# Thermodynamics

Thermodynamic processes – laws

1. The branch of science in which the mutual conversion of heat and mechanical work is studied is called thermodynamics.

2. Zeroth law of thermodynamics

   a. This law gives the concept of temperature.

   b. If the temperatures of two bodies are equal then they are said to be in thermal equilibrium.

   c. When two bodies A and B are in thermal equilibrium with a third body C individually, then the bodies A and B are in thermal equilibrium with each other.

3. Internal energy

   a. The molecules of real gas posses both PE and KE. Hence the sum of PE and KE is called the internal energy.

   b. The PE is due to inter molecular mutual force of attractions and this depends on the distance between the molecules i.e. Volume of the gas.

   c. The KE of a gas is a function of the temperature of the gas ($\frac{1}{2}mv^2 = \frac{3}{2}KT$ where K is called the Boltzmann's constant)

   d. For an ideal gas, as there are no inter molecular forces, there is no PE. Hence the internal energy is only due to KE. Hence it is a function of temperature.

   e. Internal energy depends only on the initial and final states of gas. But not on the path.

   f. Change in the internal energy $du = nC_v dT$

   g. The change in the internal energy in a cyclic process is zero.

4. Indicator diagram

   a. A graphical representation of the state of a system with the help of two thermodynamic variables is called indicator diagram.

b. If the thermodynamic variables are P and V (general case) the graph between P and V is called P-V diagram.
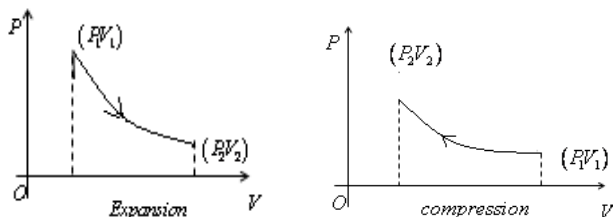
c. The work done by the system or on the system can be numerically equal to the area under the P-V diagram with volume axis.

5. Work done

a. If the volume of the gas is changed from V_1 to V_2, then the total work done is given by

$$\int_{V_1}^{V_2} dw = \int_{V_1}^{V_2} PdV = P(V)\Big|_{V_1}^{V_2} \quad \text{Or} \quad W = P(V_2 - V_1) = nRdT$$

b. Work done is path dependent.

c. For any cyclic process as shown
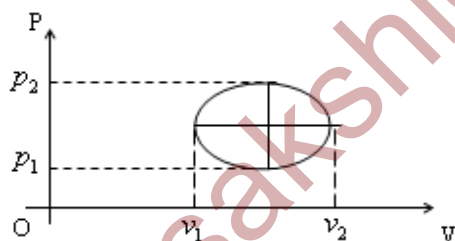
d. Work done $= \pi \, ab = \pi\left(\dfrac{p_2 - p_1}{2}\right)\left(\dfrac{v_2 - v_1}{2}\right)$

6. Sign Convention

a. Work done on the system is negative and work done by the system is positive.

b. Work done is positive if the system expands and work done is negative when the system contracts.

c. Increase in the internal energy is positive and decrease in the internal energy is negative.

d. Heat gained is positive and heat lost is negative.

(Heat given to the system is positive and heat given out by the system is negative)

7. First law of thermo dynamics

a. First law of thermodynamics obeys the law of conservation of energy.

b. According to first law heat and work are mutually convertible.

c. If an amount of heat dQ is given to a system, a part may increase the internal energy (du) while the remaining part may used as external work done (dw) by the system.
$\therefore dQ = dU + dW$

d. For a cyclic process as the change in the internal energy is zero, the total heat given is converted into work done $dQ = dw = p\ dv\ (\because du = 0)$

e. This law is special form of Joules law.

8. Limitation of 1st law of thermo dynamics

a. Heat always flows from a hot body to cold body. But the first law does not indicate the direction of flow of heat

b. First law does not indicate as to why heat energy developed in the target can not be converted into the KE of the bullet

c. The first law does not indicate why the whole heat energy cannot be converted into mechanical work continuously.

9. Specific heat

a. It is defined as the amount of heat required to raise the temperature of 1kg of a substance through 1K (or) $1^0 C$.

   Unit: cal/gm/$^0 C$ (or) J/kg/k   D.F: $\left[M^0 L^2 T^{-2} K^{-1} \right]$

b. If Q is the amount of heat required to raise the temperature of a substance of mass m through $t^0 C$, then $s = \dfrac{Q}{mt}$ (or) $Q = mst$

c. Among the solids, liquids and gases H_2 has maximum specific heat $(3.5$ cal/gm/ $^o C)$

d. Among solids and liquids water has highest specific heat. (1 cal/ gm/$^o C$ or 4200J/kg/k)

e. Specific heat may be positive or negative or zero or infinity.

f. Gases have two specific heats namely.

(1) Specific heat at constant pressure (c_P)

(2) Specific Heat at constant volume (c_V)

g. The heat given at constant volume is utilized only to increase the temperature of the gas. (Or internal energy). But heat given at constant pressure is utilized to increase the temperature and to do work against external pressure. Hence $C_P > c_V$.

h. $\underline{C_P}$: The amount of heat required to raise the temperature of a gas of mass 1gm through 1^oC at constant pressure is called C_P . (principal specific heat)

i. $\underline{C_P}$: The amount of heat required to raise the temperature of 1 mole of a gas through 1^oC at constant pressure is called molar specific heat C_P

Molar specific heat $= \dfrac{\Delta Q}{n\Delta T} (or) \Delta Q = nC_P\Delta T$

Molar specific heat = M × principal sp. heat

$$C_P = Mc_P \left(or\right)\dfrac{C_P}{c_P} = M$$

Similarly for C_V $\dfrac{C_P}{c_P} = M$

$$C_P - C_V = R \text{ (Mayer's relation)}$$

$$C_P - C_V = nR \text{ and } \dfrac{C_P}{C_V} = \gamma$$

(All are molar specific heats)

21. C_V **of the mixture**: $\quad C_V = \dfrac{n_1 C_{V_1} + n_2 C_{V_2}}{n_1 + n_2}$

22. C_P **of the mixture**: $\quad C_P = \dfrac{n_1 C_{P_1} + n_2 C_{P_2}}{n_1 + n_2}$

23. γ **of the mixture**: $\quad \dfrac{n_1 + n_2}{\gamma - 1} = \dfrac{n_1}{\gamma_1 - 1} + \dfrac{n_2}{\gamma_2 - 1}$

The fraction of energy supplied to increase the internal energy of a gas is $\dfrac{1}{\gamma}$

The fraction of energy supplied to do work is $1 - \dfrac{1}{\gamma}$

24. **Degrees of freedom**: The total no. of co-ordinates which are to be known to describe completely the position (or) state of a system is called dof.

Name of the gas	Dof	C_V	C_P	γ
General formula	f	$\left(\dfrac{f}{2}\right)R$	$\left(\dfrac{f}{2}+1\right)R$	$\left(\dfrac{2+f}{f}\right)$
Mono-atomic	3	$\dfrac{3}{2}R$	$\dfrac{5}{2}R$	$\dfrac{5}{3}$
Di-atomic	5	$\dfrac{5}{2}R$	$\dfrac{7}{2}R$	$\dfrac{7}{5}$
Tri-atomic or poly-atomic	6	$\dfrac{6}{2}R$	$\dfrac{8}{2}R$	$\dfrac{4}{3}$

10. **Isothermal process**
    a. A process in which the change in volume and pressure occur in a given gas at constant temperature is called isothermal process.
    b. This process is represented by PV=constant (Boyles' law).
    c. It is a slow process
    d. As temperature is constant, internal energy does not change.
    e. The process takes place in a thermally conducting vessel
    f. In isothermal expansion heat flows from the surrounding to the gas.

g. First law of thermo dynamics is written as $dQ = dW$ $(\therefore dU = 0)$

h. Specific heat of the gas is infinity. $(\therefore \Delta t = 0)$

i. Heat content changes due to thermal contact.

j. Work done $W = RT \log\left(\dfrac{v_2}{v_1}\right) = 2.303 RT \log\dfrac{v_2}{v_1}$

   Ex: slow expansion of a gas in a cylinder, change of state, leakage of air gas the cycle tube through a small hole, etc.

11. Adiabatic process

a. A process in which pressure and volume of a gas changes in complete thermal insulation is called adiabatic process.

b. This process is represented by

   $\boxed{PV^{\gamma} = K}$; $\boxed{TV^{\gamma-1} = K}$; $\boxed{T^{\gamma}P^{1-\gamma} = cons\tan t}$

c. It is a quick process.

d. Heat content of the system does not change.

e. The process undergoes in a perfect non-conducting vessel.

f. In adiabatic expansion internal energy decreases.

g. Adiabatic expansion produces cooling effect .

h. First law of thermodynamics is written $du = -dw$ $(\because dQ = 0)$

i. Specific heat is zero $(\because dQ = 0)$

j. Work done $w = \dfrac{R(T_2 - T_1)}{1-\gamma}$

k. $Slope\, of\, adia.curve = \gamma \times Slope\, of\, iso.\ curve$

   Ex; Busting of a cycle tyre, prorogation of sound wave in a gas etc

12. Isobaric Process

a. P=const.

b. $dw = Pdv = P(V_2 - V_1)$

c. $dQ = du + Pdv$

13. Isochoric process

a. $V = const.$

b. $dw = Pdv = 0$

c. $dQ = dU$