Ques : What is entropy? Show how the entropy of a perfect gas changes in Reversible and Irreversible processes? OR Define entropy. What is its physical significance? Show that entropy of a perfect gas remains constant in Reversible process but increases in Irreversible process. (2011, 2013, 2015).

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Ans : **Entropy** : Entropy is an important thermodynamic quantity introduced by Clausius in 1854 during his work on the formulation and application of second law of thermodynamics. Entropy is defined as thermal property of working substance which remains constant during an adiabatic process just like temperature remains constant during an isothermal process..

Change in entropy for a state from A to B is defined as

$$\Delta S = S_B - S_A = \int_A^B dS = \frac{\Delta Q}{T} = \frac{\text{Heat added or subtracted}}{\text{Absolute temperature}}$$

If a working subsatnce absorbs an amount of heat Q in reversible process at constant temperature T then increase in entropy of the working subsatnce is

$$\Delta S = \frac{Q}{T}$$

If a working subsatnce releases an amount of heat Q in reversible process at constant temperature T then decrease in entropy of the working subsatnce is

$$\Delta S = \frac{Q}{T}$$

Physical significance of entropy : It is very difficult to conceive the idea of entropy as there is no physical method to demonstrate it i.e, it can not bne felt like temperature, pressure , volume and it does not produce any effect which can be demonstrated.

Change in entropy is $\Delta S = \frac{\Delta Q}{T} = \frac{\text{Heat added or subtracted}}{\text{Absolute temperature}}$

Heat has same dimension as the product of entropy and absolue temperature. Gravitational potential energy of a body is proportional to product of its mass and height above some zero level like wise we may take temperature analogous to height and entropy analogous to mass or inertia. Thus entropy may be taken as thermal enertiawhich bears to heat motion just like mass bears linear motion and moment of inertia bears rotational motion.

S.I unit of entropy is J/K

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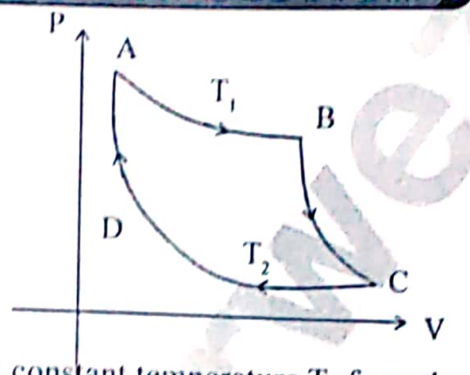
Change in entropy in Reversible process (Cycle) :



Let us consider a complete reversible Carnot's cycle ABCDA as shown in figure for an ideal gas formed by two isothermal AB at constant temperature T_1 and CD at constant temperature T_2 and two adiabatics BC and DA.

(i) Isotehrmal expansion AB :

Suppose the working substance absorbs heat Q_1 at constant temperature T_1 from the source in going from the state A to the state B during isotehrmal expansion AB.

Increase in entropy of the working substance during the thermal expansion AB is given by

$$\int_A^B dS = +\frac{Q_1}{T_1} \qquad \text{.....................} \quad (1)$$

(ii) Adiabatic expansion BC : In going from the state B to the state C during adiabatic expansion BC, there is no change in entropy of the working substance because heat remains consatnt but temperature falls from T_1 to T_2 due to expansion.

The change in entropy of the working substance during adiabatic expansion BC is

$$\int_B^C dS = 0 \qquad \text{.....................} \quad (2)$$

(iii) Isotherma compression CD : In going form the state C to the state D during isothermal compression CD, the working substance rejects heat Q_2 to the sink at constant temperature T_2. In this case, enropy of the working substance decreases.

Change in entropy of the working substance during the isothermal compression CD is

$$\int_C^D dS = -\frac{Q_2}{T_2} \qquad \text{.....................} \quad (3)$$

(iv) Adiabatic compression DA : In going from the state D to the state A during adiabatic compression DA, there is no change in entropy of the working substance but temperature rises from T_2 to T_1 due to compression.

The change in entropy of the working substance during adiabatic compression DA is

$$\int_D^A dS = 0 \qquad \text{.....................} \quad (4)$$

Thus the net gain in entropy of the working substance in the whole cycle ABCDA of the reversible process is

$$\oint dS = \int_A^B dS + \int_B^C dS + \int_C^D dS + \int_D^A dS = +\frac{Q_1}{T_1} + 0 - \frac{Q_2}{T_2} + 0$$

$$\Rightarrow \oint dS = \frac{Q_1}{T_1} - \frac{Q_2}{T_2} \qquad \text{.....................} \quad (5)$$

But for a reversible Carnot's cycle , $\frac{Q_1}{T_1} = \frac{Q_2}{T_2} \Rightarrow \frac{Q_1}{T_1} - \frac{Q_2}{T_2} = 0$ put in equation (5)

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$$\oint dS = \frac{Q_1}{T_1} - \frac{Q_2}{T_2} = 0 \quad \text{.......................} (6)$$

Therefore, in reversible process, the entropy of the system (working substance) remains constant i.e, total change in entropy of a working substance during a complete cycle of a reversible process is zero.

Change in entropy in Irreversible process or Principle of increase in entropy : Suppose an engine is performing irreversible cycle of changes in which the working substance absorbs heat Q_1 from the source at constant temperature T_1 and rejects heat Q_2 to the sink at constant temperature T_2 .

The efficiency of the engine for the irreversible cycle is given by

$$\eta' = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1}$$

From Carnot's theorem, this efficiency η' is less than the efficiency of a reversible engine working between the same two temperatures T_1 and T_2 for which efficiency η is given by

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

Thus $\eta' < \eta \Rightarrow 1 - \frac{Q_2}{Q_1} < 1 - \frac{T_2}{T_1} \Rightarrow \frac{T_2}{T_1} < \frac{Q_2}{Q_1} \Rightarrow \frac{Q_2}{T_2} > \frac{Q_1}{T_1} \Rightarrow \frac{Q_2}{T_2} - \frac{Q_1}{T_1} > 0$ .... (7)

Considering the whole system, the source loses the entropy by an amount of $\frac{Q_1}{T_1}$ and the sink gains the entropy by an amount of $\frac{Q_2}{T_2}$. Therefore net change in entropy for the whole system is $\frac{Q_2}{T_2} - \frac{Q_1}{T_1}$ which is clearly greater than zero i.e, positive from equation (7). Thus there is an increase in entropy of the system during an irreversible process.

To make it more clear, we consider the natural process of conduction of heat from a body A at temperature T_1 to to another body B at a lower temperature T_2 . this process is irreversible because heat always flows from higher temperature to lower temperature anf if Q be heat transmitted from the body A to the body B then

Decreases in entropy of the hotter body A = $\frac{Q}{T_1}$

and increase in entropy of the colder body B = $\frac{Q}{T_2}$

Net change in entropy of the system is $\Delta S = \frac{Q}{T_2} - \frac{Q}{T_1} = +\text{ve quantity} \quad \because T_2 < T_1$

Thus we conclude that the entropy of a system increases in all irreversible process. This is known as law or principle of increase in entropy. All natural process taking place in universe are irreversible process. It means the entropy of the universe increases. $\Delta S_{universe} \geq 0$