Bhubanananda Odisha School of Engineering, Cuttack

Department of Mechanical Engineering

LECTURER NOTES

SUBECT- ELEMENTS OF MECHANICAL ENGINEERING (**TH-3**)

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Th3: Elements of Mechanical Engineering

CH:1 THERMODYNAMICS

Introduction:

- It is the science of energy transfer and its effects on physical properties of system.
- Energy transfer may be heat or work or both heat and work.
- **Heat** - Low Grade Energy or Disorganized form of energy
- **Work**- High Grade Energy or Organized form of energy
- **Aim:** The main aim of thermodynamics study is to convert heat (disorganized form of energy) into work (organized form of energy) in an efficient manner.
- **Application**: Refrigeration, air-conditioning, steam power plant, I.C. engines etc.

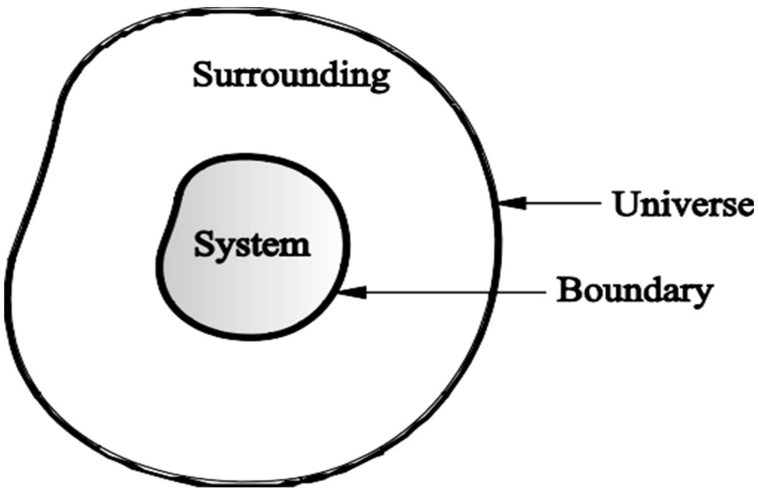
Basic Concepts:

System: It is a region in space upon which the study is focused or concentrated.

Surrounding: Anything external to the system, where the effect of system is felt, is known as surrounding.

Universe = System + Surrounding

The separation between system and surroundings is known as boundary.



Types of system:

1: Open System

- If the thermodynamic system has the capacity to exchange **both mass and energy** with its surroundings, it is said to be an open system.

Example: Turbine, Compressor, Pump, Boiler etc.

- A pool filled with water, where the water can enter or leave

2: Closed System

- If the thermodynamic system has the capacity to exchange **only energy** with its surroundings and not mass.

Example: Hot tea with lid, Water in sealed container, Piston cylinder without valve etc.

3: Isolated System

- If the thermodynamic system has the capacity to exchange **neither energy nor mass with** its surroundings.
- It is a special case of Closed system

Example: Universe, Hot tea in well insulated flask

Property of a system

- It is a characteristic of a system but all characteristics are not property. So, properties are characteristics which are quantifiable or measurable. Example: Pressure, volume, Temperature, Mass, Density, Energy etc.

Types of Property: Properties are of two types- (1) Intensive (2) Extensive

Extensive property: Extensive properties are **dependent** on size or mass of the system.

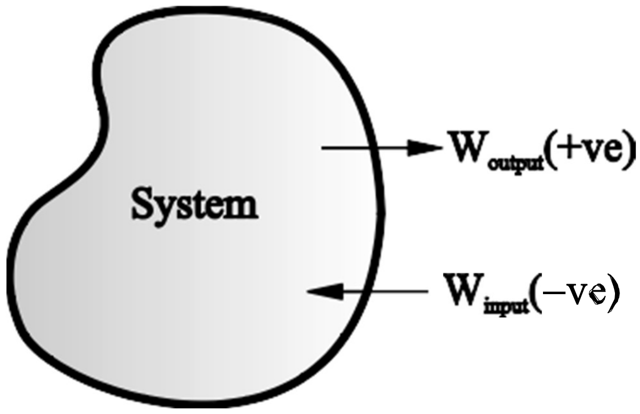
Example: Volume, Mass, All forms of energy (K.E, P.E, Internal Energy), momentum

Intensive Property: Intensive properties are **independent** of size or mass of the system.

Example**:** Pressure, temperature, density, viscosity, thermal conductivity, velocity

Work

- Work is said to be done by the system if the sole effect on things external to the system, can be equated to raising of weights.
- **Unit:** unit of work is Joule(J) or Kilojoule (KJ)



Pressure = Force/Area

So, F = PA

Work = Force X Displacement Work = PA X dx

Work = $\int \boldsymbol{p.dv}$

This work is known as closed system work or non-flow work or displacement work.

Heat

- It is the energy that is transferred from one body to another as the result of a difference in temperature.
- So, if two bodies at different temperatures are brought together, energy is transferred.
- i.e., heat flows—from the hotter body to the colder.
- All forms of energy associated with molecule is known as internal energy. It is an extensive property.
- **Unit:** unit of heat is Joule(J) or Kilojoule (KJ)

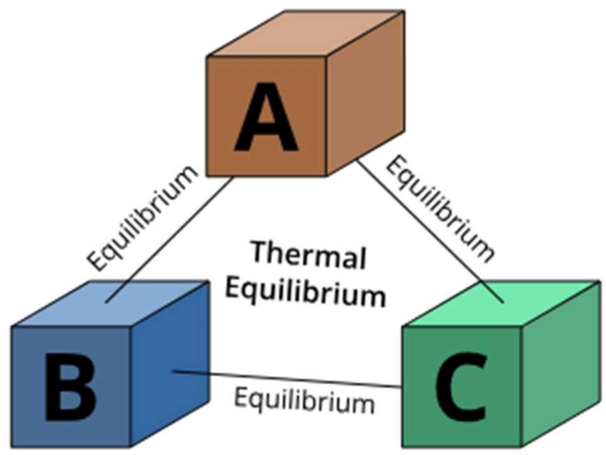
Thermal equilibrium: Thermal equilibrium is the physical state of two bodies when they are connected by a permeable path, don't undergo any heat transfer and both the bodies have the same temperature.

ZEROTH LAW OF THERMODYNAMICS

- 'When the body A is in thermal equilibrium with body B, and body B is in thermal equilibrium with body C separately, then A and C are in thermal equilibrium.

  When $T_A = T_B$ & $T_B = T_c$

  Then $T_A = T_C$



Significance of Zeroth law of Thermodynamics:

Without bringing two bodies into direct contact with the help of zeroth law it can be establish whether they are in thermal equilibrium or not.

Example: Thermometer

1st law of thermodynamics:

i. The heat and mechanical work are mutually convertible.

- When a system undergoes a thermodynamic cycle then the net heat supplied to the system from the surroundings is equal to net work done by the system on its surroundings.

i.e. $\oint dQ = \oint dW$ where $\oint$ represents the sum for a complete cycle.

ii. The energy can neither be created nor destroyed though it can be transformed from one form to another.

$dQ = du + dW$ (This is the equation of 1st law of thermodynamics for a process)

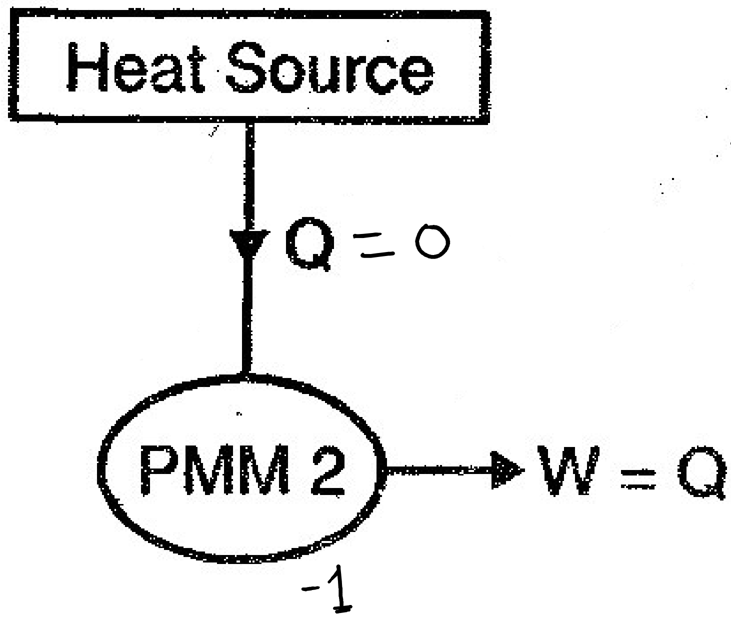
Limitation Of 1st law of thermodynamics:

1. 1st law doesn't differentiate between hit and work.
i.e.- it is assuming completely inter-convertibility of the two (heat and Work)

but though work is a high-grade energy can be fully converted into heat but heat being a low-grade energy cannot be fully converted into work.

2. 1st aw simply says that energy is conserved but it does not say whether heat will flow from a higher temperature body to a lower temperature body or vice versa.

PMM-1 (Perpetual motion machine of 1st kind)



- A machine which produces work energy without consuming any equivalent of heat energy from other source is known as PMM-1.

- So, it is a machine which is working in a cycle can produce work continuously without any heat input.

- It violets the 1st law of thermodynamics.

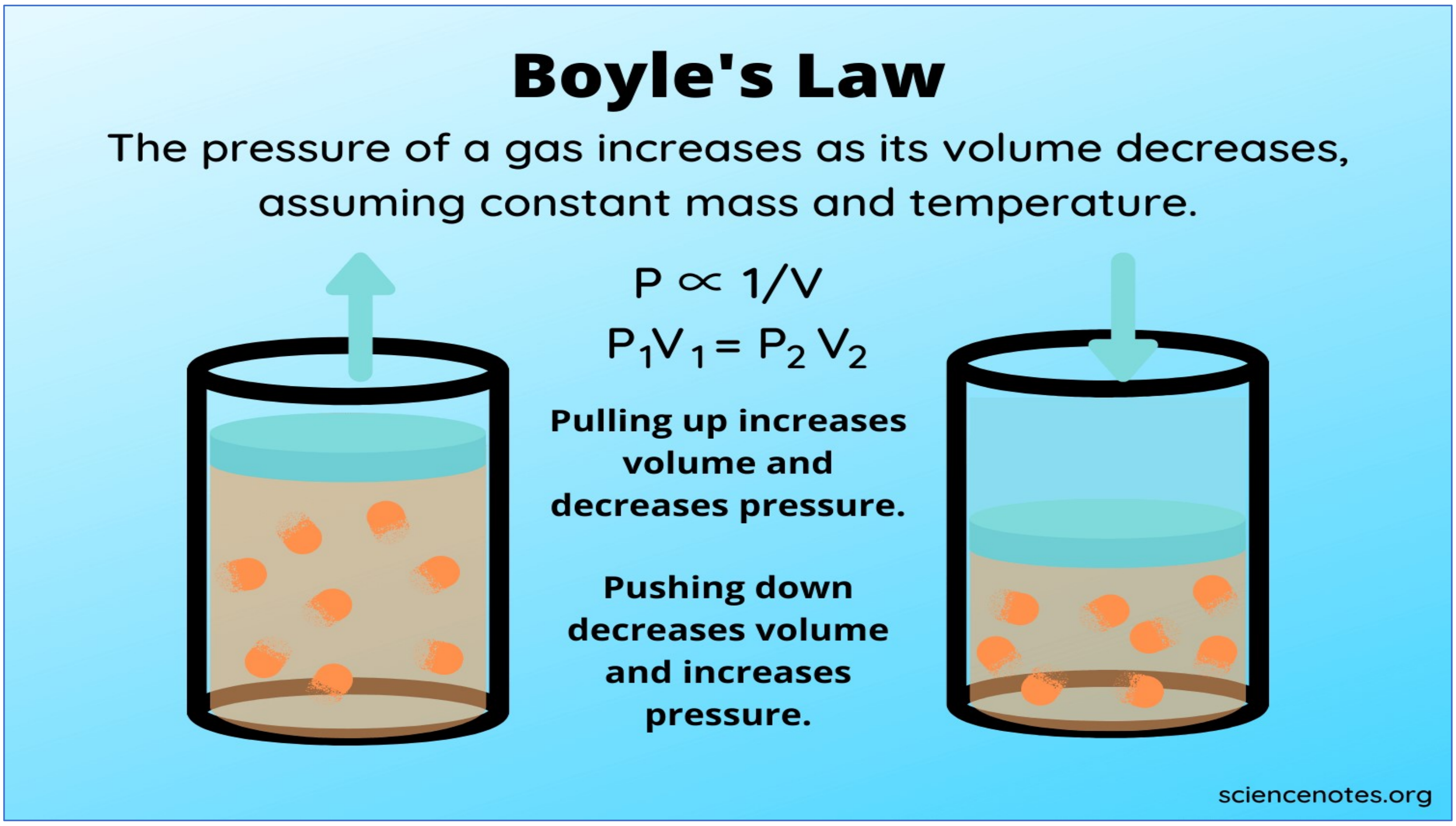
Perfect Gas

- A perfect gas may be defined as a state of substance whose evaporation from its liquid state is complete.
- It strictly obeys all the gas law under all condition of pressure and temperature.
- The gas laws are a group of laws that govern the behaviour of gases by providing relationships between the following:

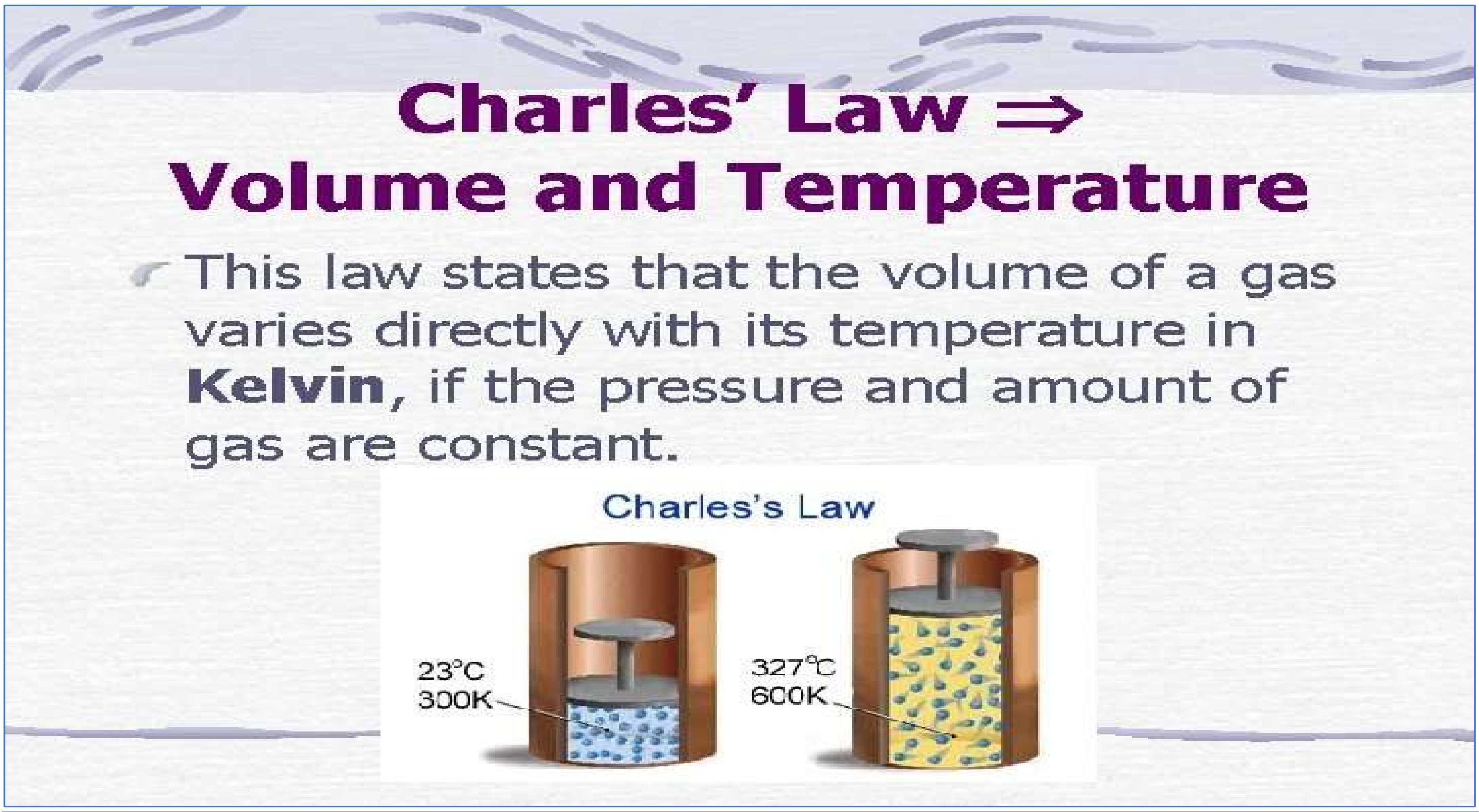
a) The volume occupied by the gas (**V**)
b) The pressure exerted by a gas on the walls of its container (**P**)
c) The absolute temperature of the gas (**T**)
d) The amount of gaseous substance (or) the number of moles of gas (**n**)

Laws of perfect gases

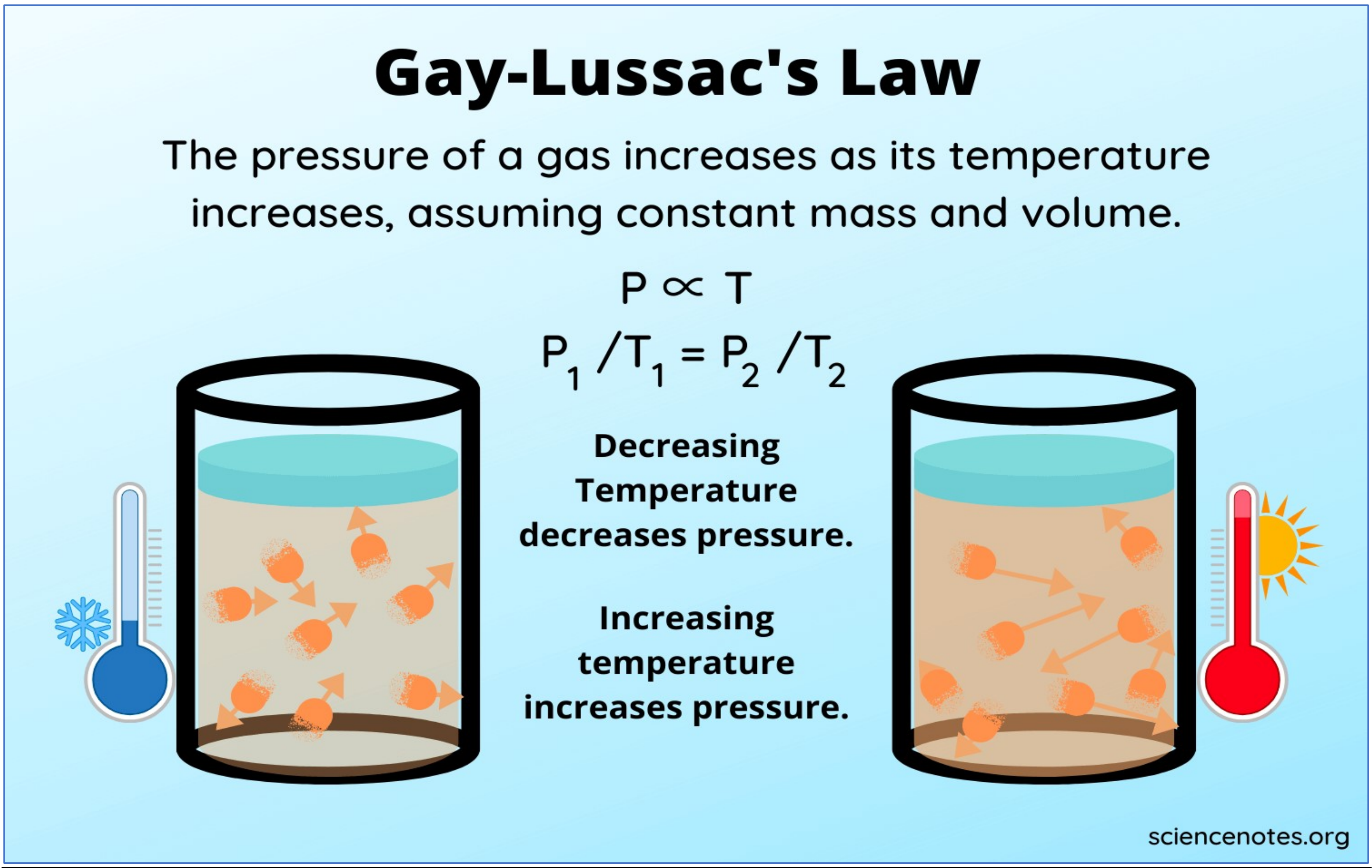
1. Boyle's Law



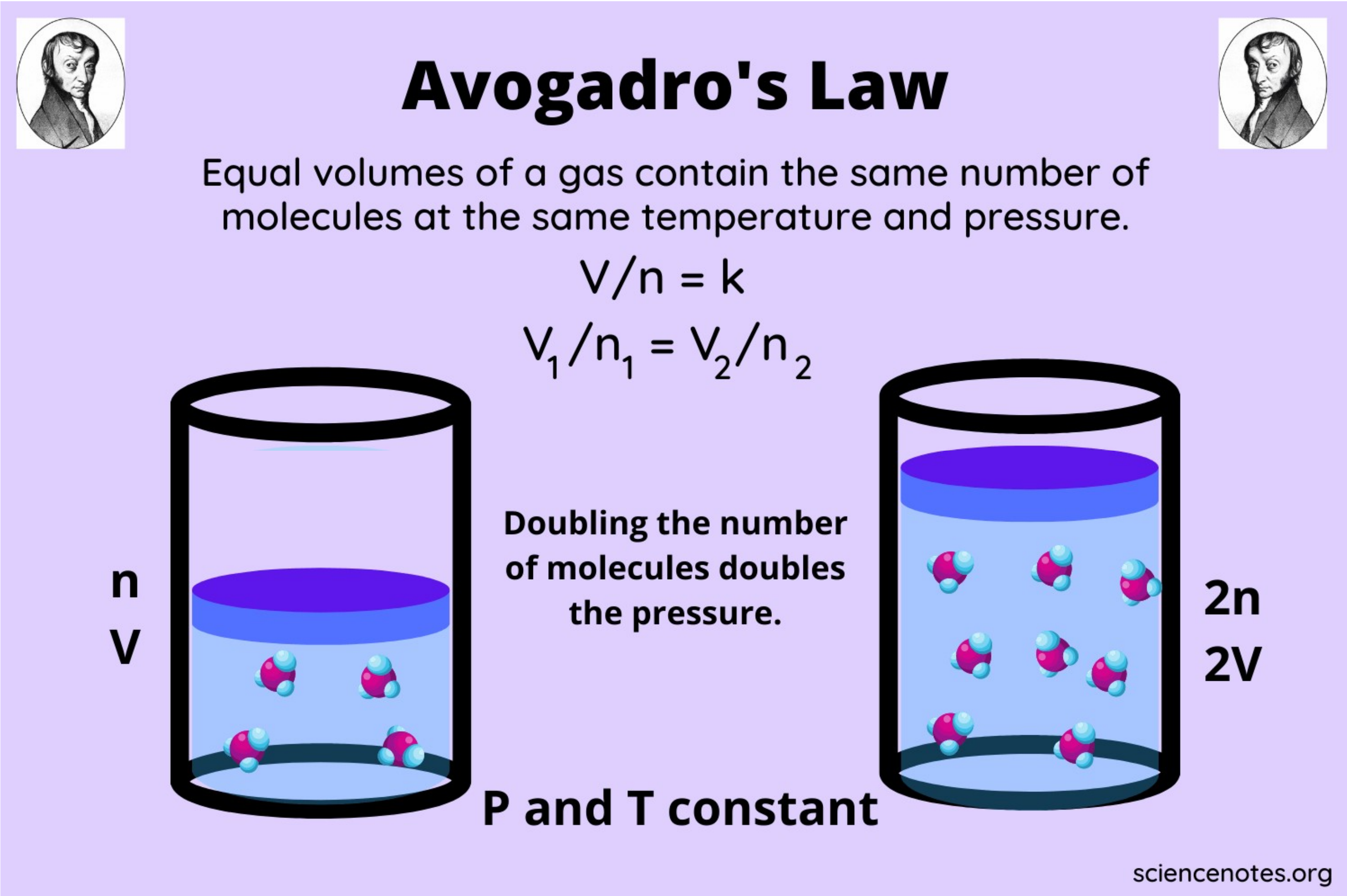
2. Charle's Law



3. Gay-Lussac Law



4. Avogadro's Law



Combined Gas Law

- The combined gas law, also known as a general gas equation, is obtained by combining three gas laws which include Charle's law, Boyle's Law and Gay-Lussac law.
- The law shows the relationship between temperature, volume and pressure for a fixed quantity of gas.
- We know from Boyle's law → $P \propto \frac{1}{V}$ or $V \propto \frac{1}{P}$ —(1)

& from Charle's law → $V \propto T$ —(2)

Combining these two equation we get

$$V \propto \frac{1}{P} \times T$$

$$\Rightarrow V = C \times \frac{1}{P} \times T$$

$$\Rightarrow V = C \times \frac{T}{P}$$

$$\Rightarrow \boxed{\frac{PV}{T} = C}$$ → This is the general gas equation.

i.e. → $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} = \frac{P_3V_3}{T_3} = \cdots\cdots \frac{P_nV_n}{T_n} = \text{Constant}$

Universal gas constant:

From Boyle's law → $V \propto \frac{1}{P}$ —(1)

Charle's law → $V \propto T$ —(2)

Avogadro's law → $V \propto n$ —(3)

Combining these three equation, we get

$$V \propto \frac{1}{P} \times T \times n \Rightarrow V = C \times \frac{1}{P} \times T \times n$$

$\Rightarrow \quad PV = CTn$

$\Rightarrow \quad PV = nCT$

$\Rightarrow \quad \boxed{PV = n\bar{R}T}$ where $C = \bar{R}$ = Universal gas constant

$\bar{R}$ = Universal gas constant is the product of gas constant and the molecular mass of the gas.

i.e → $\boxed{\bar{R} = MR}$ where M = Molecular mass of the gas in kg.mole

& R = Characteristic gas constant in kJ/kg.K

→ In S.I unit, value of $\bar{R}$ = 8.314 kJ/mole.K and the value of $\bar{R}$ is same for all gases.

Characteristic gas constant: (R)

From previous equation, we get

$$PV = n\bar{R}T$$

we know n = no. of moles & $n = \frac{m}{M} = \frac{\text{mass}}{\text{Molecular mass}}$

$$\Rightarrow PV = \frac{m}{M}\bar{R}T$$

$$\Rightarrow PV = m \times \frac{\bar{R}}{M} \times T$$

$\Rightarrow \boxed{PV = mRT}$ → This is the characteristic gas equation.

where R = characteristic gas constant in kJ/kg.K

For air, R = 0.287 kJ/kg.K or R = 287 J/kg.K

Specific heat:

- It is the amount of heat required to raise the temperature of unit mass of substance through unit degree temperature difference.
- So, to bring one degree difference of one kg mass, whatever the heat we supplied is specific heat.
- That is specific heat actually shows the heat absorbing capacity.
- we know $Q = mC\Delta T$

  If $m=1$ & $\Delta T = 1 \Rightarrow \boxed{Q = C}$

  where C = specific heat in KJ/kg.K

Specific heat at constant volume:

- It is the amount of heat required to raise the temperature of unit mass of substance through one degree when it is heated at a constant volume.
- Specific heat at constant volume includes internal energy only and there will be no work done.

By 1st law $\delta Q = dU + \delta W$

$$\Rightarrow \delta Q = dU + P(V_2 - V_1)$$

$$\Rightarrow \delta Q = dU + 0 \quad (\because V_1 = V_2)$$

$$\Rightarrow \delta Q = dU = mC_v dT$$

Specific heat at constant pressure:

- It is the amount of heat required to raise the temperature of unit mass of substance through one degree when it is heated at a constant pressure.
- Specific heat at constant pressure includes internal energy as well as work done.
- By 1st law $\delta Q = dU + \delta W$

$$\Rightarrow \delta Q = dU + P.dV$$

For air, $C_p = 1.005$ KJ/kg.K

$C_v = 0.718$ KJ/kg.K

Relationship of specific heat of gases at constant pressure and constant volume:

or Relation between C_p & C_v :-

We know from 1st law of thermodynamics

$$\delta Q = dU + \delta W$$

$$\Rightarrow m C_p dT = m C_v dT + P \cdot dV$$

$$\Rightarrow m C_p dT = m C_v dT + d(PV)$$

$$\Rightarrow m C_p dT = m C_v dT + d(mRT)$$

$$\Rightarrow m C_p dT = m C_v dT + mR dT$$

$$\Rightarrow \cancel{m dT}(C_p) = \cancel{m dT}(C_v + R)$$

$$\Rightarrow C_p = C_v + R$$

$$\Rightarrow \boxed{C_p - C_v = R}$$ Proved

& $\boxed{C_p / C_v = \gamma}$

where C_p = specific heat at constant pressure

C_v = specific heat at constant volume

R = Characteristic gas constant

Units of C_p, C_v & R is KJ/kg.K