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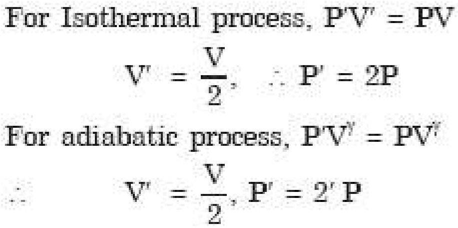
1 A refrigerator cools a body cooler than its surroundings. Does this violate the law of conservation of energy ? **2**

Ans :
No, since the compressor works on the system to cool the body cooler than the surrounding. If W work is done to take Q_2 amount of energy from and pass Q_1 energy to the sink (surrounding) then,
$W = Q_1 - Q_2$

2 What is an indicator diagram ? What is its significance ? **2**

Ans :
An indicator diagram is a P–V graph showing the variation of pressure and volume during a thermodynamical process. It gives us : (i) the nature of process, (ii) the work done during the process.

3 Which of the two will increase the pressure more–an adiabatic or an isothermal process in reducing the volume to 50% ? **2**

Ans :

For Isothermal process, $P'V' = PV$

$$V' = \frac{V}{2}, \quad \therefore P' = 2P$$

For adiabatic process, $P'V'^{\gamma} = PV^{\gamma}$

$$\therefore \quad V' = \frac{V}{2}, P' = 2^{\gamma} P$$

Since γ > 1, the adiabatic process will increase the pressure more.

4 Why does the brake drum of an automobile get heated up while moving down at constant speed ? **2**

Ans :
To make the vehicle to move at constant speed, constantly the brake has to be applied to work against the available energy. So, it gets heated up.

5 Can two isothermal curves intersect ? Why ? **2**

Ans :
No, since then for two different sets of physical parameters the system may be identified, leading to different states.

6 What is the energy required for 1 gm of ice to become steam ? **2**

Ans : Latent heat of fusion = 80 cal/gm
Latent heat of vapourisation = 540 cal/gm
Specific heat of water = 1 cal/gm °C
Energy required to make 1 gm of ice to vapour
= 1 × 80 + 1 × 1 (100 – 0) + 540
= 80 + 100 + 540 = 720 calories

7 State the law of equi-partition of energy. What is the internal energy with mono, di and tri-atomic gases ? **2**

Ans :
Law of equi-partition of energy states that every degree of freedom will provide the same amount of energy to the internal energy of the system, i.e., $\frac{1}{2}\mathrm{RT}$. Internal energy with mono, di and tri-atomic gas is, $\frac{3}{2}\mathrm{R}, \frac{5}{2}\mathrm{R}$ and $\frac{7}{2}\mathrm{R}$ respectively.

8 What is the significance of critical temperature ? **2**

Ans :
The critical temperature is the temperature beyond which a gas cannot be liquefied, whatever large the pressure applied may be.

9 What does the flat portion in an isotherm indicate ? **2**

Ans :
Flat portion refers to the transition from gas to liquid as the gas is compressed. As temperature increases, the flat portion’s size reduces.

10 How the atmosphere is important thermodynamically ? **2**

Ans :

The atmosphere is important thermodynamically because
(i) the temperature difference brings wind.
(ii) the reflected energy from surface is prevented from escaping so that appropriate life supporting temperature exists.

11 Calculate the fall in temperature of helium initially at 15 °C, when it is suddenly expanded to 8 times of its volume. Given γ = 5/3. **2**

Ans : $T_1 = 273 + 15 = 288$ K, $T_2 = ?$

$V_2 = 8\ V_1,\ \gamma = 5/3$

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

$$T_2 = T_1 \left(\frac{V_1}{V_2}\right)^{\gamma-1};\ T_2 = 288 \left(\frac{V_1}{8V_1}\right)^{\frac{5}{3}-1}$$

$$\log T_2 = \log 288 + \frac{2}{3} \log \left(\frac{1}{8}\right) = 1.8573$$

$T_2 = \text{antilog } 1.8573 = 71.99$ K

Fall in temperature of helium,

$T_1 - T_2 = 288 - 71.99 = 216.01$ K

12 Define temperature on the basis of the zeroth law of thermodynamics. **2**

Ans :

Temperature is a scalar physical quantity and is a property of all thermodynamic systems (in equilibrium states) such that temperature equality is a necessary and sufficient condition for thermal equilibrium.

13 What is an isothermal process ?
Also give essential conditions for an isothermal process to take place. **2**

Ans :

A change in pressure and volume of a gas without any change in its temperature is called an isothermal process. Two essential conditions for perfect isothermal process are :
(i) The walls of the container must be perfectly conducting to allow free exchange of heat between the gas and its surrounding.
(ii) The process of compression or expansion should be slow so as to provide time for exchange of heat.

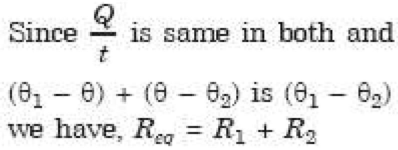
14 What do you mean by the ‘phases’ of a substance ? **2**

Ans :

The three states of a substance, namely solid, liquid and gas are called its phases. Whenever a substance can occur in several forms which are homogeneous, physically distinct, and mechanically separable from each other, the forms are called the phases of the same substance. The phases of a substance generally involve either absorption or evolution of heat.

15 When two conductors having thermal resistances R1 and R2 are joined end to end and placed between two reservoirs, find the equivalent thermal resistance. **2**

Ans :



Since $\frac{Q}{t}$ is same in both and

$(\theta_1 - \theta) + (\theta - \theta_2)$ is $(\theta_1 - \theta_2)$

we have, $R_{eq} = R_1 + R_2$

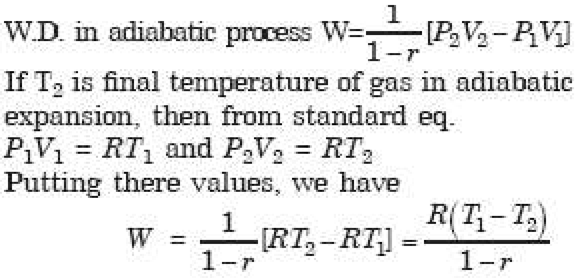
16 Can a room be cooled by leaving the door of an electric refrigerator open ? **2**

Ans :

No, the room cannot be cooled by leaving the door of an electric refrigerator open. In fact, the temperature of the room rises because the refrigerator extracts heat from the freezing chambers and rejects it to the surrounding air in the room.

17 A system containing one mole of an ideal gas is expanded adiabatically. If the temperature falls from T_1 to T_2, find the work done by the gas. **2**

Ans :



W.D. in adiabatic process $W=\frac{1}{1-r}[P_2V_2 - P_1V_1]$

If T_2 is final temperature of gas in adiabatic expansion, then from standard eq.

$P_1V_1 = RT_1$ and $P_2V_2 = RT_2$

Putting there values, we have

$$W = \frac{1}{1-r}[RT_2 - RT_1] = \frac{R(T_1 - T_2)}{1-r}$$

18 Define two principle specific heats of a gas. Which is greater and why ? **2**

Ans :

C_p : The amount of energy required for 1 mole of a gas to raise its temperature by 1 K at constant pressure condition.

C_v : The amount of energy required for 1 mole of a gas to raise its temperature by 1 K at constant volume conditions.

$C_p > C_v$ Since for constant pressure process, both volume and temperature are altered and for constant volume process, only temperature varies.

19 Give two properties of Carnot's engine as compared to other engines. (Carnot’s theorem). **2**

Ans :

(i) Efficiency is independent of fuel used.

(ii) No engine can have an efficiency greater than that of the Carnot’s engine.

20 What are the limitations of the first law of thermodynamics ? **2**

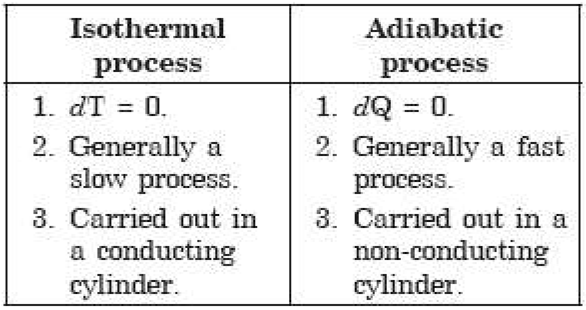
Ans : First law of thermodynamics did not tell us about

(i) the quick or slow nature of a process.

(ii) whether a process is possible or not.

21 Compare an isothermal and an adiabatic process. **2**

Ans :



Isothermal process	Adiabatic process
1. $dT = 0$.	1. $dQ = 0$.
2. Generally a slow process.	2. Generally a fast process.
3. Carried out in a conducting cylinder.	3. Carried out in a non-conducting cylinder.

22 A Carnot’s engine whose sink is at a temperature of 300 K has an efficiency of 40%. By how much should the temperature of the source be increased so as to increase the efficiency to 60% ? **3**

Ans : Let T be the temperature of the source.

$$\frac{40}{100} = \frac{T-300}{T} \text{ or } \frac{2}{5} = \frac{T-300}{T}$$

or $\qquad T = 500 \text{ K}$

Let the temperature be increased by θ, therefore

$$\frac{60}{100} = \frac{(T+\theta)-300}{(T+\theta)}$$

or $\qquad \frac{3}{5} = \frac{500+\theta-300}{500+\theta}$

or $\qquad \theta = \frac{500}{2} = 250 \text{ K}$

23 Obtain an expression for work done by a gas in an isothermal expansion. **3**

Ans : For a small change in volume, work done is given by $dW = P\,dV$.

We know, $PV = nRT \quad \therefore \; P = \frac{nRT}{V}$

For $\qquad T = \text{constant}, \; dW = nRT\,\frac{dV}{d}.$

Net work done under isothermal condition to change the volume from V_i to V_f is,

$$W = \int_{V_i}^{V_f} dW = nRT \int_{V_i}^{V_f} \frac{dV}{V}$$

$$= nRT\,\left|\log_e V\right|_{V_i}^{V_f}$$

$$= nRT\,\log_e\left(\frac{V_f}{V_i}\right)$$

$\therefore \qquad W = 2.3026\,nRT\,\log_{10}\left(\frac{V_f}{V_i}\right)$

where n is the number of moles. If P_f and P_i are the pressures, we can also write,

$$W = 2.3026\,nRT\,\log_{10}\left(\frac{P_i}{P_f}\right)$$

24 Show that an adiabatic curve is always steaper than an isothermal curve. **3**

Ans :

For Isothermal process, since PV = constant

$$\frac{dP}{P} = \frac{dV}{V}$$

But for an adiabatic process, since

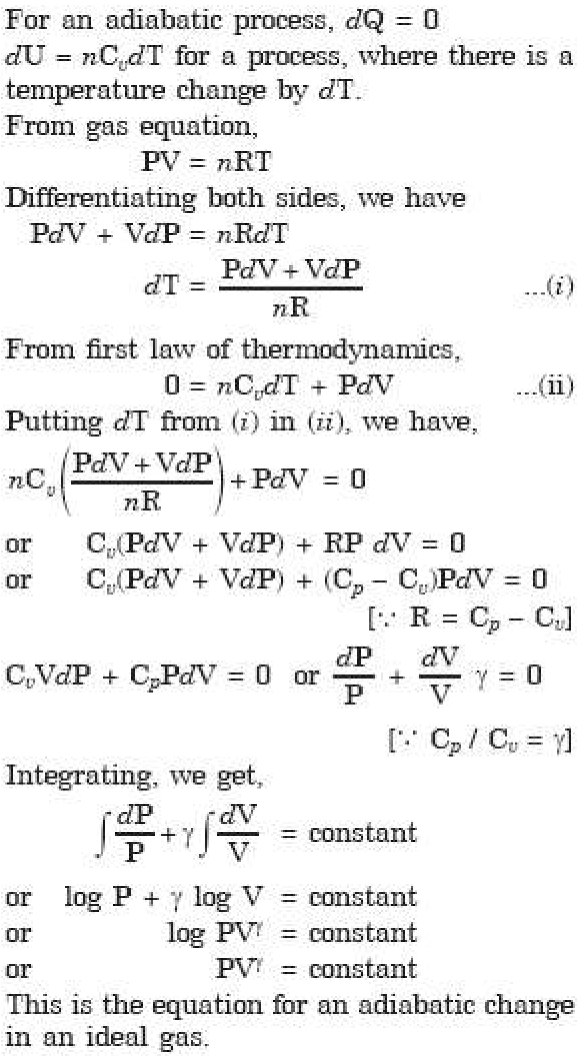
$$PV^{\gamma} = \text{constant},$$

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

So P–V graph is steaper for adiabatic process.

25 Prove that for an adiabatic process PV^{γ} = constant, where the symbols have their usual meanings. **3**

Ans :



For an adiabatic process, $dQ = 0$

$dU = nC_v dT$ for a process, where there is a temperature change by dT.

From gas equation,

$$PV = nRT$$

Differentiating both sides, we have

$$PdV + VdP = nRdT$$

$$dT = \frac{PdV + VdP}{nR} \quad \text{...(i)}$$

From first law of thermodynamics,

$$0 = nC_v dT + PdV \quad \text{...(ii)}$$

Putting dT from (*i*) in (*ii*), we have,

$$nC_v\left(\frac{PdV + VdP}{nR}\right) + PdV = 0$$

or $C_v(PdV + VdP) + RP\,dV = 0$

or $C_v(PdV + VdP) + (C_p - C_v)PdV = 0$

$[\because R = C_p - C_v]$

$$C_v VdP + C_p PdV = 0 \quad \text{or} \quad \frac{dP}{P} + \frac{dV}{V}\gamma = 0$$

$[\because C_p / C_v = \gamma]$

Integrating, we get,

$$\int \frac{dP}{P} + \gamma \int \frac{dV}{V} = \text{constant}$$

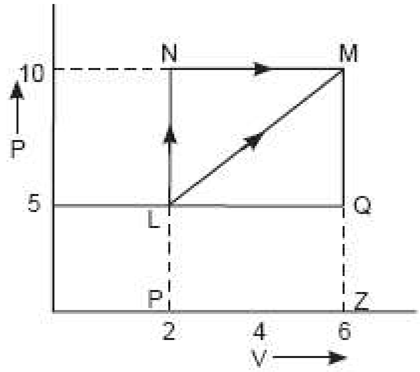
or $\log P + \gamma \log V$ = constant

or $\log PV^{\gamma}$ = constant

or PV^{γ} = constant

This is the equation for an adiabatic change in an ideal gas.

26 An ideal gas changes its state from L to M by two path LNM and LM. **3**



(i) Is the work done same for two paths ?

(ii) The internal energy of gas at L is 20 J and the amount of heat needed to change its state through LM is 400 J. What is the internal energy of gas at M ?

Ans : (*i*) $W_{LN} = PdV = 0$

$W_{NM} = P[V_M - V_N] = 10[6 - 2] = 40$ J

$W_{LNM} = W_{LN} + W_{NM} = 0 + 40 = 40$ J

Along LM W_{LM} = Area under the curve LM

= Area of ΔLMQ + Area of rectangle $LQZP$.

$= \frac{1}{2} \times LQ \times MQ + LP \times PZ$

$= \frac{1}{2} \times 4 \times 5 + 5 \times 4$

$= 10 + 20 = 30$ J

So work done is less along LM.

(*ii*) $U_L = 20$ J; $\Delta Q = 400$ J

$$dQ = dU + dW$$
$$= (U_M - U_L) + \Delta W_{LM}$$
$$U_M = dQ + U_L - \Delta W_{LM}$$
$$= 400 + 20 - 30$$
$$= 390 \text{ J}$$

27 What are reversible and irreversible processes ? Explain giving one example of each. **3**

Ans :

Reversible Process. It is a process which can be made to proceed in two opposite directions with same ease, so that the system and surroundings pass through exactly the same intermediate state as in the direct process. e.g., An ideal gas allowed to expand slowly and then compressed slowly so as to reach its initial state.

Irreversible Process. It is a process which can’t be made to proceed in the reverse direction with the same ease and the system does not pass through the same intermediate states as in direct processes. e.g., Decay of organic matter, rusting of iron.

28 What is meant by the term ‘Molar specific heat’ of a gas ? The molar specific heat of hydrogen in the temperature range of about 250 K to 750 K is about (5/2) R. At lower temperatures, the value of molar specific heat of hydrogen decreases to the value typical of monoatomic gases (3/2) R while at higher temperatures, it tends to the value (7/2) R. Explain. **3**

Ans :

Molar specific heat capacity of a gas refers to the amount of energy required for 1 mole of a substance to raise its temperature by 1 K. In the temperature beyond 70 K, rotational motion of H_2 gas starts. So at 250 K < T < 750 K, the number of degrees of freedom becomes five – 2 rotational and 3 translational.

$$\therefore \quad C_v = \frac{f}{2}R \text{ becomes } C_v = \frac{5}{2}R$$

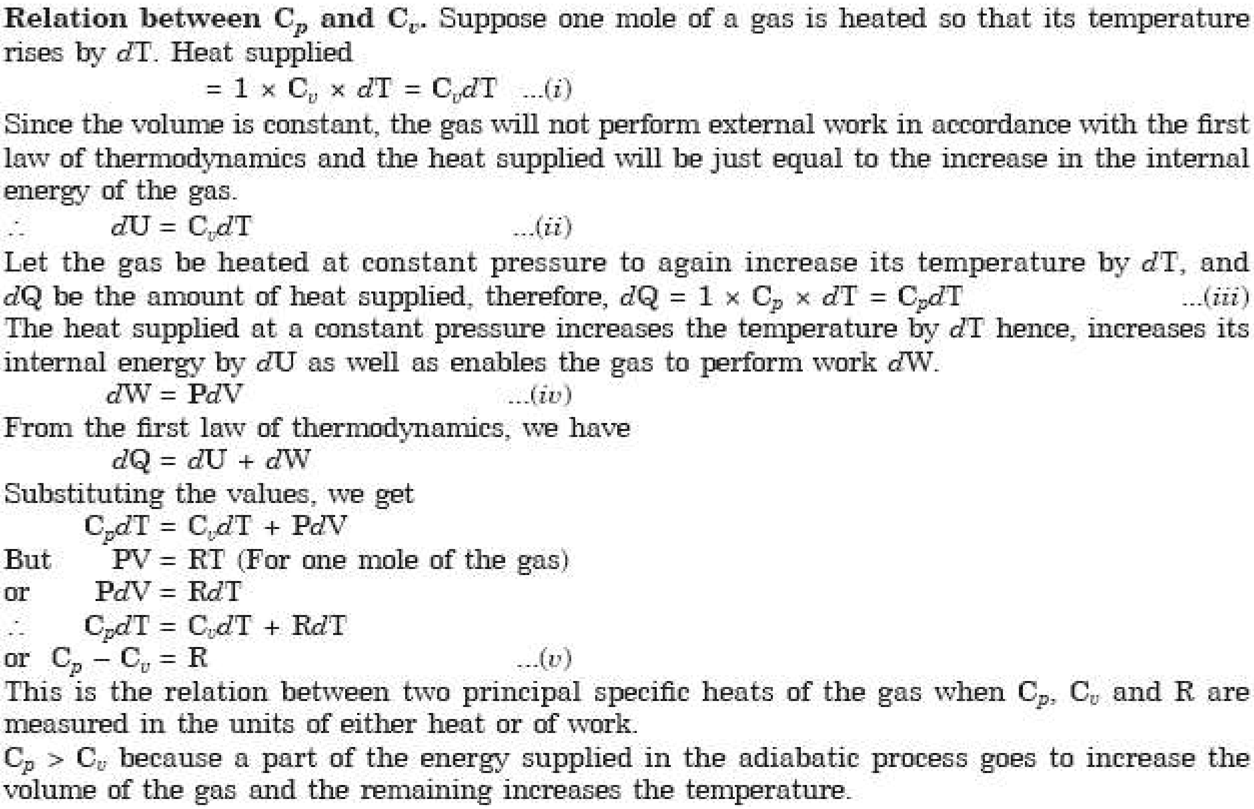
For lower temperatures only translational degrees of freedom will exist and no rotational freedom.

$\therefore \quad C_v = \frac{3}{2}R$

at higher temperature vibrational motion of H_2 also starts. So at T > 7.50 K, number of degrees of freedom are $C_v = \frac{7}{2}R$

29 Establish relation between two specific heats of a gas. Which is greater and why ? **3**

Ans :



Relation between C_p and C_v. Suppose one mole of a gas is heated so that its temperature rises by dT. Heat supplied

$$= 1 \times C_v \times dT = C_v dT \quad ...(i)$$

Since the volume is constant, the gas will not perform external work in accordance with the first law of thermodynamics and the heat supplied will be just equal to the increase in the internal energy of the gas.

$$\therefore \quad dU = C_v dT \quad ...(ii)$$

Let the gas be heated at constant pressure to again increase its temperature by dT, and dQ be the amount of heat supplied, therefore, $dQ = 1 \times C_p \times dT = C_p dT$ ...(iii)

The heat supplied at a constant pressure increases the temperature by dT hence, increases its internal energy by dU as well as enables the gas to perform work dW.

$$dW = PdV \quad ...(iv)$$

From the first law of thermodynamics, we have

$$dQ = dU + dW$$

Substituting the values, we get

$$C_p dT = C_v dT + PdV$$

But $\quad PV = RT$ (For one mole of the gas)

or $\quad PdV = RdT$

$$\therefore \quad C_p dT = C_v dT + RdT$$

or $\quad C_p - C_v = R \quad ...(v)$

This is the relation between two principal specific heats of the gas when C_p, C_v and R are measured in the units of either heat or of work.

$C_p > C_v$ because a part of the energy supplied in the adiabatic process goes to increase the volume of the gas and the remaining increases the temperature.

30 Explain why **3**

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

(b) the coolant in a chemical or a nuclear plant (i.e., the liquid used to prevent the different parts of a plant from getting too hot) should have high specific heat.

(c) air pressure in a car tyre increases during driving.

(d) the climate of a harbour town is more temperate than that of a town in a desert at the same latitude.

Ans :

(a) In thermal contact, heat flows from the body at higher temperature to the body at lower temperature till temperature become equal. The final temperature can be mean temperature $\frac{(T_1 + T_2)}{2}$ only when thermal capacities of the two bodies are equal.

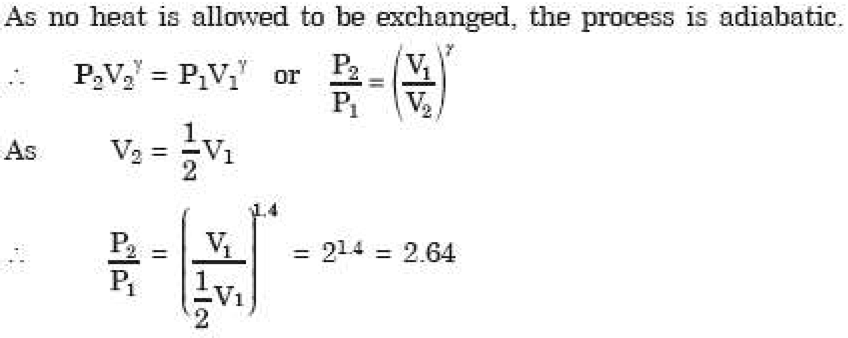
(b) This is because heat absorbed by a substance is directly proportional to the specific heat of the substance.

(c) During driving, the temperature of air inside the tyre increases due to motion. According to Charle's law, P ∝ T. Therefore, air pressure inside the tyre increases.

(d) This is because in a harbour town, the relative humidity is more than in a desert town. Hence, the climate of a harbour town is without extremes of hot and cold.

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

Ans :



As no heat is allowed to be exchanged, the process is adiabatic.

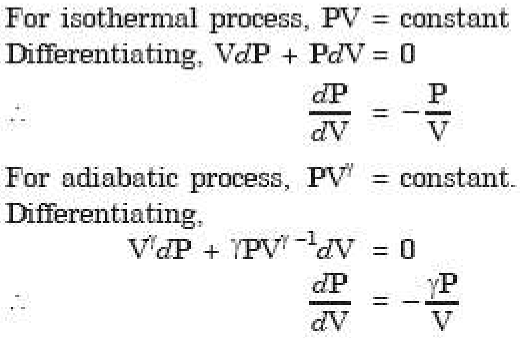
$$\therefore \quad P_2V_2^{\gamma} = P_1V_1^{\gamma} \quad \text{or} \quad \frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^{\gamma}$$

As $\quad V_2 = \frac{1}{2}V_1$

$$\therefore \quad \frac{P_2}{P_1} = \left(\frac{V_1}{\frac{1}{2}V_1}\right)^{1.4} = 2^{1.4} = 2.64$$

32 Prove that the slope of P–V graph for an adiabatic process is γ times that of the isothermal process. **3**

Ans :



For isothermal process, PV = constant

Differentiating, $VdP + PdV = 0$

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

For adiabatic process, PV^{γ} = constant.

Differentiating,

$$V^{\gamma}dP + \gamma PV^{\gamma-1}dV = 0$$

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

Comparing the two ratios, we can say, slope of adiabatic process is γ times the slope of isothermal process.

33 State the first law of thermodynamics. List the sign conventions used in the energy dealt by the law. **3**

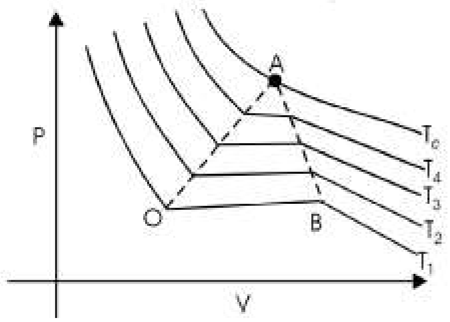
Ans :

According to the first law of thermodynamics, the total heat energy change dQ is the sum of the internal energy change dU and work done dW, i.e., $dQ = dU + dW$.
Heat energy given to the system is +ve, taken out is –ve. Internal energy change is +ve with increase in temperature. Work done is +ve if volume increases and –ve if volume decreases.

34 What is the Internal energy in the process of vapourisation ? **3**

Ans :

During vapourisation, volume increases. So work done = $P(V_f - V_i)$ and temperature does not change. So, $dQ = mL_v$. $\therefore$ from first law of thermodynamics, $dU = dQ - dW = mL_v - P(V_f - V_i)$.



35 What are isotherms ? Explain the process of liquiefication using it. **3**

Ans :

Isotherms are P–V graphs drawn at same temperature. When pressure is increased, volume is reduced at constant temperature. Beyond certain level, the pressure remains same for certain reduction in volume and then the pressure increases sharply. As temperature is increased, the constant portion reduces and at a temperature called critical temperature, the flat portion is absent. In each isotherm, before the flat portion is reached, the substance is in gaseous state and beyond the flat portion, it is in the liquid state. During the flat portion of P–V graph, the gas is under liquefication and so both gaseous and liquid states co-exist. Beyond Tc, it is not possible to liquefy the gas whatever large the pressure may be.

36 Define molar specific heat. Write its units. **3**

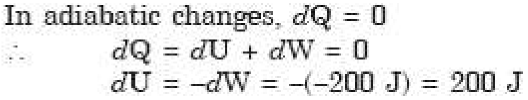
Ans :

Molar specific heat is defined as the amount of heat required to raise the temperature of one mole of a gas through 1 K at constant volume or at constant pressure.

If the volume is constant, it is called the molar specific heat at constant volume. Similarly, if the pressure is constant, it is called the molar specific heat at constant pressure. It is expressed in J mol^{-1} K^{-1} or J mol^{-1} °C^{-1}.

37 200 J of work is done on a gas to reduce its volume by compressing it. If this change is done under adiabatic conditions, find out the change in internal energy of the gas and also the amount of heat absorbed by the gas. **3**

Ans :



In adiabatic changes, $dQ = 0$

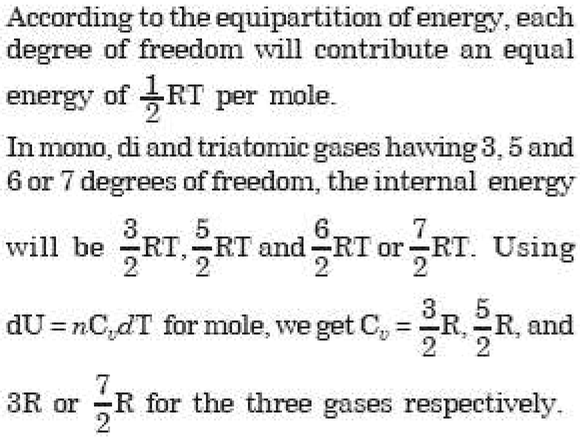
$\therefore \quad dQ = dU + dW = 0$

$dU = -dW = -(-200\text{ J}) = 200\text{ J}$

Internal energy increases by 200 J. Heat absorbed is zero.

38 State law of equi-partition of energy. Use this law to calculate specific heats of monoatomic, diatomic and triatomic gases. **3**

Ans :



According to the equipartition of energy, each degree of freedom will contribute an equal energy of $\frac{1}{2}RT$ per mole.

In mono, di and triatomic gases hawing 3, 5 and 6 or 7 degrees of freedom, the internal energy will be $\frac{3}{2}RT, \frac{5}{2}RT$ and $\frac{6}{2}RT$ or $\frac{7}{2}RT$. Using $dU = nC_v dT$ for mole, we get $C_v = \frac{3}{2}R, \frac{5}{2}R$, and $3R$ or $\frac{7}{2}R$ for the three gases respectively.

39 What is a thermostat ? Briefly explain its principle. **3**

Ans :

It is a device that helps in maintaining a constant temperature. It consists of a bi-metallic strip which comprises of two thin strips of different materials (such as brass and invar) welded together along their lengths. On heating, this combination bends into an arc. It happens because brass has a higher coefficient of expansion than invar.

40 Two thermometers are constructed in the same way except that one has a spherical bulb and the other has an elongated cylindrical bulb. Which one will respond quickly to the temperature changes ? Why ? **3**

Ans :

Thermometer with the cylindrical bulb. It is because the area of a cylinderical surface is greater than a spherical surface. Therefore, mercury in the cylindrical bulb reaches the temperature of the surrounding earlier.

41 Differentiate between evaporation and boiling. **3**

Ans :

Evaporation is a slow process from the liquid to the gaseous state which takes place at the surface of a liquid and at all temperatures. Boiling is a rapid change of a substance from the liquid to the gaseous state which takes place throughout the mass of the liquid at a definite temperature.

42 Absolute zero temperature is not the temperature of zero energy. Explain. **3**

Ans :

At absolute zero, the energy of translatory motion of molecules ceases but the other forms of energy such as inter-molecular, potential energy of molecular motion, etc. do not become zero. Therefore, absolute temperature is not the temperature of zero energy.

43 What are ‘Super heated water’ and ‘Super cooled vapour’ ? **3**

Ans :

Water in liquid phase at a temperature above 100°C and a pressure more than 1 atm is called as super heated water. In a pressure cooker, water is heated at a pressure more than 1 atm and temperature above 100°C. Steam below temperature 100°C is called super-cooled vapour.

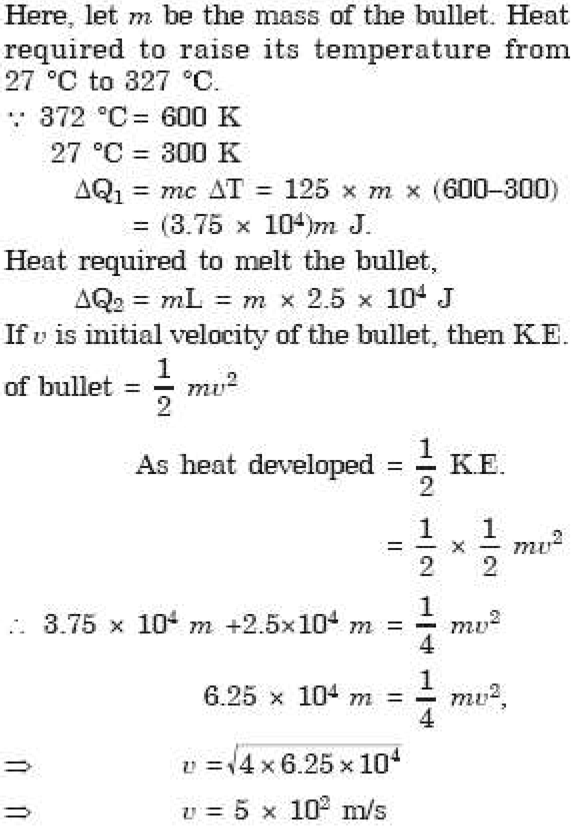
44 Distinguish between a cyclic process and a non-cyclic process. **3**

Ans :

A cyclic process is that in which the system returns to its initial state after under going a series of changes. A non-cyclic process is that in which the system does not return to its initial state.

45A lead bullet penetrates into a solid object and melts. Assuming that 50% of the K.E. was used to heat it, calculate the initial speed of the bullet. The initial temperature of bullet is 27 °C and its melting point is 327 °C. Latent heat of fusion of lead = 2.5×10^4 J kg^{-1} and sp. heat capacity of lead = 125 J kg^{-1} K^{-1}. **4**

Ans :



Here, let m be the mass of the bullet. Heat required to raise its temperature from 27 °C to 327 °C.

$\because$ 372 °C = 600 K

27 °C = 300 K

$$\Delta Q_1 = mc\,\Delta T = 125 \times m \times (600\text{–}300)$$
$$= (3.75 \times 10^4)m\ \text{J}.$$

Heat required to melt the bullet,

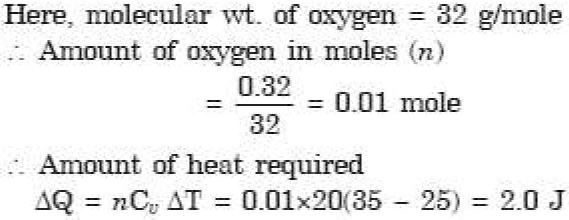
$$\Delta Q_2 = mL = m \times 2.5 \times 10^4\ \text{J}$$

If v is initial velocity of the bullet, then K.E. of bullet $= \frac{1}{2}mv^2$

$$\text{As heat developed} = \frac{1}{2}\ \text{K.E.}$$
$$= \frac{1}{2} \times \frac{1}{2}mv^2$$
$$\therefore\ 3.75 \times 10^4\,m + 2.5\times10^4\,m = \frac{1}{4}mv^2$$
$$6.25 \times 10^4\,m = \frac{1}{4}mv^2,$$
$$\Rightarrow\quad v = \sqrt{4 \times 6.25 \times 10^4}$$
$$\Rightarrow\quad v = 5 \times 10^2\ \text{m/s}$$

460.32 g of oxygen is kept in a rigid container and is heated. Find the amount of heat needed to raise the temperature from 25 °C to 35 °C. The molar heat capacity of oxygen at constant volume is 20 $Jmole^{-1}K^{-1}$. **4**

Ans :



Here, molecular wt. of oxygen = 32 g/mole

$\therefore$ Amount of oxygen in moles (n)

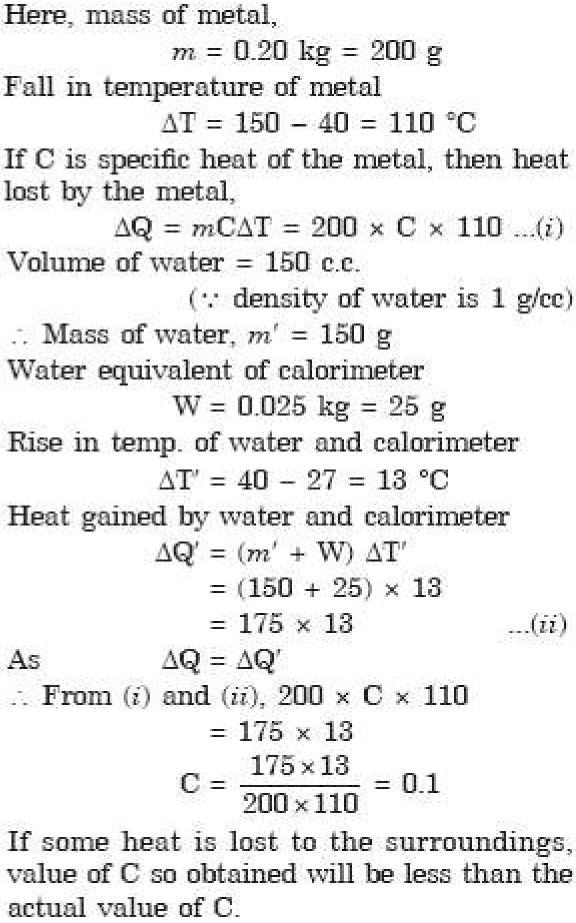
$$= \frac{0.32}{32} = 0.01\ \text{mole}$$

$\therefore$ Amount of heat required

$$\Delta Q = nC_v\,\Delta T = 0.01\times20(35 - 25) = 2.0\ \text{J}$$

47In an experiment on the specific heat of a metal, a 0.20 kg block of the metal at 150 °C is dropped in a copper calorimeter (of water equivalent 0.025 kg) containing 150 c.c. of water at 27 °C. The final temperature is 40 °C. Calculate the specific heat of the metal. If **4** heat losses to the surroundings are not negligible, is your answer greater or smaller than the actual value of specific heat of the metal ?

Ans :



Here, mass of metal,

$$m = 0.20 \text{ kg} = 200 \text{ g}$$

Fall in temperature of metal

$$\Delta T = 150 - 40 = 110\ ^\circ C$$

If C is specific heat of the metal, then heat lost by the metal,

$$\Delta Q = mC\Delta T = 200 \times C \times 110 \quad ...(i)$$

Volume of water = 150 c.c.

$$(\because \text{density of water is } 1 \text{ g/cc})$$

$\therefore$ Mass of water, $m' = 150$ g

Water equivalent of calorimeter

$$W = 0.025 \text{ kg} = 25 \text{ g}$$

Rise in temp. of water and calorimeter

$$\Delta T' = 40 - 27 = 13\ ^\circ C$$

Heat gained by water and calorimeter

$$\begin{aligned} \Delta Q' &= (m' + W)\,\Delta T' \\ &= (150 + 25) \times 13 \\ &= 175 \times 13 \qquad ...(ii) \end{aligned}$$

As $\quad \Delta Q = \Delta Q'$

$\therefore$ From (i) and (ii), $200 \times C \times 110$

$$= 175 \times 13$$

$$C = \frac{175 \times 13}{200 \times 110} = 0.1$$

If some heat is lost to the surroundings, value of C so obtained will be less than the actual value of C.

48 Calculate the heat required to convert 0.6 kg of ice at –20 °C, kept in a calorimeter to steam at 100 °C at atmospheric pressure. Given the specific heat capacity of ice = 2100 J $kg^{-1}K^{-1}$, specific heat capacity of water is 4186 J $kg^{-1}K^{-1}$, latent heat of ice = 3.35×10^5 J kg^{-1}, and latent heat of steam = 2.256 × 106 J kg^{-1}. **4**

Ans :

Heat required to convert ice at – 20°C to 0°C

$$Q_1 = m\, s_{ice}\, \Delta T_1$$
$$= 0.6 \times 2100 \times [0 - (-20)]$$
$$= 25200 \text{ J}$$

Heat required to melt ice at 0°C to water at 0°C.

$$Q_2 = m\, L_{ice} = 0.6 \times (3.35 \times 10^5)$$
$$= 201000 \text{ J.}$$

Heat required to convert water at 0°C to water at 100°C

$$Q_3 = m s_w\, \Delta T_2$$
$$= 0.6 \times 4186 \times (100 - 0)$$
$$= 251160 \text{ J.}$$

Heat required to convert water at 100 °C to steam at 100°C.

$$Q_4 = m\, L_{steam}$$
$$= 0.6 \times 2.256 \times 10^6$$
$$= 1353600 \text{ J}$$

Total heat spent $= Q_1 + Q_2 + Q_3 + Q_4$

$$= 1830960 = 1.8 \times 10^6 \text{ J}$$

49 A geyser heats water flowing at the rate of 3.0 litre per minute from 27 °C to 77 °C. If the geyser operates on a gas burner, what is the rate of combustion of fuel if its heat of combustion is 4.0×10^4 J/g ? **4**

Ans : Here, volume of water heated = 3.0 litre/min;

Mass of water heated

$$m = 3000 \text{ g/min}$$

Rise in temperature,

$$\Delta T = 77 - 27 = 50 \text{ °C}$$

Sp. heat of water,

$$C = 4.2 \text{ Jg}^{-1} \text{ °C}^{-1}$$

Amount of heat used,

$$\Delta Q = mc\,\Delta T = 3000 \times 4.2 \times 50$$
$$= 63 \times 10^4 \text{ J/min}$$

Heat of combustion

$$= 4 \times 10^4 \text{ J/g}$$

Rate of combustion of fuel

$$= \frac{63 \times 10^4}{4 \times 10^4} = 15.75 \text{ g/min}$$

50 A 10 kW drilling machine is used to drill a bore in a small aluminium block of mass 8.0 kg. How much is the rise in temperature of the block in 2.5 minutes assuming, 50% of power is used up in heating the machine itself or lost to the surroundings. Specific heat of aluminium = $0.91 \text{ J g}^{-1} \text{ °C}^{-1}$. **4**

Ans : Here, $P = 10\text{ kW} = 10^4\text{W}$

Mass, $m = 8.0\text{ kg} = 8 \times 10^3\text{ g}$

Rise in temp, $\Delta T = ?$

$t = 2.5\text{ min} = 2.5 \times 60 = 150\text{ s}$

Sp. heat, $c = 0.91\text{ Jg}^{-1}\,{}^\circ\text{C}^{-1}$

Total energy,

$P \times t = 10^4 \times 150 = 15 \times 10^5\text{ J}$

As 50% of energy is lost,

∴ Energy available,

$$\Delta Q = \frac{1}{2} \times 15 \times 10^5 = 7.5 \times 10^5\text{ J}$$

As $\Delta Q = mc\Delta T$

$$\therefore \quad \Delta T = \frac{\Delta Q}{mc} = \frac{7.5 \times 10^5}{8 \times 10^3 \times 0.91} = 103\ {}^\circ\text{C}$$

51 0.75 g of petroleum was burnt in a bomb calorimeter which contains 2 kg of water and has a water equivalent 500 grams. The rise in temp. was 3 °C. Determine the calorific value of petroleum. **4**

Ans : Heat absorbed by water,

$$Q_1 = cm\,\Delta T = 1 \times 2000 \times 3$$
$$= 6 \times 10^3\text{ cal}$$

Heat absorbed by calorimeter

$$Q_2 = W \times \Delta T = 500 \times 3$$
$$= 1.5 \times 10^3\text{ cal}$$

Total heat produced

$$= Q_1 + Q_2 = 7.5 \times 10^3\text{ cal}$$

Calorific value of fuel

$$= \frac{7.5 \times 10^3}{0.75} = 10^4\text{ cal/g}$$

52 How many grams of ice at −14 °C are needed to cool 200 grams of water from 25 °C to 10 °C ? Take specific heat of ice = 0.5 cal/g/°C and latent heat of ice = 80 cal/g. **4**

Ans :

Heat extracted from water $Q_1 = cm\,\Delta T$

$= 1 \times 200(25 - 10) = 3000\text{ cal}$

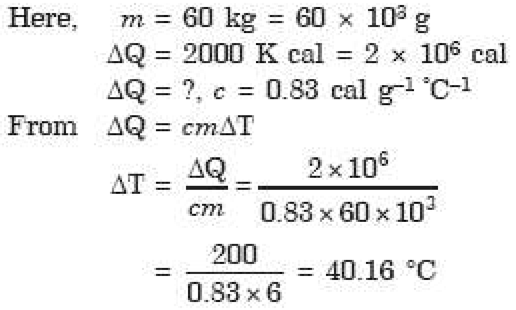
Heat absorbed by m gram of ice (at − 14°C) to convert it to water at 10°C

$$Q_2 = (cm\Delta T)_{\text{ice}} + mL + (cm\Delta T)_{\text{water}}$$
$$= 0.5\,m \times 14 + m \times 80 + 1 \times m \times 10$$

$Q_2 = 97\,m$ cal As $Q_2 = Q_1$,

$\therefore \quad 97\,m = 3000 \Rightarrow m = 31\text{ g}$

53 A person weighing 60 kg takes in 2000 kcal diet in a day. If this energy were to be used in heating the person without any loss, what would be his rise in temperature ? Given specific heat of human body is 0.83 cal $\text{g}^{-1}\,{}^\circ\text{C}^{-1}$. **4**

Ans : 

Here, $m = 60 \text{ kg} = 60 \times 10^3 \text{ g}$

$\Delta Q = 2000 \text{ K cal} = 2 \times 10^6 \text{ cal}$

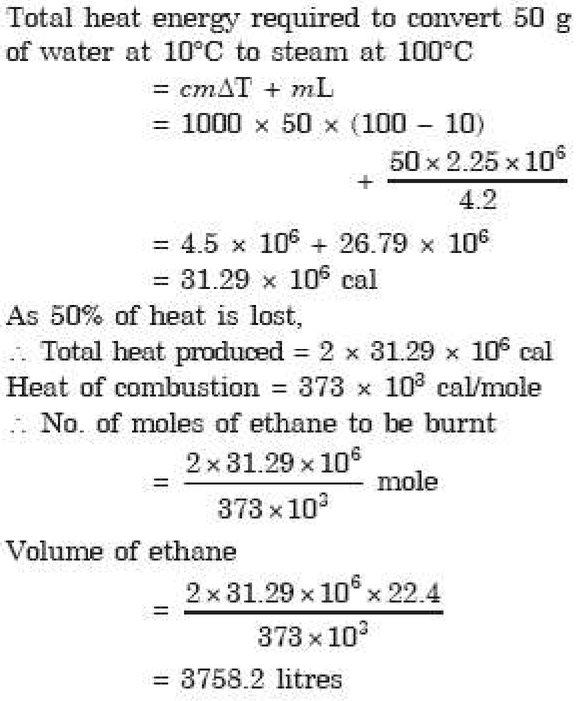
$\Delta Q = ?,\ c = 0.83 \text{ cal g}^{-1}\,{}^\circ\text{C}^{-1}$

From $\Delta Q = cm\Delta T$

$$\Delta T = \frac{\Delta Q}{cm} = \frac{2\times10^6}{0.83\times60\times10^3}$$

$$= \frac{200}{0.83\times6} = 40.16\ {}^\circ\text{C}$$

54The heat of combustion of ethane gas is 373 kcal. per mole. Assuming that 50% of heat is lost, how many litres of ethane measured at STP must be burnt to convert 50 g of water at 10 °C to steam at 100 °C ? One mole of gas occupies 22.4 litres at STP. Take latent heat of steam = 2.25×10^6 J/g^{-1}. **4**

Ans : 

Total heat energy required to convert 50 g of water at 10°C to steam at 100°C

$= cm\Delta T + mL$

$$= 1000 \times 50 \times (100 - 10) + \frac{50\times2.25\times10^6}{4.2}$$

$= 4.5 \times 10^6 + 26.79 \times 10^6$

$= 31.29 \times 10^6$ cal

As 50% of heat is lost,

∴ Total heat produced $= 2 \times 31.29 \times 10^6$ cal

Heat of combustion $= 373 \times 10^3$ cal/mole

∴ No. of moles of ethane to be burnt

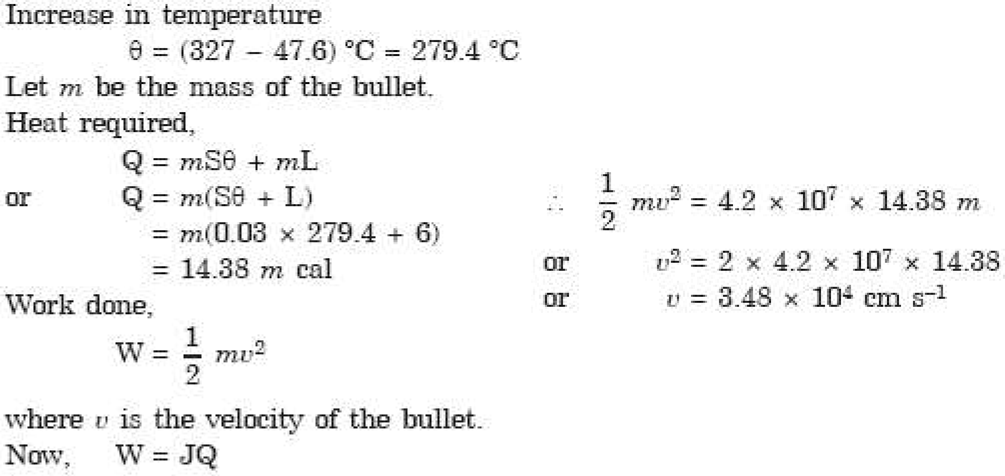
$$= \frac{2\times31.29\times10^6}{373\times10^3} \text{ mole}$$

Volume of ethane

$$= \frac{2\times31.29\times10^6\times22.4}{373\times10^3}$$

$= 3758.2$ litres

55During India-Pakistan war, a soldier discovered that his lead bullet just melted when stopped by an obstacle. Calculate the velocity of the bullet if its temp. was 47.6 °C. Given : melting point of lead = 327 °C. Specific heat of lead = 0.03 cal g−1 °C^{-1}, latent heat of fusion of lead = 6 cal g^{-1} and J = 4.2×10^7 erg cal^{-1}. Assume that no heat is lost. **4**

Ans : 

Increase in temperature

$$\theta = (327 - 47.6)\ ^\circ\text{C} = 279.4\ ^\circ\text{C}$$

Let m be the mass of the bullet.

Heat required,

$$Q = mS\theta + mL$$

or $$Q = m(S\theta + L)$$

$$= m(0.03 \times 279.4 + 6)$$

$$= 14.38\ m\ \text{cal}$$

Work done,

$$W = \frac{1}{2} mv^2$$

where v is the velocity of the bullet.

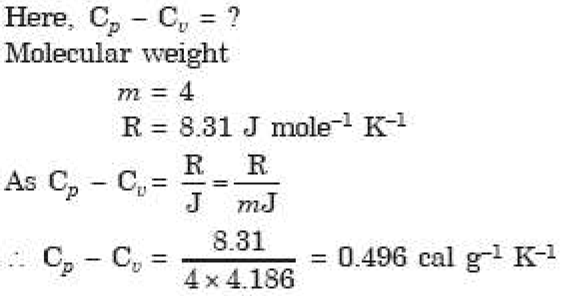
Now, $W = JQ$

$$\therefore \quad \frac{1}{2} mv^2 = 4.2 \times 10^7 \times 14.38\ m$$

or $$v^2 = 2 \times 4.2 \times 10^7 \times 14.38$$

or $$v = 3.48 \times 10^4\ \text{cm s}^{-1}$$

56Calculate the difference between two principal specific heats of 1 g of helium gas at N.T.P. Molecular weight of helium = 4u and J = 4.186 J cal^{-1} and R = 8.31 J mole^{-1} K^{-1}. **4**

Ans : 

Here, $C_p - C_v = ?$

Molecular weight

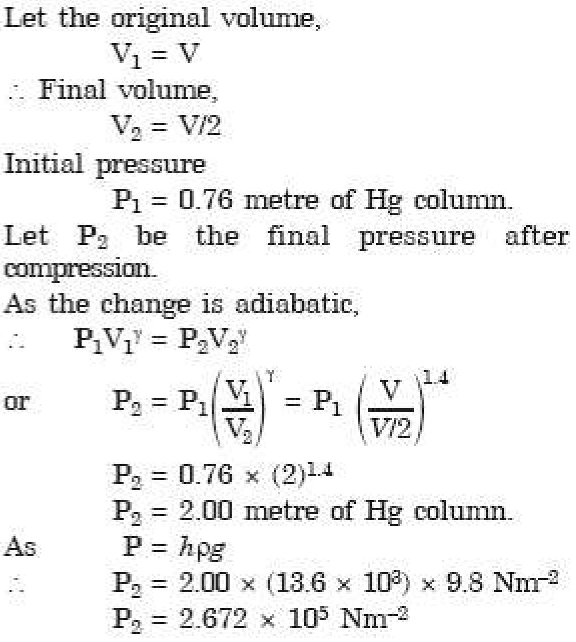
$$m = 4$$

$$R = 8.31\ \text{J mole}^{-1}\ \text{K}^{-1}$$

As $$C_p - C_v = \frac{R}{J} = \frac{R}{mJ}$$

$$\therefore \quad C_p - C_v = \frac{8.31}{4 \times 4.186} = 0.496\ \text{cal g}^{-1}\ \text{K}^{-1}$$

57A certain gas at atmospheric pressure is compressed adiabatically so that its volume becomes half of its original volume. Calculate the resulting pressure in Nm^{-2}. Take γ = 1.4 for air. **4**

Ans : 

Let the original volume,

$$V_1 = V$$

$\therefore$ Final volume,

$$V_2 = V/2$$

Initial pressure

$$P_1 = 0.76 \text{ metre of Hg column.}$$

Let P_2 be the final pressure after compression.

As the change is adiabatic,

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

or $$P_2 = P_1\left(\frac{V_1}{V_2}\right)^{\gamma} = P_1\left(\frac{V}{V/2}\right)^{1.4}$$

$$P_2 = 0.76 \times (2)^{1.4}$$

$$P_2 = 2.00 \text{ metre of Hg column.}$$

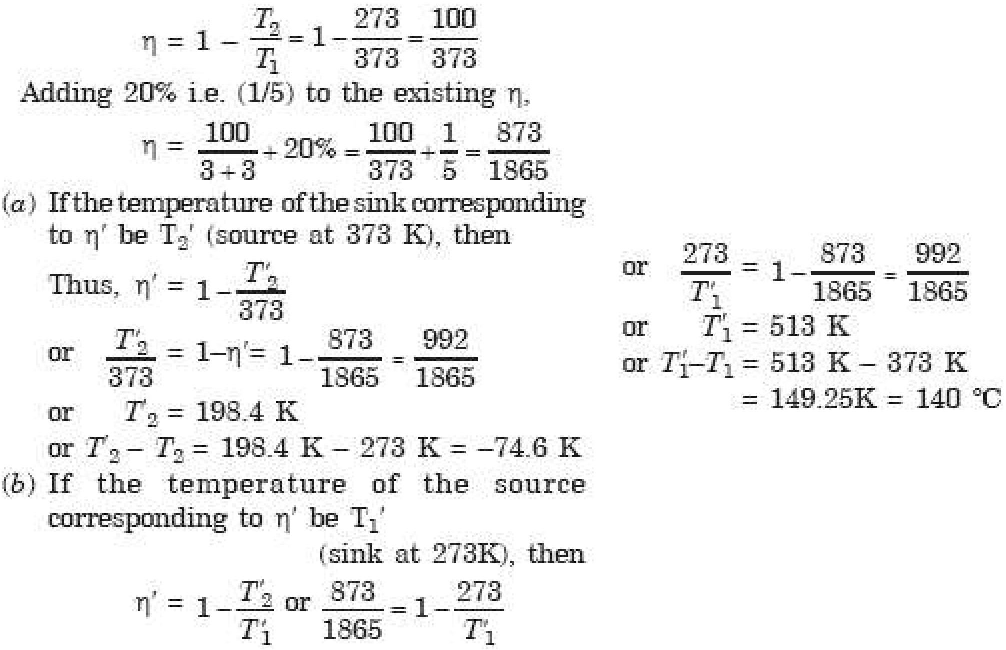
As $$P = h\rho g$$

$$\therefore \quad P_2 = 2.00 \times (13.6 \times 10^3) \times 9.8\ \text{Nm}^{-2}$$

$$P_2 = 2.672 \times 10^5\ \text{Nm}^{-2}$$

58A carnot engine works between ice point and steam point. It is desired to increase the efficiency by 20% by (a) making **4** temperature of the source as constant (b) making temperature of the sink as constant. Calculate the change in temperature in the two cases. Which one of these will you prefer and why ?

Ans :



$$\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{273}{373} = \frac{100}{373}$$

Adding 20% i.e. (1/5) to the existing η,

$$\eta = \frac{100}{3+3} + 20\% = \frac{100}{373} + \frac{1}{5} = \frac{873}{1865}$$

(*a*) If the temperature of the sink corresponding to η′ be T_2' (source at 373 K), then

Thus, $\eta' = 1 - \frac{T_2'}{373}$

or $\frac{T_2'}{373} = 1 - \eta' = 1 - \frac{873}{1865} = \frac{992}{1865}$

or $T_2' = 198.4$ K

or $T_2' - T_2 = 198.4\text{ K} - 273\text{ K} = -74.6$ K

(*b*) If the temperature of the source corresponding to η′ be T_1' (sink at 273K), then

$$\eta' = 1 - \frac{T_2'}{T_1'} \text{ or } \frac{873}{1865} = 1 - \frac{273}{T_1'}$$

or $\frac{273}{T_1'} = 1 - \frac{873}{1865} = \frac{992}{1865}$

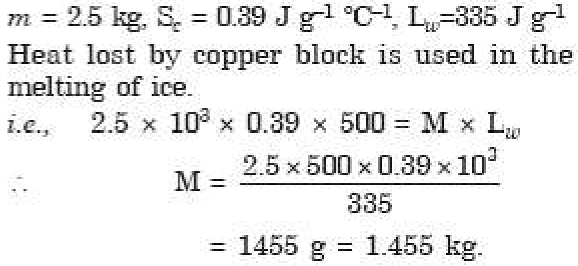
or $T_1' = 513$ K

or $T_1' - T_1 = 513\text{ K} - 373\text{ K}$

$= 149.25\text{K} = 140\ ^\circ\text{C}$

59 A copper block of mass 2.5 kg is heated in a furnace to a temperature of 500 °C and then placed on a large ice block. What is the maximum amount of ice that can be melted ? (Specific heat of copper = 0.39 J g^{-1} C^{-1} ; heat of fusion of water = 335 J g^{-1}). **4**

Ans :



$m = 2.5$ kg, $S_c = 0.39$ J g^{-1} °C^{-1}, $L_w = 335$ J g^{-1}

Heat lost by copper block is used in the melting of ice.

i.e., $2.5 \times 10^3 \times 0.39 \times 500 = M \times L_w$

$$\therefore \quad M = \frac{2.5 \times 500 \times 0.39 \times 10^3}{335}$$

$= 1455$ g $= 1.455$ kg.

60 A carnot engine with the cold body temperature of 17 °C has 50% efficiency. By how much should the temperature of its hot body be changed to increase the efficiency to 60% ? When will its efficiency be 100% ? **4**

Ans : $T_2 = 273 + 17 = 290$ K, $\eta = 50\% = 1/2$

As $\eta = 1 - \dfrac{T_2}{T_1}$, $\dfrac{1}{2} = 1 - \dfrac{290}{T_1}$

or $T_1 = 580$ K

Again $\eta' = 60\% = 3/5$

Thus, $\eta' = 1 - \dfrac{T_2}{T_1}$, or $\dfrac{3}{5} = 1 - \dfrac{290}{T_1'}$

or $T_1' = 725$ K

Thus, $T_1' - T_1 = 725\text{ K} - 580\text{K} = 145$ K

For $\eta = 1$, $1 - \dfrac{T_2}{T_1} = 1$ or $T_2 = 0$ K

61A gram molecule of a gas at 127 °C expands isothermally until its volume is doubled. Find the amount of work done and heat absorbed. **4**

Ans : Here, temperature of the gas,

$$T = 273 + 127 = 400 \text{ K}$$

Let initial volume of the gas,

$$V_1 = V$$

∴ Final volume of the gas,

$$V_2 = 2V$$

In an isothermal expansion,

$$\text{Work done (W)} = 2.3026 \text{ RT} \log_{10} \frac{V_2}{V_1}$$

$$= 2.3026 \times 8.3 \times 400 \times \log_{10} \frac{2V}{V}$$

$$= 2.3026 \times 8.3 \times 400 \times 0.3010$$

or $W = 2.30 \times 10^3$ joule

If H is the amount of heat absorbed, then

$$H = \frac{W}{J} = \frac{2.30 \times 10^3}{4.2} = 548 \text{ cal}$$

62A cylinder with a movable piston contains 3 moles of hydrogen at standard temperature and pressure. The walls of the cylinder are made of a heat insulator, and the piston is insulated by having a pile of sand on it. By what factor does the pressure of the gas increase if the gas is compressed to half of its original volume ? **4**

Ans :

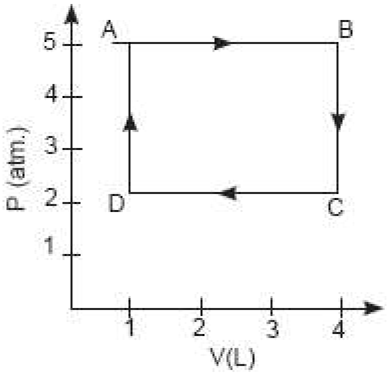
As no heat is allowed to be exchanged, the process is adiabatic.

∴ $P_2V_2^{\gamma} = P_1V_1^{\gamma}$ or $\dfrac{P_2}{P_1} = \left(\dfrac{V_1}{V_2}\right)^{\gamma}$

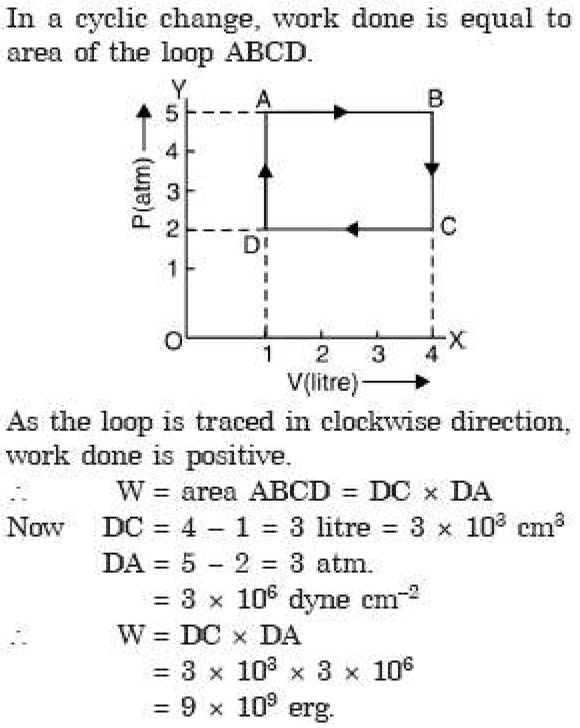
As $V_2 = \dfrac{1}{2}V_1$

∴ $\dfrac{P_2}{P_1} = \left(\dfrac{V_1}{1/2\ V_1}\right)^{1.4} = 2^{1.4} = 2.64$

63 One mole of an ideal gas undergoes a cyclic change ABCD. From the given diagram, calculate the net work done in the process. 1 atmosphere = 10^6 dyne cm^{-2}. **4**



Ans :


In a cyclic change, work done is equal to area of the loop ABCD.

As the loop is traced in clockwise direction, work done is positive.

$\therefore$ W = area ABCD = DC × DA

Now DC = 4 − 1 = 3 litre = 3×10^3 cm^3

DA = 5 − 2 = 3 atm.

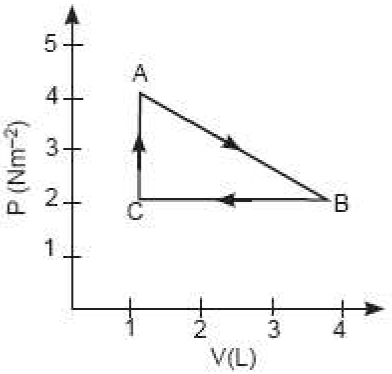
= 3×10^6 dyne cm^{-2}

$\therefore$ W = DC × DA

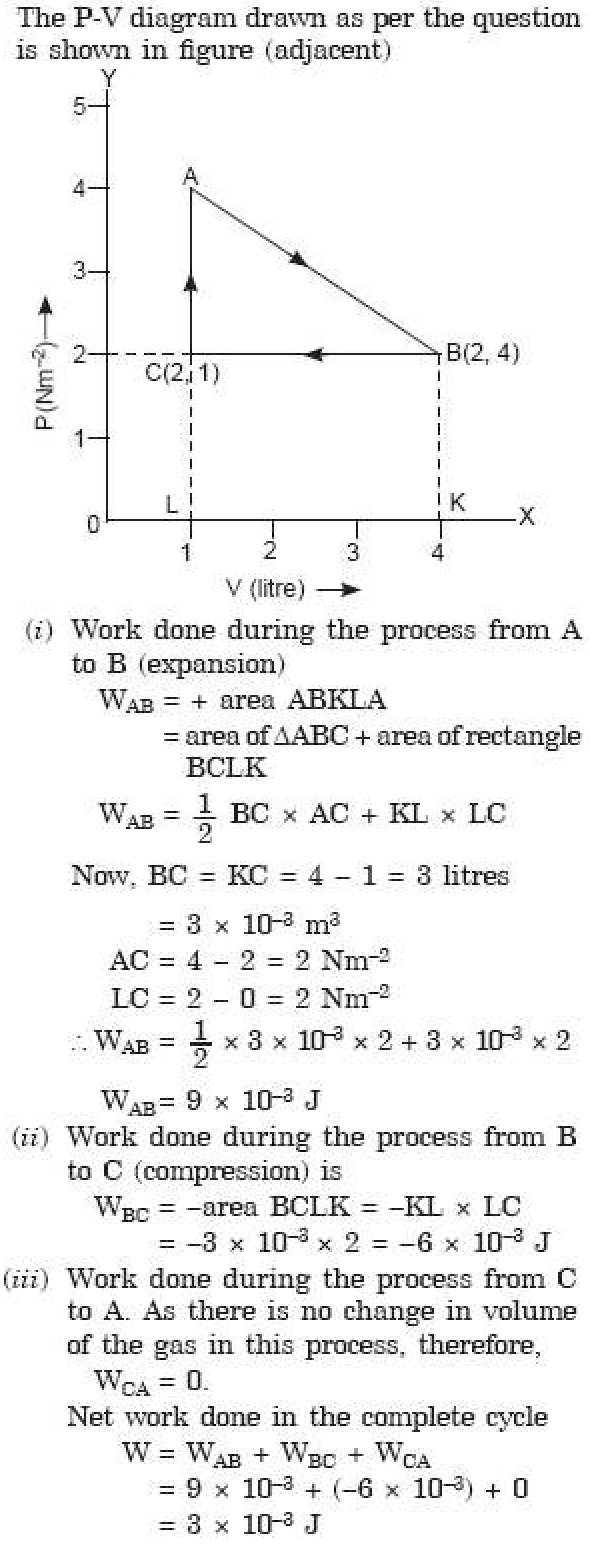
= $3 \times 10^3 \times 3 \times 10^6$

= 9×10^9 erg.

64 The P-V diagram for a cyclic process is a triangle ABC drawn in order. The co-ordinates of A, B, C are (4, 1), (2, 4) and (2, 1). The co-ordinates are in the order (P-V). Pressure is in Nm^{-2} and volume is in litre. Calculate work done during the process from A to B, B to C and C to A. Also, calculate work done in the complete cyclic. **4**



Ans :



The P-V diagram drawn as per the question is shown in figure (adjacent)

(*i*) Work done during the process from A to B (expansion)

W_{AB} = + area ABKLA

= area of ΔABC + area of rectangle BCLK

$$W_{AB} = \frac{1}{2} BC \times AC + KL \times LC$$

Now, BC = KC = 4 − 1 = 3 litres

$= 3 \times 10^{-3}\ m^3$

$AC = 4 - 2 = 2\ Nm^{-2}$

$LC = 2 - 0 = 2\ Nm^{-2}$

$$\therefore W_{AB} = \frac{1}{2} \times 3 \times 10^{-3} \times 2 + 3 \times 10^{-3} \times 2$$

$W_{AB} = 9 \times 10^{-3}\ J$

(*ii*) Work done during the process from B to C (compression) is

W_{BC} = −area BCLK = −KL × LC

$= -3 \times 10^{-3} \times 2 = -6 \times 10^{-3}\ J$

(*iii*) Work done during the process from C to A. As there is no change in volume of the gas in this process, therefore,

$W_{CA} = 0$.

Net work done in the complete cycle

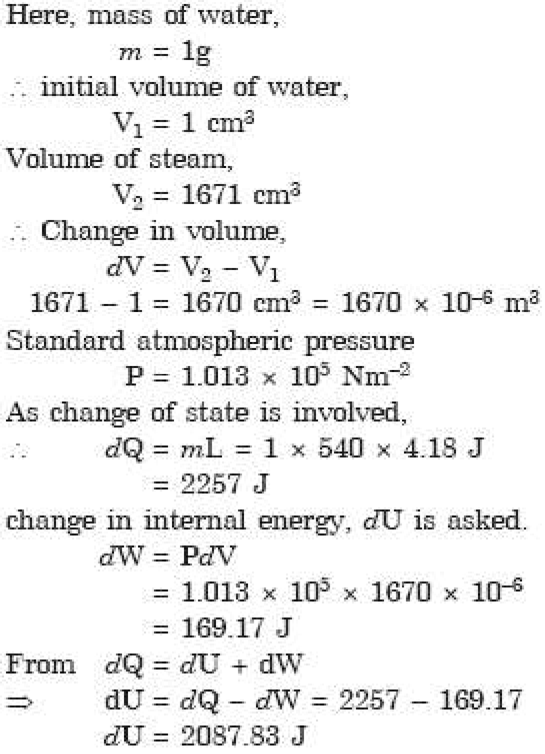
$W = W_{AB} + W_{BC} + W_{CA}$

$= 9 \times 10^{-3} + (-6 \times 10^{-3}) + 0$

$= 3 \times 10^{-3}\ J$

65 1 gram of water at 373 K is converted into steam at the same temperature. The volume of 1 cm^3 of water becomes 1671 cm^3 on boiling. Calculate change in internal energy of the system, if heat of vapourisation is 540 cal g^{-1}. Given standard atmospheric pressure is 1.013×10^5 Nm^{-2}. **4**

Ans :



Here, mass of water,

$m = 1\text{g}$

$\therefore$ initial volume of water,

$V_1 = 1 \text{ cm}^3$

Volume of steam,

$V_2 = 1671 \text{ cm}^3$

$\therefore$ Change in volume,

$dV = V_2 - V_1$

$1671 - 1 = 1670 \text{ cm}^3 = 1670 \times 10^{-6} \text{ m}^3$

Standard atmospheric pressure

$P = 1.013 \times 10^5 \text{ Nm}^{-2}$

As change of state is involved,

$\therefore \quad dQ = mL = 1 \times 540 \times 4.18 \text{ J}$

$= 2257 \text{ J}$

change in internal energy, dU is asked.

$dW = PdV$

$= 1.013 \times 10^5 \times 1670 \times 10^{-6}$

$= 169.17 \text{ J}$

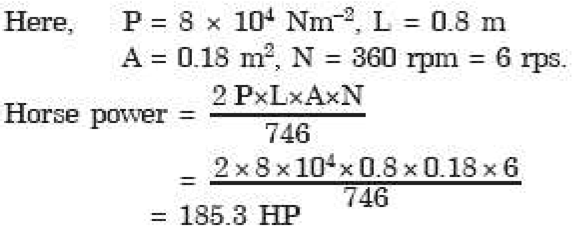
From $dQ = dU + dW$

$\Rightarrow \quad dU = dQ - dW = 2257 - 169.17$

$dU = 2087.83 \text{ J}$

66 In a double acting steam engine, the average pressure of steam is $8 \times 10^4 \text{ Nm}^{-2}$. The length of the stroke is 0.8 m and area of cross section of the piston is 0.18 m^2. If the piston makes 360 rpm, calculate the horse power of the engine. **4**

Ans :



Here, $P = 8 \times 10^4 \text{ Nm}^{-2}$, $L = 0.8$ m

$A = 0.18 \text{ m}^2$, $N = 360 \text{ rpm} = 6 \text{ rps}$.

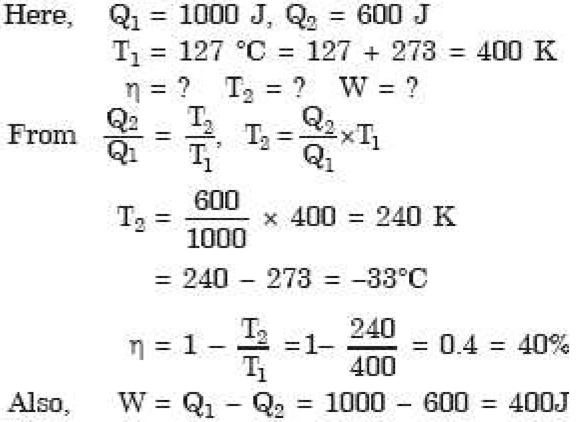
$$\text{Horse power} = \frac{2\,P \times L \times A \times N}{746}$$

$$= \frac{2 \times 8 \times 10^4 \times 0.8 \times 0.18 \times 6}{746}$$

$= 185.3$ HP

67 A Carnot engine absorbs 1000 J of heat energy from a reservoir at 12.7 °C and rejects 600 J of heat energy during each cycle. Calculate. (i) efficiency of the engine, (ii) temperature of sink, (iii) amount of useful work done per cycle. **4**

Ans :



Here, $Q_1 = 1000$ J, $Q_2 = 600$ J

$T_1 = 127$ °C $= 127 + 273 = 400$ K

$\eta = ?\quad T_2 = ?\quad W = ?$

From $\frac{Q_2}{Q_1} = \frac{T_2}{T_1}$, $T_2 = \frac{Q_2}{Q_1} \times T_1$

$$T_2 = \frac{600}{1000} \times 400 = 240 \text{ K}$$

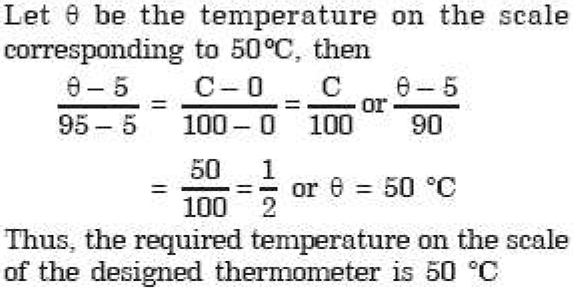
$$= 240 - 273 = -33°\text{C}$$

$$\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{240}{400} = 0.4 = 40\%$$

Also, $W = Q_1 - Q_2 = 1000 - 600 = 400$J

68A newly designed thermometer has its lower fixed point and upper fixed point marked 5 °C and 95 °C respectively. Compute the temperature on this scale corresponding to 50 °C. **4**

Ans :



Let θ be the temperature on the scale corresponding to 50°C, then

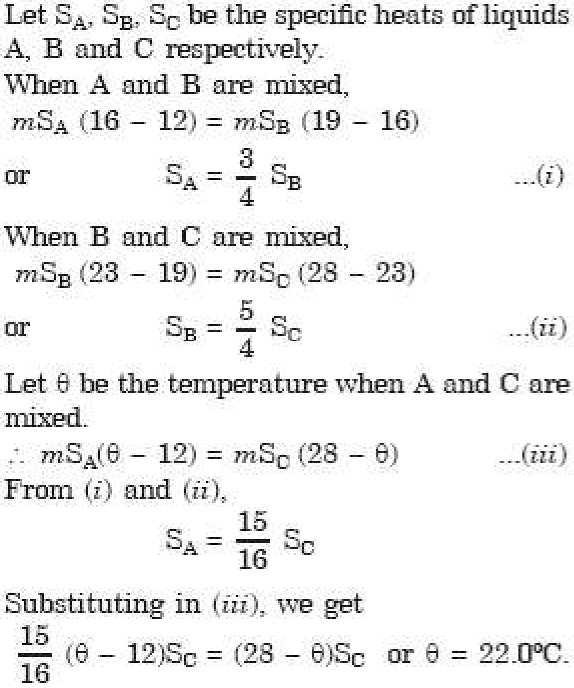
$$\frac{\theta - 5}{95 - 5} = \frac{C - 0}{100 - 0} = \frac{C}{100} \text{ or } \frac{\theta - 5}{90}$$

$$= \frac{50}{100} = \frac{1}{2} \text{ or } \theta = 50 \text{ °C}$$

Thus, the required temperature on the scale of the designed thermometer is 50 °C

69The temperature of equal masses of three different liquids A, B and C are 12°C, 19°C and 28°C respectively. The temperature when A and B are mixed is 16°C. When B and C are mixed, the temperature is 23°C. What would be the temperature when A and C are mixed ? **4**

Ans :



Let S_A, S_B, S_C be the specific heats of liquids A, B and C respectively.

When A and B are mixed,

$mS_A(16 - 12) = mS_B(19 - 16)$

or $S_A = \frac{3}{4} S_B$ ...(*i*)

When B and C are mixed,

$mS_B(23 - 19) = mS_C(28 - 23)$

or $S_B = \frac{5}{4} S_C$ ...(*ii*)

Let θ be the temperature when A and C are mixed.

$\therefore\ mS_A(\theta - 12) = mS_C(28 - \theta)$ ...(*iii*)

From (*i*) and (*ii*),

$$S_A = \frac{15}{16} S_C$$

Substituting in (*iii*), we get

$\frac{15}{16}(\theta - 12)S_C = (28 - \theta)S_C$ or $\theta = 22.0$°C.

70 A carnot engine absorbs 100 calories per cycle from its source at 1600 K. Its efficiency is 60%. Find the temperature of the sink and work done per cycle. Given J = 4.2 J/cal. **4**

Ans : $Q_1 = 100$ cal, $T_1 = 1600$ K, $\eta = 60\% = 3/5$

For glass, $\eta = 1 - \frac{T_2}{T_1}$,

$$\frac{3}{5} = 1 - \frac{T_2}{1600}$$

or $T_2 = 640$ K

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

$$= \frac{3}{5} \times 100 = 60 \text{ cal.}$$

$W = 60 \times 4.2$ J $= 252$ J

71 There is a layer of ice 10 cm thick over the surface of a pond. Temperature above the surface is −5 °C. How long will it take for the next 1 mm of ice to form ? The thermal conductivity of ice is 0.008 CGS units and its latent heat is 80 cal/g. Density of ice = 0.9 g/cc. **4**

Ans : Thickness of layer = 10 cm,

Temperature = −5°C, K = 0.008 CGS units

$L = 80$ cal g^{-1}, $\rho = 0.9$ gcc^{-1}

Suppose the area of the surface of ice to be 1 sq. cm.

Volume of 1 mm thickness of layer

= Area × Thickness = 1 × 0.1

= 0.1 cm^3

Mass of the new layer formed

= Volume × Density = 0.1 × 0.9

= 0.09 g

Amount of heat radiated by the water to freeze 0.09 g of ice = 0.09 × 80 = 7.2 cal

We know that

$$\frac{Q}{t} = KA\,\frac{\Delta T}{\Delta x}$$

Here $Q = 7.2$ cal, $K = 0.008$,

$\Delta T = 0 - (-5) = 5^\circ$C, $A = 1$ sq. cm

$$\Delta x = \frac{10 + 10.1}{2} = 10.05 \text{ cm}$$

Putting these values, we have

$$\frac{7.2}{t} = 0.008 \times \frac{1 \times 5}{10.05}$$

or $$t = \frac{7.2 \times 10.05}{0.008 \times 5} = 30 \text{ min } 9 \text{ s.}$$

72 How many metres can a man weighing 60 kg climb on the energy from a slice of bread which produces 100,000 cal of heat ? Assume **4**

that the human body works at an efficiency of 28%. Take the average value of g as 9.8 ms^{-2}.

Ans : m = 60 kg, Energy = 100000 cal,
E = 420000 joule, Efficiency = 28%
P.E. gained = 28% of available energy

$$\therefore \quad mgh = \frac{28}{100} \times 420000$$

$$h = \frac{28}{100} \times \frac{420000}{10 \times 60} = 196 \text{ m}$$

73In a perfect Carnot's engine, the temperature of the source and the sink are 500 K and 375 K respectively. If the engine consumes 6 × 10^5 cal per cycle, find (i) the efficiency of the engine (ii) work done per cycle, and (iii) the heat rejected to the sink per cycle. **4**

Ans : $(i)\ \eta = \left(1 - \frac{T_2}{T_1}\right) \times 100 = \left(1 - \frac{375}{500}\right) \times 100 = 25\%$

$(ii)\quad \eta = \frac{W}{Q_1};$

$W = \eta\ Q_1;\ Q_1 = 600 \times 10^3$ cal

$W = \frac{25}{100} \times 600 \times 10^3$ cal

$= 150 \times 10^3$ cal

$= 150 \times 10^3 \times 4.2$ J

$= 6.8 \times 10^5$ J (approx.)

$(iii)\quad W = Q_1 - Q_2\ ;\ Q_2 = Q_1 - W$

$= 600 \times 10^3 - 150 \times 10^3$

$= 45 \times 10^4$ cal.

74In changing the state of a gas adiabatically from an equilibrium state A to another equilibrium state B, an amount of work equal to 22.3 J is done on the system. If the gas is taken from A to B via a process in which the net heat absorbed by the system is 9.35 cal, how much is the net work done by the system in the latter case ? (Take 1 cal = 4.19 J). **4**

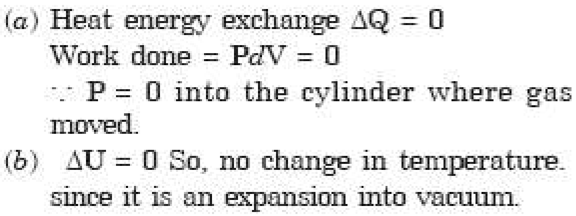
Ans : $\Delta W = -\ 22.3$ J in adiabatic way.
$\Delta Q = +\ 9.35$ cal. $= 9.35 \times 4.2$ J $= 39.270$ J
ΔU in adiabatic process $= -\ \Delta W = +\ 22.3$ J
Work done by the system in the second case
$= \Delta W = \Delta Q - \Delta U$
$= 39.270 - 22.3 = 16.970 = 17$ J

75Two cylinders A and B of equal capacity are connected to each other via a stopcock. 'A' contains a gas at S.T.P. 'B' is completely evacuated. The entire system is thermally insulated. The stop-cock is suddenly opened. Answer the following : **4**

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

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

Ans :



(*a*) Heat energy exchange $\Delta Q = 0$

Work done = $PdV = 0$

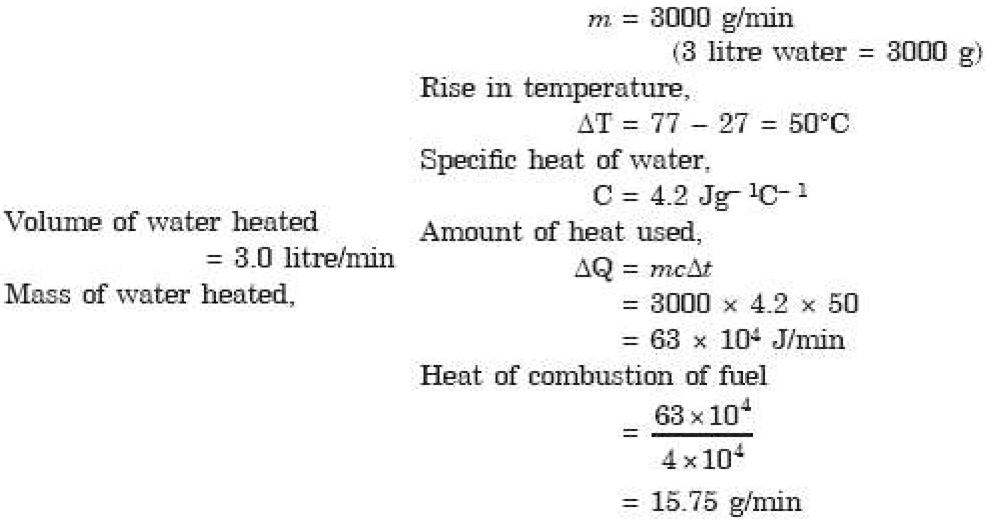
$\because P = 0$ into the cylinder where gas moved.

(*b*) $\Delta U = 0$ So, no change in temperature.

since it is an expansion into vacuum.

76A geyser heats water flowing at the rate of 3.0 litres per minutes from 27 °C to 77 °C. If the geyser operates on a gas burner, what is the rate of consumption of the fuel if its heat of combustion is 4.0 × 10^4 J/g ? **4**

Ans :



Volume of water heated

= 3.0 litre/min

Mass of water heated,

$m = 3000$ g/min

(3 litre water = 3000 g)

Rise in temperature,

$\Delta T = 77 - 27 = 50°C$

Specific heat of water,

$C = 4.2\ Jg^{-1}C^{-1}$

Amount of heat used,

$\Delta Q = mc\Delta t$

$= 3000 \times 4.2 \times 50$

$= 63 \times 10^4$ J/min

Heat of combustion of fuel

$$= \frac{63 \times 10^4}{4 \times 10^4}$$

$= 15.75$ g/min

77Define molar specific heat capacities at constant volume and pressure. Considering thermodynamical process in a cylinder with parameters P, V and T, derive the Mayer's relation. **5**

Ans :

Molar specific heat capacity is the heat energy required to raise the temperature of 1 mole of a substance by 1 K and expressed in J mol^{-1} K^{-1}.

$$C = \frac{Q}{1\,\text{mole}\,1\,K}$$

Depending on the condition that whether volume or pressure is constant, molar specific heat is written as C_v and C_p.

Relation between C_p and C_v. Suppose one mole of a gas is heated so that its temperature rises by dT.

Heat supplied = $1 \times C_v \times dT = C_v dT$ ...(*i*)

Since the volume is constant, the gas will not perform external work in accordance with the first law of thermodynamics and the heat supplied will be just equal to the increase in the internal energy of the gas.

$\therefore \quad dU = C_v dT$ ...(*ii*)

Let the gas be heated at constant pressure to again increase its temperature by dT, and dQ be the amount of heat supplied, therefore,

$dQ = 1 \times C_p \times dT = C_p dT$ ...(*iii*)

The heat supplied at a constant pressure increases the temperature by dT hence increases its internal energy by $dU = C_v dT$ as well as enables the gas to perform work dW.

$dW = PdV$ ...(*iv*)

From the first law of thermodynamics, we have

$dQ = dU + dW$

Substituting the values, we get,

$C_p dT = C_v dT + PdV$

But $\quad PV = RT$ (For one mole of the gas)

or $\quad PdV = RdT$

$\therefore \quad C_p dT = C_v dT + RdT$

or $\quad C_p - C_v = R$ ...(*v*)

This is the relation between two principal specific heats of the gas when C_p, C_v and R are measured in the units of either heat or of work.

78 A gas undergoes reduction in volume (i) adiabatically, (ii) isothermally. Find the work done in the process. **5**

Ans : (*i*) For an adiabatic process of thermo-dynamics, $dQ = 0$.

Since $dU = n\,C_v\,dT$ irrespective of the process, from 1st law, we get

$$dW = -dU = -n\,C_v dT$$

So work done, W

$$= -n\,C_v\,(T_f - T_i)$$

$$= -\frac{C_v}{R}\,(P_f V_f - P_i V_i)$$

(*ii*) For an isothermal process, dT = 0.

So $$dW = \int PdV = \int \frac{nRT}{V} dV$$

$$\text{Work done} = W = nRT\,\left|\log_e V\right|_{V_i}^{V_f}$$

$$W = nRT\,\log_e\left(\frac{V_f}{V_i}\right)$$

79 Explain how Carnot’s cycle works with the heat flow diagram. Using the same, explain the working of a refrigerator. Also, give its coefficient of performance. **5**

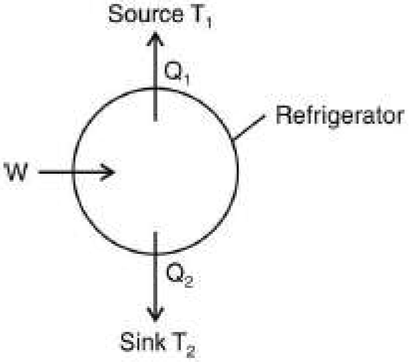
Ans :

Refrigerator absorbs heat from the body at a low temperature and liberates it to a body at a high temperature by doing work. It can be shown by the given diagram.

Q_2 → Energy absorbed from sink.

Q_1 → Energy liberated to source.

W → Work done on the system.

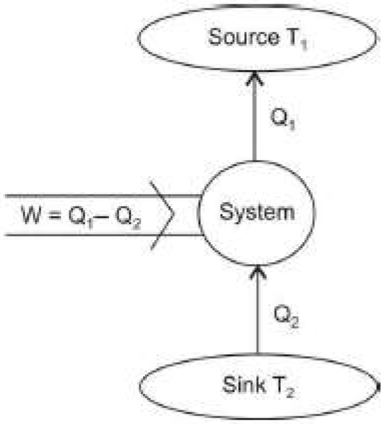


$$\text{Coefficient of performance} = \frac{Q_2}{Q_1 - Q_2}$$

$Q_1 - Q_2$ refers to the work done on the system/refrigerator.

$$\text{Coefficient of performance (COP)} = \frac{Q_2}{Q_1 - Q_2} = \frac{T_2}{T_1 - T_2}$$

Refrigerator : It works in the reverse Carnot's cycle. Heat is absorbed from sink at low temperature T_2 and given to the source at higher temperature T_1 with the help of an external agency doing work on the system. ($W = Q_1 - Q_2$).



The compressor in the refrigerator uses electrical energy and does work on the system. The coefficient of performance is defined as the heat energy absorbed from low temperature sink Q_2 to the amount of work done

$$W = Q_1 - Q_2$$

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

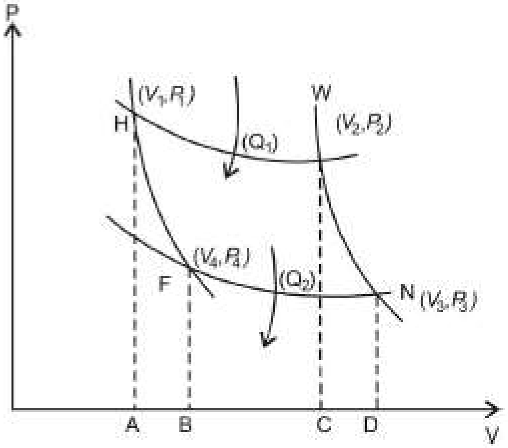
80 Describe the working of Carnot engine. Obtain an expression for its efficiency. **5**

Ans :

Carnot used a set of four devices—a source at a high temperature (say T_1), a sink at a low temperature (say T_2), a non-conducting base and a cylinder with a working substance, frictionless piston made of conducting base and non-conducting walls and piston.

He carried the system through a step of four processes to complete a cycle as shown here.

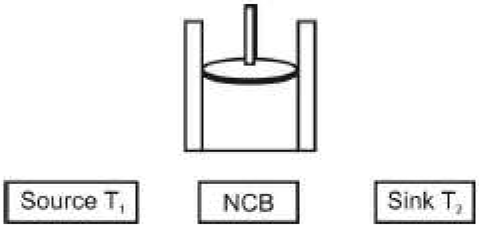
Process I–HW is an isothermal expansion. Q_1 energy flows in and temperature is maintained at T_1 by placing the cylinder over the source.



Process II–WN is an adiabatic processes at a temperature flow from T_1 to T_2 conducted with cylinder over (NCB = Non conducting base).

Process III–NF is an isothermal process at T_2 which gives out an energy Q_2 with cylinder over sink

Process IV–FH is an adiabatic process which changes the temperature from T_2 to T_1 conducted with the cylinder placed over (NCB = Non conducting base).



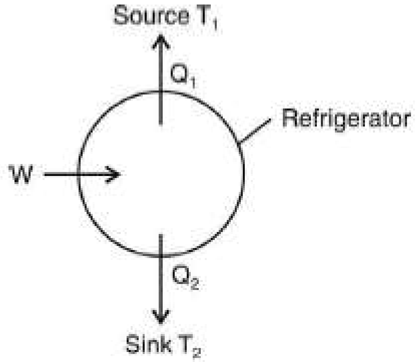
In the process, a net work equalling the area HWNFH is done with the net heat intake $Q_1 - Q_2$. So, efficiency $= \dfrac{\text{Work done}}{\text{Heat supplied}} = \dfrac{Q_1 - Q_2}{Q_1} = 1 - \dfrac{Q_2}{Q_1} = 1 - \dfrac{T_2}{T_1}$

81 Write Kelvin-Planck and Clausius statements for second law of thermodynamics. Define coefficient of efficiency and coefficient of performance. Show the heat flow in case of an engine and refrigerator using schematic diagrams. **5**

Ans :

Kelvin-Planck Statement of Second Law of Thermodynamics. It is impossible to realise a heat engine which works in a cyclic process performing the single job of taking heat from a body at a constant temperature and converting it completely into mechanical work. The law stresses the fact that work done on the system can facilitate to convert heat into work, however with some unavoidable loss.

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



Efficiency in forward cycle = $\frac{\text{Work done}}{\text{Heat supplied}} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1} = 1 - \frac{T_2}{T_1}$

Coefficient of performance = $\frac{\text{Heat drawn from sink}}{\text{Work on the system}} \quad \frac{Q_2}{Q_1 - Q_2} = \frac{T_2}{T_1 - T_2}$

82 Define 1st law of thermodynamics. By using this law, derive relationship between C_p and C_v. **5**

Ans :

First Law of Thermodynamics. It is based on the conservation of energy. The total heat energy change in any system is the sum of the internal energy change and the work done, *i.e.*, $dQ = dU + dW$

where $dU \rightarrow$ internal energy change and $dW = PdV$ is the work done by/on the system, dU is a state function and depends on dT. ($dU = nC_v dT$). dW depends on the path followed and so, is different in various processes.

Relationship between C_p and C_v. Suppose one mole of a gas is heated at constant volume so that its temperature rises by dT.

Heat supplied = $1 \times C_v \times dT = C_v dT$ ...(*i*)

Since the volume is constant, the gas will not perform external work in accordance with the first law of thermodynamics and the heat supplied will be just equal to the increase in the internal energy of the gas.

$\therefore \quad dU = C_v dT$ ...(*ii*)

Let the gas be heated at constant pressure to again increase its temperature by dT, and dQ be the amount of heat supplied, therefore,

$dQ = 1 \times C_p \times dT = C_p dT$ ...(*iii*)

The heat supplied at a constant pressure increases the temperature by dT hence increases its internal energy by $dU = C_v dT$ as well as enables the gas to perform work dW.

$dW = PdV$ ...(*iv*)

From the first law of thermodynamics, we have

$dQ = dU + dW$

Substituting the values, we get

$C_p dT = C_v dT + PdV$

But $PV = RT$ (For one mole of an ideal gas)

or $PdV = RdT$, $\therefore C_p dT = C_v dT + RdT$

or $\quad C_p - C_v = R$ ...(*v*)

This is the relationship between two principal specific heats of the gas when C_p, C_v and R are measured in the units of either heat or of work.

83(a) In a carnot engine, temperature of sink is increased. What will happen to its efficiency ? **5**

(b) A carnot engine absorbs 1000 J of heat from a reservoir at 127 °C and rejects 600 J of heat during each cycle.

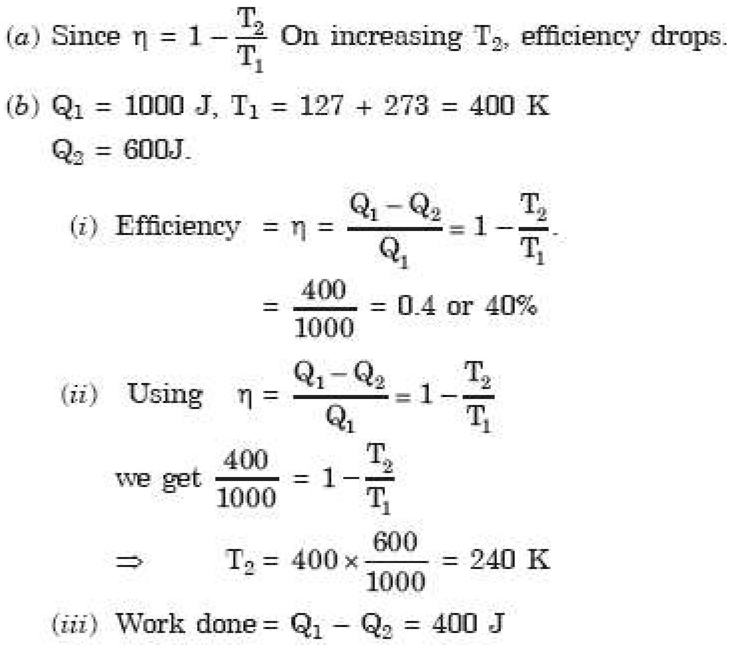
Calculate the

(i) efficiency of engine.

(ii) temperature of the sink.

(iii) amount of the useful work done during each cycle.

Ans :



(*a*) Since $\eta = 1 - \frac{T_2}{T_1}$ On increasing T_2, efficiency drops.

(*b*) $Q_1 = 1000$ J, $T_1 = 127 + 273 = 400$ K

$Q_2 = 600$J.

(*i*) $$\text{Efficiency} = \eta = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{T_2}{T_1}.$$

$$= \frac{400}{1000} = 0.4 \text{ or } 40\%$$

(*ii*) Using $$\eta = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{T_2}{T_1}$$

we get $$\frac{400}{1000} = 1 - \frac{T_2}{T_1}$$

$$\Rightarrow \quad T_2 = 400 \times \frac{600}{1000} = 240 \text{ K}$$

(*iii*) Work done $= Q_1 - Q_2 = 400$ J

84(a) Define an adiabatic process. Derive an expression for work done during an adiabatic process. **5**

(b) A Carnot engine operates between 500 K and 400 K. If it absorbs 6 × 105 cal heat at higher temperature, how much work per cycle can the engine perform ?

Ans :

(*a*) **Adiabatic process :** When no exchange of heat energy is possible between system and surrounding, the process is known as adiabatic. **Work done in adiabatic process:** Consider 1 mole of gas contained in a perfectly non-frictionless conducting cylinder fitted with a piston (non conducting).

Let $\mathbf{P}$ = Pressure of gas
V = Volume of gas
T = Temperature of gas

Compress the gas adiabatically by moving the piston inwards through a distance dx.

Force acting on piston = $\mathbf{P} \times \mathbf{A}$

Work done,

$$dW = \text{Force} \times \text{distance}$$
$$= \mathbf{P}\mathbf{A}\, dx = \mathbf{P}dV$$

where dV is the change in volume of the gas. During the adiabatic expansion, total work done by the gas

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

Adiabatic change is represented by

$PV^{\gamma} = K$, (a constant)

$$\therefore \quad P = \frac{K}{V^{\gamma}}$$

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

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

$$= \frac{1}{1-\gamma}[P_2V_2^{\gamma}V_2^{1-\gamma} - P_1V_1^{\gamma}V_1^{1-\gamma}] \qquad (\mathbf{P}_1V_1^{\gamma} - \mathbf{P}_2V_2^{\gamma} = K)$$

$$= \frac{1}{1-\gamma}[RT_2 - RT_1] \qquad \text{(from ideal gas equation)}$$

$$\text{or} \quad W = \frac{R}{1-\gamma}[T_2 - T_1]$$

This is the work done during adiabatic process.

(*b*) Given : $Q_1 = 6 \times 10^5$ cal, $T_1 = 500$ K,
$T_2 = 400$ K

$$\text{As,} \quad \frac{Q_2}{Q_1} = \frac{T_2}{T_1} \Rightarrow Q_2 = \frac{T_2}{T_1} \times Q_1$$

$$\text{or} \quad Q_2 = \frac{400}{500} \times 6 \times 10^5 = 4.8 \times 10^5 \text{ cal}$$

$\therefore$ Work done per cycle

$$W = Q_1 - Q_2$$
$$= 6 \times 10^5 - 4.8 \times 10^5$$
$$= 1.2 \times 10^5 \text{ cal}$$
$$= 1.2 \times 4.2 \times 10^5 \text{ J}$$
$$= 5.04 \times 10^5 \text{ J}$$