Ques:- Discuss the concept of absolute scale of temperature and explain how it is realised in practice? (2012, 2014, 2016).

Ans:- Absolute scale of temperature or Kelvin's thermodynamical scale of temperature: The efficiency of a reversible carnot's engine depends only upon the two temperatures (temp. of source and temp. of sink) between which it works and it is independent of the properties of the working substance. Using this property of reversible carnot's engine which only depends on temperatures and nothing else, Lord Kelvin in 1848 suggested a new scale of temperature, known as "absolute scale of temperature or Kelvin's thermodynamical scale of temperature". Lord Kelvin worked out the theory of such an absolute scale and showed that it agrees with the ideal gas scale.

Realisation of absolute scale of temperature using carnot's cycle:

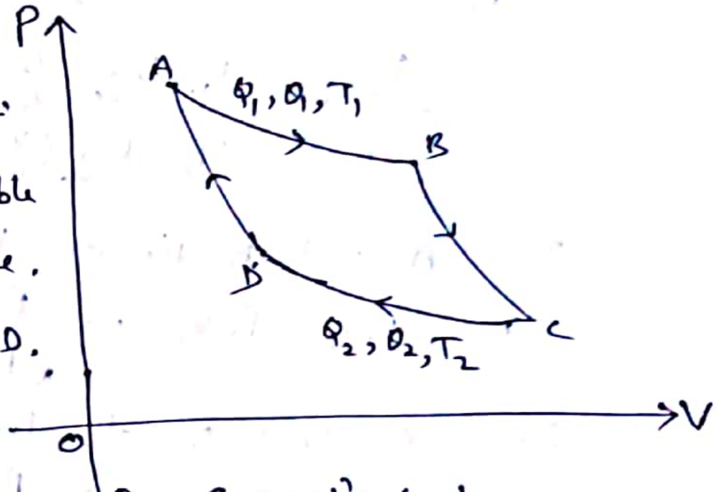

Fig:- Carnot's cycle

Consider a carnot's reversible cycle ABCDA as shown in figure. The isothermals are AB and CD. The temperature on the work scale (absolute scale) is θ_1 and on the ideal scale is T_1 for the isothermal AB and the temperature on the work scale (absolute scale) is θ_2 and on the ideal scale is T_2 for the isothermal CD. Let the pressures and volumes for the points A, B, C and D be P_1, V_1; P_2, V_2; P_3, V_3 and P_4, V_4 respectively. Suppose one gram mole of an ideal gas is used as the working substance.

From A to B, the process is isothermal and a quantity of heat Q_1 is absorbed by the gas from the source at temp T_1.

So $Q_1 = W_{AB} = \int_{V_1}^{V_2} P\,dV = \int_{V_1}^{V_2} \frac{1 \cdot RT_1}{V} \cdot dV$ (2) $\because PV = nRT \Rightarrow PV = 1 \cdot RT \Rightarrow P = \frac{RT}{V}$

$$= RT_1 \left[\log_e V\right]_{V_1}^{V_2} = RT_1 \left[\log_e V_2 - \log_e V_1\right]$$

$$\Rightarrow Q_1 = W_{AB} = RT_1 \cdot \log_e \left(\frac{V_2}{V_1}\right) \quad \text{——— (1)}$$

From C to D, the process is isothermal and a quantity of heat Q_2 is rejected by the gas to the sink at temp T_2.

So $Q_2 = W_{CD} = -\int_{V_3}^{V_4} P\,dV = -\int_{V_3}^{V_4} \frac{RT_2}{V} dV = -RT_2 \left[\log_e V\right]_{V_3}^{V_4}$

$$= -RT_2 \left[\log_e V_4 - \log_e V_3\right] = RT_2 \left[\log_e V_3 - \log_e V_4\right]$$

$$\Rightarrow Q_2 = RT_2 \cdot \log_e \left(\frac{V_3}{V_4}\right) \quad \text{——— (2)}$$

Equ (1) is divided by equ (2), we get

$$\frac{Q_1}{Q_2} = \frac{T_1 \cdot \log_e \left(\frac{V_2}{V_1}\right)}{T_2 \cdot \log_e \left(\frac{V_3}{V_4}\right)} \quad \text{——— (3)}$$

Since A and B lie on the same isothermal

so $P_1 V_1 = P_2 V_2 \Rightarrow \frac{P_2}{P_1} = \frac{V_1}{V_2}$ ——— (4)

Since C and D also lie on the same isothermal

so $P_3 V_3 = P_4 V_4 \Rightarrow \frac{P_3}{P_4} = \frac{V_4}{V_3}$ ——— (5)

Since B and C lie on the same adiabatic

so $P_2 V_2^{\gamma} = P_3 V_3^{\gamma}$ ——— (6)

Since A and D lie on the same adiabatic

so $P_1 V_1^{\gamma} = P_4 V_4^{\gamma}$ ——— (7)

Equ (6) is divided by equ (7), we get

$$\left(\frac{P_2}{P_1}\right)\left(\frac{V_2}{V_1}\right)^{\gamma} = \left(\frac{P_3}{P_4}\right)\left(\frac{V_3}{V_4}\right)^{\gamma}$$

$$\Rightarrow \left(\frac{V_1}{V_2}\right)\left(\frac{V_2}{V_1}\right)^{\gamma} = \left(\frac{V_4}{V_3}\right)\left(\frac{V_3}{V_4}\right)^{\gamma}$$ using equⁿs (4) and (5)

$$\Rightarrow \left(\frac{V_2}{V_1}\right)^{\gamma-1} = \left(\frac{V_3}{V_4}\right)^{\gamma-1} \Rightarrow \frac{V_2}{V_1} = \frac{V_3}{V_4} \quad \text{——— (8)}$$ put in equⁿ (3)

$$\frac{Q_1}{Q_2} = \frac{T_1 . \log_e\left(\frac{V_3}{V_4}\right)}{T_2 . \log_e\left(\frac{V_3}{V_4}\right)} \Rightarrow \frac{Q_1}{Q_2} = \frac{T_1}{T_2} \quad \text{——— (9)}$$

from the work scale (absolute scale) of temperature,

$$\frac{Q_1}{Q_2} = \frac{\theta_1}{\theta_2} \quad \text{——— (10)}$$

From equⁿs (9) and (10)

$$\frac{\theta_1}{\theta_2} = \frac{T_1}{T_2} \quad \text{——— (11)}$$

<u>Special consideration:</u>

(i) If θ_1 is zero then T_1 is also zero. It means the two scales are identical at absolute zero temperature.

(ii) Consider that the carnot's engine works between the steam point and ice point and there are 100 degrees between ice point and the steam point on the two scales.

i.e.,
$$\frac{\theta_{steam}}{\theta_{ice}} = \frac{T_{steam}}{T_{ice}} \Rightarrow \frac{\theta_{ice}+100}{\theta_{ice}} = \frac{T_{ice}+100}{T_{ice}}$$

$$\Rightarrow 1+\frac{100}{\theta_{ice}} = 1+\frac{100}{T_{ice}} \Rightarrow \frac{100}{\theta_{ice}} = \frac{100}{T_{ice}} \Rightarrow \boxed{\theta_{ice} = T_{ice}}$$

Therefore, the ice point is the same on the two scales.

Again
$$\frac{\theta_{steam}}{\theta_{ice}} = \frac{T_{steam}}{T_{ice}} \Rightarrow \boxed{\theta_{steam} = T_{steam}} \quad \because \theta_{ice} = T_{ice}$$

Therefore, the steam point is also the same on the two scales.

Hence the two scales are completely identical.