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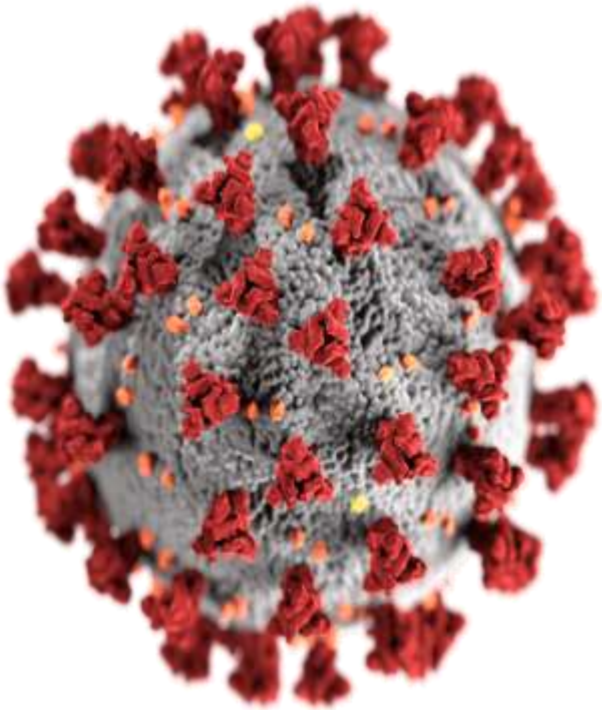
Welcome to my Class

Physics Ph 1101

11:45 AM
October 07, 2020

COVID-19 Precautions



- Don’t be afraid
- Be aware of the pandemic
- Use appropriate outfits if you compelled to go out
- Try to maintain proper diet
- Do not forget to exercise (at least one hour) regularly
- Try to follow the guidelines of WHO and Bangladesh Government
- Try to stay at home

Carnot's Reversible Engine

Heat engines are used to convert heat into mechanical work. Sadi Carnot (French) conceived a theoretical engine which is free from all the defects of practical engines. Its efficiency is maximum and an ideal heat engine.

For any engine, there are three essential requisites :

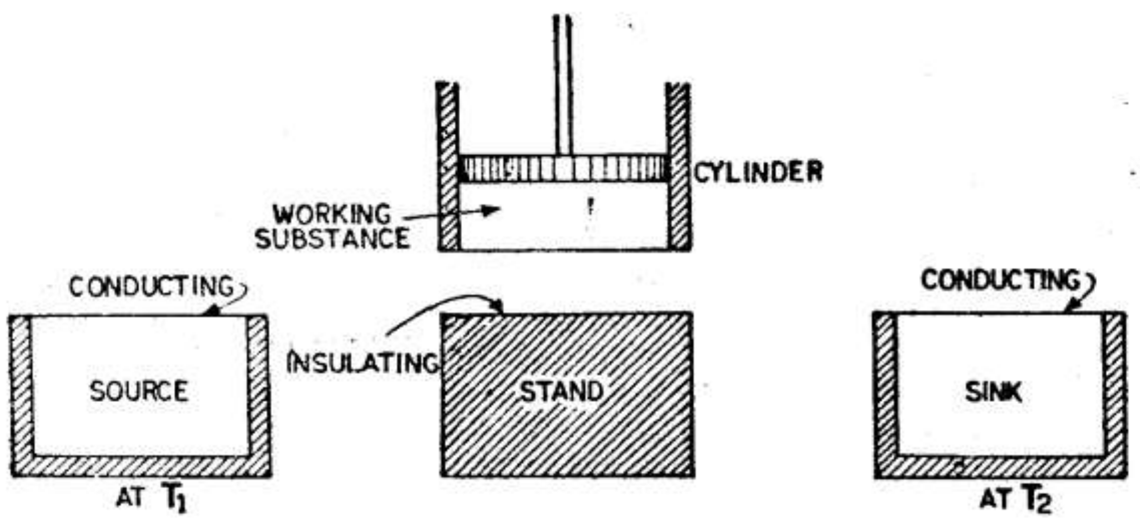


Fig. 1: Carnot's Reversible Engine.

a) Source: The source should be at a fixed high temperature T_1 from which the heat engine can draw heat. It has infinite thermal capacity and any amount of heat can be drawn from it at constant temperature T_1.

b) Sink: The sink should be at a fixed lower temperature T_2, to which any amount of heat can be rejected. It also has infinite thermal capacity and its temperature remains constant at T_2.

c) Working Substance: A cylinder with non-conducting sides and conducting bottom contains the perfect gas as the working substance. A perfect non-conducting and frictionless piston is fitted into the cylinder. The- working substance undergoes a complete cyclic operation.

A perfectly non-conducting stand is also provided so that the working substance can undergo adiabatic operation.

Carnot's Cycle

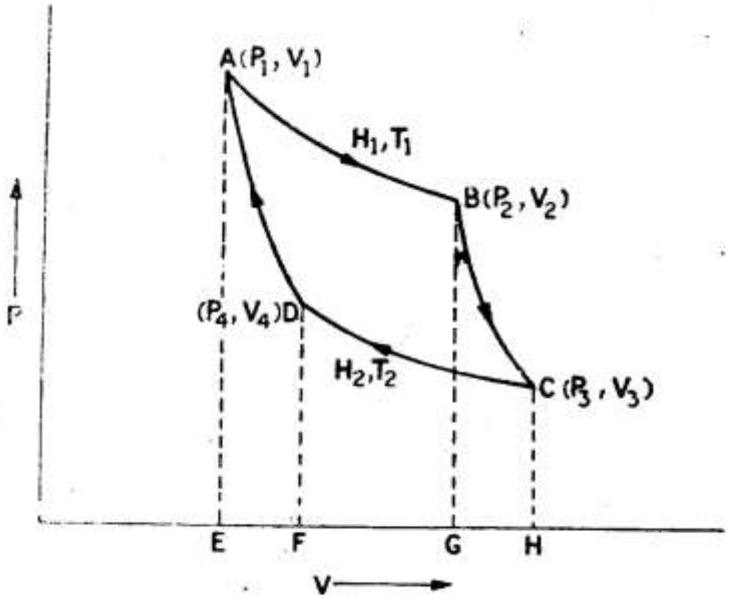
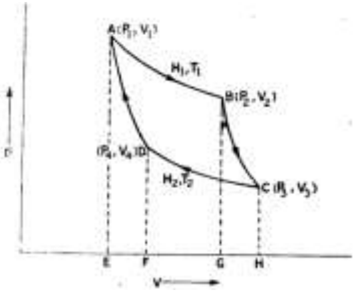


Fig. 2: Carnot's Cycle.

1. Place the engine containing the working substance over the source at temperature T_1. The working substance is also at a temperature, T_1. If pressure is P_1 and volume is V_1 as shown by the point A (Fig. 2). Decrease the pressure. The volume of the working substance increases. Work is done by the working substance. Let the amount of heat absorbed by the working substance be H_1 at the temperature T_1. The point B is obtained.

Consider one gram molecule of the working substance.

Work done from A to B (isothermal process)



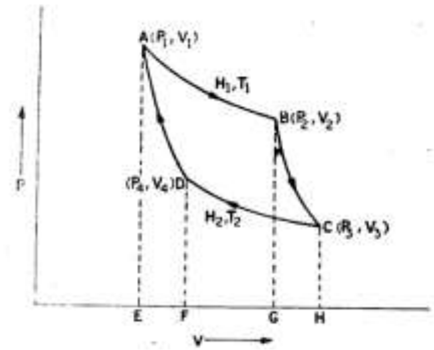
$$W_1 = \int_{V_1}^{V_2} P.dV$$

$$\therefore \qquad W_1 = RT_1 \int_{V_1}^{V_2} \frac{dV}{V} = RT \log_e \frac{V_2}{V_1} = Area\ ABGE \qquad (1)$$

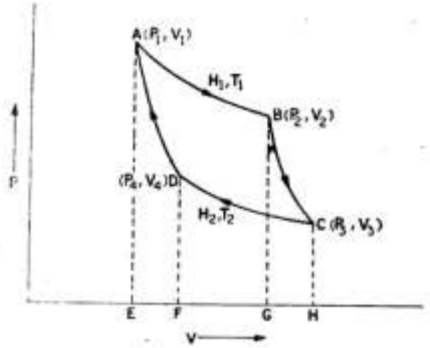
2. Place the engine on the stand having an insulated top. Decrease the pressure on the working substance. The volume increases. The process is completely adiabatic. Work is done by the working substance at the cost of its internal energy. The temperature falls. . The working substance undergoes adiabatic change from B to C. At C the temperature is T_2.

Work done from B to C (adiabatic process)

$$W_2 = \int_{V_2}^{V_3} P.dV$$



But PV^{γ} = Constant=K



$$\text{or} \qquad P = \frac{K}{V^{\gamma}}$$

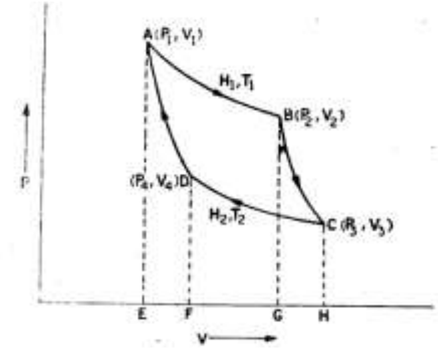
$$\therefore \quad W_2 = K\int_{V_2}^{V_3} \frac{dV}{V^{\gamma}}$$

$$= \frac{1}{1-\gamma}\left[\frac{K}{V_3^{\gamma-1}} - \frac{K}{V_2^{\gamma-1}}\right]$$

$$Now \quad P_3V_3^{\gamma} = P_2V_2^{\gamma} = K$$

$$\therefore \quad W_2 = \frac{1}{1-\gamma}\left[\frac{P_3V_3^{\gamma}}{V_3^{\gamma-1}} - \frac{P_2V_2^{\gamma}}{V_2^{\gamma-1}}\right]$$

$$= \frac{1}{1-\gamma}[P_3V_3 - P_2V_2]$$



$$However \quad P_3V_3 = RT_2$$

$$and \quad P_2V_2 = RT_1$$

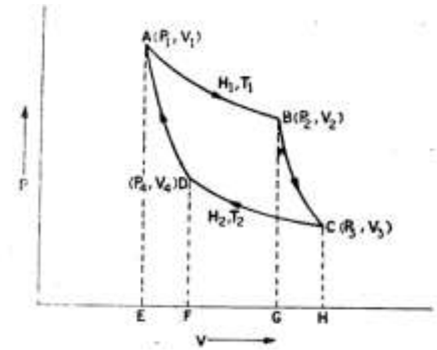
$$So \quad W_2 = \frac{1}{1-\gamma}[RT_2 - RT_1]$$

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

= Area BCHG (2)

3. Place the engine on the sink at temperature T_2. Increase the pressure. The work is done on the working substance. As the base is conducting to the sink, the process is isothermal. A quantity of heat H_2 is rejected to the sink at temperature T_2. Finally the point D is reached.

Work done from C to D (isothermal process)



$$W_3 = \int_{V_3}^{V_4} P.\,dV$$

$$= RT_2 \log_e \frac{V_4}{V_3}$$

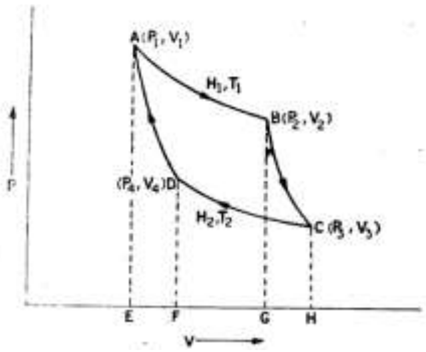
$$= -RT_2 \log_e \frac{V_3}{V_4} \qquad (3)$$

The -ve sign indicates that work is done on the working substance.

$$W_3 = \text{Area CHFD}$$

4. Place the engine on the insulating stand. Increase the pressure. The volume decreases. The process is completely adiabatic. The temperature rises and finally the point A is reached.

Work done from D to A (adiabatic process)



$$W_4 = \int_{V_4}^{V_1} P.dV$$

$$= -\frac{R}{\gamma - 1}[T_1 - T_2] \qquad (4)$$

W_4 = Area DFEA

W_2 and W_4 are equal and opposite and cancel each other.

The net work done by the working substance in one complete cycle.

= Area ABGE + Area BCHG – Area CHFD – Area DFEA

=Area ABCD

The net amount of heat absorbed by the working substance

$= H_1 - H_2$

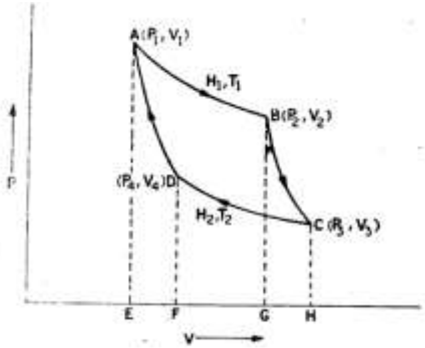
Net work $= W_1 + W_2 + W_3 + W_4$

$$W = RT_1 \log_e \frac{V_2}{V_1} + \frac{R}{\gamma - 1}[T_1 - T_2] - RT_2 \log_e \frac{V_3}{V_4} - \frac{R}{\gamma - 1}[T_1 - T_2]$$

$$\therefore \quad W = RT_1 \log_e \frac{V_2}{V_1} - RT_2 \log_e \frac{V_3}{V_4} \qquad (5)$$

The points A and D are on the same adiabatic

$$T_1 V_1^{\gamma - 1} = T_2 V_4^{\gamma - 1}$$



$$\therefore \quad \frac{T_2}{T_1} = \left(\frac{V_1}{V_4}\right)^{\gamma - 1} \qquad (6)$$

The points B and C are on the same adiabatic

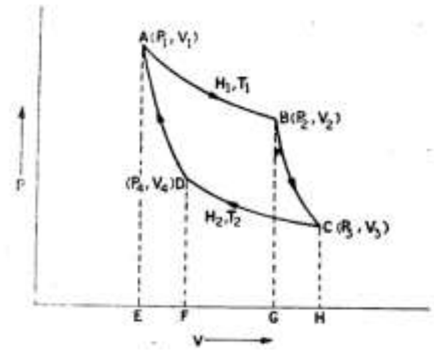
$$T_1 {V_2}^{\gamma-1} = T_2 {V_3}^{\gamma-1}$$

$$\therefore \quad \frac{T_2}{T_1} = \left(\frac{V_2}{V_3}\right)^{\gamma-1} \qquad (7)$$

From eqns. (6) & (7)

$$\left(\frac{V_1}{V_4}\right)^{\gamma-1} = \left(\frac{V_2}{V_3}\right)^{\gamma-1}$$

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



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

From eq. (5)

$$W = RT_1 \log_e \frac{V_2}{V_1} - RT_2 \log_e \frac{V_2}{V_1}$$

$$W = R \log_e \frac{V_2}{V_1} [T_1 - T_2]$$

$$W = H_1 - H_2$$

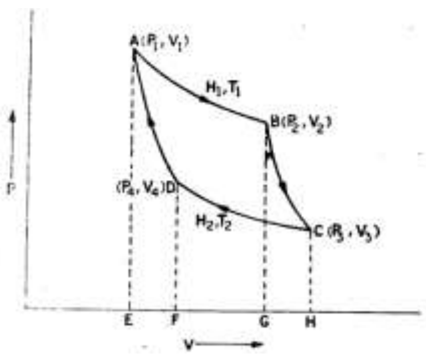
$$Efficiency \quad \eta = \frac{Useful\ output}{Input} = \frac{W}{H_1}$$

Heat is supplied from the source from A to B only.

$$H_1 = RT_1 \log_e \frac{V_2}{V_1}$$

$$\therefore \qquad \eta = \frac{W}{H_1} = \frac{H_1 - H_2}{H_1}$$

$$= \frac{R \log_e \frac{V_2}{V_1} [T_1 - T_2]}{RT_1 \log_e \frac{V_2}{V_1}}$$



$$= 1 - \frac{H_2}{H_1}$$

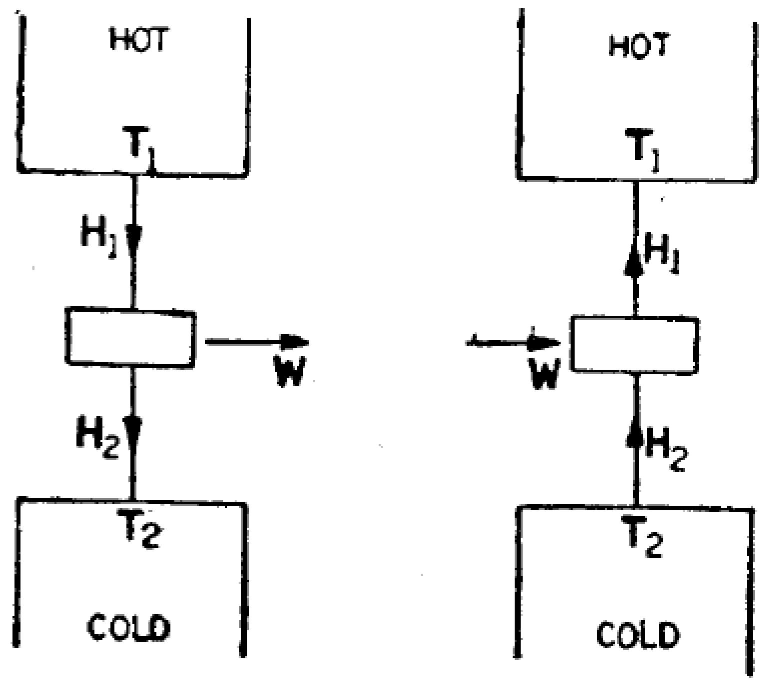
$$\eta = 1 - \frac{T_2}{T_1} \tag{8}$$

The Carnot's engine is perfectly reversible. It can be operated in the reverse direction also. Then it works as a refrigerator. The heat H_2 is taken from the sink and external work is done on the working substance and heat H_1 is given to the source at a higher temperature.

The isothermal process will take place only when the piston moves very slowly to give enough time for the heat transfer to take place. The adiabatic Process will take place when the piston moves extremely fast to avoid heat transfer. Any practical engine cannot satisfy these conditions.

All practical engines have an efficiency less than the Carnot's engine.

Carnot's Engine and Refrigerator



Heat Engine　　　　Refrigerator

Fig. 3: Comparison of heat Engine and Refrigerator.

Carnot's cycle is perfectly reversible, It can work as a heat engine and also as a refrigerator. When it works as a heat engine, it absorbs a quantity of heat H_1 from the source at a temperature T_1 does an amount of work W and rejects an amount of heat H_2 to the sink at temperature T_2. When it works as a refrigerator, it absorbs heat H_2 from the sink at temperature T_2. W amount of work is done on it by some external means and rejects heat H_1 to the source at a temperature T_1. In, the second case heat flows from a body at a lower temperature to a body at a higher temperature, with the help of external work done on the working substance and it works as a refrigerator. This will not be possible if the cycle is not completely reversible.

Coefficient of Performance

The amount of heat absorbed at the lower temperature is H_2. The amount of work done by the external process (input energy) = W and the amount of heat rejected = H_1. Here H_2 is the desired refrigerating effect.

$$\text{Coefficient of Performance} = \frac{H_2}{W} = \frac{H_2}{H_1 - H_2} \qquad (9)$$

Carnot's Theorem

All the reversible engines working between the same temperature limits have the same efficiency. No engine can be more efficient than a Carnot's reversible engine working between the same two temperatures.

Entropy and the Second law of Thermodynamics

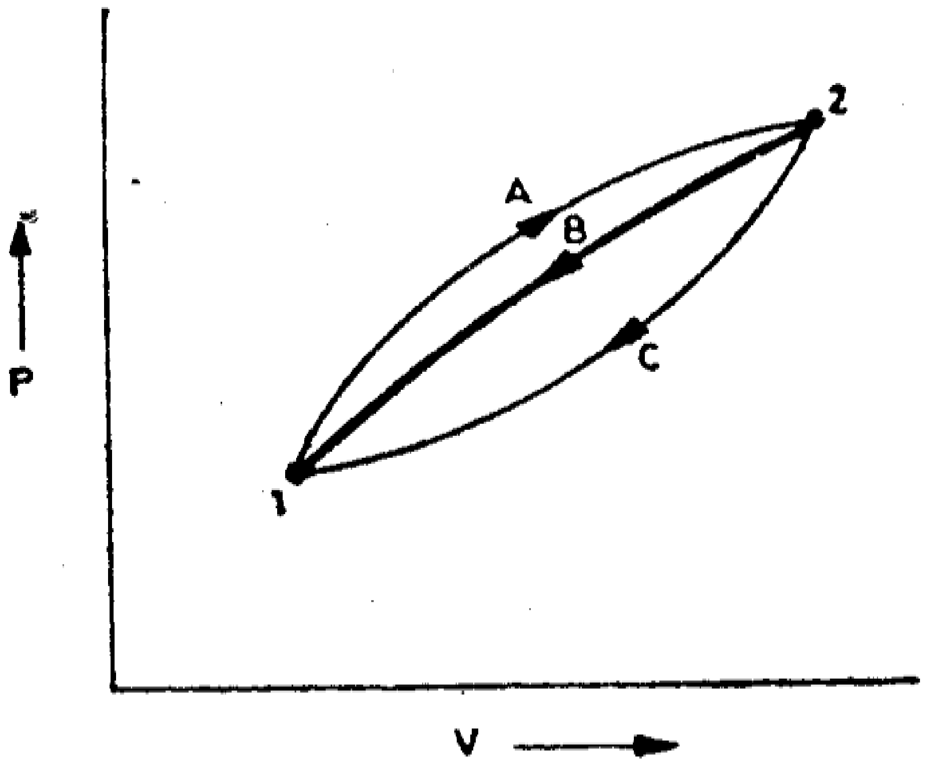
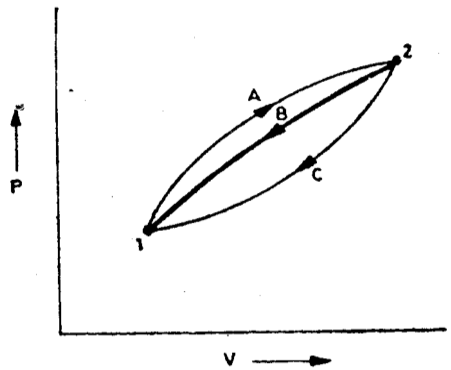


Fig. 4: P-V diagram of a system undergoing cyclic process.

Consider a closed system undergoing a reversible process from state 1 to state 2 along the path A and from state 2 to state 1 along the path B. As this is a reversible cyclic process



$$\oint \frac{\delta H}{T} = 0$$

$$\therefore \quad \oint_{1A}^{2A} \frac{\delta H}{T} + \oint_{2B}^{1B} \frac{\delta H}{T} = 0 \qquad (10)$$

Now consider the reversible cycle from state 1 to state 2 along the path A and from state 2 to state 1 along the path C. For this reversible cyclic process

$$\oint_{1A}^{2A} \frac{\delta H}{T} + \oint_{2C}^{1C} \frac{\delta H}{T} = 0 \qquad (11)$$

From eqns. (10) and (11)

$$\oint_{2B}^{1B} \frac{\delta H}{T} = \oint_{2C}^{1C} \frac{\delta H}{T} \qquad (12)$$

This shows that $\frac{\delta H}{T}$ has the sane value for all the reversible paths from state 2 to state 1. The quantity $\frac{\delta H}{T}$ independent of the path and is a function of the end states only, therefore it is a property.

This property is called entropy. Entropy is a thermodynamical property and is defined by the relation

$$dS = \frac{\delta H}{T} \qquad (13)$$

$$or \qquad S_2 - S_1 = \int_1^2 \frac{\delta H}{T} \tag{14}$$

The quantity $S_2 - S_1$ represents the change in entropy of the system when it is changed from state 1 to state 2.

Change in Entropy in a Reversible Process

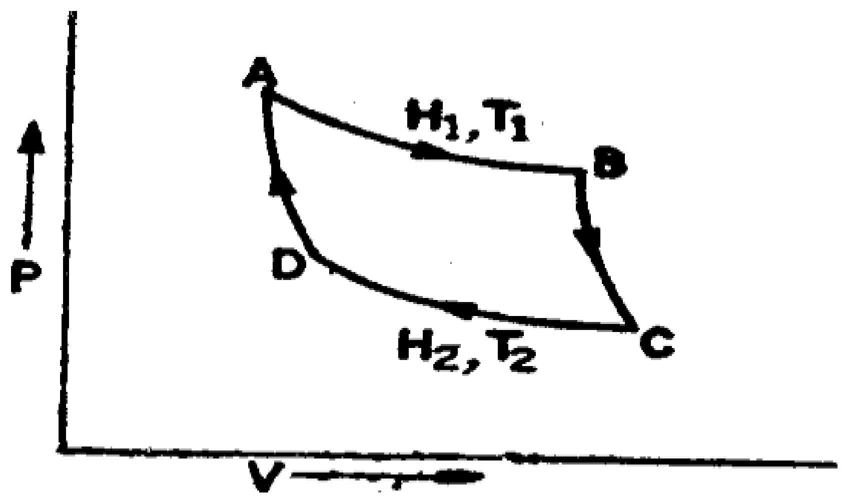
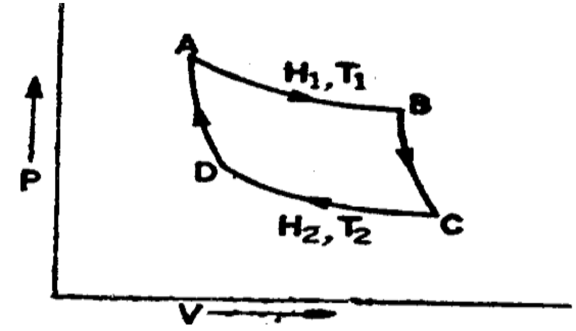


Fig. 5: Carnot’s reversible cycle

The total gain in entropy by the working substance in the cycle ABCDA

$$= \frac{H_1}{T_1} - \frac{H_2}{T_2}$$



But for a complete reversible process

$$\frac{H_1}{T_1} = \frac{H_2}{T_2}$$

Hence the total change in entropy of the working substance in a complete reversible Process

$$= \oint dS = \frac{H_1}{T_1} - \frac{H_2}{T_2} = 0$$

Change in Entropy in an Irreversible Process

$$Loss\ in\ entropy\ of\ the\ hot\ body = \frac{H}{T_1}$$

$$Gain\ in\ entropy\ of\ the\ hot\ body = \frac{H}{T_2}$$

Therefore, the total increase in entropy of the system

$$= \frac{H}{T_2} - \frac{H}{T_1}$$

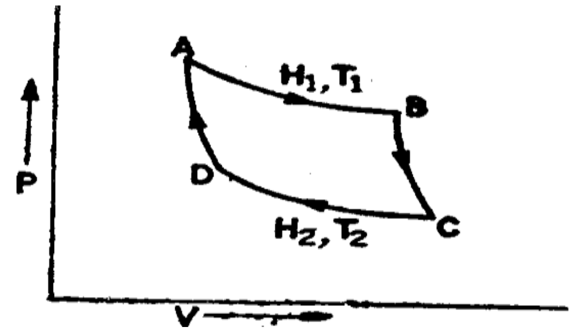
It is a positive quantity because T_2 is less than T_1. Thus the entropy of the system increases in all irreversible processes.

Third Law of Thermodynamics

In all heat engines, there is always loss of heat in the form of conduction, radiation and friction. Therefore, in actual heat engines

$$\frac{H_1}{T_1} \neq \frac{H_2}{T_2}$$

$$\frac{H_1}{T_1} - \frac{H_2}{T_2} \text{ is not zero but it is a positive quantity}$$



When cycle after cycle is repeated, the entropy of the system increases. And tends to a maximum value. When the system has attained the maximum value, a stage of stagnancy is reached and no work can be done by the engine at this stage. In this universe the entropy is increasing and ultimately the universe will also reach a maximum value of entropy when no work will be possible. With the increase in entropy the disorder of the molecules of a substance increases. The entropy is also a measure of the disorder of the system. With decrease in entropy, the disorder decreases.

At absolute zero temperature the entropy tends to zero and the molecules of a substance or a system are in perfect order (well arranged). This is the third law of thermodynamics.

Entropy of a Perfect Gas

Consider one gram of a perfect gas at a pressure P, volume V and temperature T. Let the quantity of heat given to the gas be δH.

$$\delta H = dU + \delta W$$

$$\delta H = 1 \times C_V \times dT + \frac{PdV}{J} \qquad (15)$$

$$\delta H = TdS$$

$$\therefore \quad TdS = C_V \times dT + \frac{PdV}{J} \qquad (16)$$

$$Also \quad PV = rT$$

$$or \quad P = \frac{rT}{V}$$

$$\therefore \quad TdS = C_V \times dT + \frac{rTdV}{JV}$$

$$dS = C_V \frac{dT}{T} + \frac{r}{J}\frac{dV}{V}$$

$$Integrating, \quad \int_{S_1}^{S_2} dS = C_V \int_{T_1}^{T_2} \frac{dT}{T} + \frac{r}{J}\int_{V_1}^{V_2} \frac{dV}{V}$$

$$S_2 - S_1 = C_V \log_e \frac{T_2}{T_1} + \frac{r}{J}\log_e \frac{V_2}{V_1} \qquad (17)$$

Laws of thermodynamics

0 Thermal equilibrium

1 Conservation of Energy

2 Energy can flow

3 Perfection unachievable


I Thank you