

# Lecture Notes of B.Sc.(HONS.) PHYSICS ,Part-I, Paper -II

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## TOPIC:-----Liquefaction of Gas

It is believed in ancient time that nothing could be colder than ice, temperature of ice was considered as the zero of scale used in temperature. Measurement in all system. Also we believed that air remains in gaseous state permanently at all temperature. But later on Andrew's experiment on CO<sub>2</sub> shows that below the critical temperature agas can be liquefied by the application of pressure.

Gas	Critical Temp. (°C)	Critical Pressure(atm.)	Boiling Temp. (°C)
CO <sub>2</sub>	-31.1	73	-78.6
O <sub>2</sub>	-118.8	50	-183
N <sub>2</sub>	-146	33.5	-195.8
H <sub>2</sub>	-240	12.8	-252.8
He	-267.8	2.26	-269.8

### Methods for Liquefaction of Gases

- 1. Method of freezing mixture:--** In this method salt is added to ice, a freezing mixture is formed . the salt is dissolved by the water adhering to ice and more ice melts . the heat necessary for this process is extracted from the mixture itself , therefore temperature of mixture falls down. The temperature thus reached by this process is not low enough.
- 2. Evaporation of liquid under reduced pressure :--** Whenever a liquid evaporates some heat is required to convert it from liquid to gaseous state . Which is equal to the latent heat of vaporization . If liquid is isolated the latent heat of vaporization is supplied at the

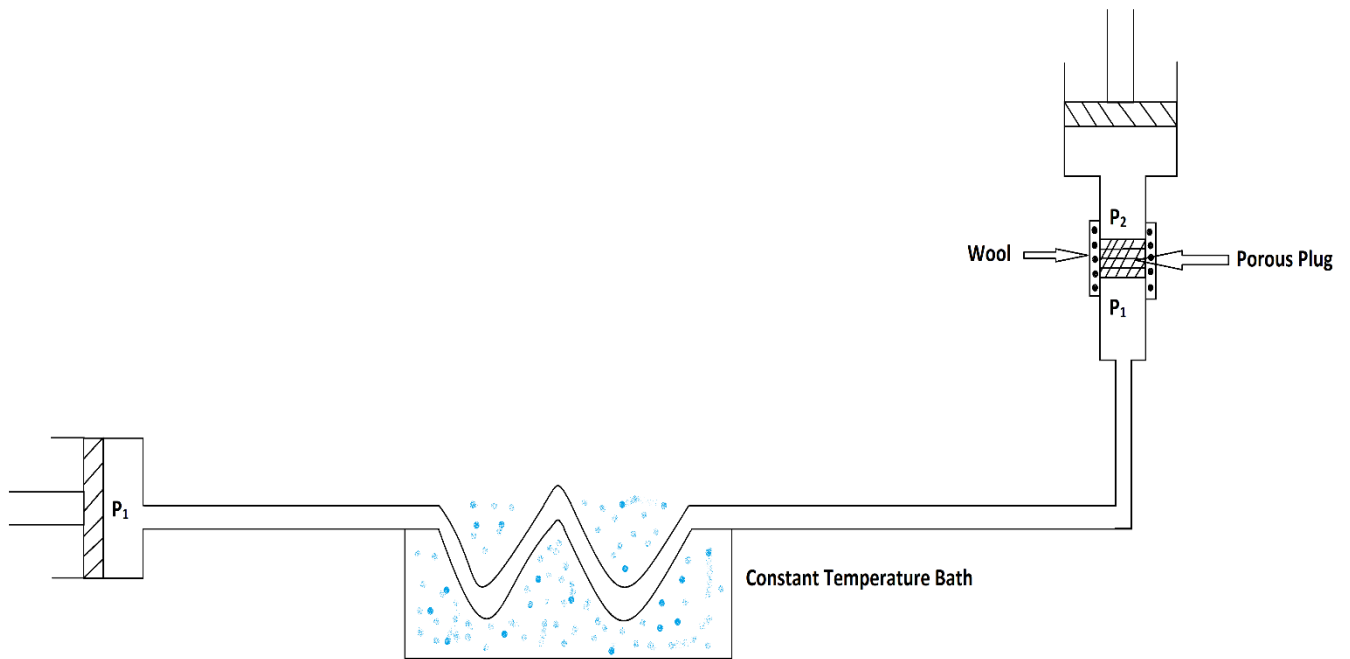
expense of total heat content of liquid itself , hence it's temperature falls .

- 3. Cooling with Adiabatic Expansion :--** In adiabatic process working gas is perfectly insulated from the surrounding so that no heat is allowed to enter or leave the system . Under this condition , when gas expands against some external pressure , the gas has to do some external work at the expense of it's internal energy. As internal energy of the gas is a function of its temperature , during adiabatic expansion of gas , it's internal energy and hence it's temperature falls.
- 4. Joule Thomson expansion :--** When a gas is allowed to escape adiabatically , through a porous plug , from the region of constant high pressure to a constant low pressure it undergoes a change of temperature . This is known as Joule Thomson effect and the process is called **Adiabatic Throttling**. The change of temperature may be positive or negative depending upon the nature of gas and the initial temperature .Now we will study the Joule Thomson Method which is the most efficient method of cooling in detail.

### **Joule Thomson Method of Cooling**

In this process the method of throttling of gas was used

Joule Thomson expansion is a continuous steady state flow process in which a compressed gas is made to expand adiabatically and irreversibly through a porous plug and work is done by the gas. The gas to be cooled is first made to flow through a copper spiral immersed in a thermostat ,so that it acquires a particular initial temperature .Then it is forced to pass through a porous plug kept in a non conducting cylinder .The plug consists of a porous material ,say cotton ,wool, silk etc. Porous plug is equivalent to a number of narrow fine holes held parallel .As a result the porous plug throttles the flowing fluid . The change in temperature is measured by the thermocouple. Though the process is irreversible the initial and final states are equilibrium states.



Experimental setup for Joule Thomson Effect

Suppose that the pressure on the two sides of porous plug are kept constant at  $P_1$  and  $P_2$  where  $P_2 < P_1$  (made possible by moving piston at an appropriate rate) Let  $U_1$  and  $U_2$  are initial and final internal energies of gas and  $V_1$  and  $V_2$  are initial and final volumes of the gas.

Therefore  $\Delta U + \Delta W = \Delta Q = 0$  { because process is adiabatic }

$\Delta W$  = work done by the gas in expanding against constant pressure  $P_2$  -  
work done on the gas in compressing at a constant pressure  $P_1$

$$= \int P_2 dV_2 - \int P_1 dV_1 = P_2 V_2 - P_1 V_1$$

$$\Rightarrow U_2 - U_1 + P_2 V_2 - P_1 V_1 = 0$$

$$\Rightarrow U_1 + P_1 V_1 = U_2 + P_2 V_2$$

$$\Rightarrow H_1 = H_2 \Rightarrow \text{Isoenthalp Process}$$

Now let  $H = H(T, P)$

$$\Rightarrow dH = \left( \frac{\partial H}{\partial T} \right)_P dT + \left( \frac{\partial H}{\partial P} \right)_T dP$$

$$\Rightarrow \left( \frac{\partial H}{\partial T} \right)_P dT = - \left( \frac{\partial H}{\partial P} \right)_T dP \quad (\text{since } dH = 0)$$

$$\Rightarrow \frac{dT}{dP} = -\frac{\left(\frac{\partial H}{\partial P}\right)_T}{\left(\frac{\partial H}{\partial T}\right)_P} \dots\dots\dots(1)$$

$$\Rightarrow \left(\frac{\partial H}{\partial P}\right)_T = \left[\left(\frac{\partial(U+PV)}{\partial P}\right)_T\right] = \left(\frac{\partial U}{\partial P}\right)_T + \left(\frac{\partial(PV)}{\partial P}\right)_T$$

$$\Rightarrow \left(\frac{dT}{dP}\right)_H = \frac{-1}{C_P} \left[ \left(\frac{\partial U}{\partial P}\right)_T + \left(\frac{\partial(PV)}{\partial P}\right)_T \right]$$

$$\Rightarrow \mu = \frac{-1}{C_P} \left[ T \left(\frac{\partial S}{\partial P}\right)_T - P \left(\frac{\partial V}{\partial P}\right)_T + P \left(\frac{\partial V}{\partial P}\right)_T + V \right]$$

$$\Rightarrow \mu = \frac{-1}{C_P} \left[ T \left(\frac{\partial V}{\partial T}\right)_P - P \left(\frac{\partial V}{\partial P}\right)_T + P \left(\frac{\partial V}{\partial P}\right)_T + V \right]$$

$$\Rightarrow \mu = \frac{-1}{C_P} \left[ V - T \left(\frac{\partial V}{\partial T}\right)_P \right] \dots\dots\dots(2)$$

This is known as **Joule Thomson Coefficient**

For Ideal Gas: PV=RT

$$\Rightarrow \left(\frac{\partial V}{\partial T}\right)_P = \frac{R}{P}$$

$$\Rightarrow \text{Joule Thomson Coefficient, } \mu = \frac{-1}{C_P} \left[ V - \frac{RT}{P} \right] = 0$$

⇒ Ideal Gas does not undergo any change in temperature during Adiabatic Throttling process. Hence there is no Joule Thomson effect for perfect gas because  $\mu = 0$ , hence using eqn.(1) we get:  $\left(\frac{\partial H}{\partial P}\right)_T = 0$

⇒ H is maximum so if we join locus of maxima of Isoenthalps, we get **Inversion Curve**, as shown in fig. below,

