Joule-Thomson Effect

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Joule-Thomson Effect

In thermodynamics, the ***Joule–Thomson effect*** (also known as the Joule–Kelvin effect or Kelvin–Joule effect) describes the temperature change of a *real* gas or liquid (as differentiated from an ideal gas) when it is forced through a valve or porous plug while keeping it insulated so that no heat is exchanged with the environment. This procedure is called a *throttling process* or *Joule–Thomson process*.

"The phenomenon of change of temperature produced when a gas is made to expand adiabatically from a region of high pressure to a region of extremely low pressure is known as the Joule-Thomson effect".

At room temperature, all gases except hydrogen, helium, and neon cool upon expansion by the Joule–Thomson process when being throttled through a porous plug. These three gases experience the same effect but only at lower temperatures

- Joule-Thomson effect is also called adiabatic expansion of gases.
- Joule and Thomson observed that when a gas at high pressure is allowed to expand to low pressure region, the gas gets cold.
- If a gas is compressed to about 200 atmospheres pressure and then allowed to expand through an orifice into a container that is at low pressure, the gas expands and gets cold.
- The reason for this is that at high pressure the intermolecular distances are so low that the molecules experience the faces of attraction.
- When the gas expands the intermolecular distances must increase for which molecules must do some work or lose some kinetic energy to overcome the intermolecular attractions.
- Kinetic energy of a gas is directly proportional to its absolute temperature.
- Hence by losing kinetic energy the gas gets cold and this phenomenon is called "Joule-Thomson effect".

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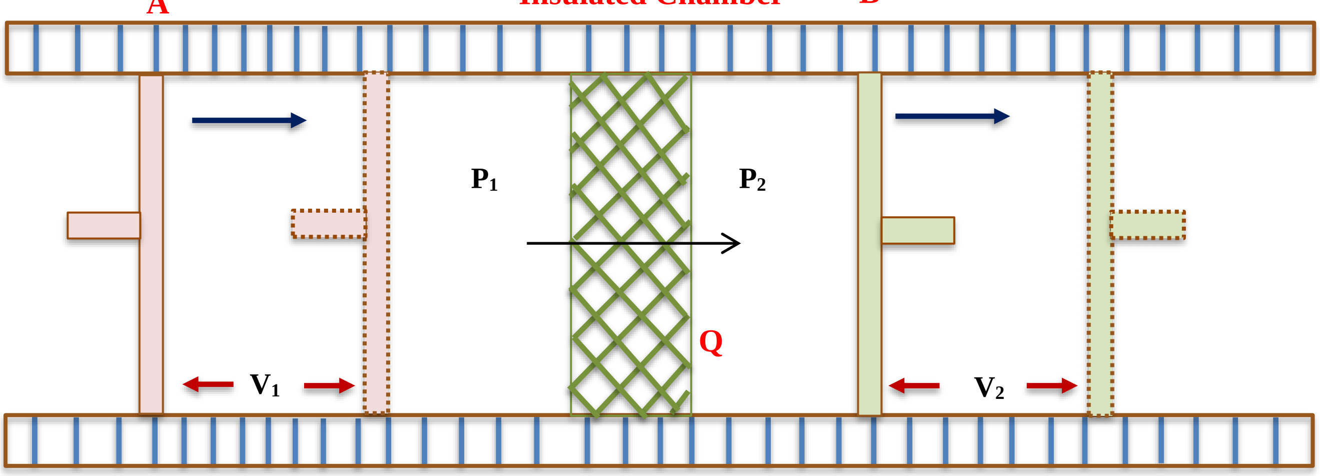
The expression for this effect is

$$T_1 - T_2 = 0.276\left[\frac{273}{T_1}\right]^2 (P_1 - P_2)$$

- Where P_1 and T_1 are the initial pressure and temperature and P_2 and T_2 are the pressure and temperature after expansion.
- From this we understand that more the difference between P_1 and P_2 more would be the difference between T_1 and T_2.

Joule Thomson Experiment

- The apparatus used by Joule and Thomson to Measure the temperature change on expansion of a given volume of gas under adiabatic condition is illustrated schematically in the figure as shown below.



Joule-Thomson experiment (expansion of a real gas through a porous plug)

- An insulated Chamber (to ensure adiabatic conditions) is fitted with a porous plug **Q** in the middle and two pistons **A** and **B** on the sides.
- The pressure of the left side of the plug is P_1 and that of right side is P_2 where $P_1 > P_2$.
- The gas of volume V_1 at high pressure P_1 is allowed to go into the part of low pressure through porous plug **Q** by moving the piston **A** inwards and is allowed to expand to volume V_2 at a lower pressure P_2.
- This process is carried out slowly so as not to change the pressure P_1.

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- The change in temperature is found by taking readings on the two thermometers (not shown in figure) and it was observed that when the experiment is done at room temperature, all gases show a decrease in temperature on expansion except H_2 and He gases.

Since the process is carried under adiabatic condition,

$$Q = 0.$$

According to first law of thermodynamics,

$$\Delta E = Q - W$$

$$\therefore \quad \Delta E = -W$$

$$\text{or} \quad W = -\Delta E$$

Thus, the work done during the expansion of the gases under adiabatic condition is at the expense of internal energy (ΔE). In other words, when the work of expansion is done under adiabatic conditions, the internal energy decreases and hence temperature of the gas decreases (Since $\Delta E \propto T$).

Joule-Thomson Coefficient

Joule and Thomson introduces the term Joule-Thomson coefficient, represented by 'μ_{JT}' for expressing the change in temperature produced by change in pressure during adiabatic expansion of a real gas.

They defined μ_{JT} by the expression

$$\mu_{JT} = \left(\frac{\partial T}{\partial P} \right)_H$$

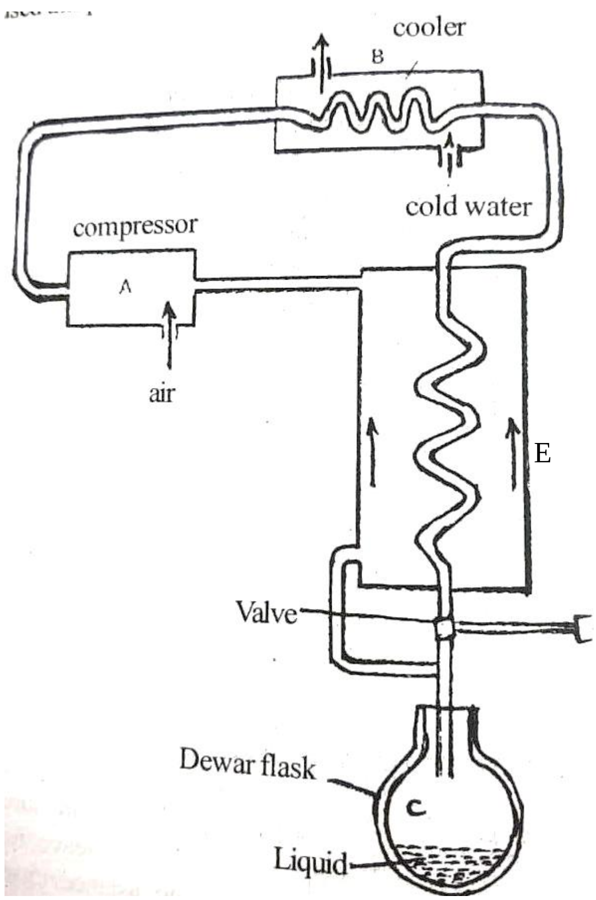
i. If μ_{JT} is positive, the gas cools on adiabatic expansion.
ii. If μ_{JT} is negative, the gas warms up on adiabatic expansion at room temperature.
iii. If μ_{JT} is equal to zero, the gas neither cools nor warms up on adiabatic expansion.

Inversion Temperature (T_i)

At a particular pressure, every gas has a definite temperature at which Joule- Thomson coefficient μ_{JT} becomes zero ($\mu_{JT} = 0$). This temperature is called "**inversion temperature (T_i)**". Below this temperature μ_{JT} is positive (i.e., gas undergoes cooling on adiabatic expansion) and above this temperature μ_{JT} is negative (i.e., gas undergoes heating on adiabatic expansion). This inverse temperature is written as 2a / Rb (where a, b are the Van Der Waals constants)

Application of Joule - Thomson Effect:

Joule-Thomson effect is applied in the Linde technique as a standard process in the petrochemical industry, where the cooling effect is used to liquefy gases.



Linde liquefaction Unit

- Linde used this principle to liquefy air.
- The air is separated from dust particles and CO_2 and then sent it to a compressor that compresses it to about 200 atmospheres.
- The heat produced in this process is removed by passing the compressed gas into the cooler ‘B’ in which water is circulated.
- From the cooler the air is sent into spiral tube of hundreds of meters length and finally enters into the space of low pressure through the valve.
- In this process the air gets cooled by Joule-Thomson effect.
- This cooled air then enters ‘E’.
- This would cool air that enters inside before expansion.
- From ‘E’ the air again enters into the compressor and gets compressed again expands compressed and expands again.
- This process is repeated several times in a cyclic process until the air gets cooled below. It's critical temperature -140°C. When the air is below its critical temperature on further expansion it gets liquefied and reaches Dewar’s flask.

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