MODULE 1

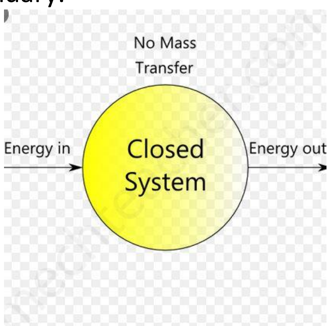
THERMAL ENGINEERING NOTES

Thermodynamics

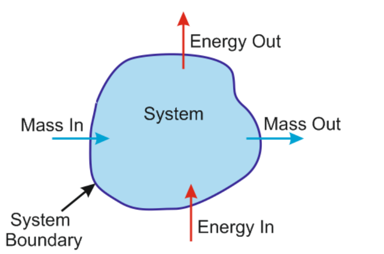
The science which studies the thermal energy of system is called thermodynamics.

A system is defined as a quantity of matter or a region in space chosen for study.

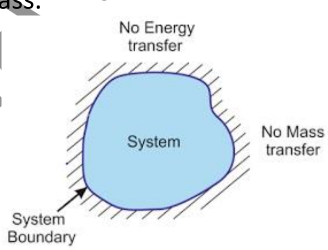
- **Closed system**: In which no mass is permitted to cross the system boundary. Only energy is cross boundary.



- **Open system**: In which permit mass to cross the system boundary in either direction (from the system to surroundings or vice versa). As well as energy can be cross the boundary.



- **Isolated System**: In which there is no interaction between system and the surroundings. Here is no transaction of energy and mass.



The mass or region outside the system is called the **surroundings.**

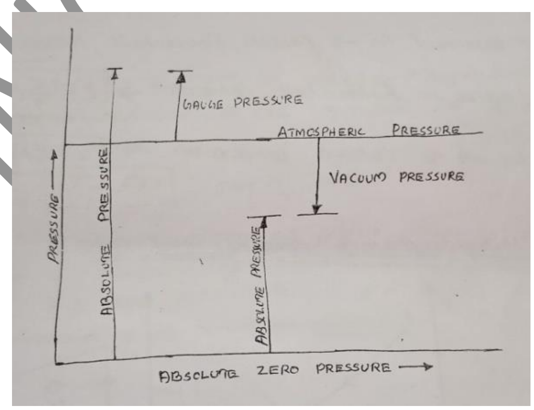
The real or imaginary surface that separates the system from its surroundings is called the **boundary.**

- **Diathermic** wall is a boundary which transfers heat b/w system and surroundings.
- **Adiabatic** wall is a boundary which will not transfers heat b/w system and surroundings.

A property of a system is a characteristic of the system which depends upon its state, but not upon how the state is reached.

- **Intensive properties**. These properties do not depend on the mass of the system. Pressure, temp., velocity.
- **Extensive properties**. These properties depend on the mass of the system. Volume, energy.
- **Specific extensive** properties are intensive properties. Specific volume, density, specific energy.

Relationship between pressures



Pressure of a gas is the force exerted by it per unit area on the sides or walls of the container due to the continuous collision of gas molecules.

- Atmospheric pressure; it is the pressure exerted by air.
- Absolute pressure= atm + gauge pressure
- Absolute pressure=atm – vacuum pressure
- Unit Pascal
- 1pa = 1 N/M^2
- 1 bar = 10^5 Pa
- 1 atm = 1.0325 bar

Temperatureis associated with the ability to distinguish hot from cold. It is the degree of hotness or coldness.

- T k = t^0 c + 273
- NTP : 0^0 c and 1 bar.
- STP : 15^{0}c and 1 bar.

The energy transfer across the boundary of a system on account of the temp difference b/w the system and surroundings is called **Heat**.

- Unit = KJ

Specific heat(C): It is the amount of heat required raise the temp. of unit mass of the substance by unit degree.
Unit : J/Kg . K

Specific heat at constant pressure (Cp): The amount of heat required raises the temp. of unit mass of the substance by unit degree, when it is heated at constant pressure.

Specific heat at constant volume (Cv): The amount of heat required raise the temp. of unit mass of the substance by unit degree, when it is heated at constant volume.

- Cp>Cv
- When heat a gas at constant **pressure** , the heat is used to partly in raising temp. and partly in doing work against external pressure.
- When the gas is heated at constant volume, no work is done and the heat supplied is used only for raising the temperature.
- Cp – Cv = R
  R = gas constant
- $\frac{Cp}{Cv} = \gamma$ > 1
  $\gamma = adiabatic\ index$
- Cv = R / $(\gamma - 1)$

Internal Energy(u) is the grand total of all molecular energies inside a substance. It includes P.E due to force of attraction b/w atoms and K.E due to movements of atoms.
Unit= KJ/Kg.

- So a substance does not contain heat ,- it contains internal energy.
- Internal energy change is equal to heat transferred in a constant volume process involving no work other than pdv work.
- du = m c_vdT

Enthalpy(h) is the heat transferred in a constant pressure process involving no work other than pdv work.

- dh= m c_pdT
- unit = KJ/Kg.

Entropy(s) is the degree of disorder or randomness.

$$dS = \frac{dQ}{dT}$$

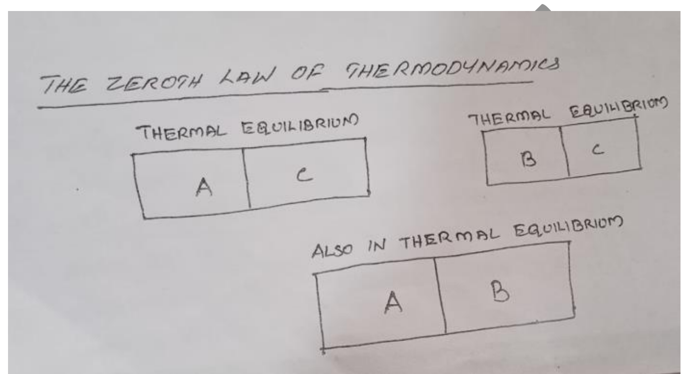
Thermodynamic Equilibrium exist only if the system have the following equilibrium conditions

- Mechanical equilibrium: there are no unbalanced forces.
- Chemical equilibrium: there are no chemical reactions.
- Thermal equilibrium: there are no temperature differences inside the system.

Zeroth law of Thermo dynamics

If two systems are in thermal equilibrium with a 3rd system, separately, then they are also in thermal equilibrium with each other.

- It is the basis of temp. Measurement.



First law of Thermo dynamics

For a closed system operating in a cycle, the net heat transfer is equal to the net work transfer.

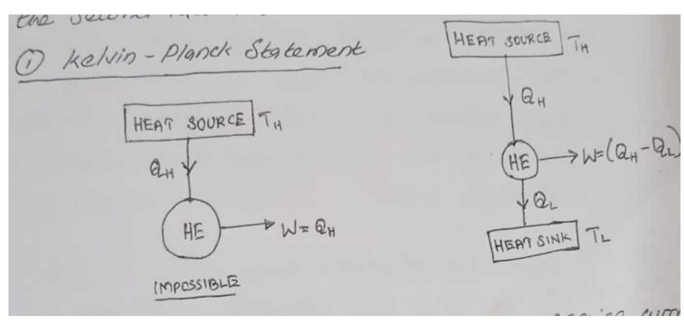
- $\oint dQ = \oint dW$
- It is theorem of conservation of energy.
- For closed system , dQ = dU + dW
- It establishes an exact relation b/w heat and work.

Limitations

- It does not place any distinction on the direction of the process under consideration.
- It does not help to predict whether the system will or will not undergo a change.

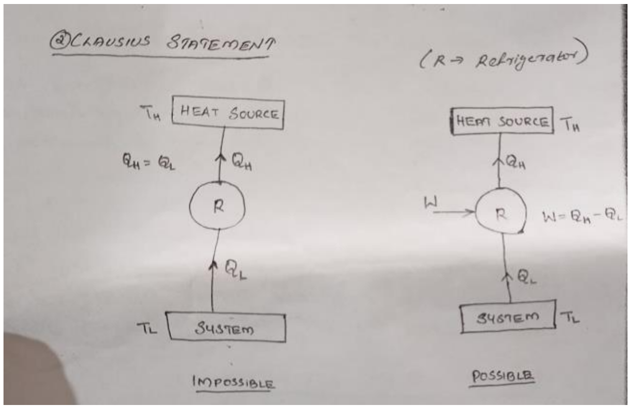
Second law of Thermo dynamics

Kelvin Plank statement: It is impossible for a heat engine to produce a net work in a complete cycle if it exchanges heat only with bodies at a single fixed temperature.



Clausius statement: it is impossible for heat to flow from a body at lower temperature to a body at higher temperature without aid of any external agency.

- Only a fraction of heat may be converted into useful work.
- No heat engine is 100% efficient.



GAS LAW'S

Boyle's law states that at constant temperature, the volume of a given mass of gas is inversely proportional to the absolute pressure.

- $V \alpha \frac{1}{P}$
- $P V = C$
- $P_1 V_1 = P_2 V_2$

Charles's law states that at constant pressure, the volume of given mass of gas is directly proportional to the absolute temperature.

- $V \alpha T$
- $\frac{V}{T} = C$
- $V_1/T_1 = V_2 / T_2$

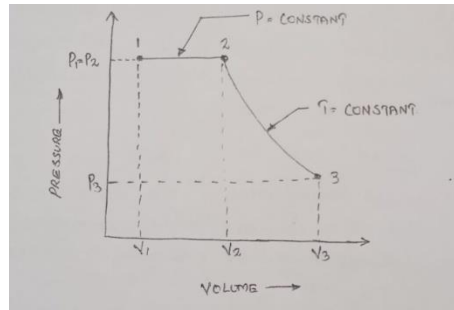
Avogadro's law states that at constant temperature and pressure, volume occupied by a mole of any gas is constant.

Joule's law states that the internal energy of perfect gas is a function of temperature only and is independent of pressure and volume.

- $\Delta U = m\, Cv\, \Delta T$

Regnault's law states that the two specific heat Cp&Cv of a gas do not changes with change in temperature.

<u>**General Gas Equation & Characteristic Gas Equation**</u>



Consider a process 1-2 ,with an initial condition P_1 ,V_1& T_1 and the final condition as P_2, V_2& T_2 also there is a intermediate point A such that
1 – 2 is constant pressure process and
2 – 3 is constant temperature process

$V_2/T_2 = V_1/T_1$ [Charles law]
So
$V_2 = V_1 T_2 / T_1$ ………………… (1)

$P_2V_2 = P_3 V_3$ [Boyles law]

$V_2 = P_3V_3/P_2$ ………………………(2)

Equating the above equations 1 & 2
$V_1 T_2 / T_1 = P_3V_3/P_2$

We have $T_2 = T_3$ & $P_1 = P_2$

So the equation becomes
$V_1 T_3/ T_1 = P_3V_3/P_1$
After re-arranging the terms,
$P_1 V_1/ T_1 = P_3V_3/T_3$
$P_1 V_1/ T_1 = P_2V_2/T_2 = P_3V_3/T_3 = ……… =$ constant
PV/T = Constant
The above equation is known as General gas equation
For unit mass of gas, the general gas equation becomes,
$Pv/T = R$
Now multiply both sides of wquation by mass 'm'
Then, $P(mv)/T = mR$
$PV/T = mR$
PV = mRT
This above equation is known as characteristic equation of perfect gas

- R = Characteristic gas constant

Thermodynamic Process

When a system changes its state from one equilibrium condition to other it is said to have undergone a process.

1. **Constant volume Process (Isochoric process)**
   - Volume constant
   - Work done $W = \int PdV = \mathbf{0}$.
   - Change in internal energy $\Delta U = m\, C_v\, \Delta T$
   - Heat supplied $Q = \Delta U + W$

     $Q = \Delta U = \mathbf{m\, C_v\, \Delta T}$

2. **Constant pressure process (Isobaric process)**
   - Pressure constant
   - Work done $W = \int_1^2 P\, dV = \mathbf{P(V_2 - V_1)}$
   - $\mathbf{\Delta U = m\, C_v\, \Delta T}$
   - $Q = \Delta U + W$

     $= m\, C_v\, \Delta T + \mathbf{P(V_2 - V_1)}$

     $= \mathbf{m} C_v\, \Delta T + mR\, \Delta T$

     $\mathbf{= m}\, \Delta T\, \mathbf{(C_v + R)}$

     $= \mathbf{m\, C_p\, \Delta T}$

3. **Constant Temperature Process (Isothermal process)**
   - **T**emperature constant
   - $PV = C$
   - $\Delta U = m\, C_v\, \Delta T = m\, C_v\, 0 = \mathbf{0}$
   - $W = \int_1^2 P\, dV$

     Put $P = P_1V_1/V$

     $W = \mathbf{P_1V_1 \ln (V_2/V_1) = P_1V_1 \ln (P_1/P_2)}$
   - $Q = \Delta U + W$

     $\mathbf{Q = W = P_1V_1 \ln (V_2/V_1) = P_1V_1 \ln (P_1/P_2)}$

4. **Aiabatic Process (Isentropic process)**
   - Heat transfer $\mathbf{Q = 0.}$
   - Work done by the gas at the expense of internal energy.
   - $W = -\Delta U$
   - $\Delta U = m\, C_v\, \Delta T$
   - $\mathbf{P V^{\gamma} = constant}$
   - $W = \int_1^2 P\, dV$

     Put $P = C/V^{\gamma}$

   After integration

   $\mathbf{W = P_1V_1 - P_2V_2 / \gamma - 1}$

   $\mathbf{W = mR\, (T1 - T2) / \gamma - 1}$

5. **Polytropic process**
   - Here both pressure and volume changes in a certain manner.
   - $\mathbf{PV^n = C}$
   - $W = \int_1^2 P\, dV$

   Put $P = C/V^n$

   After integration

   $\mathbf{W = P_1V_1 - P_2V_2 / n - 1}$

   $\mathbf{W = mR\, (T1 - T2) / n - 1}$
   - $\mathbf{\Delta U = m\, C_v\, \Delta T}$
   - $Q = \Delta U + W$

   $$\mathbf{Q} = \frac{\gamma - n}{\gamma - 1}\,\frac{mR(T1 - T2)}{(n - 1)}$$

   $$\mathbf{Q} = \frac{\gamma - n}{\gamma - 1} \mathbf{X\ work\ done}$$

   - **n = 0 ; isobaric process**
   - **n= 1; isothermal**
   - **n= γ ; isentropic**
   - **n= α ; isochoric**

6. **Throttling process**

When a fluid expands through a small opening such as narrow throat , the fluid is said to be throttled.

- Fluid flows from high pressure to low pressure.
- No heat transfer and no work is done.
- Temperature change is zero.
- So it is called isenthalpic process
- $\Delta H = 0$.

Sign convection

- Heat flow to the system is +ve.
- Heat flow from the system – ve.
- Work done by the system +ve.
- Work done on the system -ve.