Chapter 2

Ideal gas
&
First Law of Thermodynamics

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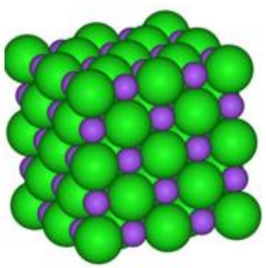
❑Intermolecular Forces & State of Matter

Four states of matter are observable in everyday life: Solid, Liquid, Gas, and Plasma.

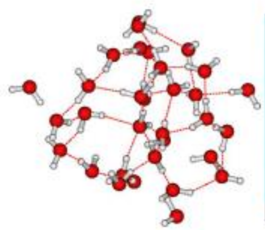
1. Solid

- In a solid the particles (ions, atoms or molecules) are **closely packed together**.
- The forces between particles are strong so that the particles **cannot move freely** but **can only vibrate**.



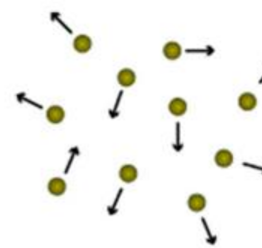
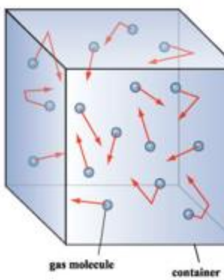

2. Liquid

- Weak Intermolecular cohesive forces force are present between the molecules of the liquid.
- The molecules move relative to each other, and the **structure is mobile and take the shape of the container**.




3. Gas

- Molecular distance much larger than the molecular size.
- the effect of **intermolecular forces is very small**
- A gas has no definite shape or volume but **occupies the entire container in which it is confined**.

4.Plasma

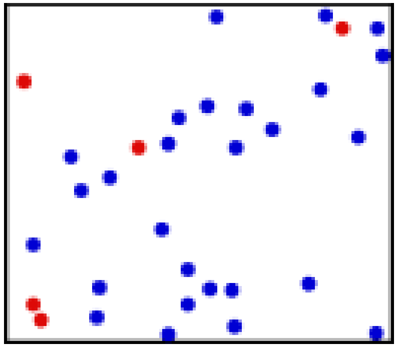
- A gas when energy is added, heating a gas will form a plasma – a soup of positively charged particles (ions) and negatively charged particles (electrons).

❑Ideal Gas

➢ Ideal Gas = Perfect Gas

The Ideal gas is a theoretical gas which can be described as:

1. Consisting of **identical particles** of negligible volume.
2. The total energy of the gas is in the form of kinetic energy
   (potential energy= 0).
1. The gas molecules moves in free random motion.
2. The gas molecules make perfectly elastic collisions with each other and with the walls of the container.



➢ The Ideal gas is a good approximation of the real gases at low pressure

➢ **The relation between variable states of an ideal gas (pressure, volume, temperature) can be described by the equation of state or the ideal gas equation.**

➢The ideal gas equation is based on:

1. **Boyle's law**
2. **Charles's law**
3. **Gay–Lussac's Pressure Law**
4. **Avogadro's law**

$$\boxed{PV = nRT}$$

$R = 8.314 \frac{J}{mole.K} \rightarrow Universal\ gas\ constant$

$n = number\ of\ moles$

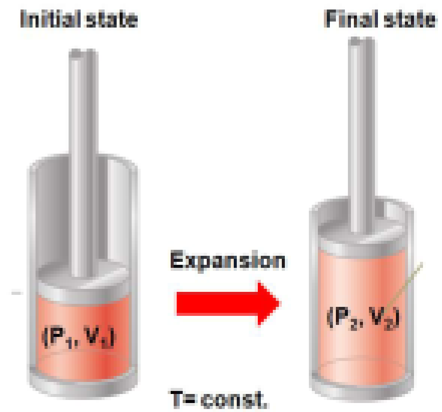
❑Ideal Gas Laws

1. Boyle's law:

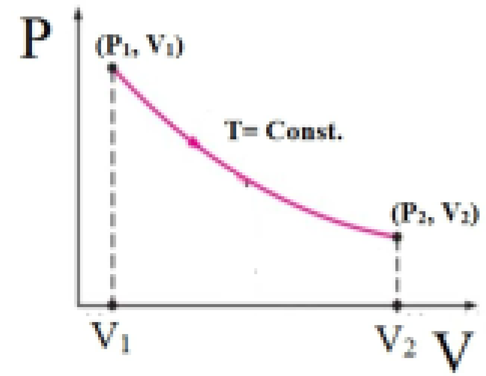
States that " *At constant temperature, the ideal gas pressure is inversely proportional to its volume*".

$$P \propto \frac{1}{V} \quad \Rightarrow \quad P = \frac{const.}{V}$$

$$\boxed{PV = const. \qquad T = const.\,(isothermal\,)}$$



$$\boxed{P_1V_1 = P_2V_2} \qquad \boxed{\frac{P_1}{P_2} = \frac{V_2}{V_1}} \qquad T = const.\,(isothermal\,)$$



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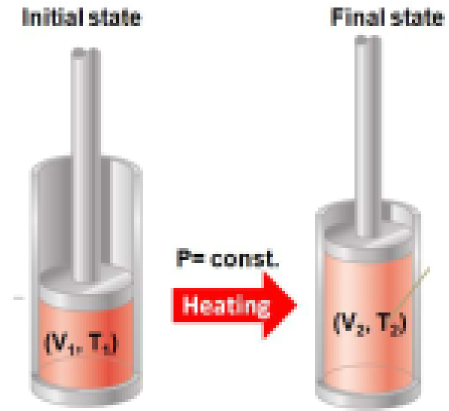
❑Ideal Gas Laws

2. Charles' Law:

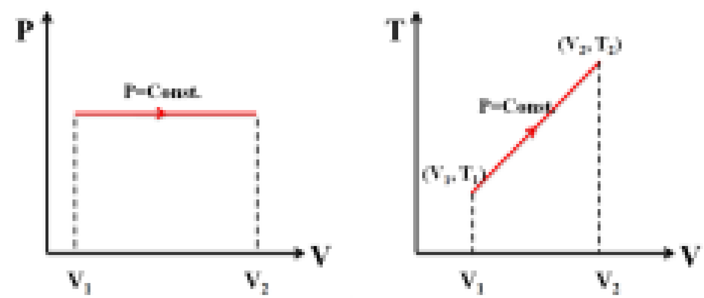
States that " *At constant pressure, the ideal gas volume is directly proportional to its absolute temperature*".



$$V \propto T \quad \Rightarrow \quad V = const. \times T$$

$$\boxed{\frac{V}{T} = const. \qquad P = const.\,(\textbf{isobaric})}$$

$$\boxed{\frac{V_1}{V_2} = \frac{T_1}{T_2}} \qquad P = const.\,(\textbf{isobaric})$$



❑Ideal Gas Laws

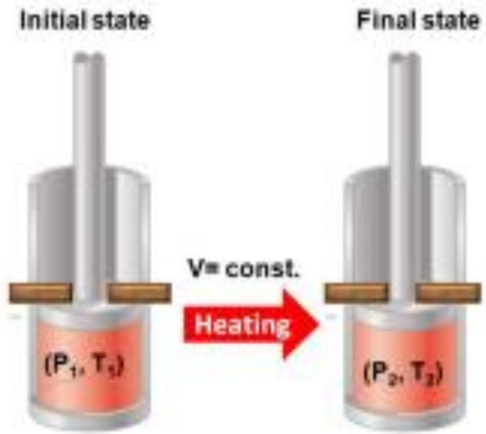
3. Gay–Lussac's Law (Pressure Law):

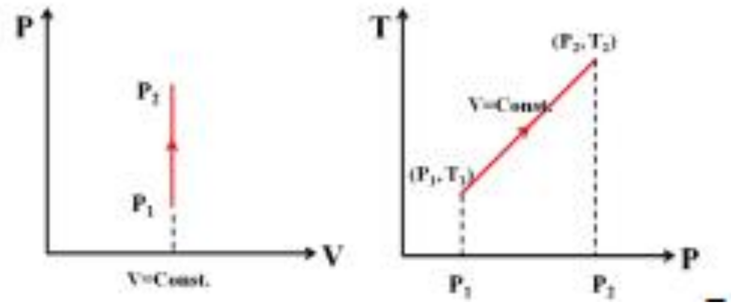
States that " ***At constant volume, the ideal gas pressure is directly proportional to its absolute temperature***".

$$P \propto T \quad \Rightarrow \quad P = const. \times T$$

$$\boxed{\frac{P}{T} = const. \quad V = const. \, (\textit{\textbf{Isochoric}})}$$

$$\boxed{\frac{P_1}{P_2} = \frac{T_1}{T_2}} \quad V = const. \, (\textit{\textbf{Isochoric}})$$





❑Ideal Gas Laws

➤***From Boyle's law:*** $V \propto \dfrac{1}{P}$

➤***From Charles' law:*** $V \propto T$

$$\therefore V \propto \frac{T}{P} \quad \Rightarrow \quad V = const.\frac{T}{P}$$

$$\boxed{\frac{PV}{T} = const.}$$

const.⟶ is a constant depends on the ***gas mass and the properties***

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❑Ideal Gas Laws

- ***From Boyle's law:*** $V \propto \frac{1}{P}$
- ***From Charles' law:*** $V \propto T$

$$\therefore V \propto \frac{T}{P} \quad \Rightarrow \quad V = const. \frac{T}{P}$$

$$\boxed{\frac{PV}{T} = const. = R}$$

- ***By using Avogadro's law:***

At Standard Temperature and pressure (**STP**) T= 273 K (0 ᵒC) and P= 101.3 KPa, the volume one mole of any gas is V= 22.4 Lit

$$R = 8.314 \frac{J}{mole.K} \rightarrow Universal\ gas\ constant$$

- ***For n moles of gas:*** $\boxed{PV = nRT}$ ***Ideal Gas Law***

$$n\ (No. of\ moles) = \frac{m}{M} = \frac{mass\ of\ gass}{Molecular\ weight}$$

Example (1)

Pure helium gas is admitted into a tank containing a movable piston. The initial volume, pressure, and temperature of the gas are 15×10^{-3} m^3, 200 KPa, and 300K. If the volume is decreased to 12×10^{-3} m^3 and the pressure increased to 350 KPa, (a) Find the final temperature of the gas. (b) How many moles contained in the tank? (Assume that the helium like an ideal gas).

Solution

$V_1 = 15\times10^{-3}\ m^3$, $P_1 = 200\times10^3\ Pa$, $T_1 = 300\ K$, $V_2 = 12\times10^{-3}\ m^3$, $P_2 = 350\times10^3\ Pa$, $T_2 = ??$, $n = ??$

$$PV = nRT$$

(a) $$P_1V_1 = nRT_1$$

$$P_2V_2 = nRT_2$$

$$\frac{P_1V_1}{P_2V_2} = \frac{T_1}{T_2}$$

Solution

$V_1 = 15\times10^{-3}$ m^3, $P_1=200\times10^3$ Pa, $T_1=300$ K, $V_2=12\times10^{-3}$ m^3, $P_2=350\times10^3$ Pa, $T_2=??$, $n=??$

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$\frac{(200\times10^3)(15\times10^{-3})}{(300)} = \frac{(350\times10^3)(12\times10^{-3})}{T_2}$$

$$\boxed{T_2 = 420K}$$

(b) $$P_1V_1 = nRT_1$$

$$(200\times10^3)(15\times10^{-3}) = n(8.31)(300)$$

$$\boxed{n = 1.2\ moles}$$

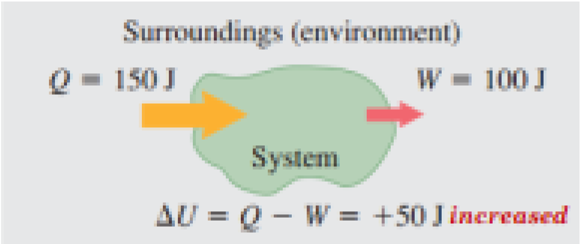
❑The First Law of Thermodynamics

➢The first law of thermodynamics represents another version of the **the law of conservation of energy** for thermodynamic systems.

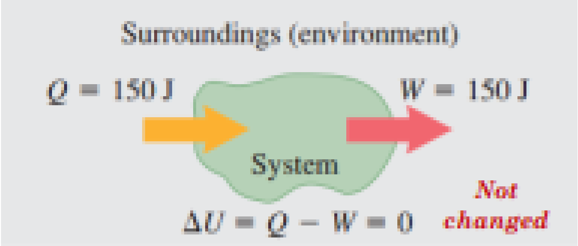
➢**The first law of thermodynamics states that:**

The change in the internal energy of a closed system is equal to the amount of heat added to the system, minus the amount of work done by the system on its surroundings.

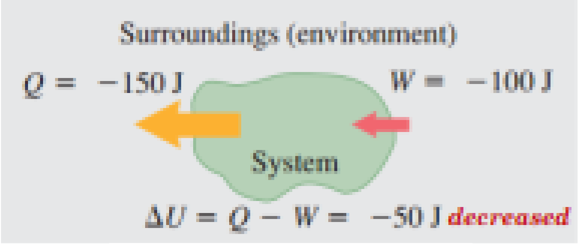
$$\boxed{\Delta U = Q - W} \xrightarrow{\text{Differential form}} \boxed{dU = dQ - dW}$$



$$Q = \Delta U + W$$



$$Q = W, \quad \Delta U = 0$$



$$\Delta U = Q - W$$

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❑The First Law of Thermodynamics

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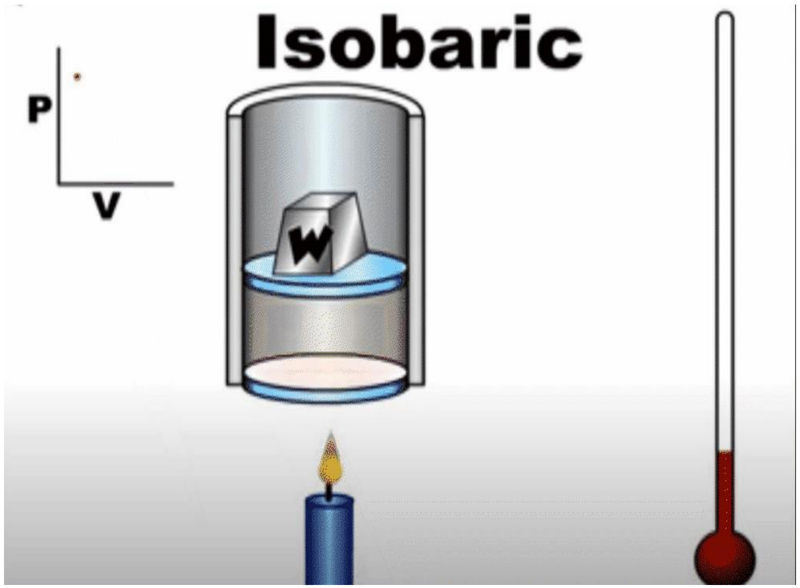
$$\boxed{\Delta U = Q - W}$$

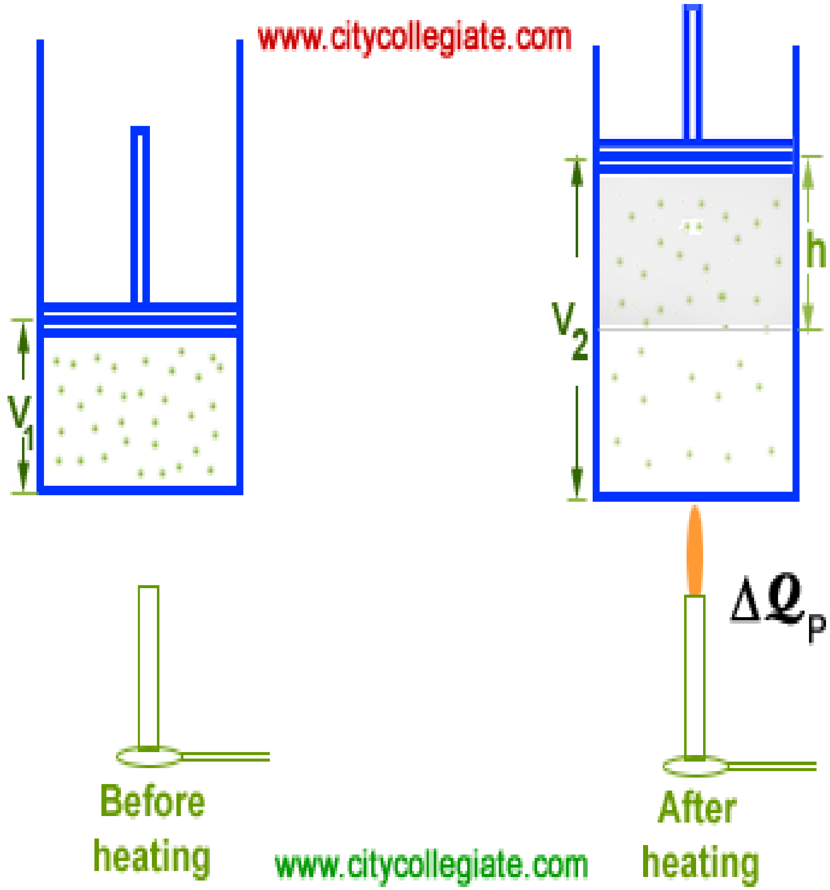
$$\boxed{dU = dQ - dW}$$

Thermodynamic processes

1-Isobaric process

P = constant





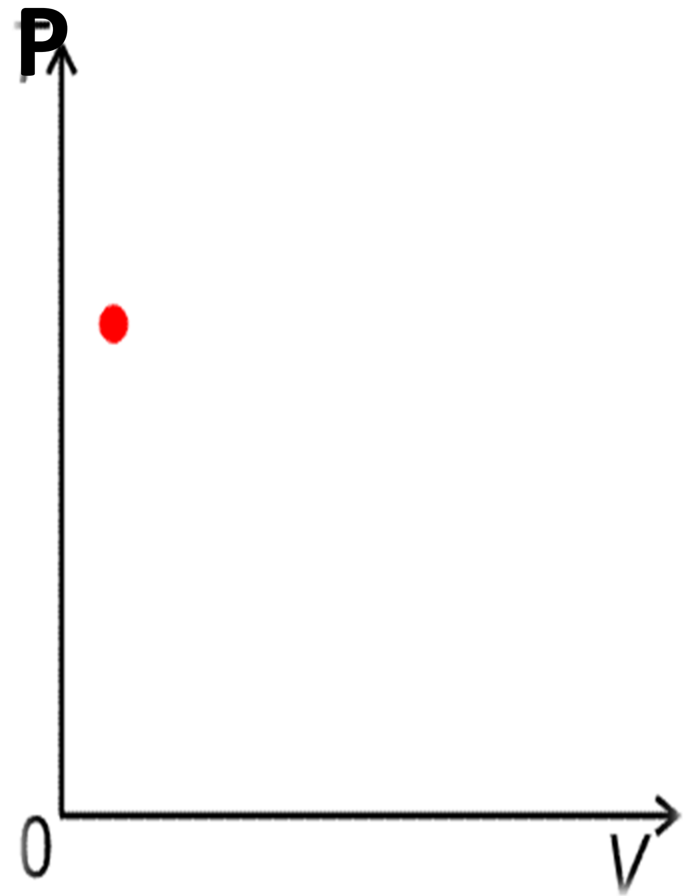
Thermodynamic processes

Isobaric work:

$W_{(1\text{-}2)} = \int_1^2 P\, dV$

$W_{(1\text{-}2)} = P \int_1^2 dV$

$= P(V_2 - V_1)$



❑Thermodynamic Processes

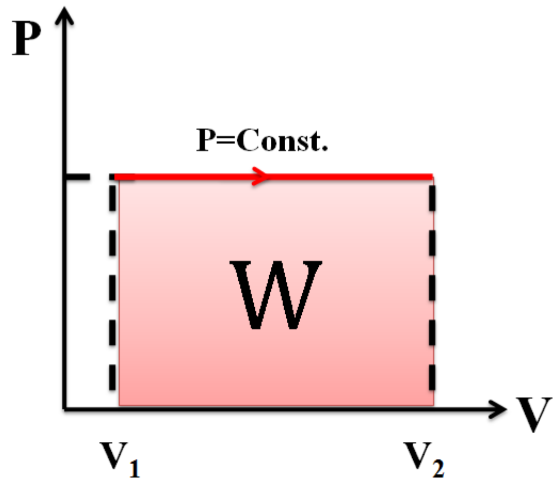
1. Isobaric process

for isobaric process $P = constant$

$$Q = nc_P\Delta T$$

$$W = P(V_2 - V_1) = nR(T_2 - T_1)$$

$$Q = \Delta U + W$$

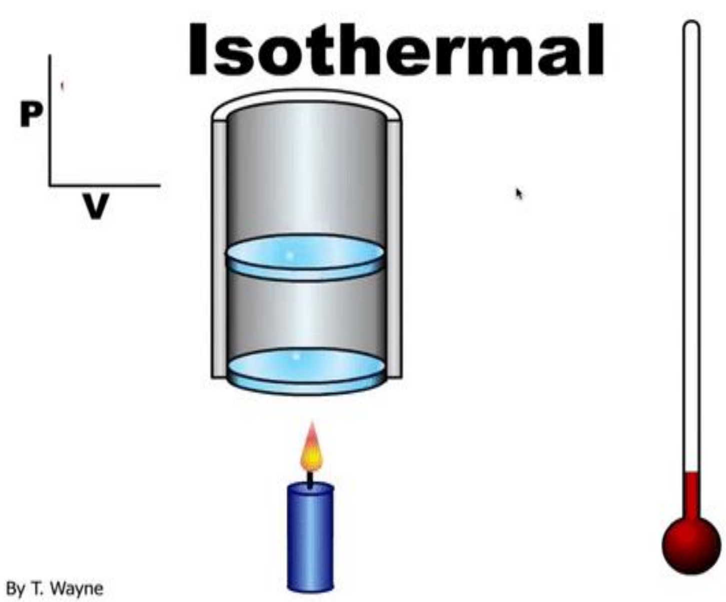


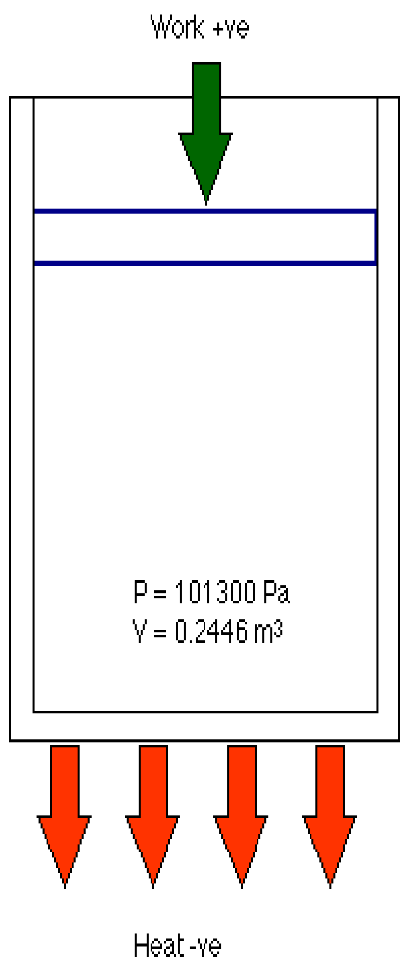
Thermodynamic processes

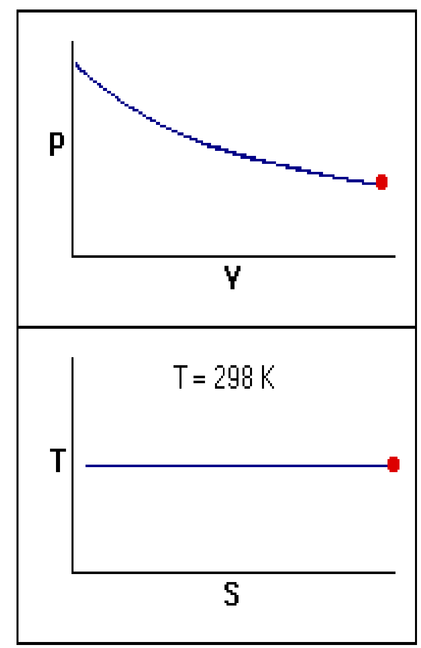
2- Isothermal process

ISO particular property remains constant

T = constant







Thermodynamic processes

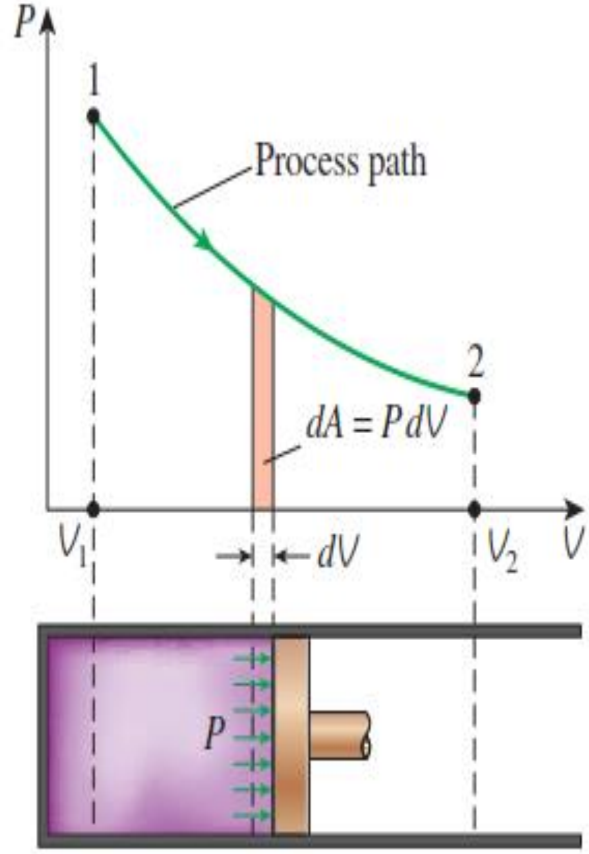
Isothermal work:

$W_{(1\text{-}2)} = \int_1^2 P\,dV$

For idea gas **PV = nRT**

So, $\mathbf{P = \frac{nRT}{V}}$

$$\mathbf{W_{(1\text{-}2)} = \int_1^2 \frac{nRT}{V}\,dV = nRT \ln \frac{V_2}{V_1}}$$



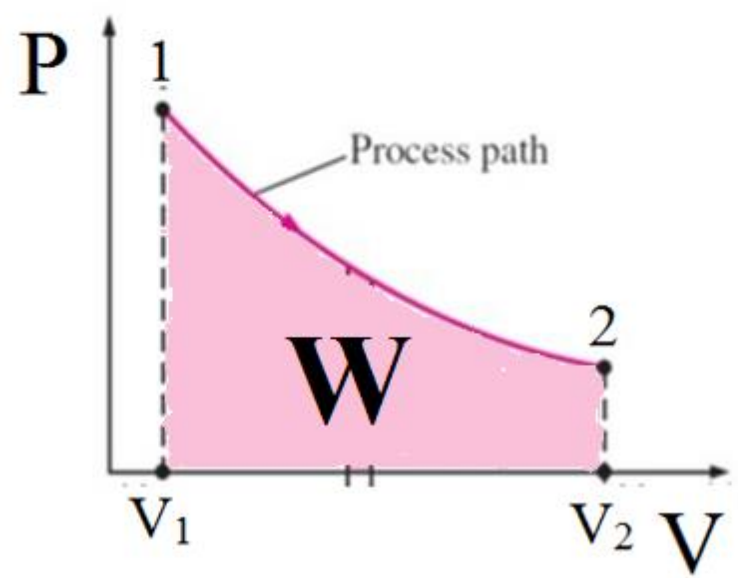
❑Thermodynamic Processes

2. Isothermal process

$$for\ isothermal\ process \qquad T = constant$$

$$\therefore \Delta U = 0$$

$$Q = W = nRT ln(\frac{V_2}{V_1})$$

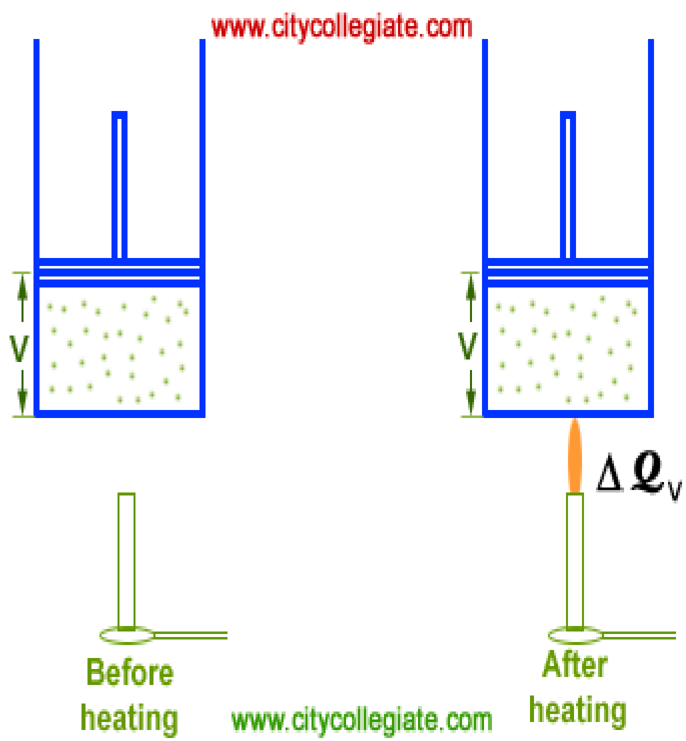


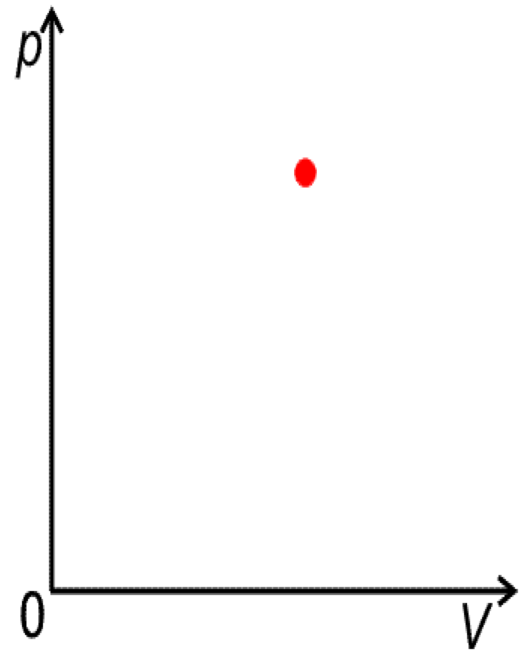
Thermodynamic processes

3-Isochoric work:

$$W_{(1\text{-}2)} = \int_1^2 P\, dV$$

There isn't dV





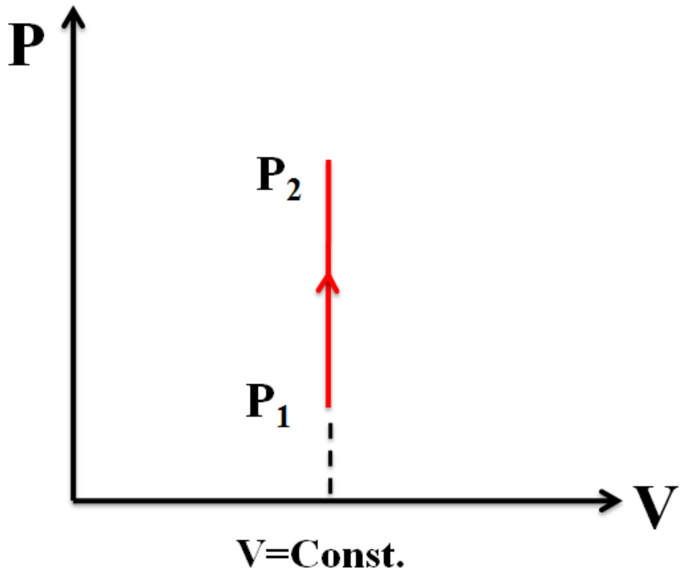
$$W_{(1\text{-}2)} = zero$$

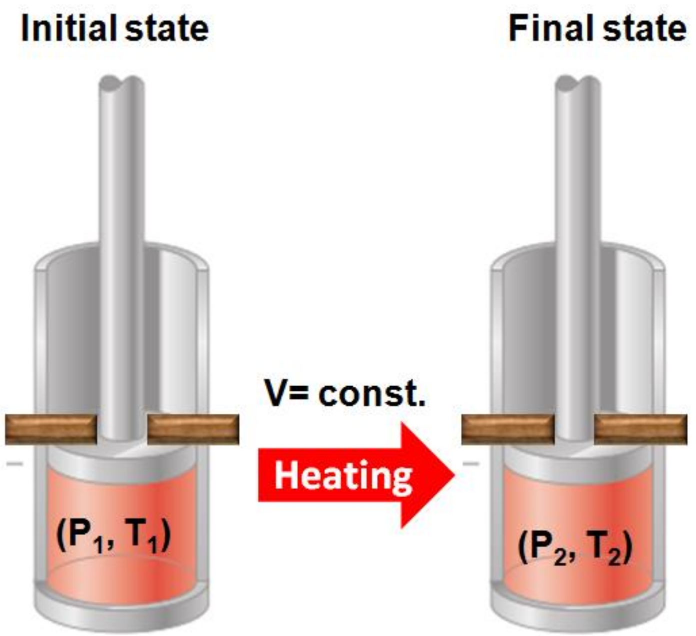
Thermodynamic Processes

3. Isochoric process (isovolumetric process)

$$for\ isochoric\ process \quad V = constant$$

$$\Delta U = Q = nc_v \Delta T \quad \& \quad W = 0$$





❑Relation between c_p and c_v

$$\boxed{\therefore c_p = c_v + R} \quad \frac{J}{mole.K}$$

- **Gamma Constant (γ)**

  Is the ratio between c_p and c_v.

$$\boxed{\gamma = \frac{c_p}{c_v} > 1}$$

Example

A 1.0-mol sample of an ideal gas is kept at 0.0°C during an expansion from 3.0 L to 10.0 L.

a) How much work is done on the gas during the expansion?
b) How much energy transfer by heat occurs between the gas and its surroundings in this process?

Solution

n= 1.0 mole, V_1 =3.0 L, T_1= T_2=0.0°C= 273.15 K, V_2 =10.0 L, W=?? , Q=??

$a)\ for\ isothermal\ process$

$$W = nRTln(\frac{V_2}{V_1})$$

$$W = (1.0) \times (8.31) \times (273.15) ln(\frac{10.0}{3.0})$$

$$\boxed{W = +2.7 \times 10^3 Joule}$$

Work done by the system

$b) from\ the\ first\ law,\ Q = \Delta U + W$

$$T = const. \qquad \therefore \Delta U = 0$$

$$\boxed{Q = W = +2.7 \times 10^{3} Joule}$$

Heat is added to the system