Unit 1
Thermodynamics & Second Law of Thermodynamics

THERMODYNAMICS

THERMODYNAMIC PROPERTIES

Thermodynamic properties describe the physical characteristics of a system.
(a) Intensive Properties: These do not depend on the amount of matter in the system.
Examples: Pressure (P), Temperature (T), Density (ρ)
(b) Extensive Properties: These depend on the mass of the system.
Examples: Volume (V), Internal Energy (U), Enthalpy (H)
(c) Specific Properties: These are extensive properties per unit mass.
Examples: Specific Volume ($v = V/m$), Specific Energy ($u = U/m$)

State, Path, Process, Cycle
State: Condition of system defined by properties (P, V, T…. Etc).
Process: Change from one state to another state.
Path: The method followed during the process.
Cycle: A process that returns the system to its original state.

THERMODYNAMIC SYSTEMS

A. System
Part of the universe under study. Everything else is surroundings.
B. Types of Systems

Type	Description	Example
Closed System	Mass does NOT cross boundary, but energy can	Piston-cylinder
Open System	Both mass and energy can cross the boundary	Steam turbine, pump
Isolated System	Neither mass nor energy cross the boundary	Perfect thermos, universe

FLOW & NON-FLOW PROCESSES

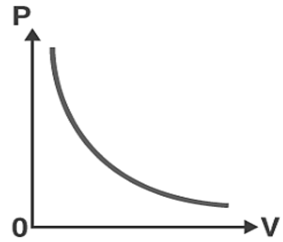
Flow Process
A flow process takes place in an open system where mass and energy continuously enter and leave the system. It is commonly seen in devices like turbines or nozzles, and is analysed using the Steady Flow Energy Equation (SFEE).
Non-Flow Process
A non-flow process occurs in a closed system where no mass enters or leaves, only energy is exchanged as heat or work. This process is typical in sealed systems like piston-cylinders and is governed by the First Law of Thermodynamics ($Q - W = \Delta U$).

GAS LAWS

A. Boyle's Law (Isothermal Process):

At constant temperature, the pressure of a fixed mass of gas is inversely proportional to its volume.

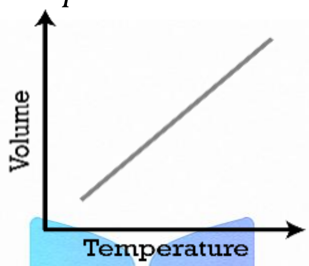
$$PV = Constant$$



B. Charles's Law (Isobaric Process):

At constant pressure, the volume of a fixed mass of gas is directly proportional to its absolute temperature.

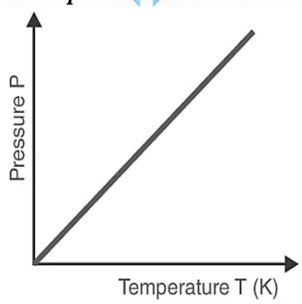
$$\frac{V}{T} = Constant$$



C. Gay-Lussac's Law (Isochoric Process):

At constant volume, the pressure of a fixed mass of gas is directly proportional to its absolute temperature.

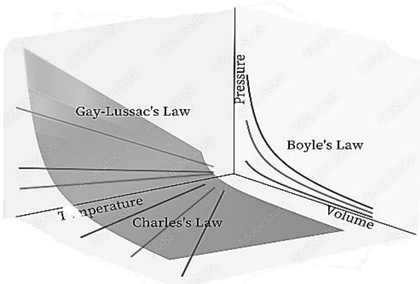
$$\frac{P}{T} = Constant$$



D. Combined Gas Equation:

It combines Boyle's, Charles's, and Gay-Lussac's laws into one equation.

$$\frac{PV}{T} = Constant$$



E. Ideal Gas Law:

Relates pressure, volume, and temperature of an ideal gas to the number of moles or mass of gas.

$$PV = nRT$$

LAW OF THERMODYNAMICS

Statement: Energy can neither be created nor destroyed. It only changes form.
Mathematical Form (Closed System):

$$Q - W = \Delta U$$

Where:

Q = Heat supplied
W = Work done
ΔU = Change in internal energy

Note: *Zeroth Law of Thermodynamics:* If body A is in thermal equilibrium with body B, and body B is in thermal equilibrium with body C, then body A is also in thermal equilibrium with body C.

INTERNAL ENERGY (U)

- Internal energy is microscopic energy associated with the random motion of molecules.
- It is a function of temperature.
- It increases when temperature increases.

APPLICATION OF FIRST LAW TO NON-FLOW PROCESSES

(a) Isochoric Process (Constant Volume):

$$W = 0 \quad \Rightarrow \quad Q = \Delta U = \mathrm{m}\, C_v (T_2 - T_1)$$

(b) Isobaric Process (Constant Pressure):

$$W = P(V_2 - V_1) \quad ; \quad Q = \mathrm{m}\, C_P (T_2 - T_1)$$

(c) Isothermal Process (Constant Temperature):

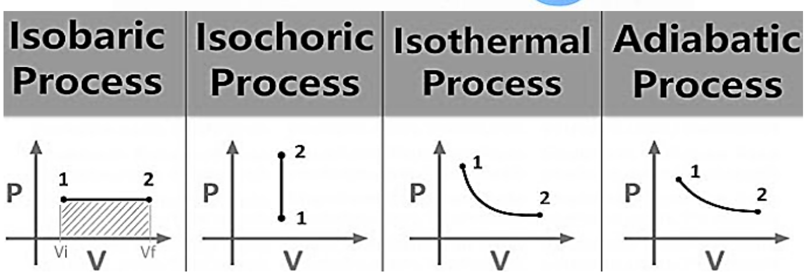
$$\Delta U = 0 \quad ; \quad Q = W = \mathrm{nRTln}\left(\frac{V_2}{V_1}\right)$$

(d) Adiabatic Process (No Heat Transfer):

$$Q = 0 \;\; ; \;\; W = \Delta U = \mathrm{m}\, C_v (T_1 - T_2)$$

Also:

$$PV^{\gamma} = Constant$$



SECOND LAW OF THERMODYNAMICS

KELVIN-PLANCK AND CLAUSIUS STATEMENTS

A. Kelvin-Planck Statement
"It is impossible for any device that operates in a cycle to receive heat from a single reservoir and convert it entirely into work."
B. Clausius Statement
"Heat cannot flow from a cold body to a hot body without external work."
Both statements are equivalent and lead to the concept of entropy.

REVERSIBLE & IRREVERSIBLE PROCESSES

Reversible Process	Irreversible Process
Ideal (theoretical)	Real (practical)
No friction or loss	Involves friction, heat loss
Can be reversed	Cannot be reversed
Maximum efficiency	Less than max efficiency

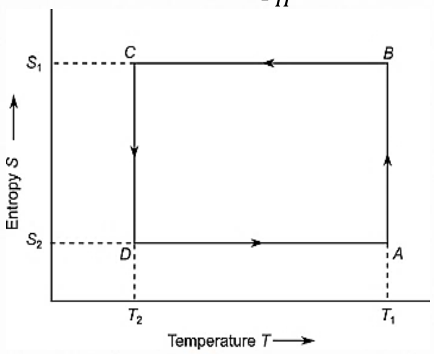
CARNOT CYCLE (Ideal Engine)

A reversible cycle using two thermal reservoirs.
Four Steps:

1. Isothermal Expansion – Heat absorbed at T_H
2. Adiabatic Expansion – No heat, temperature drops
3. Isothermal Compression – Heat rejected at T_L
4. Adiabatic Compression – Temp increases, no heat

Carnot Efficiency:

$$\eta = 1 - \frac{T_L}{T_H}$$



CARNOT THEOREM

- No engine working between two heat reservoirs can be more efficient than a Carnot engine.
- All reversible engines between the same two temperatures have the same efficiency.

REVERSED CARNOT CYCLE (Heat Pump & Refrigerator)

Used For:

- Refrigerator: Absorbs heat from cold region and releases to hot region.
- Heat Pump: Absorbs heat from cold region and delivers to room.

Coefficient of Performance (COP)

- Refrigerator:

$$COP_R = \frac{Q_L}{w} = \frac{T_L}{T_H - T_L}$$

- Heat Pump:

$$COP_{HP} = \frac{Q_H}{w} = \frac{T_H}{T_H - T_L}$$