Liquefaction of gases.

(1) A gas may be liquefied by cooling or by the application of high pressure or by the combined effect of both. The first successful attempt for liquefying gases was made by **Faraday (1823)**.

(2) Gases for which the intermolecular forces of attraction are small such as H_2, N_2, Ar and O_2, have low values of T_c and cannot be liquefied by the application of pressure are known as "permanent gases" while the gases for which the intermolecular forces of attraction are large, such as polar molecules NH_3, SO_2 and H_2O have high values of T_c and can be liquefied easily.

(3) **Methods of liquefaction of gases:**The modern methods of cooling the gas to or below their T_c and hence of liquefaction of gases are done by Linde's method and Claude's method.

(i) **Linde's method:**This process is based upon **Joule-Thomson effect** which states that "When a gas is allowed to expend adiabatically from a region of high pressure to a region of extremely low pressure, it is accompanied by cooling."

(ii) **Claude's method:**This process is based upon the principle that when a gas expands adiabatically against an external pressure (as a piston in an engine), it does some external work. Since work is done by the molecules at the cost of their kinetic energy, the temperature of the gas falls causing cooling.

(iii) By adiabatic demagnetization.

(4)**Uses of liquefied gases:**Liquefied and gases compressed under a high pressure are of great importance in industries.

(i) Liquid ammonia and liquid sulphur dioxide are used as refrigerants.

(ii) Liquid carbon dioxide finds use in soda fountains.

(iii) Liquid chlorine is used for bleaching and disinfectant purposes.

(iv) Liquid air is an important source of oxygen in rockets and jet-propelled planes and bombs.

(v) Compressed oxygen is used for welding purposes.

(vi) Compressed helium is used in airships.

(5) **Joule-Thomson effect:** When a real gas is allowed to expand adiabatically through a porous plug or a fine hole into a region of low pressure, it is accompanied by cooling (except for hydrogen and helium which get warmed up).

Cooling takes place because some work is done to overcome the intermolecular forces of attraction. As a result, the internal energy decreases and so does the temperature.

Ideal gases do not show any cooling or heating because there are no intermolecular forces of attraction i.e., they do not show Joule-Thomson effect.

During Joule-Thomson effect, enthalpy of the system remains constant.

Joule-Thomson coefficient. $\mu = (\partial T / \partial P)_H$. For cooling, $\mu = +ve$ (because dT and dP will be $-ve$) for heating $\mu = -ve$ (because $dT = +ve$, $dP = -ve$). For no heating or cooling $\mu = 0$ (because $dT = 0$).

6) **Inversion temperature:** It is the temperature at which gas shows neither cooling effect nor heating effect i.e., Joule-Thomson coefficient $\mu = 0$. Below this temperature, it shows cooling effect and above this temperature, it shows heating effect.

Any gas like H_2, He etc., whose inversion temperature is low would show heating effect at room temperature. However, if these gases are just cooled below inversion temperature and then subjected to Joule-Thomson effect, they will also undergo cooling.