Rohini College Of Engineering And Technology

Department Of Mechanical Engineering

ME3391 ENGINEERING THERMODYNAMICS

UNIT I BASICS, ZEROTH AND FIRST LAW

BASICS, ZEROTH AND FIRST LAW

What is Thermodynamics?

❖ Thermodynamics is a science dealing with Energy and its transformation and its effect on the physical properties of substances.

❖ It deals with equilibrium and feasibility of a process.

❖ Deals with the relationship between heat and work and the properties of systems in equilibrium.

Scope of Thermodynamics:

❖ Steam power plant

❖ Separation and Liquification Plant

❖ Refrigeration

❖ Air-conditioning and Heating Devices.

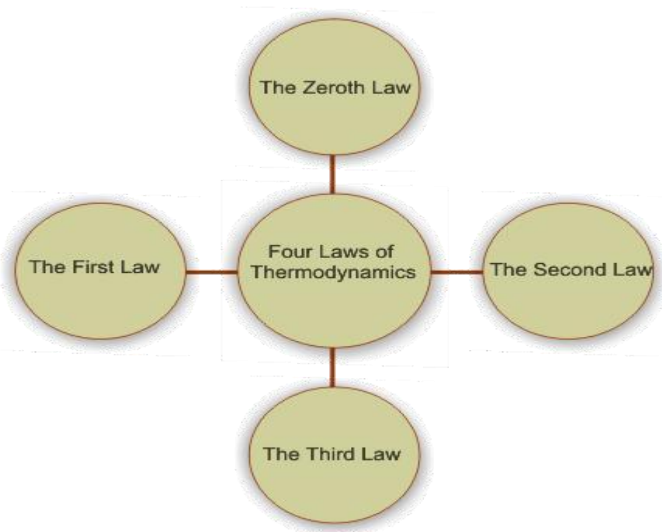
❖ Internal combustion engine

❖ Chemical power plants

❖ Turbines

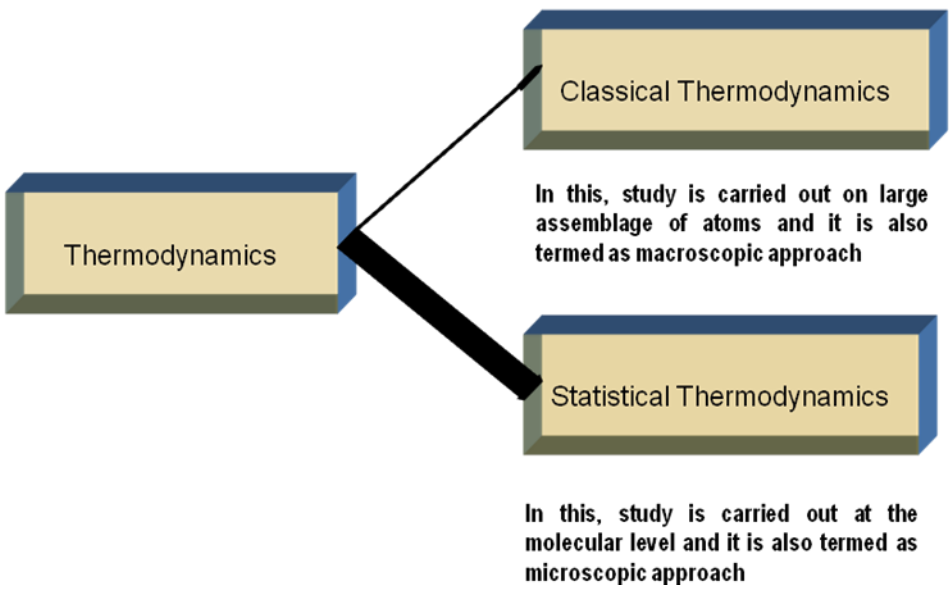
❖ Compressors, etc

The principles of thermodynamics are summarized in the form of four thermodynamic laws:



- **The Zeroth Law** deals with thermal equilibrium and provides a means for measuring temperatures.
- **The First Law** deals with the conservation of energy and introduces the concept of internal energy.
- **The Second Law** of thermodynamics provides with the guidelines on the conversion of internal energy of matter into work. It also introduces the concept of entropy.
- **The Third Law** of thermodynamics defines the absolute zero of entropy. The entropy of a pure crystalline substance at absolute zero temperature is zero.

Different Approaches of Thermodynamics :



Write the difference between Macroscopic and Microscopic approach of Thermodynamics:

Macroscopic Approach	**Microscopic Approach**
1.Macroscopic approach is known as Classical Thermodynamics.	1. Microscopic approach is known as Statistical Thermodynamics
2. Attention is focussed on a certain quantity of matter without taking into account the events occuring at molecular level.	2. A knowledge of the structure of matter under consideration is essential.

3. Only a few variables are used to describe the state of the matter under consideration.	3. A large no. of variables are required for a complete specification of the state of matter under consideration.
4. The values of the variables used to describe the state of the matter are easily measurable.	4. The variables used to describe the state of matter cannot be measured easily and precisely

Define Thermodynamic System?

A thermodynamic system is defined as a definite quantity of matter or a region of space within a prescribed boundary upon which attention is focussed in the analysis of a problem.

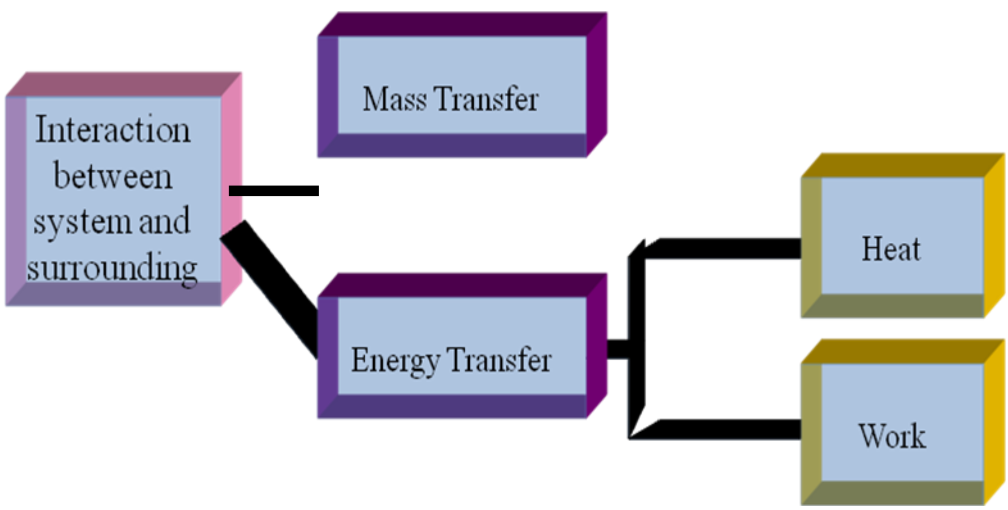
Surrounding: Everything external to the system is Surroundings.

Boundary:

- The surface which separates the system from the surrounding.
- System and surrounding interact through boundary in the form of Heat and Work.
- Boundary can be real (or) imaginary.
- Boundary can be fixed (or) moving.

System and Surrounding put together is known as **Universe**

Interaction Between System and Surrounding

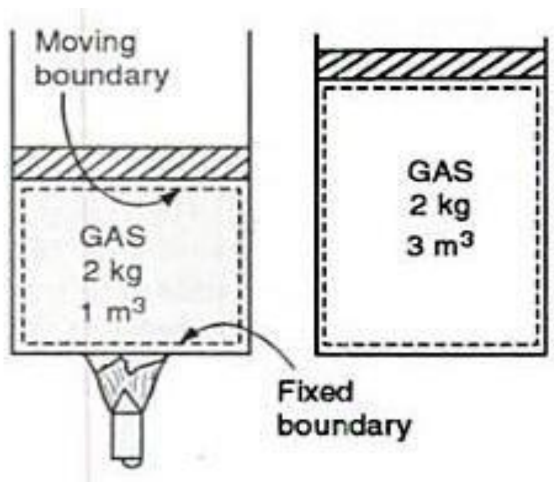


Based on the type of interaction, the systems are classified as

- **CLOSED SYSTEM**
- **OPEN SYSTEM**
- **ISOLATED SYSTEM**

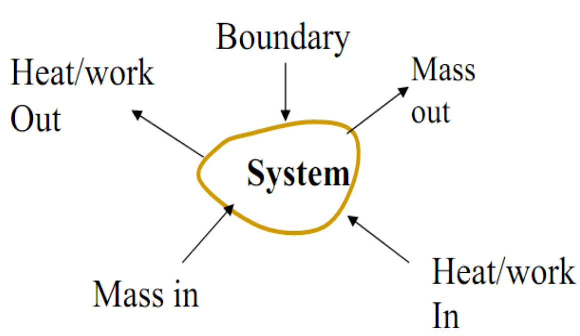
CLOSED SYSTEM (Control Mass) : It is also termed as control mass or fixed mass analysis.

There is no mass transfer across the system boundary but energy in the form of Heat or Work can cross the system boundary.



Eg. A certain amount of gas enclosed in a cylinder piston arrangement.

Open System (Control Volume): The open system is one in which both mass and energy cancross the boundary of the system.



Open system is also termed as control volume analysis.

Write down the concept of Control Volume:

A large engineering problems involve mass flow in and out of a system and therefore, are modeled as control volumes.

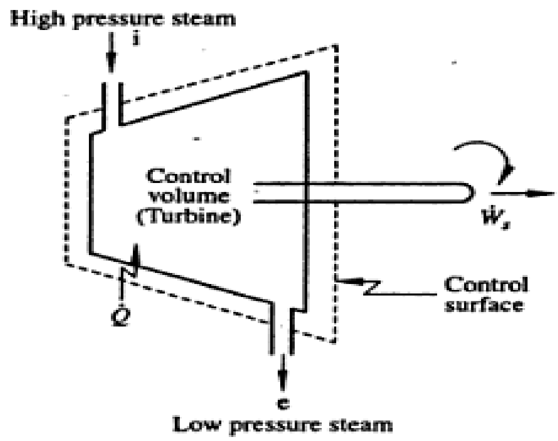
Control volume refers to a definite volume on which attention is focused for energy analysis.

Examples: Nozzles, Diffusers, Turbines, Compressors,

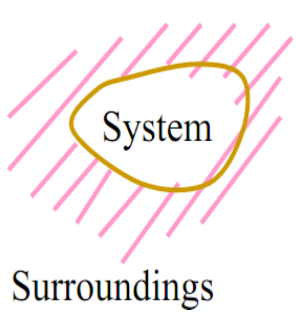
Heat Exchanger, De-super heater, Throttling valves,

I.C engine etc.

Control Surface: The closed surface that surrounds the control volume is called **CONTROL SURFACE.** Mass as well as energy crosses the control surface. Control surface can be real or imaginary.



Isolated System: The isolated system is one in which there is no interaction between the system and the surroundings that neither the mass nor the energy interactions. Therefore it is of fixed mass and energy.

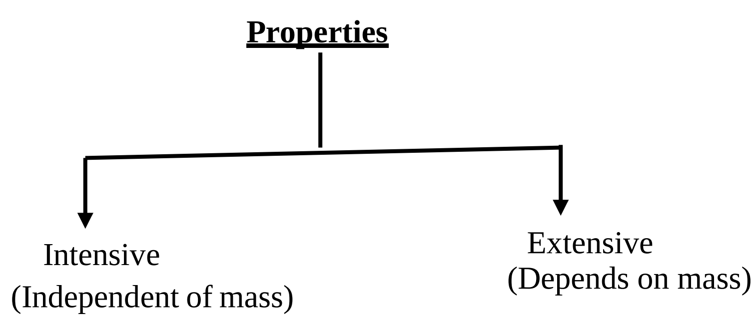


Note:

Mass Transfer	Energy Transfer	Type of System
No	**Yes**	**Closed System**
Yes	**Yes**	**Open System**
No	**No**	**Isolated System**
Yes	**No**	**Impossible**

What do you mean by Property?

Any observable characteristics required to describe the conditions or state of a system is known as Thermodynamic property of a system.



Differentiate Intensive and Extensive Property?

Extensive Property	Intensive Property
1. Extensive properties are dependent on the mass of a system.	1. Intensive properties are independent of the mass of a system.
2.Extensive properties are additive.	2. Intensive properties are not additive.

3. Its value for an overall system is the sum of its values for the parts into which the system is divided.	3. Its value remains the same whether one considers the whole system or only a part of it.
4.Example:mass(m),volume(V),Energy(E),Enthalpy(H) etc.	4.Example:Pressure(P),Temperature(T),Density etc.
5. Uppercase letters are used for extensive properties except mass.	5. Lowercase letters are used for intensive properties except pressure(P) and temp.(T)

Specific property= Extensive property/mass.

Example: Specific volume (**v**) = Volume(**V**)/mass(**m**)

Specific enthalpy (**h**) = Enthalpy(**H**)/mass(**m**)

Specific entropy (**s**) = Entropy(**S**)/mass(**m**)

State:

- It is the condition of a system as defined by the values of all it's properties.
- It gives a complete description of the system.
- Any operation in which one or more properties of a system change is called ***change of state*** .

Path and Process:

- The series of state through a system passes during a change of state is ***Path of the system***.
- If the path followed by the system during change of state is specified or defined completely, then it is called a process.

We can allow one of the properties to remain a constant during a process.

Isothermal ⟹ Constant Temperature (**T**)

Isobaric ⟹ Constant Pressure (**P**)

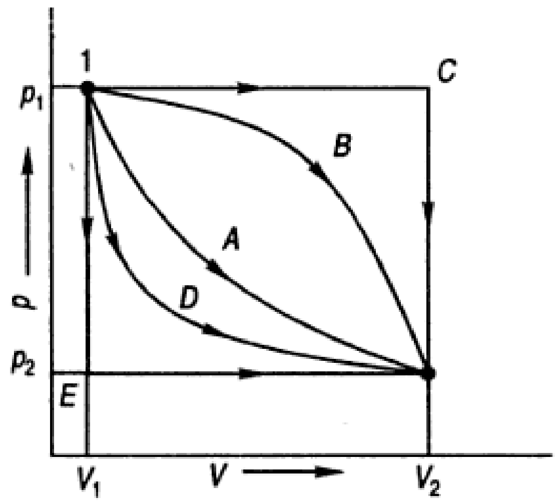
Isochoric ⟹ Constant Volume (**V**)

Isentropic ⟹ Constant Entropy (**s**)

Isenthalpic ⟹ Constant Enthalpy (**h**)

Cycle: When a system in a given initial state undergoes a series of processes and returns to initial state at the end of process, then the system is said to have undergone a thermodynamic cycle.

DIFFERENTIATE BETWEEN POINT FUNCTION VS PATH FUNCTION



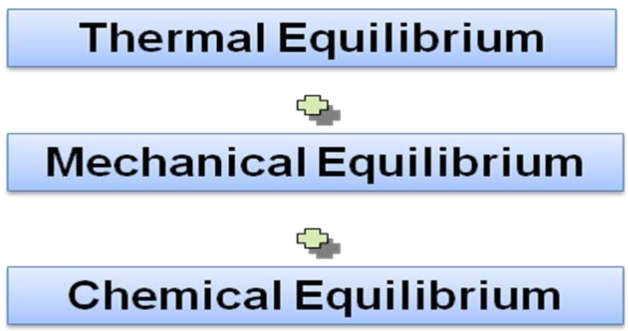
Point Function	**Path Function**
1. Any quantity whose change is independent of the path is known as point function.	1. Any quantity, the value of which depends on the path followed during a change of state is known as path function.
2. The magnitude of such quantity in a process depends on the state.	2. The magnitude of such quantity in a process is equal to the area under the curve on a property diagram.
3. These are exact differential.	3.These are inexact differential. Inexact differential is denoted by δ
4. Properties are the examples of point function like pressure(P), volume(V),Temp.(T),Energy etc.	4. Ex: Heat and work

Thermodynamic Equilibrium

A system is said to exist in a state of Thermodynamic Equilibrium when no changes in macroscopic property is observed if the system is isolated from its surrounding.

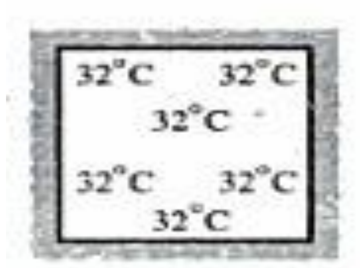
At the state of equilibrium, the properties of the system are uniform and only one value can be assigned to it.

A system will be in a state of thermodynamic equilibrium, if the condition for following three types of equilibrium are satisfied.



<u>Thermal Equilibrium</u> (Equality of Temperature):

A state of thermal equilibrium can be described as one in which the temperature of the system is uniform.



<u>Mechanical Equilibrium</u>(Equality of Pressure):

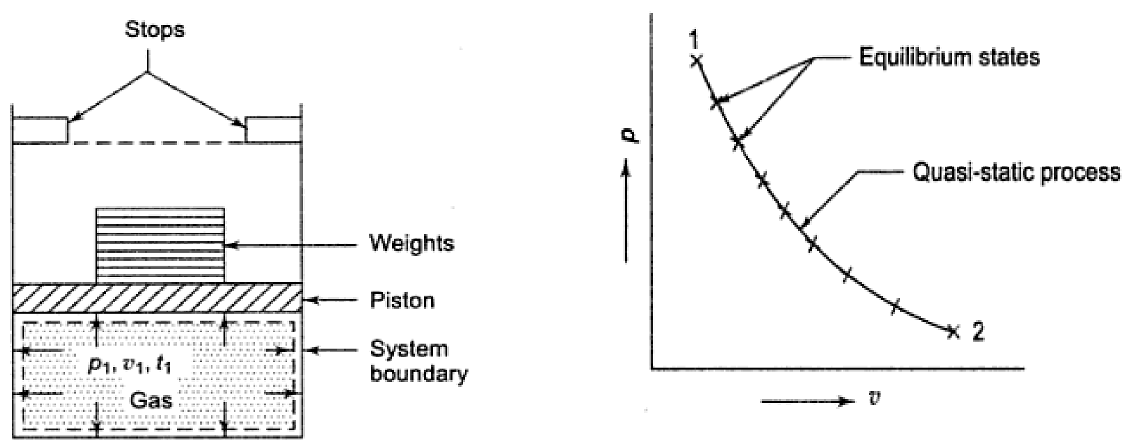
In the absence of any unbalanced force within the system itself and also between the system and the surroundings, the system is said to be in a state of mechanical equilibrium.

- Mechanical equilibrium is related to pressure.
- A system is in mechanical equilibrium if there is no change in pressure at any point of the system .

<u>Chemical Equilibrium</u>(Equality of chemical potential):

- A system is in chemical equilibrium when its chemical composition does not change with time, that is no chemical reaction occurs .
- It is related to chemical potential.

QUASI-STATIC PROCESS



A quasi-static process is one in which the deviation from thermodynamic equilibrium is infinitesimal.

Characteristics:

- Infinite slowness is the characteristic feature of this process.
- A quasi-static process is thus a *succession of equilibrium states*.
- It can be represented as a continuous line on the property diagram.
- It is also known as a reversible process.

REVERSIBLE PROCESS

Reversible process is one which is performed in such a way that at the end of the process both the system and surrounding may be restored to their initial state without producing any changes in rest of the Universe.

Reasons for studying Reversible Process:

1. They are easy to analyze.

2. They served as an idealized process to which actual process can be compared.

3. They are taken for consideration because work producing devices such as steam turbine, automobile engines etc delivers the max. work and work consuming devices like compressors, pumps etc consumes the least work.

Characteristics of Reversible Process

- ✓ A Reversible process is carried out infinitely slowly with an infinitesimal gradient so that every state pass through by the system is in equilibrium.
- ✓ It is possible to execute the process in either of the direction.
- ✓ No dissipative effect such as friction, loss in a resistor, etc are present.
- ✓ Heat and work interactions of the system and the surroundings in the reverse process are equal and opposite in direction to the same in the forward process.

Examples:

1. Frictionless isothermal expansion or compression of a fluid.
2. Frictionless adiabatic expansion or compression of a fluid.
3. Elastic stretching of a solid.
4. Electric current with zero resistance.

IRREVERSIBLE PROCESS

An irreversible process is one that is carried out in such a way that the system and surrounding can not be exactly restored to their respective initial state at the end of the reverse process, that a net change occurs in the Universe.

Note: In an irreversible the surrounding would always be affected by loss of work and gain of low temperature heat, which can be considered as waste heat for the surrounding.

Causes of an Irreversibility:

The irreversibility of a process may be due to either one or both of the following.

(i) Lack of Equilibrium.

(ii) Involvement of Dissipative effects.

Lack of Equilibrium(Mechanical,Thermal,Chemical)

The lack of equilibrium between the system and the surroundings or between the two systems causes a spontaneous change which makes the process irreversible.

Examples:

1. Heat transfer through a finite temperature difference.
2. Compression or Expansion through a finite pressure difference between the system and the surroundings.
3. Free expansion or Unrestrained expansion.
4. Mixing of substances.

Dissipative Effects:

Dissipation results in the transformation of work into molecular energy of the system.

Examples:

1. Friction.
2. Flow of electricity through a resistor.
3. Paddle wheel work transfer. etc

Characteristics of an Irreversible Process:

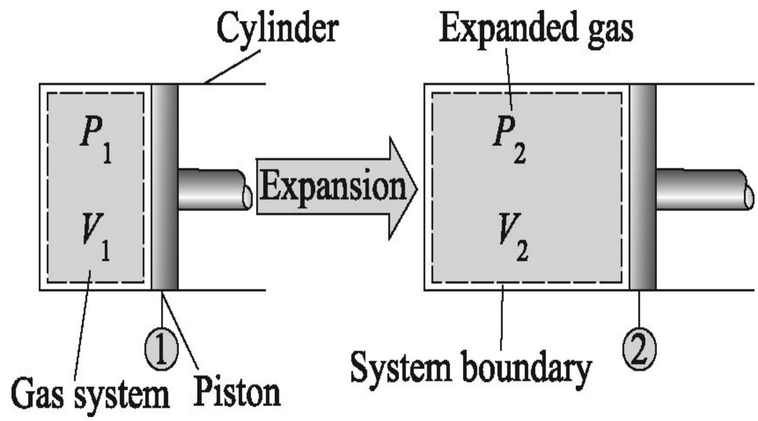
1. It can be carried out in one direction only.
2. It occurs at a finite rate.
3. During an irreversible process, the system is not in equilibrium.

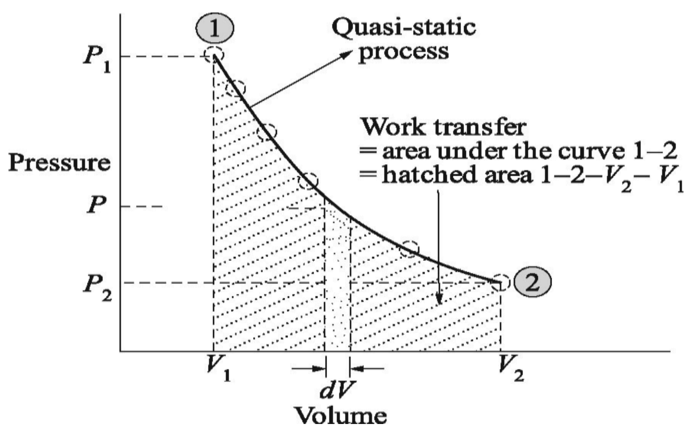
An irreversible process cannot be reversed without causing permanent changes in the surroundings.

Heat & Work Transfer

Thermodynamic Work: Work is said to be done by a system if the sole effect on things external to the system can be reduced to the raising of a weight.

Displacement (or) pdV Work:





Expression for pdV Work:

$$W = \int dW$$

$$= \int (p * \text{piston area} * displacement)$$

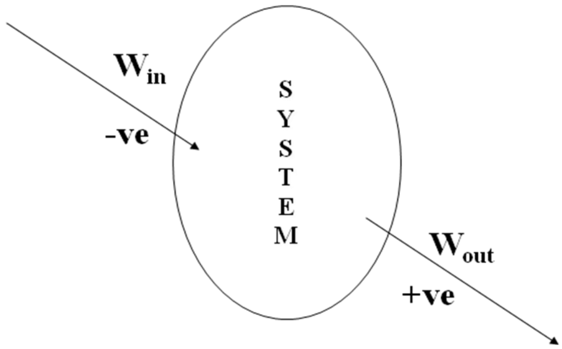
$$= \int p * A * dL$$

$$= \int pdV$$

$$W_{12} = \int_1^2 pdV$$

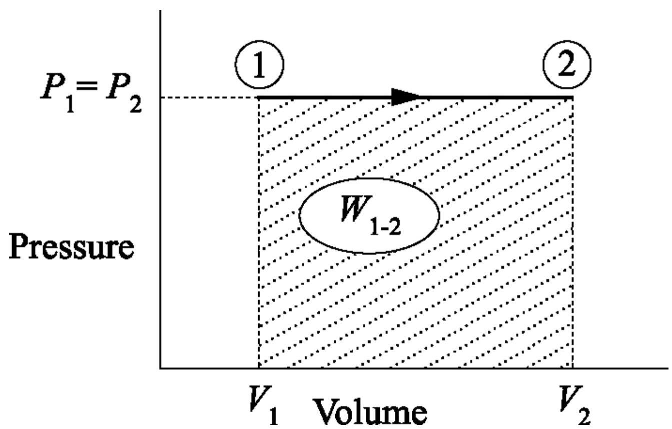
Sign Convention for work transfer:

Work done by the system is **positive and** Work done on the system is **negative.**



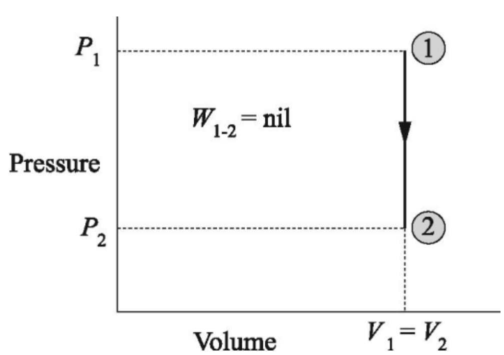
Work done during various Quasi-static Processes:

Constant Pressure Proces:



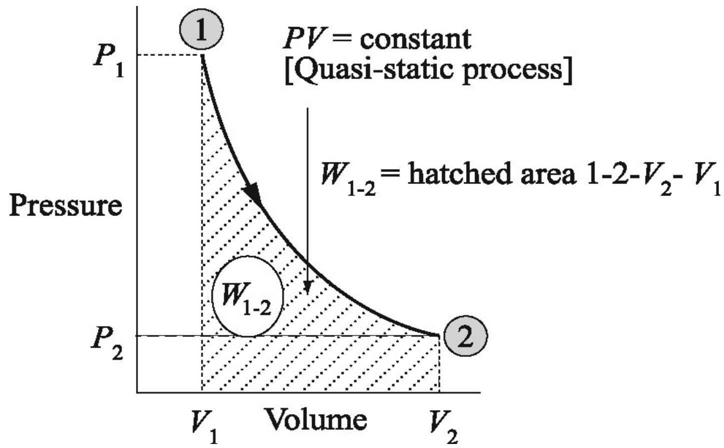
$$W_{1-2} = \int_{V_1}^{V_2} p dV \;=\; p(V_2 - V_1)$$

Constant Volume Process:



$$W_{1-2} = \int_{V_1}^{V_2} pdV = 0$$

Constant Temperature Process:



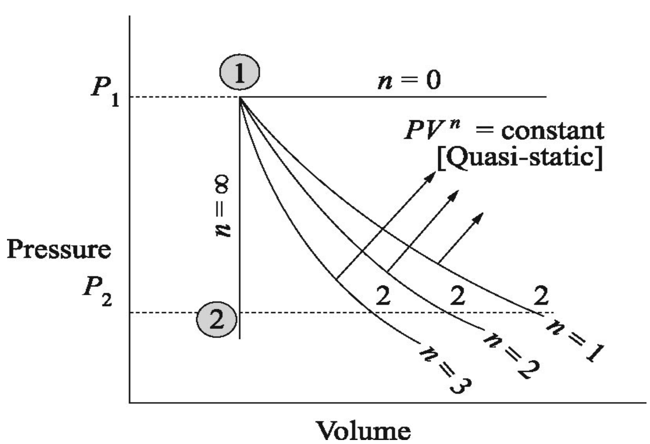
$$W_{1-2} = \int_{V_1}^{V_2} pdV$$

$$pV = p_1V_1 = C$$

$$p = \frac{p_1V_1}{V}$$

$$W_{1-2} = p_1V_1\int_{V_1}^{V_2}\frac{dV}{V} = p_1V_1 \ln\frac{V_2}{V_1}$$

Polytropic Process $pV^n = C$**,** where n is a constant



$$pV^n = p_1V_1^n = p_2V_2^n = C$$

$$p = \frac{(p_1V_1^n)}{V^n}$$

$$W_{1-2} = \int_{V_1}^{V_2} p\,dV$$

$$= \int_{V_1}^{V_2} \frac{p_1V_1^n}{V^n}\,dV$$

$$= \frac{p_1V_1 - p_2V_2}{n-1}$$

Heat Transfer: Energy transfer by virtue of temperature difference is called Heat Transfer. Heat Transfer is also a boundary phenomenon.

Specific Heat: It is the amount of heat required to raise the temperature of unit mass of a substance by unit degree.

For **Solids** and **Liquids**

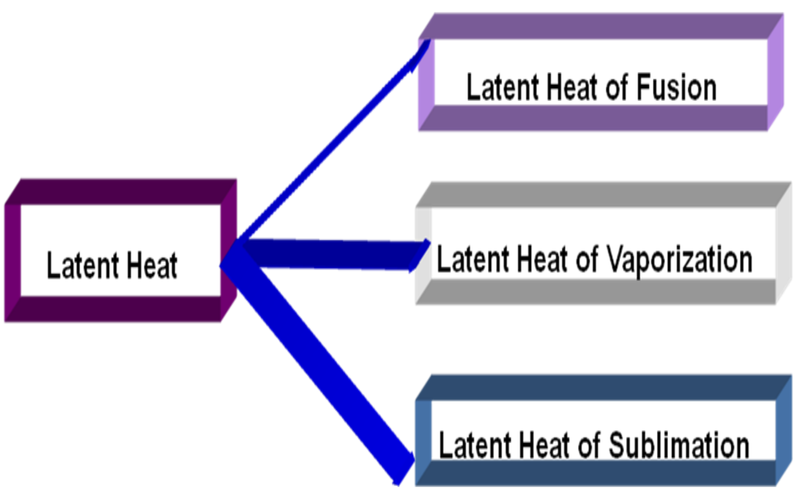
$c_p = c_v = c$

For **Gases**

c_p – specific heat capacity at constant pressure

c_v – specific heat capacity at constant volume

Latent Heat: It is the amount of heat transferred to cause a phase change.



FIRST LAW OF THERMODYNAMICS

- This is based on Law of Conservation of Energy.
- This is also called as First Principle.

For a closed system, undergoing a cycle

Sum of all Work transfers = Sum of all Heat Transfers

$$(W_1+W_2+W_3+\ldots) = \Sigma(Q_1+Q_2+Q_3+\ldots)$$

$$\Sigma(W) = \Sigma(Q)$$

$$\oint dW = \oint dQ$$

For a closed system,undergoing a Process

Whenever heat is absorbed by a system it increases its internal energy and does some work.

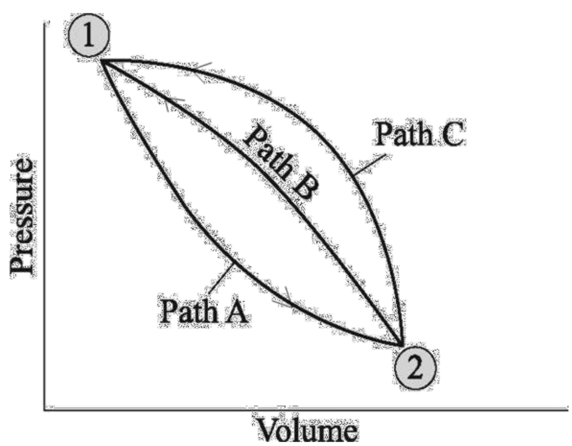
$$Q = \Delta E + W$$

Where Q – heat absorbed by the system

W – Work output from the system

ΔE – Change in Stored Energy of the system

Show that Energy is a property of the system



For path A,

$$Q_A = W_A + \Delta E_A \qquad (1)$$

For path B,

$$Q_B = W_B + \Delta E_B \qquad (2)$$

For path B,

$$Q_C = W_C + \Delta E_C \qquad (3)$$

For Cycle 1-A-2-B-1,

$$W_A + W_B = Q_A + Q_B \qquad (4)$$

$$Q_A - W_A = -(Q_B - W_B)$$

$$\Delta E_A = -\Delta E_B \qquad (A)$$

For Cycle 1-A-2-C-1,

$$W_A + W_C = Q_A + Q_C$$

$$Q_A - W_A = -(Q_C - W_C)$$

$$\Delta E_A = -\Delta E_C \qquad (C)$$

Comparing A and C

$$\Delta E_B = \Delta E_C$$

Enthalpy:

- It is the energy content of the flowing fluid.
- It is defined by the summation of internal energy and flow work.

H = U + PV

Note: For an ideal gas h = u + Pv.

= u + RT

So, h = f(T)

Define C_v with the help internal energy and Temperature:

The amount of heat required to raise the temperature of unit mass of a substance by 1^o C in a reversible constant volume process.

$$C_v = \left(\frac{\partial u}{\partial T}\right)_v$$

C_v is also defined as the change of internal energy of the substance per unit change in temperature at constant volume.

Define C_p with the help enthalpy and Temperature:

The amount of heat required to raise the temperature of unit mass of a substance by 1^o C in a reversible constant pressure process.

$$C_p = \left(\frac{\partial h}{\partial T}\right)_p$$

C_p is also defined as the change of internal energy of the substance per unit change in temperature at constant pressure.

Application of First law to different Thermodynamic process:

Process	**Index=n**	Q	W= $\int PdV$	P-V-T Relation
Rev. Const.Vol.	∞	$Q = \Delta U$ $= mC_v(T_2 - T_1)$	W=0	$\frac{P_1}{T_1} = \frac{P_2}{T_2}$
Rev.Const.pressure	n=0	$Q = \Delta H$ $= mC_p(T_2 - T_1)$	$W = P(V_2 - V_1)$ $= mR(T_2 - T_1)$	$\frac{V_1}{T_1} = \frac{V_2}{T_2}$
Rev. Isothermal	n=1	$Q = W = P_1V_1 \ln\left(\frac{V_2}{V_1}\right)$	$W = P_1V_1 \ln\left(\frac{V_2}{V_1}\right)$	$P_1V_1 = P_2V_2$
Rev.Adiabatic	n=γ	Q=0	$W = \frac{P_1V_1 - P_2V_2}{\gamma - 1}$	$P_1V_1^{\gamma} = P_2V_2^{\gamma}$
Rev.Polytropic	n	$Q = \Delta U + W$	$W = \frac{P_1V_1 - P_2V_2}{n - 1}$	$P_1V_1^n = P_2V_2^n$