

Lecture Notes of B.Sc.(HONS.) PHYSICS ,Part-I, Paper -II

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TOPIC:----First Law of Thermodynamics and its Applications

Thermodynamics :-- It is the exact mathematical science that describes the relationship of Heat and Mechanical energy .

Thermodynamics makes no hypothesis about the structure of matter . We only deal with microscopic (Large Scale) properties don't go into detailed structure .

System & Surrounding :-- A Thermodynamics system is that part of the universe which is being subjected to Thermodynamics study , everything else in the universe constitute the surrounding.

Open & Closed System :-- An open system is one which can exchange matter and energy with the surroundings while a closed system is one which can't exchange matter but can exchange energy with surroundings.

Isolated System :-- If a system can't exchange matter or energy of any kind with it's surrounding, it is called Isolated system.

State of System :-- It is specified by set of experimentally measured quantity called variables of state or Thermodynamic variables. Such as T,V,P etc.

Thermal Equilibrium :-- It is condition of system in which variables characterising it, don't change with time .

Thermodynamic Variables :-- The state of system is determined by state variables example pressure, density, temperature, volume etc. These are called Thermodynamic variables . Thermodynamic variables are of two types :-

1. Intensive Variables
2. Extensive Variables

Intensive Variables:-- Those variable of a system in a given state

that are independent of it's mass or number of particles are intensive variable, for example -pressure , tension , electric field etc .

Extensive Variables:-- Those variable of a system in a given state that depends on it's mass or number of particles are extensive variable, for example – volume , charge , area , length etc.

Homogenous System:-- A homogenous system is one whose intensive properties like density and pressure are continuous function of position.

Heterogenous System:-- If the intensive properties of a system are discontinuous , the system is said to inhomogeneous or heterogenous. Let y be macroscopic parameter specifying the state of homogenous system . Let system is divided into two parts introducing partition, let y_1 and y_2 are parameters for two subsystem,

Then y is extensive if $y = y_1 + y_2$

y is intensive if $y = y_1 = y_2$

Thermodynamic Equilibrium :-- A system which is in thermal , mechanical and chemical equilibrium said to be in thermodynamic equilibrium . The state of a system is thermodynamic equilibrium can be represented by specifying its pressure, volume and temperature .It is basically of three types:-

1. **Mechanical Equilibrium**- In this case there is no unbalanced forces between systems.
2. **Thermal Equilibrium** -If temperature in all parts of the system is uniform and same as that of surroundings, then the system is said to be in Thermal Equilibrium.
3. **Chemical Equilibrium** – If chemical composition of system is same, the system is said to be in chemical Equilibrium.

Thermodynamic Process -The process in which the thermodynamic variables associated with the system changes from one equilibrium state to another. It is basically of four types :-

- a. Reversible Process
- b. Irreversible Process
- c. Quasi Static Process
- d. Non Quasi Static Process

First Law of Thermodynamics:-When a certain amount of heat Q is supplied to a system which does external work W in passing from state 1 to state 2, the amount of heat is equal to sum of the increase in the internal energy of the system and the external work done by the system .

$$Q = (U_2 - U_1) + W$$

Here U_1 is the internal energy of state 1 and U_2 is internal energy of state 2.

For a very small change in the state of the system this law is expressed in the differential form as

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

Where δQ and δW are not perfect differential but dU is perfect differential because U is function of the state of the system .All the quantities in expression are expressed in units of energy.

δQ : is +ve if heat is supplied to system.

δQ : is -ve if heat is removed from it .

δW : is +ve if external work is done by the system.

δW : is -ve if external work is done on the system.

Significance of First Law of Thermodynamics:-

1. It is applicable to any process by which a system undergoes a physical or chemical change.
2. It introduces the concept of Internal energy.
3. It provides method of determining the change in the internal energy.

Applications of First Law of Thermodynamics:-

1. Specific heat of gas (V and T independent)

$$U = f_n(V, T)$$

$$dU = \left(\frac{\partial U}{\partial T}\right)_V dT + \left(\frac{\partial U}{\partial V}\right)_T dV$$

$$\text{Now } \delta Q = dU + PdV$$

$$\delta Q = \left(\frac{\partial U}{\partial T}\right)_V dT + \left(\frac{\partial U}{\partial V}\right)_T dV + PdV$$

$$\frac{\delta Q}{\delta T} = \left(\frac{\partial U}{\partial T}\right)_V + \left[\left(\frac{\partial U}{\partial V}\right)_T \frac{dV}{dT} + P \frac{dV}{dT}\right]$$

$$\frac{\delta Q}{\delta T} = \left(\frac{\partial U}{\partial T}\right)_V + \left[\left(\frac{\partial U}{\partial V}\right)_T + P\right] \frac{dV}{dT} \dots\dots\dots(1)$$

If gas is heated at constant volume then,

$$\left(\frac{\delta Q}{\delta T}\right) = C_V \text{ and } \left(\frac{dV}{dT}\right) = 0$$

When Gas is heated at constant pressure,

$$\left(\frac{\delta Q}{\delta T}\right) = C_P, \text{ Therefore } C_P = \left(\frac{\partial U}{\partial T}\right)_V + \left[\left(\frac{\partial U}{\partial V}\right)_T + P\right] \left(\frac{dV}{dT}\right)_P$$

$$\Rightarrow C_P - C_V = \left[\left(\frac{\partial U}{\partial V}\right)_T + P\right] \left(\frac{dV}{dT}\right)_P \dots\dots\dots(2)$$

For Ideal Gas $PV = RT$

$$P \left(\frac{\partial V}{\partial T}\right)_P = R \dots\dots\dots(3)$$

Using eqn.(2) in eqn. (3) we get –

$$C_P - C_V = P \left(\frac{\partial V}{\partial T}\right)_P + \left(\frac{\partial U}{\partial V}\right)_T \left(\frac{\partial V}{\partial T}\right)_P = R + \left(\frac{\partial U}{\partial V}\right)_T \left(\frac{\partial V}{\partial T}\right)_P \dots\dots\dots(4)$$

for Ideal gas $U = f_n(T)$, Hence $\left(\frac{\partial U}{\partial V}\right)_T = 0$

therefore from eqn. no.(4) we get-

$$C_P - C_V = R$$

This relation is known as **Mayer's relation**

2. Adiabatic equation of Perfect Gas

Consider 1 gm. of working substance (Ideal gas) perfectly insulated from the surroundings .Let external work done by the gas be δW then by the First Law of Thermodynamics:-

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

{since $\delta Q = 0$ for adiabatic process}

$$\Rightarrow 0 = C_V dT + PdV \dots\dots\dots(1)$$

For Ideal gas of 1gm. by the eqn. of state: $PV =RT$

Differentiating the eqn. of state we get: $PdV + VdP = RdT$

$$\Rightarrow dT = \frac{PdV + VdP}{R} \dots\dots\dots(2)$$

using eqn. (1) we get: $C_V \left(\frac{PdV + VdP}{R} \right) + PdV = 0$

$$\Rightarrow C_V [PdV + VdP] + RPdV = 0$$

$$\Rightarrow C_V PdV + C_V VdP + C_P PdV - C_V PdV = 0$$

$$\Rightarrow C_P PdV + C_V VdP = 0 \text{ {by using Mayer's relation} } \dots\dots\dots(3)$$

Now dividing eqn.(3) by $C_V PV$ we get,

$$\Rightarrow \frac{C_P}{C_V} \frac{dV}{V} + \frac{dP}{P} = 0$$

$$\Rightarrow \gamma \frac{dV}{V} + \frac{dP}{P} = 0 \text{ { } \frac{C_P}{C_V} = \gamma \text{ } } \dots\dots\dots(4)$$

Now integrating eqn.(4) we get;

$$\Rightarrow \gamma \log V + \log P = \text{constant}$$

$$\Rightarrow \log PV^\gamma = \text{constant}$$

$$\Rightarrow \boxed{PV^\gamma = \text{constant}}$$

This is eqn. connecting Pressure and Volume During Adiabatic Process and is known as **Poisson's Law**

By Ideal Gas eqn. $PV=RT$

$$\Rightarrow P = \frac{RT}{V}$$

$$\Rightarrow PV^\gamma = \left(\frac{RT}{V}\right) V^\gamma = \text{constant}$$

$$\Rightarrow \boxed{TV^{\gamma-1} = \text{constant}}$$

Also $V = \frac{RT}{P}$

$$\Rightarrow PV^\gamma = P \left(\frac{RT}{P}\right)^\gamma = \text{constant}$$

$$\Rightarrow T^\gamma P^{1-\gamma} = \text{constant}$$

$$\Rightarrow \boxed{TP^{\frac{1-\gamma}{\gamma}} = \text{constant}}$$

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