pV = const. ($\therefore n = 1$) (Note all the above graphs are basically pV^n = const. plotted)

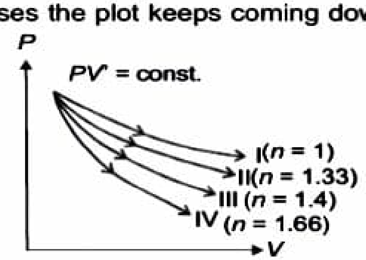
For Adiabatic process pV^{γ} = const. Now,

For monotomic gas $\gamma = \frac{5}{3} = 1.66$ ($\therefore n = 1.66$)

For diatomic gas $\gamma = \frac{7}{5} = 1.4$ ($\therefore n = 1.4$)

and for triatomic gas $\gamma = \frac{8}{6} = 1.33$ ($\therefore n = 1.33$)

In expansion p-V graph we know that as the value of 'n' increases the plot keeps coming down. So, we can represent the graphs as follows :



Hence the final answer is that

Plot I is Isothermal process

Plot II is Triatomic adiabatic

Plot III is diatomic adiabatic &

Plot IV is monoatomic adiabatic.

***Note :** If $n \neq \gamma$ then the process pV^n = const. is known as 'Polytropic process' e.g. pV^2 = constant denotes a polytropic process. Real life engine processes are polytropic only.*

Isochoric Process

A process in which the volume of a thermodynamic system is constant is called an isochoric process also known as isometric process. In this process no work is done on or by the gas, all the energy added as heat remains in the system as an increase in internal energy and its temperature. The change in temperature for a given amount of heat is determined by the specific heat of the gas at constant volume. Heating a gas in a closed constant-volume container is an example of an isochoric process

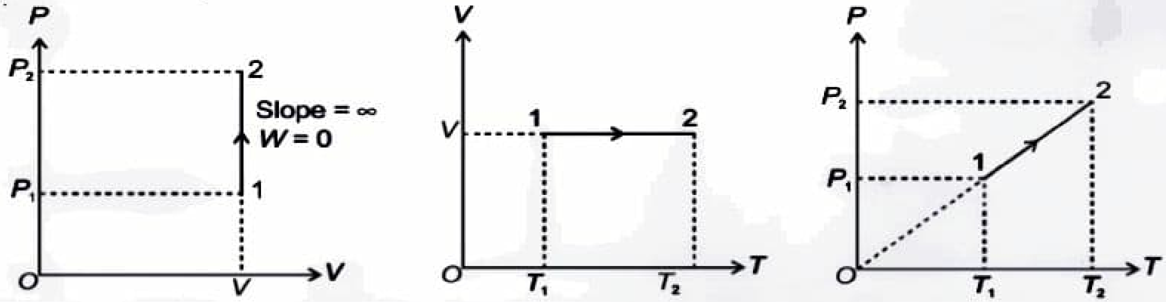
As $W = P\Delta V = 0$

Now from first law of thermodynamics

$$\Delta Q = \Delta U = nC_v\,\Delta T$$

Knowledge Cloud

Graphs for isochoric process



Isobaric Process

A process in which the pressure remains constant is called isobaric process. Work done by gas is

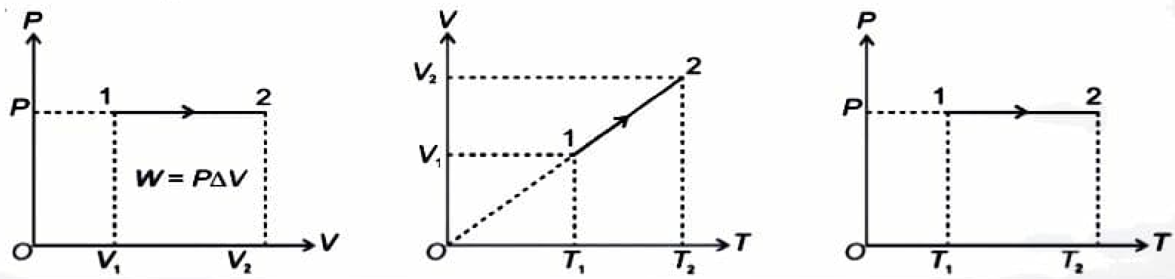
$$W = P\Delta V = P(V_2 - V_1)$$

$$= \mu R\,[T_2 - T_1] \qquad \text{(because, for ideal gas } PV = \mu RT\text{)}$$

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

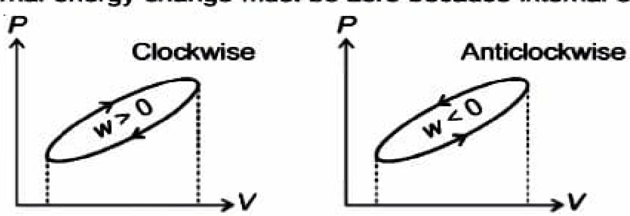
Knowledge Cloud

Graphs for isobaric process



Cyclic Process

A process that eventually returns a system to its initial state is called a cyclic process. Since the final state is the same as the initial state, and so the total internal energy change must be zero because internal energy is a state variable.



$\therefore \quad \Delta U = 0$

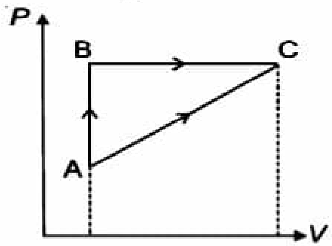
From first law of thermodynamics,

$\Delta Q = \Delta W \qquad$ [Or $Q = W$]

FACT FILE

Every day, your body (a thermodynamic system) goes through a cyclic thermodynamic process. Heat Q is added by metabolizing food, and your body does work W in breathing, walking, and other activities. If you return to the same state at the end of the day, $Q = W$ and the net change in your internal energy is zero.

Example 13 : *A thermodynamical process is shown in figure with $P_A = 3 \times 10^4$ Pa; $V_A = 2 \times 10^{-3} m^3$; $P_B = 8 \times 10^4$ Pa, $V_c = 5 \times 10^{-3} m^3$. In the processes AB and BC, 600 J and 200 J of heat is added to the system respectively. The change in internal energy of the system in process AC would be:*



(1) 560 J (2) 800 J

(3) 600 J (4) 640 J

Solution : Since internal energy is a state function so the change in internal energy during the process AC will be same as that during the total process *AB* plus *BC*. Calculate the total work ΔW during *AB* plus *BC* and total heat ΔQ during these processes. Then calculate $\Delta U = \Delta Q - \Delta W$.

During the process AB the volume doesn't change so work done is zero.

During *BC* the pressure is constant, so total work done

$= P_B (V_C - V_B) = P_B (V_C - V_A) \quad \because V_B = V_A$

$= 8 \times 10^4 \text{ [N/m}^2\text{]} \left(5 \times 10^{-3} \text{m}^3 - 2 \times 10^{-3} \text{m}^3\right) = 240 \text{ J}$

$\therefore$ ΔW during process *AB* plus *BC* = 240 J

Now given ΔQ during the same total process = 600 + 200 = 800 J.

$\therefore$ $\Delta U = \Delta Q - \Delta W = 800 - 240 = 560$ J

Example 14 : *Heat is supplied at constant pressure to diatomic gas. The part of this heat which goes to increase its internal energy will be*

(1) $\frac{5}{7}$ (2) $\frac{3}{5}$

(3) $\frac{2}{5}$ (4) $\frac{2}{3}$

Solution : Use $dQ = dU + W$. Now the part of dQ which increases dU is $\frac{dU}{dQ}$. You know that for constant pressure process $dQ = nC_p \cdot dT$ and $dU = nC_V dT$ always.

So, you have $\frac{dU}{dQ} = \frac{nC_V dT}{nC_P dT} = \frac{C_V}{C_P} = \frac{1}{\gamma}$. Now, you know ratio of specific heats for diatomic gas is $\frac{7}{5}$

$\therefore$ $\frac{1}{\gamma} = \frac{5}{7}$. So the correct option is (1)

***Note :** If in this question you were asked what part of heat at constant process goes to work done, then answer had been* $1 - \frac{5}{7} = \frac{2}{7}$

Example 15 : *70 calories of heat are required to raise the temperature of 2 moles of an ideal diatomic gas at constant pressure from 30°C to 35°C. The amount of heat required in calories to raise the temperature of the same gas through the same range (30°C – 35°C) at constant volume is*

(1) 30 cal (2) 50 cal

(3) 370 cal (4) 90 cal

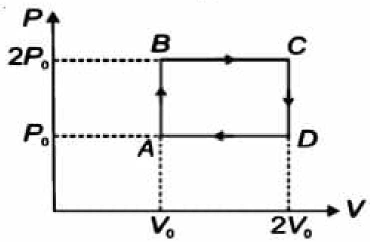
Solution : You know at constant pressure heat absorbed $dQ_p = n.C_p.dT$ ...(i)

and at constant volume heat supplied is $dQ_v = n.C_V.dT$ ...(ii)

Dividing (i) by (ii) we get

$$\frac{dQ_P}{dQ_V} = \frac{C_P}{C_V} = \gamma \Rightarrow \frac{70}{dQ_V} = \frac{7}{5} \qquad \therefore dQ_V = 50 \text{ calorie}$$

Example 16 : *N moles of a monatomic gas is carried round the reversible rectangular cycle ABCDA as shown in the diagram. The temperature at A is T_o. The thermodynamic efficiency of the cycle is*



(1) 15% (2) 50%

(3) 20% (4) 25%

Solution : First of all note that point C is at highest temperature and A is at lowest temperature.

So during process A to B and B to C heat is being added to the cycle.

Work output can be calculated by calculating the area under the cycle of P-V diagram.

Then efficiency can be calculated as work output upon heat input.

Note that the temperature at A is T_0, that at B is $2T_0$ and that at C is $4T_0$.

Also note C_V for monatomic gas is $\frac{3R}{2}$

For $A - B$,

$$\Delta Q = NC_V\Delta T \qquad (\because \text{ constant volume process})$$

$$= N\frac{3R}{2}(2T_0 - T_0) = \frac{N}{2}3RT_0$$

For $B - C$,

$$\Delta Q = NC_P\Delta T \qquad (\because \text{ constant pressure process})$$

$$= N\frac{5R}{2}(4T_0 - 2T_0)$$

$$= 5NRT_0$$

Now, Total heat input $Q = \left(\frac{3}{2} + 5\right)NRT_0 = \frac{13}{2}NRT_0$

Work output = Area Under the Cycle

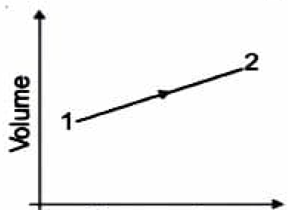
$$= (2P_0 - P_0)(2V_0 - V_0)$$
$$= P_0V_0$$
$$= NRT_0$$

$$\therefore \text{ Efficiency } = \frac{W}{Q} = \frac{NRT_0}{\frac{13}{2}NRT_0}$$

$$= \frac{2}{13} \text{ or } 15.38\%$$

***Note :** Just as an exercise do the same problem for diatomic gas and find the answer 10.5% for efficiency.*

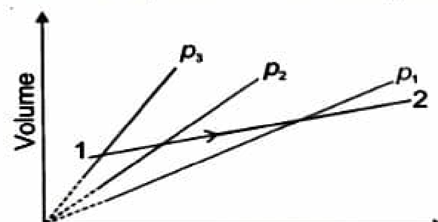
Example 17 : *On a volume-temperature diagram a process 1-2 is an upward sloping straight line having the tendency to cut the volume axis as shown in the figure ahead. During this process the pressure*



(1) Remains constant *(2) Continuously increases*

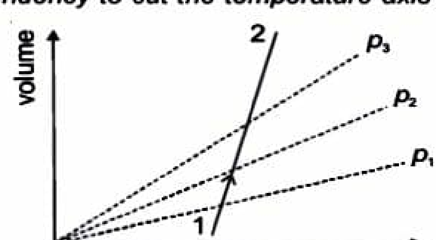
(3) Continuously decreases *(4) Data Insufficient*

Solution : If this line had the tendency to pass through the origin, the pressure had been constant, hence answer (1) is wrong. Look at this process in the background of several isobaric lines.



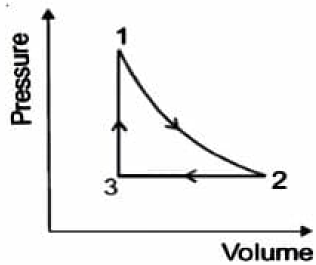
Here note that $p_1 > p_2 > p_3$. The process line 1 - 2 cuts p_3 first then p_2 then p_1. So during the process 1 - 2 the pressure continuously increases. Hence the correct answer is (2).

***Note :** But be careful. Let us suppose on the same volume temperature diagram, the upward sloping line has the tendency to cut the temperature axis as shown below.*



Now in the process 1 to 2 the answer will be reversed because first we are touching p_1 then p_2 then p_3. So, we are moving from high pressure p_1 to low pressure p_3 hence, pressure continuously decreases now.

Example 18 : *Given here is a cyclic process on P-V diagram. Process 1-2 is isothermal, 2-3 is isobaric and 3-1 is an isochoric process. Plot this cycle on V-T diagram and T-P diagrams.*



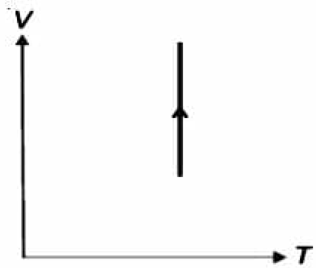
Solution : *For shifting of plots take care of following two steps.*

Step I : *Locate a process on the original diagram and find out which quantity-pressure, volume or temperature is constant in it! Then plot this process on the new diagram as a line or curve.*

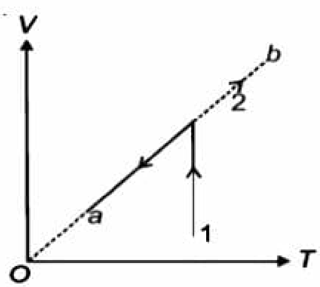
Step II : *Look at the other variable in the new diagram and with the help of original diagram find out whether the other variable is increasing or decreasing. Now accordingly put the arrow on the processes in the new plot.*

Let us first plot this cycle on *V-T* diagram. You can start off from any point. Remember on the *P-V* diagram, you should draw various isothermal lines as the construction lines. Since, we have to plot it on *V - T* diagram, all the time on a process you have to think in terms of volume temperature increase or decrease.

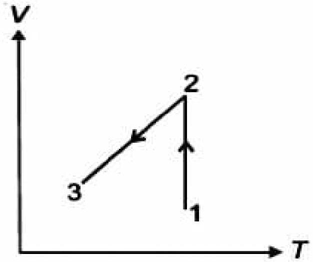
Suppose you are moving from 1-2, then in this process the volume is increasing so the plot on *V-T* diagram will be a vertical line and the arrow pointing up, as shown below.



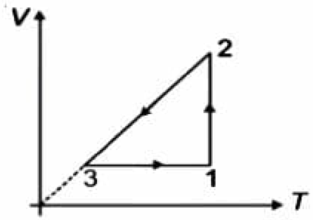
Now, in the process 2-3 on *P-V* diagram the pressure is constant and the volume is decreasing. On *V-T* diagram the constant pressure line passes through origin. So, we have to draw a straight line form point 2. Which has the tendency to pass through the origin. This can be done in two ways either 2-*a* or 2-*b*.



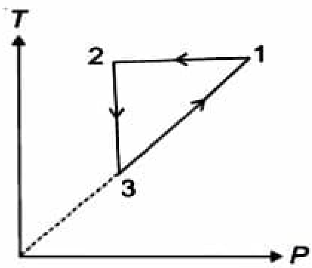
But remember that in 2-*a* or 2-*b* the volume should decrease as shown in the *p*-*V* diagram. So, don't go to 2-*b* because here the volume is increasing. Hence the next plot is as follows:



Now, 3-1 is an isochoric process which will be a horizontal straight line on *V*-*T* diagram. So, complete your answer with the diagram shown below.

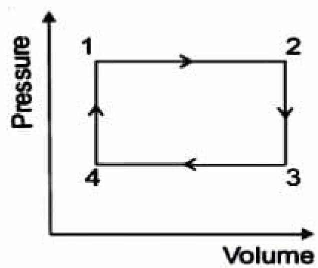


Thinking on the similar line plot the *T*-*P* diagram as follows :

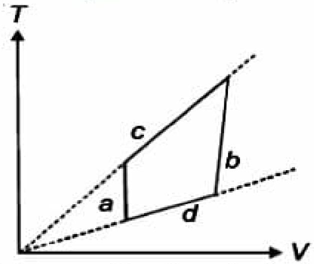


Some guiding clues are as follows. On *P*-*V* diagram in 1-2 the temperature is constant but the pressure is decreasing hence on *T*-*P* diagram its a horizontal line, arrow pointing to the left. In the process 2-3 on the *P*-*V* diagram the pressure is constant but the temperature is decreasing. So, on *T*-*P* diagram this process will come down. Finally in the process 3-1 the volume is constant and the temperature is rising. So, on the *T*-*P* diagram the 3-1 process line will be straight and will have the tendency to pass through the origin.

Example 19 : *A particular cyclic process on a P-V diagram is a rectangle as shown below. Plot it on (a) T-V and (b) P-T diagram.*

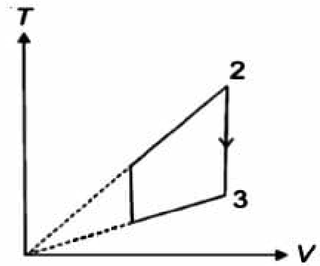


Solution : (a) Given on *P-V* diagram we have two isobaric and two isochoric lines. On a *T-V* diagram, isobaric lines will have the tendency to pass through the origin and the isochoric lines will be vertical. So, the basic shape of the cycle 1-2-3-4 on *T-V* diagram will appear as follows:

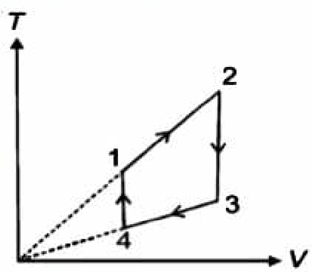


Here *a, b* are isochoric lines and c, d are isobaric lines. Now, if we can locate a single corner to be point 1, 2, 3 or 4 and put the arrow of its process, the cycle will be automatically completed.

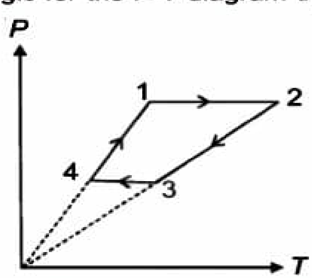
Here isochoric lines are easy to deal with. Note the process 2-3 on *P-V* diagram is for larger volume - so is the line b on *T-V* diagram. In the process 2-3 the temperature decreases (You can check by drawing several isothermal lines). So on the line '*b*' the arrow should point down because that is the direction of decreasing temperature. So the point 2 will be on the upper side of line '*b*' and the process arrow will be down to point 3 on the *T-V* diagram depicted below.



Now, rest of the cycle to be completed is very easy. The arrow here indicates that the clockwise cycle will continue. From point 3 to point 4 then to 1 and finally to point 2 as shown below. Hence the final answer.



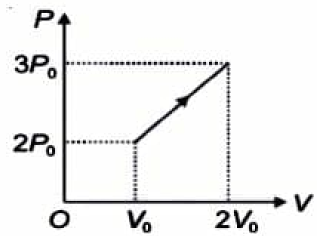
(b) Going by the same logic for the *P-T* diagram try to get the final answer as follows :



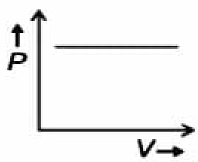
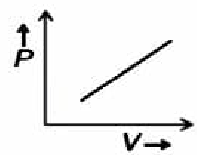
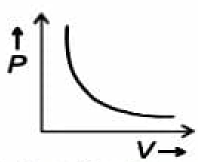
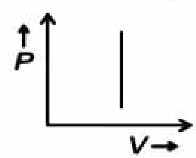
Because on P-T diagram the isobaric lines will be horizontal and the isochoric line will have the tendency to pass through the origin. If you concentrate on the process 1-2 in *P-V* diagram, you can note that it's a higher pressure line and the temperature increases from 1 to 2. Same thing we have shown on *P-T* diagram here higher pressure line is the top horizontal line and the arrow will point left to right because that is the direction of increasing temperature.

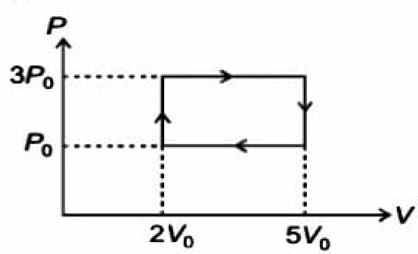
Try Yourself

8. Draw P–T curve for isochoric process.
9. Draw P–T curve for isobaric process.
10. The PV-graph for a monatomic gas is shown in figure. Find the energy absorbed by the gas during this process.



EXERCISE

1. Two gases are said to be in thermal equilibrium when they have same
   (1) Pressure
   (2) Volume
   (3) Temperature
   (4) Area
2. Which of the following P–V curve best represents an isothermal process?
   (1) 
   (2) 
   (3) 
   (4) 
3. Work done in given cyclic process is



   (1) P_0V_0
   (2) $3P_0V_0$
   (3) $6P_0V_0$
   (4) $5P_0V_0$
4. Indicator diagram is a
   (1) P–T curve
   (2) P–V curve
   (3) V–T curve
   (4) $Q - T$ curve

5. In an isothermal process for an ideal gas

(1) $\Delta Q = 0$ (2) $\Delta W = 0$

(3) $\Delta U = 0$ (4) $\Delta V = 0$

6. When gas in a vessel expands, its thermal energy decreases. The process involved is

(1) Isobaric (2) Isochoric

(3) Isothermal (4) Adiabatic

7. Which of the following laws of thermodynamics defines the term internal energy?

(1) Zeroth law (2) First law

(3) Second law (4) Third law

8. Select the incorrect statement

(1) For isothermal process of ideal gas, $\Delta U = 0$ (2) For isochoric process, $W = 0$

(3) For adiabatic process, $\Delta U = -\Delta W$ (4) For cyclic process, $\Delta W = 0$

9. Which is not a path function?

(1) ΔQ (2) $\Delta Q + W$

(3) W (4) ΔU

10. What is the work done by 0.2 mole of a gas at room temperature to double its volume during isobaric process? (Take $R = 2$ cal mol^{-1} °C^{-1})

(1) 30 cal (2) 40 cal

(3) 120 cal (4) 160 cal

HEAT ENGINES

The essence of technology in our society is the ability to use sources of energy like wind energy, water energy or by burning fossil fuels or from nuclear reactions.

Most of the energy that we use is in form of heat, which is further taken to do useful work. Any device that transforms heat, partly into work or mechanical energy is called a heat engine. Generally, a quantity of matter inside the heat engine undergoes inflow and outflow of heat, expansion and compression, and sometimes change in phase. We call this matter the working substance of the engine. For example, a mixture of fuel vapour and air in a gasoline or diesel engine or steam in a steam engine are the working substance.

The most common and simplest kind of engine to analyze is one in which the working substance undergoes a cyclic process, *i.e.*, a sequence of processes that eventually brings the substance in the same state in which it started. In some of these processes, working substance absorbs a total amount of heat Q_1 from an external reservoir at some high temperature T_1. While in some other processes of the cycle, it releases a total amount of heat Q_2 to an external reservoir at some lower temperature T_2. The schematic representation of basic features of a heat engine may be shown as below

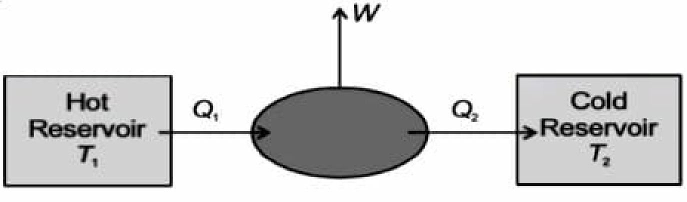


Fig.: The engine takes heat Q_1 from a hot reservoir at temperature T_1, releases heat Q_2 to a cold reservoir at temperature T_2 and delivers work W to the surroundings.

The cycle is repeated again and again to get useful work for some purpose. The efficiency of a heat engine is given by

$$\eta = \frac{W}{Q_1} \quad \text{...(i)}$$

where Q_1 is the heat absorbed by the working substance in one complete cycle and W is the work done on the environment in a cycle. Now as a certain amount of heat (Q_2) may also be rejected to the surrounding then by the first law of thermodymamics, over one complete cycle

$$W = Q_1 - Q_2 \quad \text{...(ii)}$$

$$\therefore \quad \eta = \frac{Q_1 - Q_2}{Q_1}$$

Or $$\boxed{\eta = 1 - \frac{Q_2}{Q_1}} \quad \text{...(iii)}$$

For the engine to have 100% efficiency, Q_2 should be 0, such that $\eta = 1$. In such a case energy conservation does not rule out but practically it is not possible, even if we can eliminate various kinds of losses associated with actual heat engines.

REFRIGERATORS AND HEAT PUMPS

We have seen that a heat engine takes heat from a hot place and gives off heat to a colder place. A refrigerator does the opposite. It takes heat from a cold place (the inside of the refrigerator) and gives it off to a warmer place (usually the air in the room where the refrigerator is located).

Note : A heat engine has a net output of mechanical work, the refrigerator requires a net input of mechanical work.

A heat pump is the same as a refrigerator. The term refrigerator or a heat pump depends on the purpose of the device *i.e.*, if we use the device to cool the portion of space, like the inside of a chamber and reservoir at high temperature surrounding it, we call the device a refrigerator. But if the purpose is to pump heat into a portion of space (*i.e.*, the room in the building when the outside environment is cold) the device is called a heat pump.

In a refrigerator the working substance is generally in gaseous form (*e.g.*, freon, ammonia) which goes through the following steps.

(a) There is sudden expansion of the gas from high to low pressure which cools it and converts it into a vapour-liquid mixutre.

(b) Absorption of heat by the cold fluid from the region to be cooled and converting it into vapour.

(c) Heating up of the vapour due to external work done on the system.

(d) Release of heat by the vapour to the surroundings, bringing it to the initial state and completing the cycle.

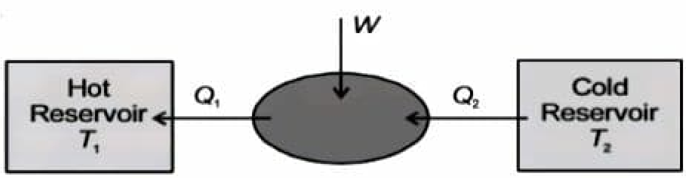


Fig.: Schematic representation of a refrigerator or a heat pump.

In above figure it is clear that the working substance extracts some heat Q_2 from the cold reservoir at temperature T_2 and some external work W is done on it while heat Q_1 is relased to the hot reservoir at temperature T_1. The ratio of quantity of heat removed per cycle from the cold reservoir (Q_2) to the energy spent per cycle (W) to remove this heat is known as the coefficient of performance of a refrigerator.

$$\beta = \frac{Q_2}{W} \quad \text{...(i)}$$

By energy conservation,

$$Q_1 = W + Q_2$$

$$\therefore \quad W = Q_1 - Q_2$$

$$\therefore \quad \beta = \frac{Q_2}{Q_1 - Q_2} \qquad ...(ii)$$

Coefficient of performance of heat pump

$$r = \frac{Q_1}{W} = \frac{Q_1}{Q_1 - Q_2} = \frac{1}{\eta}$$

> **Note :** *As we have seen that in a heat engine, heat cannot be completely converted into work i.e., $\eta = 1$ is never possible. Similarly a refrigerator (or a heat pump) cannot work without some external work done on the system i.e. the coefficient of performance 'β' cannot be infinite.*

SECOND LAW OF THERMODYNAMICS

After first law of thermodynamics which disallows many phenomena, the second law of thermodynamics is stated.

Kelvin-Planck Statement

No process is possible whose sole result is absorption of heat from a reservoir and the complete conversion of the heat into work.

Clausius Statement

No process is possible whose sole result is the transfer of heat from a colder object to a hotter object.

REVERSIBLE AND IRREVERSIBLE PROCESSES

Suppose there are some processes in which a system (*i.e.* a thermodynamic system) goes from its initial state to final sate. For this the system may absrob heat Q from the surroundings and perform work W on it. But the question to think is that, is it possible to reverse this process and bring both the system and surroundings to their initial states with no other effect anywhere?

The answer will be surely 'no' (practically).

A system that undergoes such an idealized reversible process is always very close to being in thermodynamic equilibrium within itself and with its surroundings. Any change of state that takes place can then be reversed by making only an infinitesimal change in the conditions of the system.

> **Note :** *In reality, a process cannot be reversed exactly. Irreversibility is a rule rather an exception in nature. Thermodynamic processes that occur in nature are all irreversible process.*

In simpler language we may say that the reversible processes are those process in which at any stage of an process it can be traversed back in the opposite direction in such a way that the system passes through exactly the same conditions at every step in the reverse process as in the direct process.

The basic requirements for a process to be reversible are

(i) The process should take place very slowly *i.e.*, under quasi-static conditions.

(ii) The difference in pressure between the working substance and surrounding should be very small at any stage of the operation.

(iii) There should be no friction.

(iv) There should be no loss of energy.

On the other hand irreversible process may be defined as the process in which the system cannot be retraced to its initial state.

Diffusion of two different gases, exchange of heat between two bodies at different temperatures, work done against friction are few examples of irreversible process.

CARNOT ENGINE

According to second law of thermodynamics, no heat engine can have 100% efficiency. But how much greater an efficiency can an engine have, working between temperature T_1 (hot reservoirs) and T_2 (cold reservoirs)?. The question was answered by a French engineer, Sadi Carnot, who developed a hypothetical, idealized heat engine that has the maximum possible efficiency consistent with the second law of thermodynamics. For maximum heat engine efficiency the processes should be reversible so we must avoid all irreversible process. A reversible heat engine operating between two temperatures is called a Carnot engine and the sequences of steps constituting one cycle is called the Carnot cycle.

***Note :** Irreversible engine have less efficiency due to the dissipative effects while a reversible engine are consisting of reversible process which are quasi-static and non-dissipative.*

A Carnot cycle (reversible heat engine) consists of a sequence of isothermal and adiabatic process.

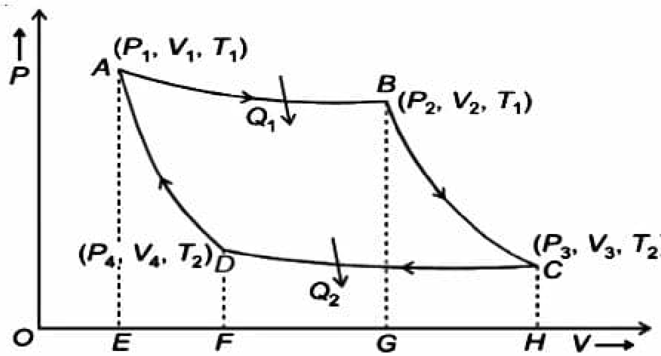


Fig.: A Carnot cycle for a heat engine with an ideal gas as the working substance.

All of these four stages of Carnot engine whose working substance is considered to be an ideal gas is discussed below.

(a) **Isothermal Expansion :** Consider the initial states be P_1, V_1 and T_1 and final states be P_2, V_2 and T_1 from A to B. The heat absorbed by the gas (Q_1) from the reservoir at temperature T_1 which is also the work done and is given by

$$W_1 = Q_1 = \mu RT_1 \ln\left(\frac{V_2}{V_1}\right) = \text{area } ABGEA \quad \text{...(i)}$$

and $P_1V_1 = P_2V_2$ ...(ii)

(b) **Adiabatic Expansion :** Now from B to C, the states will change from P_2, V_2 and T_1 to P_3, V_3 and T_2. Work done by the gas will be

$$W_2 = \frac{\mu R(T_1 - T_2)}{\gamma - 1} = \text{area } BCHGB \quad \text{...(iii)}$$

and $P_2V_2^\gamma = P_3V_3^\gamma$ ...(iv)

(c) **Isothermal Compression :** Now the gas compresses isothermally from C to D and its state changes from P_3, V_3, T_2 to P_4, V_4, T_2.

Heat released (Q_2) by the gas to the reservoir at temperature T_2 is also the work done on the gas by the environment which is given by

$$W_3 = -Q_2 = \mu RT_2 \ln\frac{V_4}{V_3} = -\text{ Area } CHFDC = -\mu RT_2 \ln\frac{V_3}{V_4} \quad \text{...(v)}$$

and $P_3V_3 = P_4V_4$ ...(vi)

(d) **Adiabatic Compression :** Now from D to A states will be P_4, V_4, T_2 to P_1, V_1, T_1

The work done on the gas will be

$$W_4 = -\frac{\mu R[T_1 - T_2]}{\gamma - 1} = -\text{ area } DFEAD \quad ...(vii)$$

and $P_4V_4^{\gamma} = P_1V_1^{\gamma}$ ...(viii)

Now, the total work done by the gas in one complete cycle will be

$$W = W_1 + W_2 + (W_3) + (W_4)$$

$$= W_1 + W_3 = \text{Area } ABCDA \quad (\because W_2 = -W_4) \quad ...(ix)$$

$$= Q_1 - Q_2$$

$$\therefore \quad W = \mu RT_1 \ln\frac{V_2}{V_1} - \mu RT_2 \ln\frac{V_3}{V_4} \quad ...(x)$$

From (ix), we also get that the total work done during the cyclic process is equal to the area enclosed in the cycle.

Now the efficiency η of the Carnot engine is

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

$$\therefore \quad \eta = 1 - \frac{Q_2}{Q_1}$$

$$\therefore \quad \eta = 1 - \frac{T_2}{T_1}\frac{\ln\frac{V_3}{V_4}}{\ln\frac{V_2}{V_1}} \quad ...(xi)$$

By multiplying (ii), (iv), (vi) and (viii) with each other, we get

$$(P_1V_1)(P_2V_2^{\gamma})(P_3V_3)(P_4V_4^{\gamma}) = (P_2V_2)(P_3V_3^{\gamma})(P_4V_4)(P_1V_1^{\gamma})$$

$$\therefore \quad V_1V_2^{\gamma}V_3V_4^{\gamma} = V_1^{\gamma}V_2V_3^{\gamma}V_4$$

$$\therefore \quad (V_2V_4)^{\gamma-1} = (V_1V_3)^{\gamma-1}$$

$$\therefore \quad V_2V_4 = V_1V_3$$

$$\therefore \quad \frac{V_2}{V_1} = \frac{V_3}{V_4}$$

So, $\ln\frac{V_2}{V_1} = \ln\frac{V_3}{V_4}$

Hence, equation (x) may be written as

$$\eta = 1 - \frac{T_2}{T_1}\frac{\ln\frac{V_2}{V_1}}{\ln\frac{V_2}{V_1}}$$

$$\therefore \quad \boxed{\eta = 1 - \frac{T_2}{T_1}} \quad ...(xii)$$

As we have seen that a Carnot engine is a reversible engine. In fact it is the only reversible engine possible that works between two reservoirs at different temperatures.

Example 20 : *A Carnot engine takes in 3000 kcal of heat from a reservoir at 627°C and gives a part of it to a sink at 27°C. The work done by the engine is*

(1) $4.2 \times 10^6 J$ (2) $8.4 \times 10^6 J$

(3) $16.8 \times 10^6 J$ (4) Zero

Solution : Here $T_1 = 273 + 627 = 900$ K and $T_2 = 273 + 27 = 300$ K

Now, $\eta = \dfrac{W}{Q_1} = 1 - \dfrac{T_2}{T_1}$

$$\therefore \quad \frac{W}{3000\,\text{kcal}} = 1 - \frac{300}{900}$$

$\therefore \quad W = 2000$ kcal

$= 2000 \times 4.2$ kJ $= 8.4 \times 10^6$ joule

Hence, the correct choice is (2).

Example 21 : *A scientist claims to have developed 60% efficient engine while working between 27°C and 327°C. Does he claim right?*

Solution : Here sink temperature $T_2 = 273 + 27 = 300$ K.

(low temperature happens to be sink temperature)

Given source temperature $T_1 = 327 + 273 = 600$ K.

So, within this temperature difference the maximum possible efficiency is

$$\eta_{max} = 1 - \frac{T_2}{T_1} = 1 - \frac{300}{600} = 0.5 = 50\%$$

But the scientist is claiming more efficiency, So as per Carnot's theorem his claim is not correct.

Example 22 : *The efficiency of a Carnot's engine at a particular source and sink temperature is $\frac{1}{2}$. When the sink temperature is reduced by 100°C, the engine efficiency becomes $\frac{2}{3}$. Find the source temperature.*

Solution : $1 - \dfrac{T_2}{T_1} = \dfrac{1}{2}$ ...(i) (T_2 : sink temperature T_1 : Source Temperature)

and $1 - \dfrac{(T_2 - 100)}{T_1} = \dfrac{2}{3}$ ...(ii)

or, $\dfrac{T_2}{T_1} = \dfrac{1}{2}$ from (i)

and $\dfrac{(T_2 - 100)}{T_1} = \dfrac{1}{3}$ from (ii)

Dividing these two we get

$$\frac{T_2}{T_2 - 100} = \frac{3}{2}$$

or, $T_2 = 300$ K

So, $T_1 = 600$ K

Example 23 : *An ideal refrigerator runs between –23°C and 27°C. Find the heat rejected to atmosphere for every joule of work input.*

Solution : Let the heat rejected to the atmosphere $Q_1 = x$ and given $W = 1$ joule. Now $Q_2 = Q_1 - W = x - 1$.
Given Hot temperature $T_1 = 273 + 27 = 300$ K and cold temperature $T_2 = 273 - 23 = 250$ K

For ideal process we know

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

$$\therefore \quad \frac{x}{x-1} = \frac{300}{250}$$

or, $x = 6$ joule

Try Yourself

11. A Carnot engine has efficiency of 80%. If its sink is at 127°C, then find the temperature of source.

    Hint : By $\eta = 1 - \frac{T_2}{T_1}$

12. Find the efficiency of carnot engine whose source and sink are at 927°C and 27°C.

    Hint : By $\eta = 1 - \frac{T_2}{T_1}$

Carnot Theorem

We have already seen that the efficiency of a Carnot's heat engine depends on temperature of hot reservoir (source) 'T_1' and temperature of cold reservoir (sink) 'T_2'

Carnot gave the most important results which are

(a) No engine can have efficiency more than that of the Carnot engine.

(b) The efficiency of the Carnot engine is independent of the nature of the working substance.

The above mentioned results are sometimes said to be as Carnot's theorem.

Proof : Consider two engines, engine *A* is irreversible and other reversible engine *B* (Carnot's Engine) working between the same hot reservoir (source) and cold reservoir (sink).

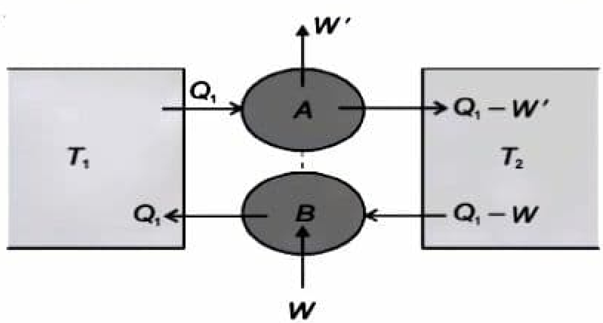


Fig.: An irreversible engine (*A*) coupled with a reversible engine (*B*)

Let us operate A and B in such a manner that A acts like heat engine while B acts like a refrigerator.

Now let engine A absrob heat Q_1 at temperature T_1 from the source, deliver work W' and release the heat $Q_1 - W'$ to the sink at temperature T_2 while B returns Q_1 heat to the source, taking heat Q_2 from the sink and requiring work $W = (Q_1 - Q_2)$ to be done on it. Suppose efficiency of engine A be greater than the efficiency of engine B.

Now, if B is considered as an engine, it will produce less output as that of engine A. *i.e.*, $W < W'$ with B acting like a refrigerator, this would mean $Q_2 = Q_1 - W > Q_1 - W'$

As a whole the coupled $A - B$ system extracts heat $(Q_1 - W) - (Q_1 - W') = (W' - W)$ from the cold reservoir and delivers the same amount of work in one cycle, without any change in the source or anywhere else.

The above discussion is strictly against the statement of 2nd law given by Kelvin–Planck.

Hence $\eta_A > \eta_B$ is very wrong. So we may say that no engine can have efficiency greater than that of the Carnot engine.

Similarly from the same argument it can be proved that the maximum efficiency of Carnot's engine is independent of the nature of the system performing the Carnot cycle. Hence the use of ideal gas as a working substance is justified. The ideal gas has a simple equation of state, which allows us to readily calculate the efficiency.

So, finally we may say that in Carnot cycle

$$\boxed{\frac{Q_1}{Q_2} = \frac{T_1}{T_2}}$$

This expression is a universal relation independent of the nature of the system.

EXERCISE

11. The value of η may lie between

(1) 0 to 1 (2) 1 to ∞

(3) –1 to +1 (4) 0 to ∞

12. If a Carnot engine works between 127°C and 527°C, then its efficiency is

(1) 25% (2) 37.5%

(3) 50% (4) 75%

13. If the temperature of sink is at absolute zero, then the efficiency of Carnot engine will be

(1) 0 (2) 100%

(3) 50% (4) 75%

14. A Carnot engine whose sink is at 300 K has an efficiency of 50%. By how much should the temperature of source be increased so as the efficiency becomes 70%?

(1) 100 K (2) 200 K

(3) 300 K (4) 400 K

15. A Carnot engine takes 6000 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

(1) 2 kcal (2) 3 kcal

(3) 4 kcal (4) 8 kcal

16. A process can be reversible if

(1) It is quasi-static (2) Non-dissipative

(3) Both (1) & (2) (4) Neither (1) nor (2)

17. In practice, all heat engines have efficiency less than that of a Carnot engine because

(1) Carnot engine is irreversible

(2) A reversible process can never be attained in a real world

(3) Irreversible engine has higher efficiency than reversible engine

(4) Efficiency of Carnot engine is always one

18. The efficiency of reversible engine is _____ the irreversible engine.

(1) Less than (2) Greater than

(3) Equal to (4) Negligible than

19. A Carnot cycle consists of

(1) Two stages (2) Four stages

(3) Six stages (4) Eight stages

20. A Carnot engine is working in such a temperature of sink that its efficieny is maximum and never changes with any non-zero temperature of source. The temperature of sink will most likely to be

(1) 0 K (2) 0°C

(3) 0°F (4) Data insufficient

ADDITIONAL INFORMATION

1. Comparison of Different Thermodynamic Process

An adiabat is steeper than an isotherm i.e., the slope of an adiabatic is greater than the slope of an isotherm.

For an isotherm we have

PV = constant

$\Rightarrow \quad PdV + VdP = \text{constant}$

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

i.e., slope of isotherm $\left(\frac{dP}{dV}\right) = -\frac{P}{V}$

For an adiabatic process, we have

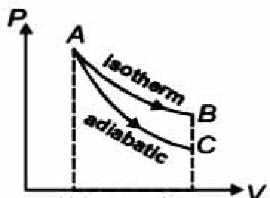
PV^{γ} = constant

$\therefore \quad P\gamma V^{\gamma - 1}\, dV + V^{\gamma} dP = 0$

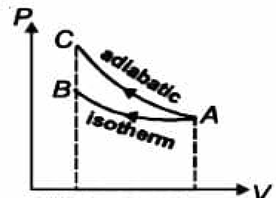
$$\Rightarrow \quad \frac{dP}{dV} = -\gamma\frac{P}{V}$$

i.e., slope of adiabat $\left(\frac{dP}{dV}\right) = -\gamma\frac{P}{V}$

$\therefore$ Slope of an adiabatic process = $\gamma \times$ (slope of the isotherm)



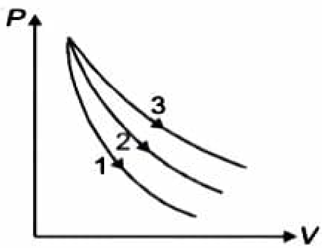
(I) Expansions



(II) Compressions

It is clear from the area under above graphs the work done by the system in isothermal expansion is more than the work done in adiabatic expansion, provided the expansion is same. In case of compression the work done by the system in adiabatic compression is more than the work done in isothermal compression, provided the compression is same.

As the slope of adiabat depends on the atomicity of gas i.e., γ, therefore if different gases expand adiabatically from same initial state, then graph for monatomic gas is more steeper than graph for diatomic and polyatomic gas as shown in the following diagram.

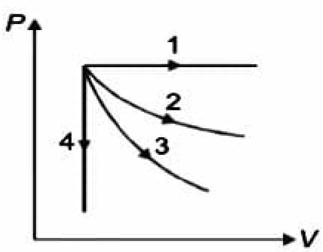


$1 \rightarrow$ monatomic gas $\left(\gamma = \frac{5}{3}\right)$

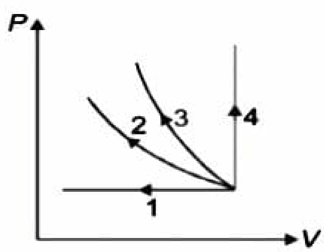
$2 \rightarrow$ diatomic gas $\left(\gamma = \frac{7}{5}\right)$

$3 \rightarrow$ polyatomic gas $\left(\gamma = \frac{4}{3}\right)$

Finally the expansion and compression of an ideal gas from same initial state can be compared by using following graphs.



(i) Expansion



(ii) Compression

In these graphs

$1 \rightarrow$ Isobaric process

$2 \rightarrow$ Isothermal process

$3 \rightarrow$ Adiabatic process

$4 \rightarrow$ Isochoric process

2. Polytropic Process

PV^N = constant

N = Polytropic constant

Molar heat capacity of the gas

$$C = C_V + \frac{R}{1-N}$$

If the temperature of n mole gas is increased from T_1 to T_2

Heat absorbed $Q = nC(T_2 - T_1)$

Some Important Definitions

- **Thermodynamics :** It is study of exchange of heat energy among bodies and conversion of heat energy into machenical energy and vice-versa.
- **Thermodynamic equilibrium :** A system is said to be in thermodynamic equilibrium, if its thermodynamic variables such as pressure, volume, temperature, mass and composition do not change with time.
- **Thermal Equilibrium :** Two or more systems are said to be in thermal equilibrium, if there is no exchange of heat energy between them when they are brought in thermal contact.
- **Zeroth law of thermodynamics :** If each of two systems A and B are in thermal equilibrium with a third system C, then A and B are also in thermal equilibrium with each other.
- **Internal Energy :** It is sum of the kinetic energy of all constituent particles of the system and the potential energy of interaction among these particles.
- **First law of thermodynamics :**

  According to Clausius statement of first law of thermodynamics, the heat given to a system is used up in two ways in increasing internal energy of the system and in doing work against external pressure.
- **Isothermal Process :** The process during which the temperature of the system remains constant.
- **Adiabatic Process :** The process during which heat is neither given to the system, nor taken from it.
- **Isochoric Process :** The process during which the volume remains constant.
- **Isobaric Process :** The process during which the pressure remains constant.
- **Quasi-static Process :** The process in which the system departs only infinitesimally from the equilibrium state.
- **Cyclic Process :** The process in which the system returns to its initial state.
- **Reversible Process :** The process in which the system can be retraced to its original state by reversing the conditions.
- **Irreversible Process :** The process in which the system cannot be retraced to its original state by reversing the conditions.
- **Heat Engine :** It is a device by which a system is made to undergo a cyclic process that results in conversion of heat into work.
- **Second law of thermodynamics :**

  Kelvin-Plank statement : It is impossible for a self acting device, unaided by an external agency and acting in a cycle to absorb heat from the source and convert whole of it into work.

  Clausius statement : It is impossible to construct a machine which can transfer heat from a cold body to a hot body over a cycle without the help of any external agency.

Formulae Chart

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

2. W = Area under PV graph = $\int_{V_i}^{V_f} PdV$

3. $C_V = \dfrac{R}{\gamma - 1}$; $C_P = \dfrac{\gamma R}{\gamma - 1}$

4. Relation between specific heats for a gas, $C_p - C_v = R$

5. For isothermal process, PV = constant

   $$W = \mu RT \ln\frac{V_2}{V_1}$$

   $$W = 2.303\ \mu RT \log\frac{V_2}{V_1}$$

6. For adiabatic process,

   PV^{γ} = constant where, $\gamma = \dfrac{C_P}{C_V}$

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

   $$W = \frac{\mu R[T_1 - T_2]}{\gamma - 1}$$

7. $\Delta U = nC_V\Delta T = \dfrac{P_2V_2 - P_1V_1}{\gamma - 1}$

8. Slope of adiabatic = γ (slope of isotherm)

9. For polytropic process

   PV^N = constant

   and $W = \dfrac{P_2V_2 - P_1V_1}{1 - N}$

   and $C = C_V + \dfrac{R}{1 - N}$

10. Carnot engine

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

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

    $$W = Q_1 - Q_2$$

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

11. Refrigerator

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

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

12. Heat pump

$$r = \frac{Q_1}{W} = \frac{Q_1}{Q_1 - Q_2} = \frac{1}{\eta}$$

Quick Recap

1. Zeroth law of thermodynamics states that 'two systems in thermal equilibrium with a third systems are in thermal equilibrium with each other'.
2. Zeroth law leads to the concept of temperature.
3. Heat and work are two modes of energy transfer to the system.
4. Heat gets transferred due to temperature difference between the system and the surroundings.
5. Work is energy transfer which arises by other means, such as moving the piston of a cylinder containing the gas, by raising or lowering some weight connected to it.
6. Internal energy of any thermodynamic system depends only on its state. The internal energy change in a process depends only on the initial and final states, not on the path.
7. The internal energy of an isolated system is constant.
8. (a) For isothermal process

   $$\Delta T = 0$$

   (b) For adiabatic process

   $$\Delta Q = 0$$

9. First law of thermodynamics states that when heat Q is added to a system while the system does work W, the internal energy U changes by an amount equal to $Q - W$. This law can also be expressed for an infinitesimal process.
10. First law of thermodynamics is general law of conservation of energy.
11. Second law of thermodynamics does not allow some processes which are consistent with the first law of thermodynamics.

    It states

    Clausius statement : No process is possible whose sole result is the transfer of heat from a colder object to a hotter object.

    Kelvin-Planck statement : No process is possible whose sole result is the absorption of heat from a reservoir and complete conversion of the heat into work.
12. No engine can have efficiency equal to 1 or no refrigerator can have co-efficient of performance equal to infinity.
13. Carnot engine is an ideal engine.

14. The Carnot cycle consists of two reversible isothermal process and two reversible adiabatic process.

15. If $Q > 0$, heat is added to the system.

    If $Q < 0$, heat is removed from the system.

    If $W > 0$, work is done by the system.

    If $W < 0$, work is done on the system.

❑ ❑ ❑

Assignment

(SET - 1)

School/Board Examinations

Students are required to solve and write the solutions in their exercise book.

For referring solutions to the assignment (Set-1), please visit our Library at the Centre or log on to our website: www.aakash.ac.in

SECTION - A

School/Board Exam. Type Questions

Very Short Answer Type Questions :

1. Does internal energy change during an isothermal process for an ideal gas?
2. Which thermodynamic variable is defined by 1st law?
3. Can water be made to boil without heating?
4. Is it possible to convert whole of the heat into work?
5. Which thermodynamic variable is defined by zeroth law?
6. Given any two examples of state variables.
7. Why does a gas get heated on compression?
8. In summers when valve of a bicycle tube is removed, escaping air appears cold. Why?
9. Does internal energy of an ideal gas change in an adiabatic process?
10. Does the temperature increase during boiling?

Short Answer Type Questions :

11. Can temperature of a body be raised without heating it? Is the converse also true?
12. Can two isothermal curves intersect each other?
13. State 2nd law of thermodynamics.
14. Discuss briefly the limitations of 1st law of thermodynamics.
15. State the sign conventions used in all thermodynamic process.
16. Define the four thermodynamic process.
17. State zeroth law of thermodynamics.
18. What do you mean by the term thermal equilibrium? Explain it briefly.
19. Calculate work done during a cyclic process.
20. Discuss briefly any two applications of 1st law of thermodynamics.
21. Write differences between isothermal and adiabatic changes.
22. Consider a Carnot's cycle operating between 227°C and 27°C producing 2 kJ of mechanical work per cycle. Find the heat transferred to the engine by the reservoirs.
23. If coefficient of performance of a refrigerator is 5 and it operates at room temperature (*i.e.*, 27°C), find the temperature inside the refrigerator.
24. A Carnot engine works between 400 K and 600 K. If it absrobs 3×10^6 cal heat at highest temperature, how much work per cycle can the engine perform?

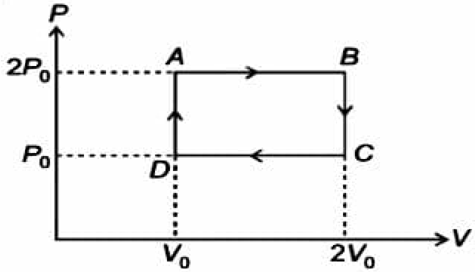
25. A Carnot engine has an efficiency of 30% when sink is at 17°C. By how much the temperature of the source be increased to have its efficiency equal to 50%, keeping sink temperature constant?

26. If the door of a refrigerator is kept open in a room, will it make the room warm or cool? Explain your answer.

27. What do you mean by irreversible process? Given some examples.

28. What will be the efficiency of a Carnot engine working between 127°C and 27°C?

29. *N* moles of a monatomic gas is carried round the reversible rectangular cycle *ABCDA* as shown below



The temperature at *A* is T_0. Then find the thermodynamic efficiency of the cycle.

30. What are the basic requirements for a process to be reversible?

Long Answer Type Questions :

31. Explain briefly the working principle of a refrigerator and obtain an expression for its coefficent of performance.

32. Define and derive an expression for efficiency of a Carnot engine.

33. Explain the essential requisites of Carnot engine.

34. What is thermodynamic system? Prove that the work done by a thermodynamic system is equal to the area under *P–V* diagram.

35. Define adiabatic process. Derive an expression for work done during adiabatic process.

36. Using PV^γ = constant, show that (i) $T^\gamma P^{1-\gamma}$ = constant (ii) $TV^{\gamma-1}$ = constant.

37. State zeroth law of thermodynamics. Explain with example the term thermal equilibrium.

38. State the Kelvin-Planck and Clausius statements of second law of thermodynamics. Show that both the statements are equivalent.

39. Wrtie a short note on (i) Isobaric process (ii) Isochoric process.

40. Explain some applications and limitations of first law of thermodynamics.

41. Prove $C_P - C_V = R$.

42. Write a short note on quasi-static process.

43. State and prove Carnot's theorem.

44. What should be the minimum power needed by a refrigerator to freeze 10 kg of water at 0°C to ice at 0°C in a time interval of 10 minutes. Assume that room temperature is 25°C.

45. Two engines *A* and *B* have their sources at 327°C and 427°C and sinks at 27°C and 127°C. Which engine is more efficient and by how much?

SECTION - B

Model Test Paper

Very Short Answer Type Questions : **[1 Mark]**

1. Give any one example of working substance in refrigerator.

2. Define internal energy.

Short Answer Type Questions : **[2 Marks]**

3. Write any two limitations of first law of thermodynamics.

4. What is a heat pump?

5. Define one calorie. State SI unit of specific heat capacity.

6. Is it possible that the temperature of an isolated system change?

7. Give reason : "With increase in temperature of a gas its pressure increases".

8. Find the change in internal energy of a gas when it absorbs 100 calorie of heat and performs 100 joule of work.

Short Answer Type Questions : **[3 Marks]**

9. Write difference between reversible and irreversible process with one example of each.

10. Define coefficient of efficiency of heat engine and coefficient of performance of refrigerator. How are they related to each other?

11. Show that $C_P > C_V$.

12. A Carnot engine works between 27°C and 427°C. How is it possible to make its efficiency 50%?

13. A Carnot engine operates between 600 K and 400 K. If it absorbs 1 kcal heat at higher temperature, how much work per cycle can the engine perform?

14. (a) Can water boil without heating? Give reason.

    (b) Is it possible to increase the temperature of a gas without heating? If yes, how?

Long Answer Type Questions : **[5 Marks]**

15. Deduce the expression for work done in an isothermal process.

16. State and prove Carnot's theorem.

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Assignment

(SET - 2)

NEET & AIIMS

SECTION - A

Objective Type Questions

1. In thermodynamics the Zeroth law is related to

(1) Work done (2) Thermal equilibrium

(3) Entropy (4) Diffusion

2. For a cyclic process

(1) $\Delta U = 0$ (2) $\Delta Q = 0$

(3) $W = 0$ (4) Both (1) & (3)

3. Select the incorrect relation. (Where symbols have their usual meanings)

(1) $C_P = \frac{\gamma R}{\gamma - 1}$ (2) $C_P - C_V = R$

(3) $\Delta U = \frac{P_f V_f - P_i V_i}{1 - \gamma}$ (4) $C_V = \frac{R}{\gamma - 1}$

4. Internal energy of a non-ideal gas depends on

(1) Temperature (2) Pressure

(3) Volume (4) All of these

5. For an adiabatic expansion of an ideal gas the fractional change in its pressure is equal to

(1) $-\gamma \frac{V}{dV}$ (2) $-\frac{dV}{\gamma V}$

(3) $\frac{dV}{V}$ (4) $-\gamma \frac{dV}{V}$

6. Which of the following laws of thermodynamics defines internal energy?

(1) Zeroth law (2) Second law

(3) First law (4) Third law

7. Select the correct statement for work, heat and change in internal energy

(1) Heat supplied and work done depend on initial and final states

(2) Change in internal energy depends on the initial and final states only

(3) Heat and work depend on the path between the two points

(4) All of these

8. Morning breakfast gives 5000 cal to a 60 kg person. The efficiency of person is 30%. The height upto which the person can climb up by using energy obtained from breakfast is

(1) 5 m (2) 10.5 m

(3) 15 m (4) 16.5 m

9. Select the incorrect statement about the specific heats of a gaseous system

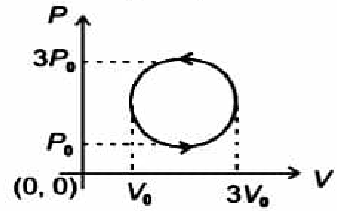
(1) Specific heat at no exchange condition, $C_A = 0$

(2) Specific heat at constant temperature, $C_T = \infty$

(3) Specific heat at constant pressure, $C_P = \frac{\gamma R}{\gamma - 1}$

(4) Specific heat at constant volume, $C_V = \frac{R}{\gamma}$

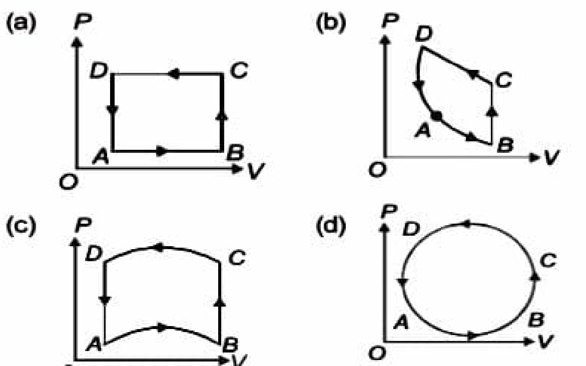
10. Work done in the cyclic process shown in figure is



(1) $4P_0V_0$ (2) $-4P_0V_0$

(3) $-\frac{22}{7}P_0V_0$ (4) $-13P_0V_0$

11. In following figures (a) to (d), variation of volume by change of pressure is shown in figure. The gas is taken along the path *ABCDA*. Change in internal energy of the gas will be



(1) Positive in all cases from (a) to (d)

(2) Positive in cases (a), (b) and (c) but zero in case (d)

(3) Negative in cases (a), (b) and (c) but zero in case (d)

(4) Zero in all the four cases

12. In a thermodynamic process pressure of a fixed mass of a gas is changed in such a manner that the gas releases 20 J of heat when 8 J of work was done on the gas. If the initial internal energy of the gas was 30 J, then the final internal energy will be

(1) 2 J (2) 18 J

(3) 42 J (4) 58 J

13. A perfect gas goes from state A to state B by absorbing 8×10^5 joule and doing 6.5×10^5 joule of external work. If it is taken from same initial state A to final state B in another process in which it absorbs 10^5 J of heat, then in the second process work done

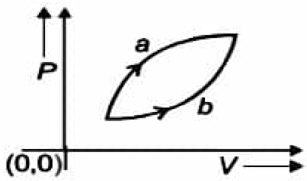
 (1) On gas is 10^5 J

 (2) On gas is 0.5×10^5 J

 (3) By gas is 10^5 J

 (4) By gas is 0.5×10^5 J

14. Figure shows two processes a and b for a given sample of gas. If ΔQ_1, ΔQ_2 are the amount of heat absorbed by the system in the two cases; and ΔU_1, ΔU_2 are changes in internal energy respectively, then



 (1) $\Delta Q_1 = \Delta Q_2$; $\Delta U_1 = \Delta U_2$

 (2) $\Delta Q_1 > \Delta Q_2$; $\Delta U_1 > \Delta U_2$

 (3) $\Delta Q_1 < \Delta Q_2$; $\Delta U_1 < \Delta U_2$

 (4) $\Delta Q_1 > \Delta Q_2$; $\Delta U_1 = \Delta U_2$

15. A gas undergoes a change at constant temperature. Which of the following quantities remain fixed?

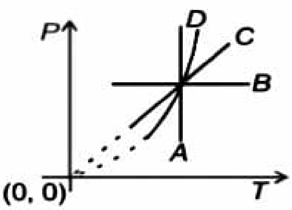
 (1) Pressure

 (2) Entropy

 (3) Heat exchanged with the system

 (4) All the above may change

16. Following figure shows P-T graph for four processes A, B, C and D. Select the correct alternative



 (1) A – Isobaric process

 (2) B – Adiabatic process

 (3) C – Isochoric process

 (4) D – Isothermal process

17. An ideal gas with adiabatic exponent γ is heated at constant pressure. It absorbs Q amount of heat. Fraction of heat absorbed in increasing the temperature is

 (1) γ (2) $\frac{1}{\gamma}$

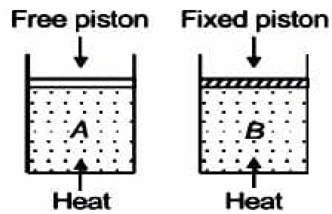
 (3) $1-\frac{1}{\gamma}$ (4) 2γ

18. A certain amount of an ideal monatomic gas needs 20 J of heat energy to raise its temperature by 10°C at constant pressure. The heat needed for the same temperature rise at constant volume will be

 (1) 30 J (2) 12 J

 (3) 200 J (4) 215.3 J

19. Two cylinders contain same amount of ideal monatomic gas. Same amount of heat is given to two cylinders. If temperature rise in cylinder A is T_0 then temperature rise in cylinder B will be



 (1) $\frac{4}{3}T_0$

 (2) $2T_0$

 (3) $\frac{T_0}{2}$

 (4) $\frac{5}{3}T_0$

20. A sample of an ideal gas undergoes an isothermal expansion. If dQ, dU and dW represent the amount of heat supplied, the change in internal energy and the work done respectively, then

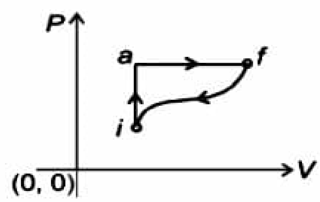
 (1) dQ = +ve, dU = +ve, dW = +ve

 (2) dQ = +ve, dU = 0, dW = +ve

 (3) dQ = +ve, dU = +ve, dW = 0

 (4) dQ = –ve, dU = –ve, dW = –ve

21. In the diagram shown Q_{iaf} = 80 cal and W_{iaf} = 50 cal. If W = –30 cal for the curved path fi, value of Q for path fi, will be



 (1) 60 cal (2) 30 cal

 (3) –30 cal (4) –60 cal

22. A mass of dry air at N.T.P. is compressed to $\frac{1}{32}$th of its original volume suddenly. If $\gamma = 1.4$, the final pressure would be

(1) 32 atm (2) 128 atm

(3) $\frac{1}{32}$ atm (4) 150 atm

23. Two samples A and B of a gas initially at the same temperature and pressure, are compressed from volume V to $\frac{V}{2}$ (A isothermally and B adiabatically). The final pressure

(1) $P_A > P_B$ (2) $P_A = P_B$

(3) $P_A < P_B$ (4) $P_A = 2P_B$

24. The adiabatic elasticity of a diatomic gas at NTP is

(1) Zero (2) 1×10^5 N/m^2

(3) 1.4×10^5 N/m^2 (4) 2.75×10^5 N/m^2

25. For an isometric process

(1) $\Delta W = -\Delta U$ (2) $\Delta Q = \Delta U$

(3) $\Delta Q = \Delta W$ (4) $\Delta Q = -\Delta U$

26. A mixture of gases at NTP for which $\gamma = 1.5$ is suddenly compressed to $\frac{1}{9}$th of its original volume. The final temperature of mixture is

(1) 300°C (2) 546°C

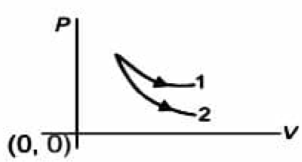
(3) 420°C (4) 872°C

27. In which process P-V diagram is a straight line parallel to the volume axis?

(1) Isochoric (2) Isobaric

(3) Isothermal (4) Adiabatic

28. The P-V plots for two gases during adiabatic processes are shown in the figure. The graphs 1 and 2 should correspond respectively to



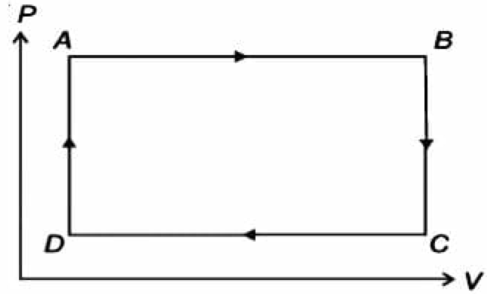
(1) O_2 and He

(2) He and O_2

(3) O_2 and CO

(4) N_2 and O_2

29. The pressure and volume of a gas are changed as shown in the P-V diagram in this figure. The temperature of the gas will



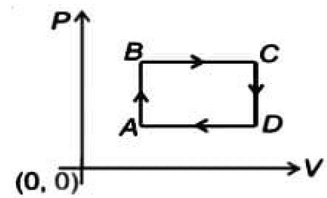
(1) Increase as it goes from A to B

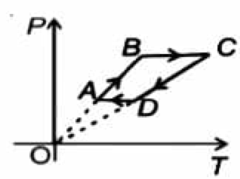
(2) Increase as it goes from B to C

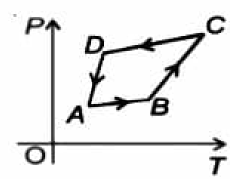
(3) Remain constant during these changes

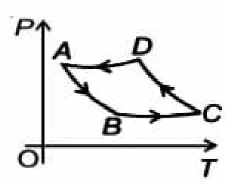
(4) Decrease as it goes from D to A

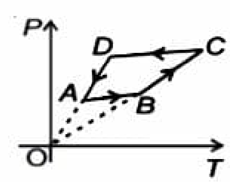
30. The figure shows P-V diagram of a thermodynamic cycle. Which corresponding curve is correct?



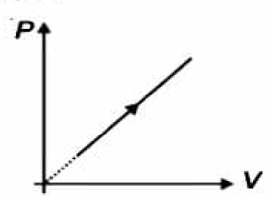
(1) 

(2) 

(3) 

(4) 

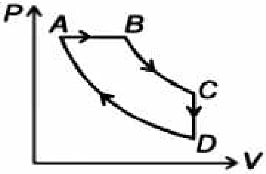
31. During the thermodynamic process shown in figure for an ideal gas

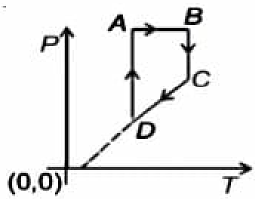


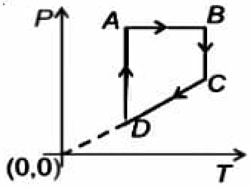
(1) $\Delta T = 0$ (2) $\Delta Q = 0$

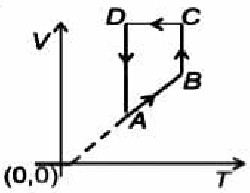
(3) $W < 0$ (4) $\Delta U > 0$

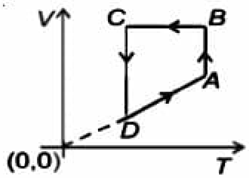
32. For P-V diagram of a thermodynamic cycle as shown in figure, process BC and DA are isothermal. Which of the corresponding graphs is correct?



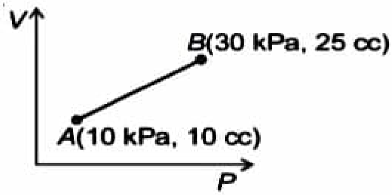
(1) 

(2) 

(3) 

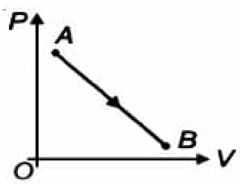
(4) 

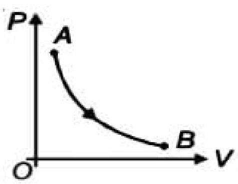
33. Work done for the process shown in the figure is

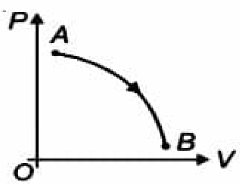


(1) 1 J
(2) 1.5 J
(3) 4.5 J
(4) 0.3 J

34. During which of the following thermodynamic process represented by PV diagram the heat energy absorbed by system may be equal to area under PV graph?

(1) 

(2) 

(3) 

(4) All of these

35. The specific heat of a gas in a polytropic process is given by

(1) $\frac{R}{\gamma-1}+\frac{R}{N-1}$
(2) $\frac{R}{1-\gamma}+\frac{R}{1-N}$
(3) $\frac{R}{\gamma-1}-\frac{R}{N-1}$
(4) $\frac{R}{1-\gamma}-\frac{R}{1-N}$

36. For a certain process, pressure of diatomic gas varies according to the relation $P = aV^2$, where a is constant. What is the molar heat capacity of the gas for this process?

(1) $\frac{17R}{6}$
(2) $\frac{6R}{17}$
(3) $\frac{13R}{6}$
(4) $\frac{16R}{7}$

37. In a thermodynamic process two moles of a monatomic ideal gas obeys $P \propto V^{-2}$. If temperature of the gas increases from 300 K to 400 K, then find work done by the gas (where R = universal gas constant)

(1) 200 R
(2) –200 R
(3) –100 R
(4) –400 R

38. Entropy of a system decreases

(1) When heat is supplied to a system at constant temperature
(2) When heat is taken out from the system at constant temperature
(3) At equilibrium
(4) In any spontaneous process

39. If during an adiabatic process the pressure of mixture of gases is found to be proportional to square of its absolute temperature. The ratio of C_P/C_V for mixture of gases is

(1) 2
(2) 1.5
(3) 1.67
(4) 2.1

40. If the efficiency of a carnot engine is η, then the coefficient of performance of a heat pump working between the same temperatures will be

(1) $1-\eta$
(2) $\frac{1-\eta}{\eta}$
(3) $\frac{1}{\eta}$
(4) $1+\frac{1}{\eta}$

41. In a Carnot engine, when heat is absorbed from the source, temperature of source

(1) Increases (2) Decreases

(3) Remains constant (4) Cannot say

42. A Carnot engine working between 300 K and 600 K has a work output of 800 J per cycle. The amount of heat energy supplied to engine from the source in each cycle is

(1) 800 J (2) 1600 J

(3) 3200 J (4) 6400 J

43. An ideal heat engine operates on Carnot cycle between 227°C and 127°C. It absorbs 6×10^4 cal at the higher temperature. The amount of heat converted into work equals to

(1) 4.8×10^4 cal (2) 3.5×10^4 cal

(3) 1.6×10^4 cal (4) 1.2×10^4 cal

44. The maximum possible efficiency of a heat engine is

(1) 100%

(2) $\frac{T_1}{T_2}$

(3) $\frac{T_1}{T_2}+1$

(4) Dependent upon the temperature of source (T_1) and sink (T_2) and is equal to $\left(1-\frac{T_2}{T_1}\right)$

45. A frictionless heat engine can be 100% efficient only if its exhaust temperature is

(1) Equal to its input temperature

(2) Less than its input temperature

(3) 0 K

(4) 0°C

46. A reversible engine and an irreversible engine are working between the same temperatures. The efficiency of the

(1) Two engines are same

(2) Reversible engine is greater

(3) Irreversible engine is greater

(4) Two engines cannot be compared

47. Which of the following can be coefficient of performance of refrigerator?

(1) 1 (2) 0.5

(3) 9 (4) All of these

48. The temperature inside and outside a refrigerator are 273 K and 300 K respectively. Assuming that the refrigerator cycle is reversible, for every joule of work done, the heat delivered to the surrounding will be nearly

(1) 11 J (2) 22 J

(3) 33 J (4) 50 J

49. By opening the door of a refrigerator placed inside a room you

(1) Can cool the room to certain degree

(2) Can cool it to the temperature inside the refrigerator

(3) Ultimately warm the room slightly

(4) Can neither cool nor warm the room

50. A Carnot engine whose sink is at 300 K has an efficiency of 40%. By how much should the temperature of source be increased to as to increase its efficiency by 50% of original efficiency?

(1) 150 K (2) 250 K

(3) 300 K (4) 450 K

SECTION - B

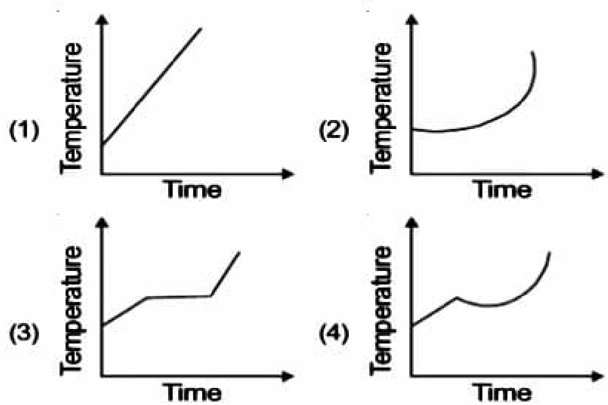
Objective Type Questions

1. A container is filled with 20 moles of an ideal diatomic gas at absolute temperature T. When heat is supplied to gas temperature remains constant but 8 moles dissociate into atoms. Heat energy given to gas is

(1) $4RT$ (2) $6RT$

(3) $3RT$ (4) $5RT$

2. Liquid oxygen at 50 K is heated to 300 K at constant pressure of 1 atm. The rate of heating is constant. Which one of the following graphs represents the variation of temperature with time?



3. For an isobaric process, the ratio of ΔQ (amount of heat supplied) to the ΔW (work done by the gas) is $\left(\gamma = \frac{C_P}{C_V}\right)$

(1) γ (2) $\gamma - 1$

(3) $\frac{\gamma}{\gamma+1}$ (4) $\frac{\gamma}{\gamma-1}$

4. 3 moles of an ideal gas are contained within a cylinder by a frictionless piston and are initially at temperature T. The pressure of the gas remains constant while it is heated and its volume doubles. If R is molar gas constant, the work done by the gas in increasing its volume is

(1) $\frac{3}{2}RT\ln 2$ (2) $3\,RT\ln 2$

(3) $\frac{3}{2}RT$ (4) $3\,RT$

5. Two moles of a gas at temperature T and volume V are heated to twice its volume at constant pressure. If $\frac{C_p}{C_v} = \gamma$ then increase in internal energy of the gas is

(1) $\frac{RT}{\gamma-1}$ (2) $\frac{2RT}{\gamma-1}$

(3) $\frac{2RT}{3(\gamma-1)}$ (4) $\frac{2T}{\gamma-1}$

6. A triatomic, diatomic and monoatomic gas is supplied same amount of heat at constant pressure, then

(1) Fractional energy used to change internal energy is maximum in monatomic gas

(2) Fractional energy used to change internal energy is maximum in diatomic gas

(3) Fractional energy used to change internal energy is maximum in triatomic gases

(4) Fractional energy used to change internal energy is same in all the three gases

7. 105 calories of heat is required to raise the temperature of 3 moles of an ideal gas at constant pressure from 30°C to 35°C. The amount of heat required in calories to raise the temperature of the gas through the range (60°C to 65°C) at constant volume is $\left(\gamma = \frac{C_p}{C_v} = 1.4\right)$

(1) 50 cal (2) 75 cal

(3) 70 cal (4) 90 cal

8. To an ideal triatomic gas 800 cal heat energy is given at constant pressure. If vibrational mode is neglected, then energy used by gas in work done against surroundings is

(1) 200 cal

(2) 300 cal

(3) 400 cal

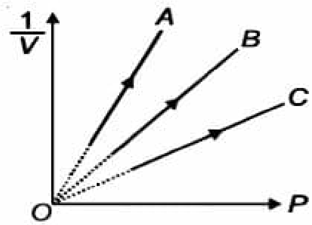
(4) 60 cal

9. A closed cylindrical vessel contains N moles of an ideal diatomic gas at a temperature T. On supplying heat, temperature remains same, but n moles get dissociated into atoms. The heat supplied is

(1) $\frac{5}{2}(N-n)RT$ (2) $\frac{5}{2}nRT$

(3) $\frac{1}{2}nRT$ (4) $\frac{3}{2}nRT$

10. Figure shows the isotherms of a fixed mass of an ideal gas at three temperatures T_A, T_B and T_C, then



(1) $T_A > T_B > T_C$ (2) $T_A < T_B < T_C$

(3) $T_B < T_A < T_C$ (4) $T_A = T_B = T_C$

11. An ideal monatomic gas at 300 K expands adiabatically to 8 times its volume. What is the final temperature?

(1) 75 K

(2) 300 K

(3) 560 K

(4) 340 K

12. Slope of isotherm for a gas (having $\gamma = \frac{5}{3}$) is 3×10^5 N/m². If the same gas is undergoing adiabatic change then adiabatic elasticity at that instant is

(1) 3×10^5 N/m²

(2) 5×10^5 N/m²

(3) 6×10^5 N/m²

(4) 10×10^5 N/m²

13. A gas may expand either adiabatically or isothermally. A number of P–V curves are drawn for the two processes over different range of pressure and volume. It will be found that

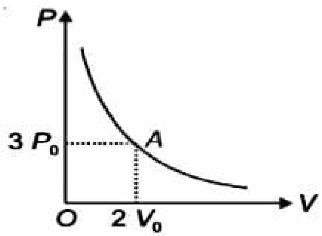
(1) An adiabatic curve and an isothermal curve may intersect

(2) Two adiabatic curves do not intersect

(3) Two isothermal curves do not intersect

(4) All of these

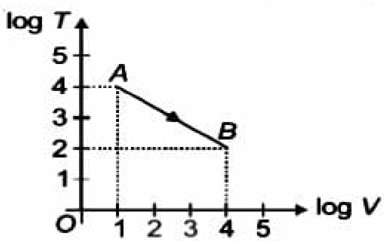
14. The variation of pressure P with volume V for an ideal monatomic gas during an adiabatic process is shown in figure. At point A the magnitude of rate of change of pressure with volume is



(1) $\frac{3P_0}{5V_0}$ (2) $\frac{5P_0}{3V_0}$

(3) $\frac{3P_0}{2V_0}$ (4) $\frac{5P_0}{2V_0}$

15. Figure shows, the adiabatic curve on a log T and log V scale performed on ideal gas. The gas is



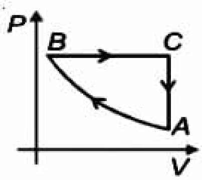
(1) Monatomic

(2) Diatomic

(3) Polyatomic

(4) Mixture of monatomic and diatomic

16. A cyclic process on an ideal monatomic gas is shown in figure. The correct statement is



(1) Work done by gas in process AB is more than that in the process BC

(2) Net heat energy has been supplied to the system

(3) Temperature of the gas is maximum at state B

(4) In process CA, heat energy is absorbed by system

17. A diatomic gas undergoes a process represented by $PV^{1.3}$ = constant. Choose the incorrect statement

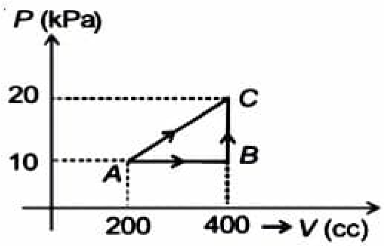
(1) The gas expands by absorbing heat from the surroundings

(2) The gas cools down during expansion

(3) The work done by surroundings during expansion of the gas is negative

(4) None of these

18. If a gas is taken from A to C through B then heat absorbed by the gas is 8 J. Heat absorbed by the gas in taking it from A to C directly is



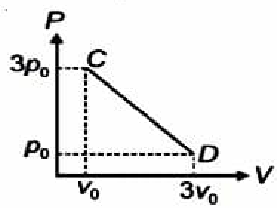
(1) 8 J

(2) 9 J

(3) 11 J

(4) 12 J

19. The process CD is shown in the diagram. As system is taken from C to D, what happens to the temperature of the system?



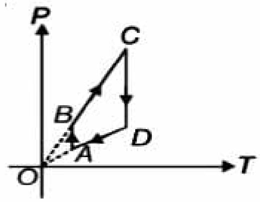
(1) Temperature first decreases and then increases

(2) Temperature first increases and then decreases

(3) Temperature decreases continuously

(4) Temperature increases continuously

20. A P-T graph is shown for a cyclic process. Select correct statement regarding this



(1) During process CD, work done by gas is negative

(2) During process AB, work done by the gas is positive

(3) During process BC internal energy of system increases

(4) During process BC internal energy of the system decreases

21. A hydrogen cylinder is designed to withstand an internal pressure of 100 atm. At 27°C, hydrogen is pumped into the cylinder which exerts a pressure of 20 atm. At what temperature does the danger of explosion first sets in?

(1) 500 K

(2) 1500 K

(3) 1000 K

(4) 2000 K

22. An ideal gas of volume V and pressure P expands isothermally to volume 16 V and then compressed adiabatically to volume V. The final pressure of gas is [γ = 1.5]

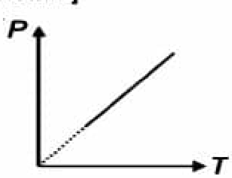
(1) P

(2) $3P$

(3) $4P$

(4) $6P$

23. The pressure P of an ideal diatomic gas varies with its absolute temperature T as shown in figure. The molar heat capacity of gas during this process is [R is gas constant]



(1) 1.7 R

(2) 3.25 R

(3) 2.5 R

(4) 4.2 R

24. An ideal gas expands according to the law P^2V = constant. The internal energy of the gas

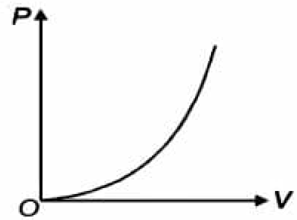
(1) Increases continuously

(2) Decreases continuously

(3) Remain constant

(4) First increases and then decreases

25. The variation of pressure P with volume V for an ideal diatomic gas is parabolic as shown in the figure. The molar specific heat of the gas during this process is



(1) $\frac{9R}{5}$ (2) $\frac{17R}{6}$

(3) $\frac{3R}{4}$ (4) $\frac{8R}{5}$

26. Neon gas of a given mass expands isothermally to double volume. What should be the further fractional decrease in pressure, so that the gas when adiabatically compressed from that state, reaches the original state?

(1) $1-2^{-2/3}$ (2) $1-3^{1/3}$

(3) $2^{1/3}$ (4) $3^{2/3}$

27. When 1 kg of ice at 0°C melts to water at 0°C, the resulting change in its entropy, taking latent heat of ice to be 80 cal/°C is

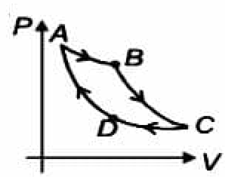
(1) 293 cal/K

(2) 273 cal/K

(3) 8×10^4 cal/K

(4) 80 cal/K

28. Carnot cycle is plotted in P-V graph. Which portion represents an isothermal expansion?



(1) AB

(2) BC

(3) CD

(4) DA

29. Efficiency of a heat engine working between a given source and sink is 0.5. Coefficient of performance of the refrigerator working between the same source and the sink will be

(1) 1 (2) 0.5

(3) 1.5 (4) 2

30. A heat engine rejects 600 cal to the sink at 27°C. Amount of work done by the engine will be

(Temperature of source is 227°C & J = 4.2 J/cal)

(1) 1680 J

(2) 840 J

(3) 2520 J

(4) None of these

SECTION - C

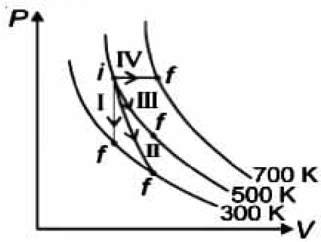
Previous Years Questions

1. A Carnot engine having an efficiency of $\frac{1}{10}$ as heat engine, is used as a refrigerator. If the work done on the system is 10 J, the amount of energy absorbed from the reservoir at lower temperature is **[NEET-2017]**

(1) 1 J (2) 90 J

(3) 99 J (4) 100 J

2. Thermodynamic processes are indicated in the following diagram.



Match the following

	Column-I		Column-II
P.	Process I	a.	Adiabatic
Q.	Process II	b.	Isobaric
R.	Process III	c.	Isochoric
S.	Process IV	d.	Isothermal

[NEET-2017]

(1) P → a, Q → c, R → d, S → b

(2) P → c, Q → a, R → d, S → b

(3) P → c, Q → d, R → b, S → a

(4) P → d, Q → b, R → a, S → c

3. One mole of an ideal monatomic gas undergoes a process described by the equation PV^3 = constant. The heat capacity of the gas during this process is **[NEET (Phase-2)-2016]**

(1) $\frac{3}{2}R$ (2) $\frac{5}{2}R$

(3) $2R$ (4) R

4. The temperature inside a refrigerator is t_2 °C and the room temperature is t_1 °C. The amount of heat delivered to the room for each joule of electrical energy consumed ideally will be

[NEET (Phase-2)-2016]

(1) $\frac{t_1}{t_1 - t_2}$

(2) $\frac{t_1 + 273}{t_1 - t_2}$

(3) $\frac{t_2 + 273}{t_1 - t_2}$

(4) $\frac{t_1 + t_2}{t_1 + 273}$

5. A refrigerator works between 4°C and 30°C. It is required to remove 600 calories of heat every second in order to keep the temperature of the refrigerated space constant. The power required is (Take 1 cal = 4.2 J) **[NEET-2016]**

(1) 2365 W

(2) 2.365 W

(3) 23.65 W

(4) 236.5 W

6. A gas is compressed isothermally to half its initial volume. The same gas is compressed separately through an adiabatic process until its volume is again reduced to half. Then **[NEET-2016]**

(1) Which of the case (whether compression through isothermal or through adiabatic process) requires more work will depend upon the atomicity of the gas

(2) Compressing the gas isothermally will require more work to be done

(3) Compressing the gas through adiabatic process will require more work to be done

(4) Compressing the gas isothermally or adiabatically will require the same amount of work

7. 4.0 g of a gas occupies 22.4 litres at NTP. The specific heat capacity of the gas at constant volume is 5.0 $JK^{-1}\ mol^{-1}$. If the speed of sound in this gas at NTP is 952 ms^{-1}, then the heat capacity at constant pressure is (Take gas constant R = 8.3 $JK^{-1}\ mol^{-1}$) **[Re-AIPMT-2015]**

   (1) 8.5 $JK^{-1}\ mol^{-1}$

   (2) 8.0 $JK^{-1}\ mol^{-1}$

   (3) 7.5 $JK^{-1}\ mol^{-1}$

   (4) 7.0 $JK^{-1}\ mol^{-1}$

8. The coefficient of performance of a refrigerator is 5. If the temperature inside freezer is –20°C, the temperature of the surroundings to which it rejects heat is **[Re-AIPMT-2015]**

   (1) 21°C

   (2) 31°C

   (3) 41°C

   (4) 11°C

9. An ideal gas is compressed to half its initial volume by means of several processes. Which of the process results in the maximum work done on the gas? **[Re-AIPMT-2015]**

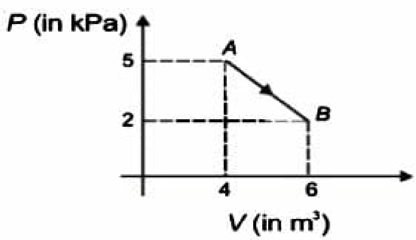
   (1) Isothermal

   (2) Adiabatic

   (3) Isobaric

   (4) Isochoric

10. One mole of an ideal diatomic gas undergoes a transition from A to B along a path AB as shown in the figure



The change in internal energy of the gas during the transition is **[AIPMT-2015]**

   (1) –12 kJ

   (2) 20 kJ

   (3) –20 kJ

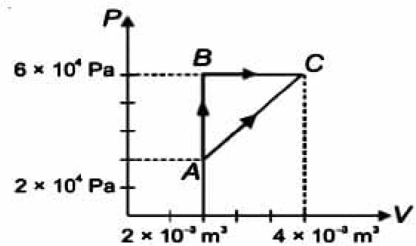
   (4) 20 J

11. A Carnot engine, having an efficiency of $\eta = \frac{1}{10}$ as heat engine, is used as a refrigerator. If the work done on the system is 10 J, the amount of energy absorbed from the reservoir at lower temperature is **[AIPMT-2015]**

   (1) 1 J (2) 100 J

   (3) 99 J (4) 90 J

12. Figure below shows two paths that may be taken by a gas to go from a state A to a state C. In process AB, 400 J of heat is added to the system and in process BC, 100 J of heat is added to the system. The heat absorbed by the system in the process AC will be **[AIPMT-2015]**



   (1) 300 J (2) 380 J

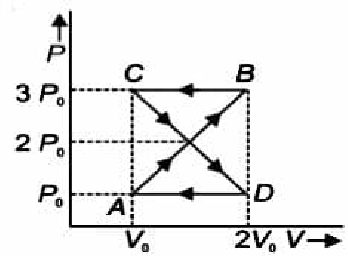
   (3) 500 J (4) 460 J

13. A monoatomic gas at a pressure P, having a volume V expands isothermally to a volume $2V$ and then adiabatically to a volume $16V$. the final pressure of the gas is: (take $\gamma = 5/3$) **[AIPMT-2014]**

   (1) $64P$ (2) $32P$

   (3) $P/64$ (4) $16P$

14. A thermodynamic system undergoes cyclic process $ABCDA$ as shown in figure. The work done by the system in the cycle is



[AIPMT-2014]

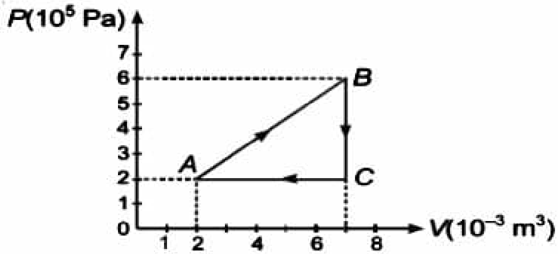
   (1) $P_0 V_0$

   (2) $2P_0 V_0$

   (3) $\frac{P_0 V_0}{2}$

   (4) Zero

15. A gas is taken through the cycle $A \rightarrow B \rightarrow C \rightarrow A$, as shown. What is the net work done by the gas?



[NEET-2013]

(1) 1000 J
(2) Zero
(3) – 2000 J
(4) 2000 J

16. The molar specific heats of an ideal gas at constant pressure and volume are denoted by C_p and C_v respectively. If $\gamma = \frac{C_p}{C_v}$ and R is the universal gas constant, then C_v is equal to [NEET-2013]

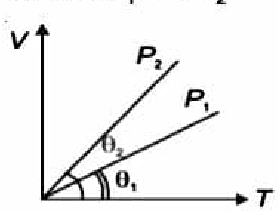
(1) $\frac{R}{(\gamma - 1)}$
(2) $\frac{(\gamma - 1)}{R}$
(3) γR
(4) $\frac{1+\gamma}{1-\gamma}$

17. During an adiabatic process, the pressure of a gas is found to be proportional to the cube of its temperature. The ratio of $\frac{C_p}{C_v}$ for the gas is:

[NEET-2013]

(1) 2
(2) $\frac{5}{3}$
(3) $\frac{3}{2}$
(4) $\frac{4}{3}$

18. In the given $(V - T)$ diagram, what is the relation between pressures P_1 and P_2?

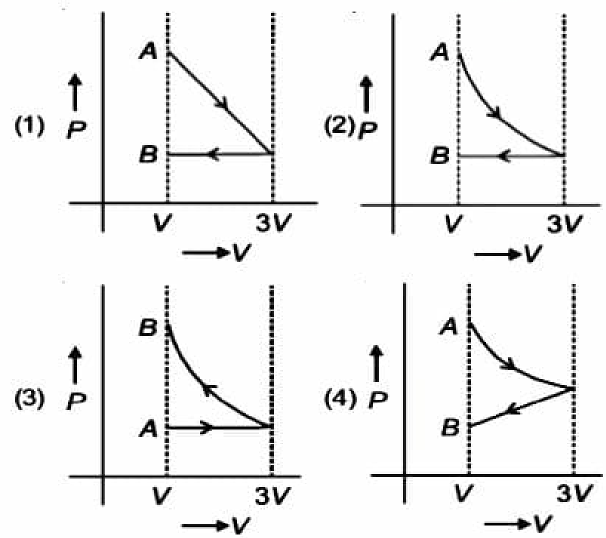


[NEET-2013]

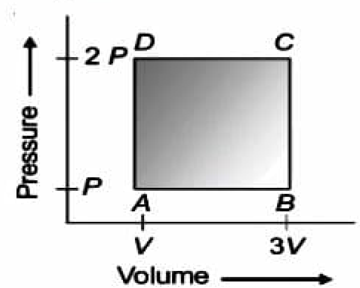
(1) $P_2 > P_1$
(2) $P_2 < P_1$
(3) Cannot be predicted
(4) $P_2 = P_1$

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

[AIPMT (Prelims)-2012]



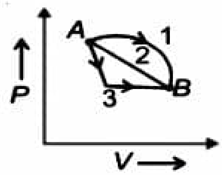
20. A thermodynamic system is taken through the cycle $ABCD$ as shown in figure. Heat rejected by the gas during the cycle is



[AIPMT (Prelims)-2012]

(1) $\frac{1}{2} PV$
(2) PV
(3) $2\ PV$
(4) $4\ PV$

21. An ideal gas goes from state A to state B via three different processes as indicated in the P-V diagram



If Q_1, Q_2, Q_3 indicate the heat absorbed by the gas along the three processes and ΔU_1, ΔU_2, ΔU_3 indicate the change in internal energy along the three processes respectively, then

[AIPMT (Mains)-2012]

(1) $Q_1 > Q_2 > Q_3$ and $\Delta U_1 = \Delta U_2 = \Delta U_3$

(2) $Q_3 > Q_2 > Q_1$ and $\Delta U_1 = \Delta U_2 = \Delta U_3$

(3) $Q_1 = Q_2 = Q_3$ and $\Delta U_1 > \Delta U_2 > \Delta U_3$

(4) $Q_3 > Q_2 > Q_1$ and $\Delta U_1 > \Delta U_2 > \Delta U_3$

22. During an isothermal expansion, a confined ideal gas does –150 J of work against its surroundings. This implies that **[AIPMT (Prelims)-2011]**

(1) 150 J of heat has been added to the gas

(2) 150 J of heat has been removed from the gas

(3) 300 J of heat has been added to the gas

(4) No heat is transferred because the process is isothermal

23. A mass of diatomic gas ($\gamma = 1.4$) at a pressure of 2 atmospheres is compressed adiabatically so that its temperature rises from 27°C to 927°C. The pressure of the gas in the final state is

[AIPMT (Mains)-2011]

(1) 256 atm (2) 8 atm

(3) 28 atm (4) 68.7 atm

24. If ΔU and ΔW represent the increase in internal energy and work done by the system respectively in a thermodynamical process, which of the following is true? **[AIPMT (Prelims)-2010]**

(1) $\Delta U = -\Delta W$, in a isothermal process

(2) $\Delta U = -\Delta W$, in a adiabatic process

(3) $\Delta U = \Delta W$, in a isothermal process

(4) $\Delta U = \Delta W$, in a adiabatic process

25. If C_p and C_v denote the specific heats (per unit mass) of an ideal gas of molecular weight M, where R is the molar gas constant **[AIPMT (Mains)-2010]**

(1) $C_p - C_v = R/M^2$ (2) $C_p - C_v = R$

(3) $C_p - C_v = R/M$ (4) $C_p - C_v = MR$

26. A monoatomic gas at pressure P_1 and V_1 is compressed adiabatically to $\frac{1}{8}$th its original volume. What is the final pressure of the gas?

[AIPMT (Mains)-2010]

(1) $64\ P_1$ (2) P_1

(3) $16\ P_1$ (4) $32\ P_1$

27. In thermodynamic processes which of the following statements is not true? **[AIPMT (Prelims)-2009]**

(1) In an isochoric process pressure remains constant

(2) In an isothermal process the temperature remains constant

(3) In an adiabatic process PV^{γ} = constant

(4) In an adiabatic process the system is insulated from the surroundings

28. The internal energy change in a system that has absorbed 2 Kcals of heat and done 500 J of work is **[AIPMT (Prelims)-2009]**

(1) 6400 J (2) 5400 J

(3) 7900 J (4) 8900 J

29. If Q, E and W denote respectively the heat added, change in internal energy and the work done in a closed cycle process, then

[AIPMT (Prelims)-2008]

(1) $Q = 0$

(2) $W = 0$

(3) $Q = W = 0$

(4) $E = 0$

30. At 10°C the value of the density of a fixed mass of an ideal gas divided by its pressure is x. At 110°C this ratio is **[AIPMT (Prelims)-2008]**

(1) $\frac{283}{383}x$ (2) x

(3) $\frac{383}{283}x$ (4) $\frac{10}{110}x$

31. An engine has an efficiency of 1/6. When the temperature of sink is reduced by 62°C, its efficiency is doubled. Temperature of the source is

[AIPMT (Prelims)-2007]

(1) 99°C

(2) 124°C

(3) 37°C

(4) 62°C

32. 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? **[AIPMT (Prelims)-2006]**

(1) 275 K (2) 325 K
(3) 250 K (4) 380 K

33. The molar specific heat at constant pressure of an ideal gas is $\frac{7}{2}R$. The ratio of specific heat at constant pressure to that at constant volume is : **[AIPMT (Prelims)-2006]**

(1) $\frac{7}{5}$ (2) $\frac{8}{7}$
(3) $\frac{5}{7}$ (4) $\frac{9}{7}$

34. Which of the following processes is reversible ? **[AIPMT (Prelims)-2005]**

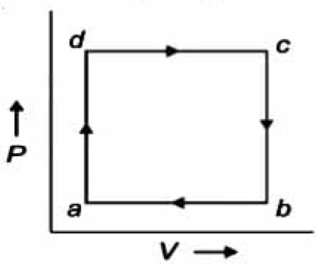
(1) Transfer of heat by radiation
(2) Electrical heating of a nichrome wire
(3) Transfer of heat by conduction
(4) Isothermal compression

35. 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 to work is **[AIPMT (Prelims)-2005]**

(1) 2.4×10^4 cal (2) 6×10^4 cal
(3) 1.2×10^4 cal (4) 4.8×10^4 cal

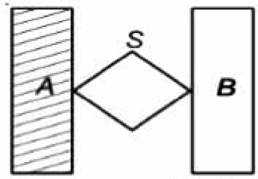
Questions asked Prior to Medical Ent. Exams. 2005

36. A system is taken from state *a* to state *c* by two paths *adc* and *abc* as shown in the figure. The internal energy at *a* is $U_a = 10$ J. Along the path *adc* the amount of heat absorbed $\delta Q_1 = 50$ J and the work obtained $\delta W_1 = 20$ J whereas along the path abc the heat absorbed $\delta Q_2 = 36$ J. The amount of work along the path *abc* is



(1) 6 J (2) 10 J
(3) 12 J (4) 36 J

37. Consider two insulated chambers (*A*, *B*) of same volume connected by a closed knob, *S*. 1 mole of perfect gas is confined in chamber *A*. What is the change in entropy of gas when knob *S* is opened? $R = 8.31$ J $mol^{-1}K^{-1}$.



(1) 1.46 J/K (2) 3.46 J/K
(3) 5.46 J/K (4) 7.46 J/K

38. A Carnot engine has efficiency 25%. It operates between reservoirs of constant temperatures with temperature difference of 80°C. What is the temperature of the low-temperature reservoir?

(1) –25°C (2) 25°C
(3) –33°C (4) 33°C

39. In an adiabatic change, the pressure and temperature of a monatomic gas are related as $P \propto T^c$, where *c* equals

(1) $\frac{3}{5}$ (2) $\frac{5}{3}$
(3) $\frac{2}{5}$ (4) $\frac{5}{2}$

40. An ideal Carnot engine, whose efficiency is 40%, receives heat at 500 K. If its efficiency is 50%, then the intake temperature for the same exhaust temperature is

(1) 800 K (2) 900 K
(3) 600 K (4) 700 K

41. A monatomic gas initially at 18°C is compressed adiabatically to one eighth of its original volume. The temperature after compression will be

(1) 1164 K (2) 144 K
(3) 18 K (4) 887.4 K

42. An ideal gas, undergoing adiabatic change, has which of the following pressure temperature relationship?

(1) $P^{\gamma}T^{1-\gamma}$ = constant (2) $P^{1-\gamma}T^{\gamma}$ = constant
(3) $P^{\gamma-1}T^{\gamma}$ = constant (4) $P^{\gamma}T^{\gamma-1}$ = constant

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

(1) Adiabatic
(2) Equal in all cases
(3) Isothermal
(4) Isobaric

44. The efficiency of a Carnot engine operating with reservoir temperature of 100°C and – 23°C will be

(1) $\frac{373+250}{373}$ (2) $\frac{373-250}{373}$

(3) $\frac{100+23}{100}$ (4) $\frac{100-23}{100}$

45. We consider a thermodynamic system. If ΔU represents the increase in its internal energy and W the work done by the system, which of the following statements is true?

(1) $\Delta U = -W$ in an isothermal process

(2) $\Delta U = W$ in an isothermal process

(3) $\Delta U = -W$ in an adiabatic process

(4) $\Delta U = W$ in an adiabatic process

46. If the ratio of specific heat of a 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

(1) $\frac{PV}{(\gamma-1)}$ (2) PV

(3) $\frac{R}{(\gamma-1)}$ (4) $\frac{\gamma PV}{(\gamma-1)}$

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

(1) 275 K (2) 375 K

(3) 475 K (4) 175 K

48. Two Carnot engines A and B are operated in series. The engine A receives heat from the source at temperature T_1 and rejects the heat to the sink at temperature T. The second engine B receives the heat at temperature T and rejects to its sink at temperature T_2. For what value of T the efficiencies of the two engines are equal?

(1) $\frac{T_1+T_2}{2}$ (2) $\frac{T_1-T_2}{2}$

(3) T_1T_2 (4) $\sqrt{T_1T_2}$

49. The (W/Q) of a Carnot engine is 1/6. Now the temperature of sink is reduced by 62°C, then this ratio becomes twice, therefore the initial temperature of the sink and source are respectively

(1) 33°C, 67°C

(2) 37°C, 99°C

(3) 67°C, 33°C

(4) 97K, 37K

50. A scientist says that the efficiency of his heat engine which works at source temperature 127°C and sink temperature 27°C is 26%, then

(1) It is impossible

(2) It is possible but less probable

(3) It is quite probable

(4) Data are incomplete

51. The efficiency of Carnot engine is 50% and temperature of sink is 500 K. If temperature of source is kept constant and its efficiency raised to 60%, then the required temperature of sink will be

(1) 100 K (2) 600 K

(3) 400 K (4) 500 K

52. An ideal gas heat engine operates in a Carnot cycle between 227°C and 127°C. It absorbs 6 kcal at the higher temperature. The amount of heat (in kcal) converted into work is equal to

(1) 4.8 (2) 3.5

(3) 1.6 (4) 1.2

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

(1) $(T + 2.4)$ K (2) $(T - 2.4)$ K

(3) $(T + 4)$ K (4) $(T - 4)$ K

54. The amount of heat energy required to raise the temperature of 1 g of Helium at NTP, from T_1K to T_2K is

(1) $\frac{3}{2}N_a k_B(T_2 - T_1)$ (2) $\frac{3}{4}N_a k_B(T_2 - T_1)$

(3) $\frac{3}{4}N_a k_B\left(\frac{T_2}{T_1}\right)$ (4) $\frac{3}{8}N_a k_B(T_2 - T_1)$

55. Which of the following relations does not give the equation of an adiabatic process, where terms have their usual meaning?

(1) $P^{\gamma}.T^{1-\gamma}$ = constant (2) $P^{1-\gamma}T^{\gamma}$ = constant

(3) PV^{γ} = constant (4) $TV^{\gamma-1}$ = constant

56. According to C.E. van der Waal, the interatomic potential varies with the average interatomic distance (R) as

(1) R^{-1} (2) R^{-2}

(3) R^{-4} (4) R^{-6}

57. In a vessel, the gas is at a pressure P. If the mass of all the molecules is halved and their speed is doubled, then the resultant pressure will be

(1) $4P$ (2) $2P$

(3) P (4) $P/2$

58. The mean free path of collision of gas molecules varies with its diameter (d) of the molecules as

(1) d^{-1} (2) d^{-2}

(3) d^{-3} (4) d^{-4}

59. At 0 K, which of the following properties of a gas will be zero?

(1) Volume (2) Density

(3) Kinetic energy (4) Potential energy

60. The value of critical temperature in terms of van der Waals' constants a and b is given by

(1) $T_C = \frac{8a}{27Rb}$ (2) $T_C = \frac{27a}{8Rb}$

(3) $T_C = \frac{a}{2Rb}$ (4) $T_C = \frac{a}{27Rb}$

61. The degrees of freedom of a triatomic gas is

(Consider moderate temperature)

(1) 6 (2) 4

(3) 2 (4) 8

62. To find out degree of freedom, the expression is

(1) $f = \frac{2}{\gamma - 1}$ (2) $f = \frac{\gamma + 1}{2}$

(3) $f = \frac{2}{\gamma + 1}$ (4) $f = \frac{1}{\gamma + 1}$

63. The equation of state for 5 g of oxygen at a pressure P and temperature T, when occupying a volume V, will be (where R is the gas constant)

(1) $PV = \frac{5}{32}RT$ (2) $PV = 5RT$

(3) $PV = \frac{5}{2}RT$ (4) $PV = \frac{5}{16}RT$

SECTION - D

Assertion - Reason Type Questions

In the following questions, a statement of assertion (A) is followed by a statement of reason (R)

(1) If both Assertion & Reason are true and the reason is the correct explanation of the assertion, then mark **(1)**.

(2) If both Assertion & Reason are true but the reason is not the correct explanation of the assertion, then mark **(2)**.

(3) If Assertion is true statement but Reason is false, then mark **(3)**.

(4) If both Assertion and Reason are false statements, then mark **(4)**.

1. A : Work done by a gas in isothermal expansion is more than the work done by the gas in the same expansion adiabatically.

   R : Temperature remains constant in isothermal expansion and not in adiabatic expansion

2. A : Efficiency of heat engine can never be 100%.

   R : Second law of thermodynamics puts a limitation on the efficiency of a heat engine.

3. A : Heat absorbed in a cyclic process is zero.

   R : Work done in a cyclic process is zero.

4. A : Coefficient of performance of a refrigerator is always greater than 1.

   R : Efficiency of heat engine is greater than 1.

5. A : Adiabatic expansion causes cooling.

   R : In adiabatic expansion, internal energy is used up in doing work.

6. A : The specific heat of an ideal gas is zero in an adiabatic process.

   R : Specific heat of a gas is process independent.

7. A : The change in internal energy does not depend on the path of process.

   R : The internal energy of an ideal gas is independent of the configuration of its molecules.

8. A : Heat supplied to a gaseous system in an isothermal process is used to do work against surroundings.

   R : During isothermal process there is no change in internal energy of the system.

9. A : In nature all thermodynamic processes are irreversible.

   R : During a thermodynamic process it is not possible to eliminate dissipative effects.

10. A : During a cyclic process work done by the system is zero.

    R : Heat supplied to a system in the cyclic process converts into internal energy of the system.