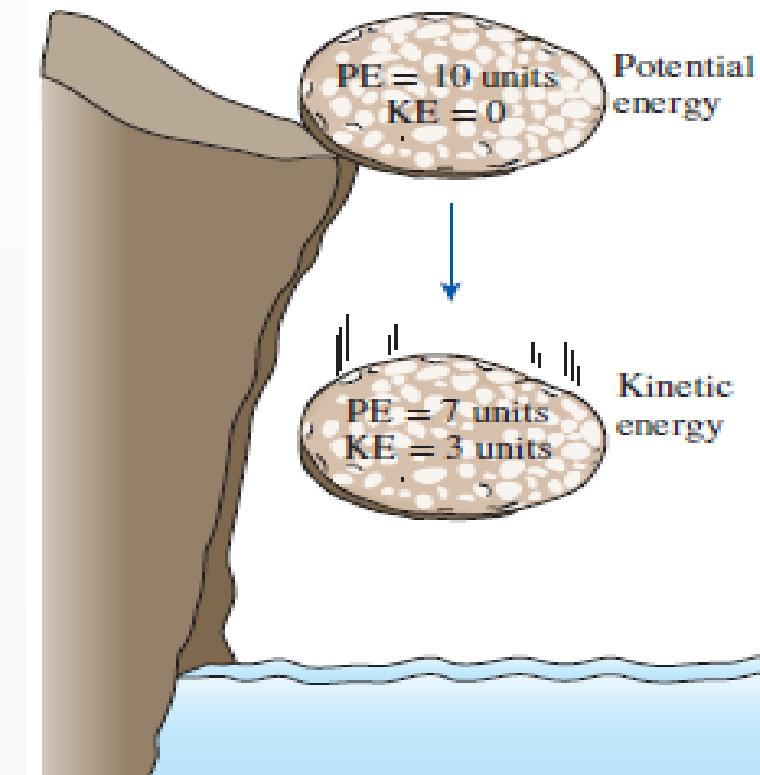


# Basic Mechanical Engineering

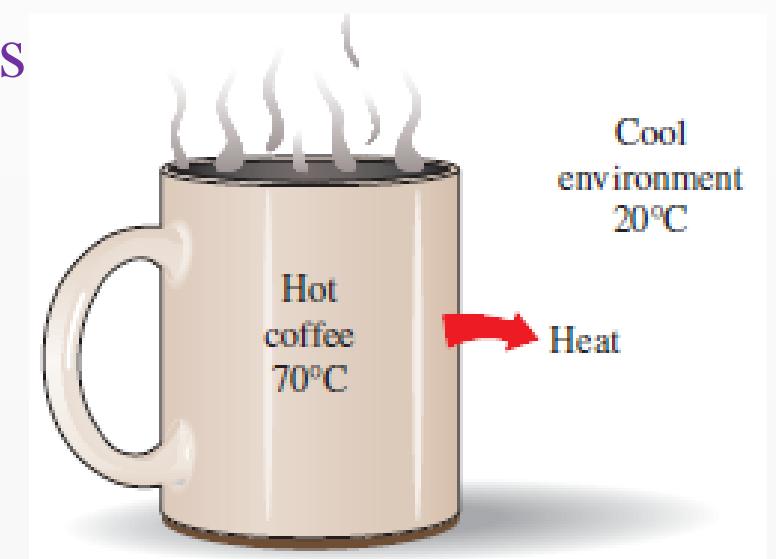
# THERMODYNAMICS AND ENERGY

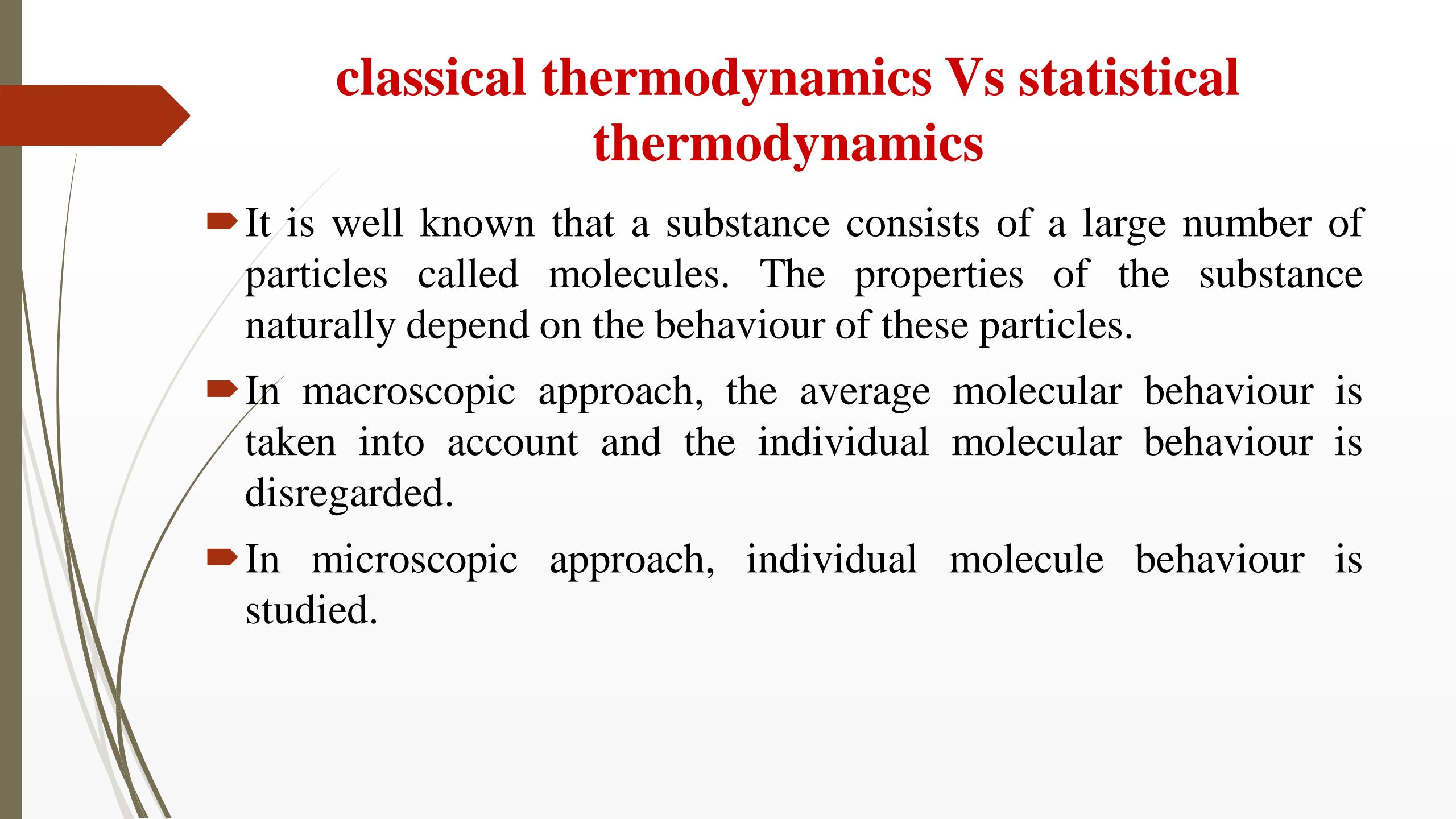
- Thermodynamics can be defined as the science of *energy*.
- The name *thermodynamics* stems from the Greek words *therme* (heat) and *dynamis* (power), which is most descriptive of the early efforts to convert heat into power.
- One of the most fundamental laws of nature is the **conservation of energy principle**.
- The first law of thermodynamics is simply an expression of the conservation of energy principle, and it asserts that energy is a thermodynamic property.



# THERMODYNAMICS AND ENERGY

- The **second law of thermodynamics** asserts that energy has *quality* as well as *quantity*, and actual processes occur in the direction of decreasing quality of energy.
- “Thermodynamics is a fundamental subject that describes the **basic laws governing the occurrence of physical processes associated with transfer of energy or transformation of energy** and it also establishes the relationship between different physical properties which have been affected by these processes.”
- How to adopt these interactions to our benefit?





# classical thermodynamics Vs statistical thermodynamics

- ▶ It is well known that a substance consists of a large number of particles called molecules. The properties of the substance naturally depend on the behaviour of these particles.
- ▶ In macroscopic approach, the average molecular behaviour is taken into account and the individual molecular behaviour is disregarded.
- ▶ In microscopic approach, individual molecule behaviour is studied.

# Application Areas of Thermodynamics



(a) Refrigerator



(b) Boats



(c) Aircraft and spacecraft



(d) Power plants



(e) Human body



(f) Cars



(g) Wind turbines



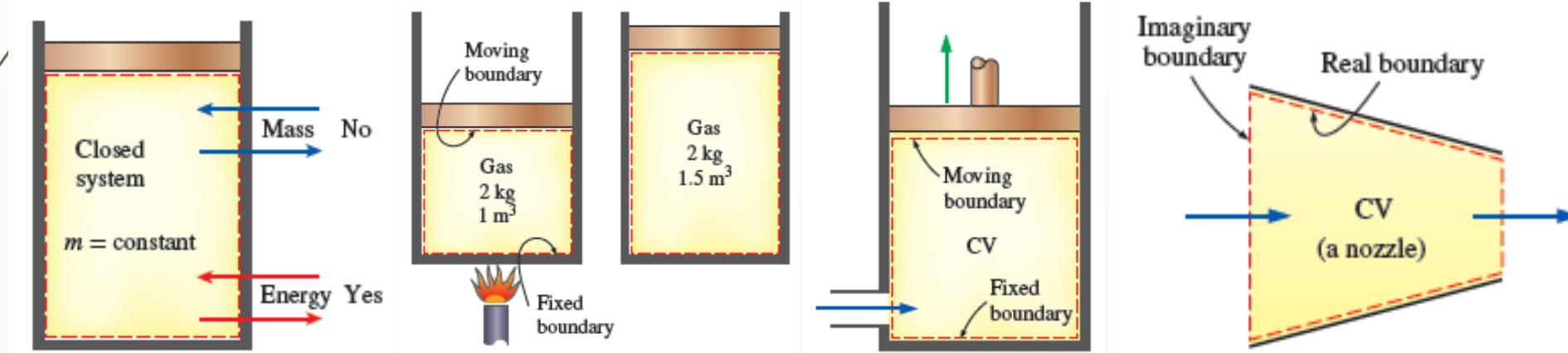
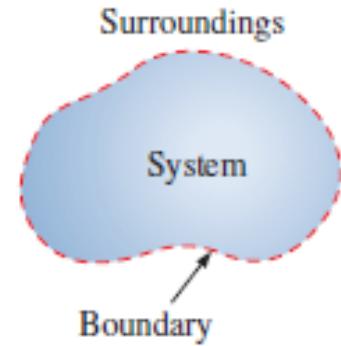
(h) Food processing



(i) A piping network in an industrial facility.

# SYSTEMS AND CONTROL VOLUMES

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



Closed or Control Mass System

Open or Control Volume System

# SYSTEMS AND CONTROL VOLUMES

Types of System	Mass Transfer	Energy Transfer	Example
Closed	X	✓	Piston Cylinder Arrangement with Valve Closed.
Open	✓	✓	Piston Cylinder Arrangement with Valve Open.
Isolated	X	X	Insulated Flask, Universe

# PROPERTIES OF A SYSTEM

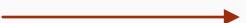
- ▶ These are the characteristic features by which a system can be specified.
- ▶ These are macroscopic in nature.
- ▶ We must choose the most appropriate set of properties.
- ▶ Properties are considered to be either *intensive* or *extensive*.
- ▶ **Intensive properties** are those that are independent of the mass of a system, such as temperature, pressure, and density.
- ▶ **Extensive properties** are those whose values depend on the size—or extent—of the system. Total mass, total volume, and total momentum are some examples of extensive properties.
- ▶ Note: All specific properties are intensive properties.

# Characteristics of Properties

- Properties are state or point function
- They are independent of path.
- Properties are exact differentials.



$m$
$U$
$T$
$P$
$\rho$



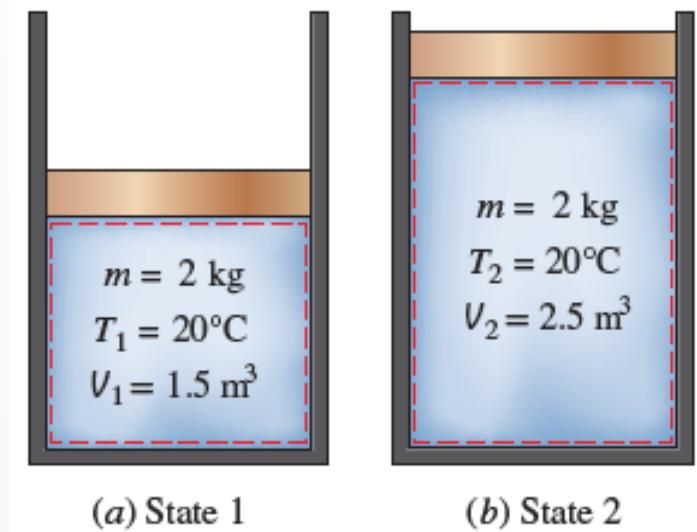
$\frac{1}{2} m$	$\frac{1}{2} m$
$\frac{1}{2} U$	$\frac{1}{2} U$
$T$	$T$
$P$	$P$
$\rho$	$\rho$

Extensive Properties

Intensive Properties

# STATE AND EQUILIBRIUM

- State: It is the condition of the system as defined by the value of all its properties. It gives complete description of the system.
- Thermodynamics deals with *equilibrium* states. The word **equilibrium** implies a state of balance.
- There are many types of equilibrium, and a system is not in thermodynamic equilibrium unless the conditions of all the relevant types of equilibrium are satisfied.



# The State Postulate

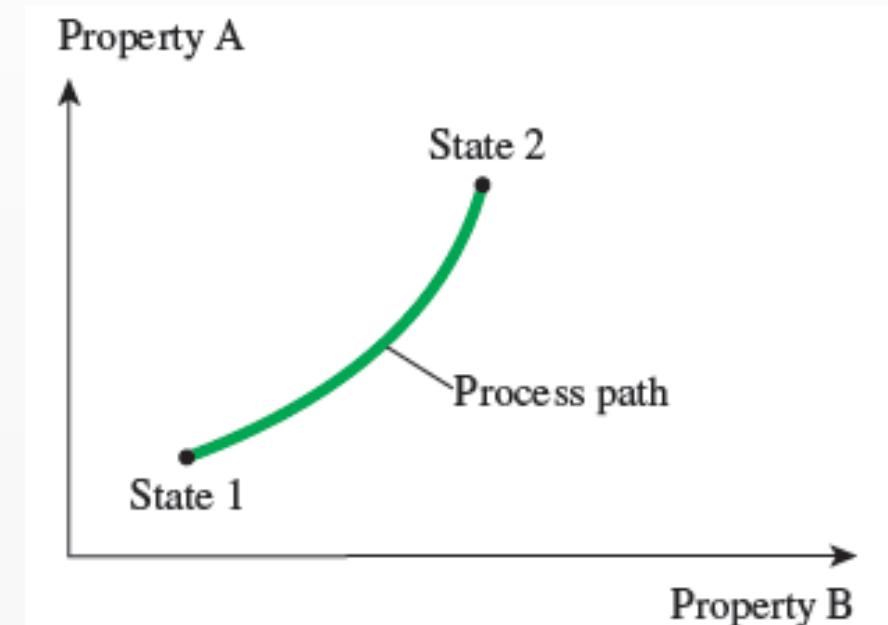
► The number of properties required to fix the state of a system is given by the **state postulate**.

►  $F = C - \phi + 2$

Where,  $F$  = number of properties required to specify / fix the state.

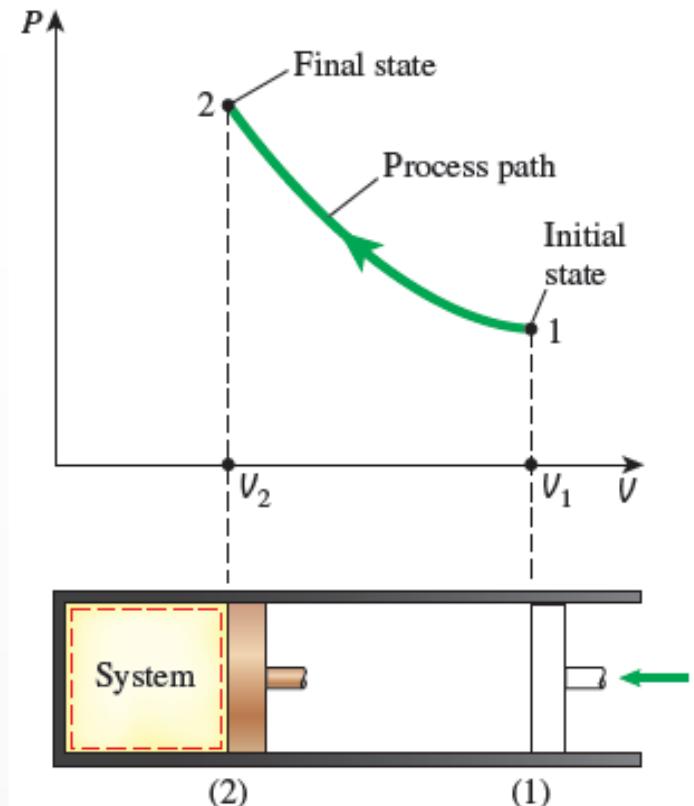
$C$  = number of component

$\phi$  = number of phase



# PROCESSES AND CYCLES

- Any change that a system undergoes from one equilibrium state to another is called a **process**, and the series of states through which a system passes during a process is called the **path** of the process.
- To describe a process completely, one should specify the initial and final states of the process, as well as the path it follows, and the interactions with the surroundings.
- Processes are of two types: Reversible & Irreversible

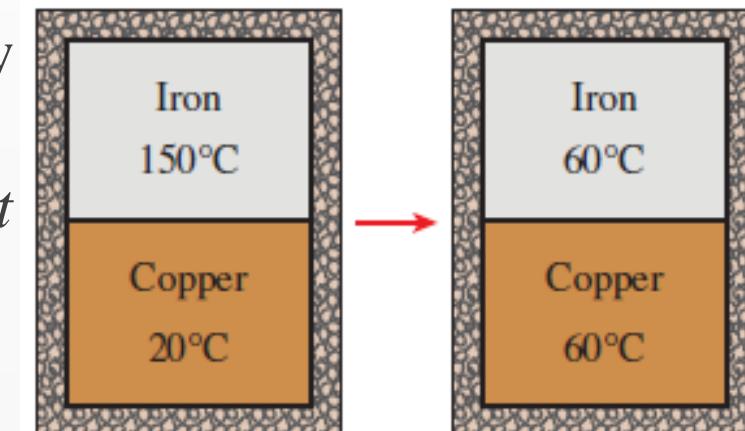


# Quasi-static / Quasi-equilibrium process

- When a process proceeds in such a manner that the system remains infinitesimally close to an equilibrium state at all times, it is called a **quasi-static**, or **quasi-equilibrium, process**.
- A quasi-equilibrium process can be viewed as a sufficiently slow process that allows the system to adjust itself internally so that properties in one part of the system do not change any faster than those at other parts.
- Engineers are interested in quasi-equilibrium processes for two reasons. First, they are easy to analyze; second, work-producing devices deliver the most work when they operate on quasi-equilibrium processes.
- Therefore, quasi-equilibrium processes serve as standards to which actual processes can be compared.

# TEMPERATURE AND THE ZEROTH LAW OF THERMODYNAMICS

- Although we are familiar with temperature as a measure of “hotness” or “coldness,” it is not easy to give an exact definition for it.
- Fortunately, several properties of materials change with temperature in a *repeatable* and *predictable* way, and this forms the basis for accurate temperature measurement.
- The **zeroth law of thermodynamics** states that if two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other.
- By replacing the third body with a thermometer, the zeroth law can be restated as *two bodies are in thermal equilibrium if both have the same temperature reading even if they are not in contact.*



# Temperature Scales

- ▶ All temperature scales are based on some easily reproducible states such as the freezing and boiling points of water, which are also called the *ice point* and the *steam point*, respectively.
- ▶ The temperature scales used in the SI and in the English system today are the **Celsius scale** and the **Fahrenheit scale** On the Celsius scale, the ice and steam points were originally assigned the values of 0 and 100°C, respectively. The corresponding values on the Fahrenheit scale are 32 and 212°F.
- ▶ In thermodynamics, it is very desirable to have a temperature scale that is independent of the properties of any substance or substances. Such a temperature scale is called a **thermodynamic temperature scale**, which is developed later in conjunction with the second law of thermodynamics.
- ▶ The absolute scale related to Celsius scale is the Kelvin scale and is designated as K.
  - ▶  $K = {}^\circ C + 273.15$
- ▶ 1K is defined as the 1/273.16 of the temperature at the triple point of water.

## Problem-1 on Temperature Scale

► The resistance of a platinum wire is found to be 11.000 ohms at Ice Point, 15.247 ohms at Steam Point, and 28.887 ohms at 445°C. Find the constants A and B in the equation:  $R = R_0 (1 + At + Bt^2)$ , where R is resistant, t is temperature and is constant and also the resistance of platinum wire at 300°C.

[ANS: A =  $3.919 \times 10^{-3}$ , B =  $-5.97 \times 10^{-7}$ , R = 23.345 ohms]

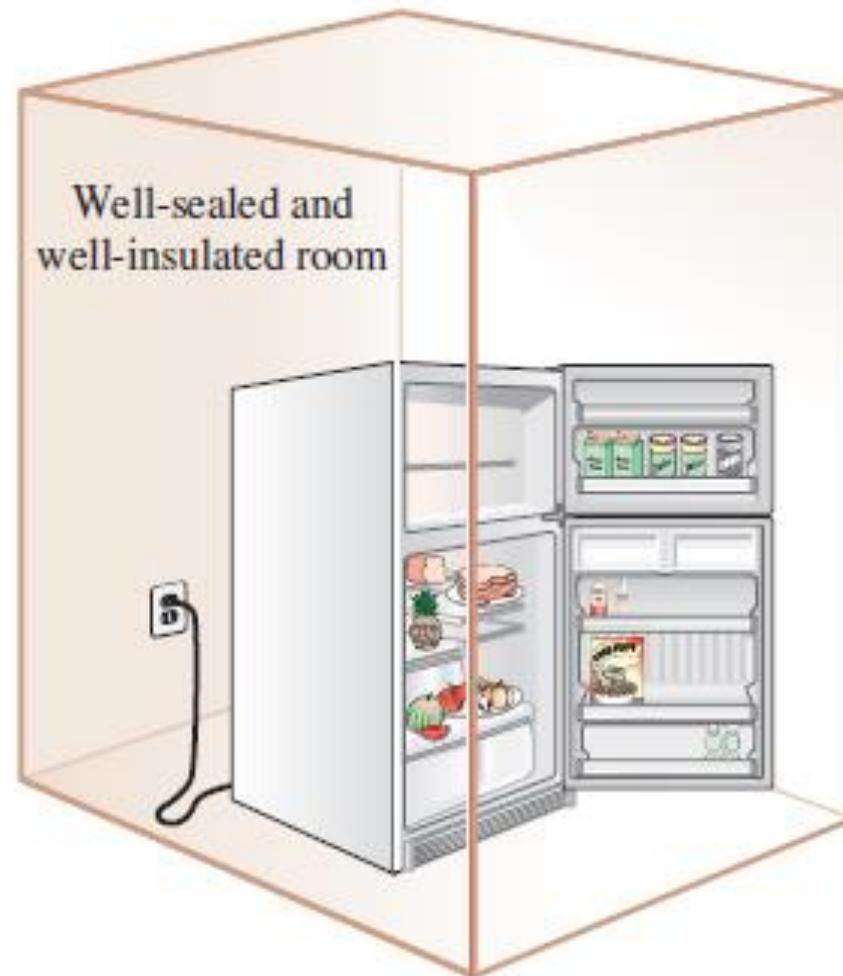
## Problem-2 on Temperature Scale

- A temperature scale of a certain thermometer is given by the relation:  $T = a \cdot \ln(P) + b$ , Where ‘ $a$ ’ and ‘ $b$ ’ are constants and  $P$  is the thermometric property of fluid in thermometer. If at the ice point and steam point, the thermometric property is found to be 1.83 and 6.78 respectively, what will be the temperature corresponding to the thermometric property of 2.42 on Celsius scale.

## Problem-3 on Temperature Scale

- The readings  $t_A$  and  $t_B$  of two thermometer of A and B at ice point and steam point and related by equation  $t_A = m t_B + n t_B^2 + L$  between these points, where L, m and n are constant. When both are immersed in oil A reads  $51^\circ\text{C}$  and B reads  $50^\circ\text{C}$ . Determine the reading on A, When B reads  $25^\circ\text{C}$ . Discuss the question which thermometer is correct.
- Ans:  $m=1.04$ ,  $n= -4 \times 10^{-4}$  and  $t_A=25.75^\circ\text{C}$

# ENERGY

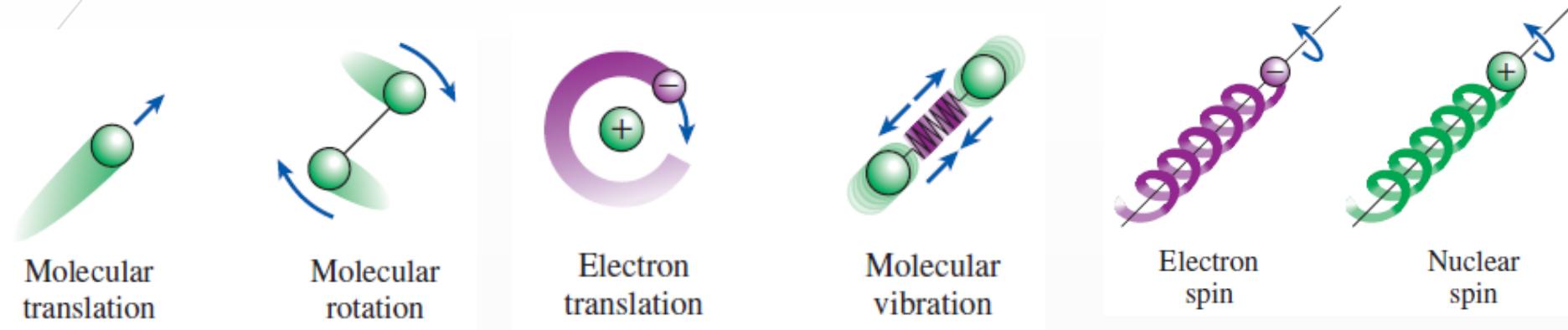


# ENERGY

- Energy can exist in numerous forms such as thermal, mechanical, kinetic, potential, electric, magnetic, chemical, and nuclear, and their sum constitutes the **total energy**  $E$  of a system.
- Thermodynamics provides no information about the absolute value of the total energy. It deals only with the *change* of the total energy.
- In thermodynamic analysis, it is often helpful to consider the various forms of energy that make up the total energy of a system in two groups: *macroscopic* and *microscopic*.
- The **macroscopic** forms of energy are those a system possesses as a whole with respect to some outside reference frame, such as kinetic and potential energies. The **microscopic** forms of energy are those related to the molecular structure of a system and the degree of the molecular activity, and they are independent of outside reference frames.
- The sum of all the microscopic forms of energy is called the **internal energy** of a system and is denoted by  $U$

# Some Physical Insight to Internal Energy

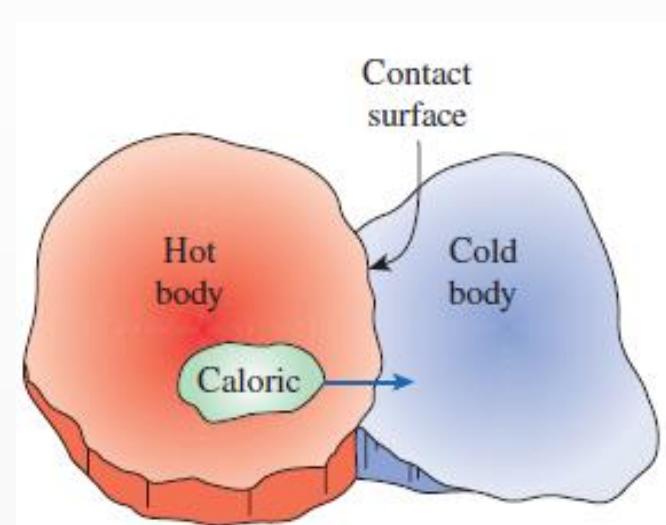
- The portion of the internal energy of a system associated with the kinetic energies of the molecules is called the **sensible energy**.



- The internal energy associated with the phase of a system is called the **latent energy**.

# ENERGY TRANSFER BY HEAT

- ▶ **Heat** is defined as *the form of energy that is transferred between two systems (or a system and its surroundings) by virtue of a temperature difference*. That is, an energy interaction is heat only if it takes place because of a temperature difference. Then it follows that there cannot be any heat transfer between two systems that are at the same temperature.
- ▶ Heat transfer to a system is considered positive.
- ▶ Heat transfer from a system is negative.
- ▶ A process during which there is no heat transfer is called as an adiabatic process.



# Specific Heat

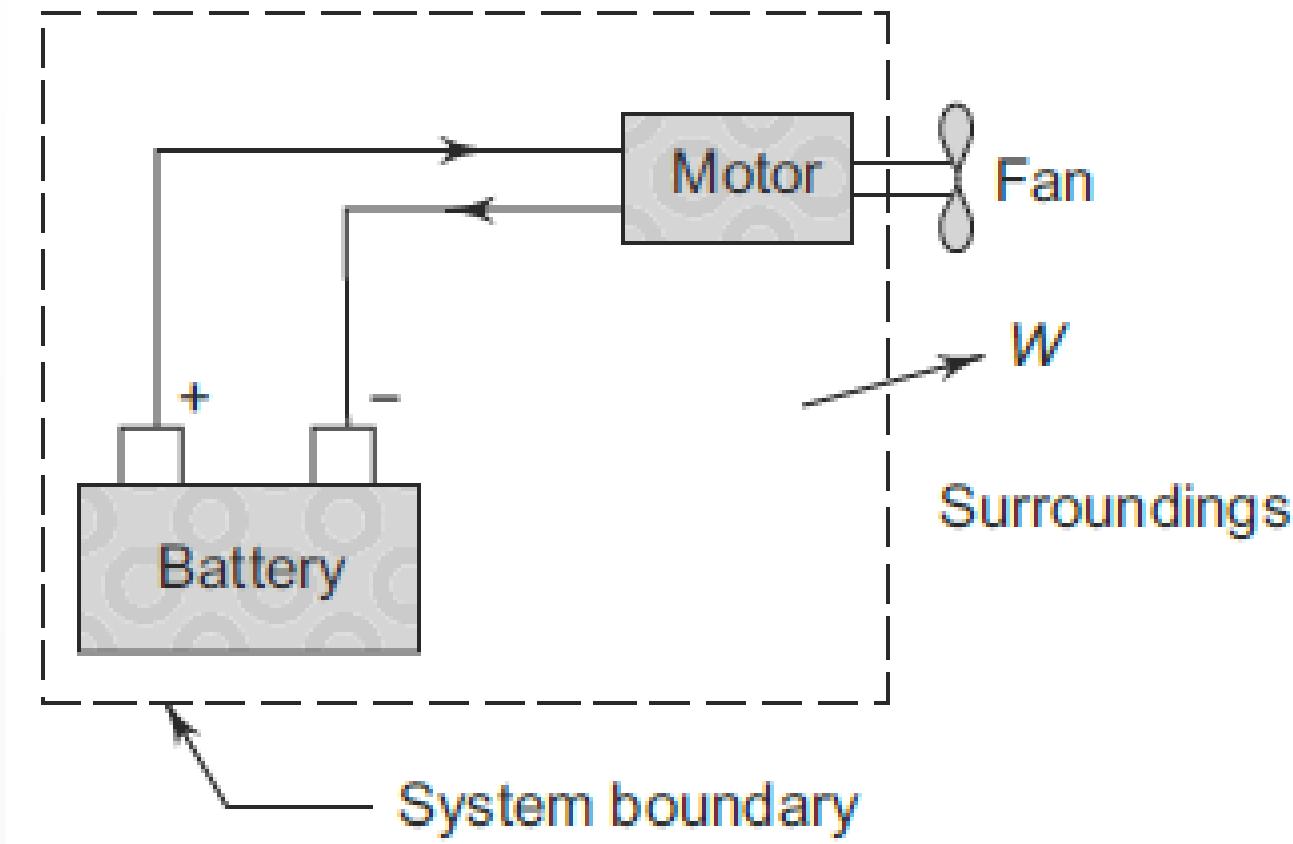
- It is the amount of heat required to raise the temperature of unit mass of a substance to a unit degree of temperature difference.

- $C_n = \frac{\partial q}{dt}$

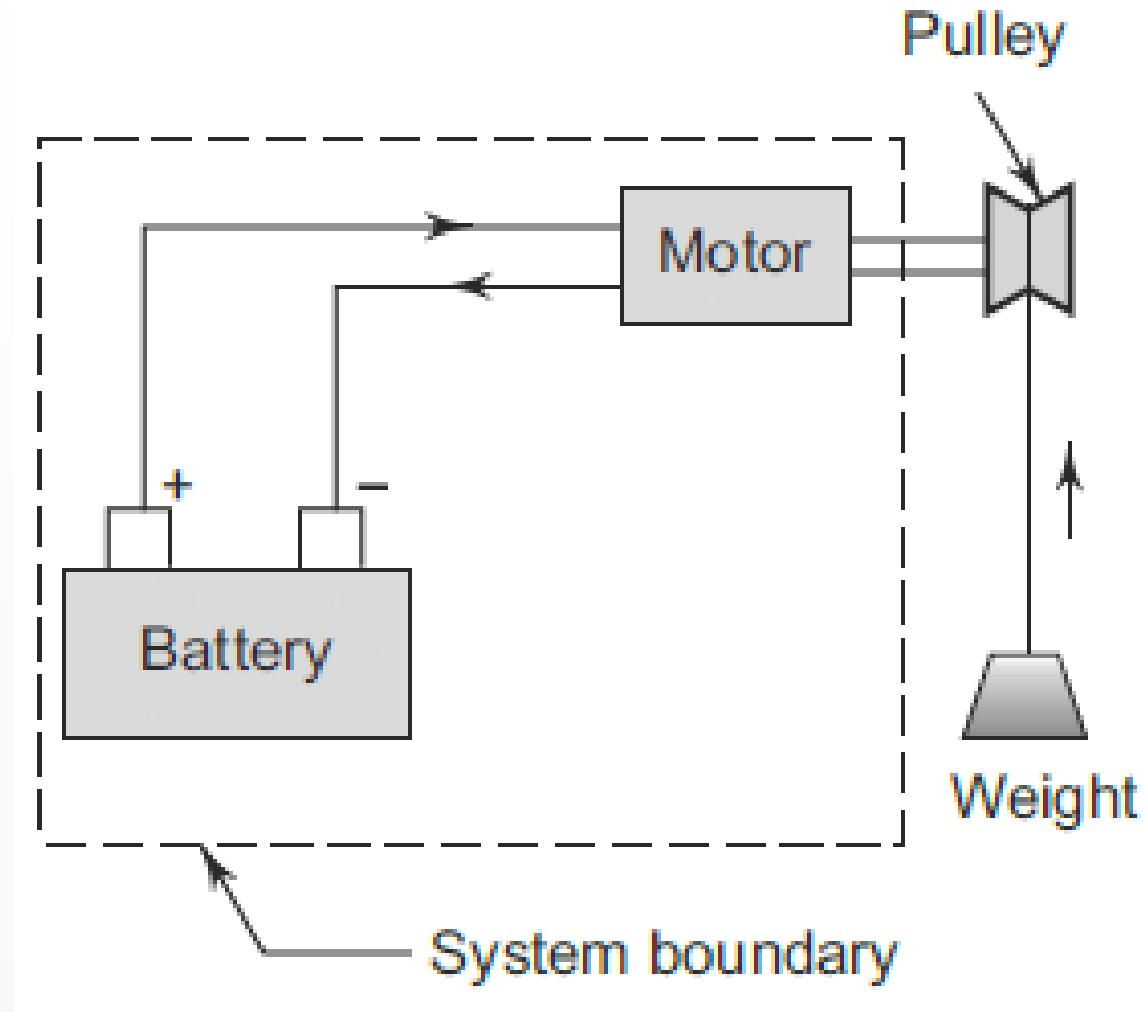
- $\partial q = C_n dt$

- $\partial q = mC_n dt$

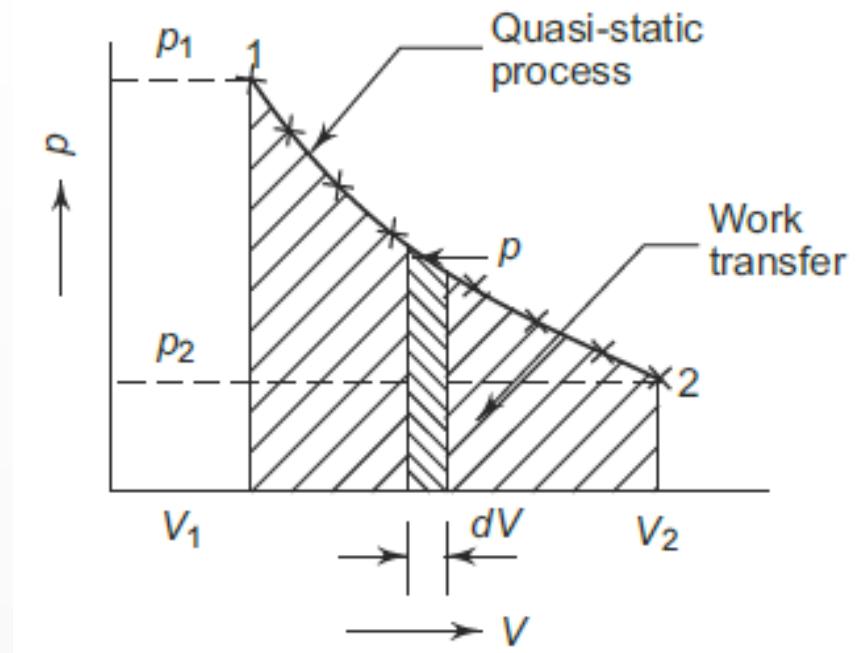
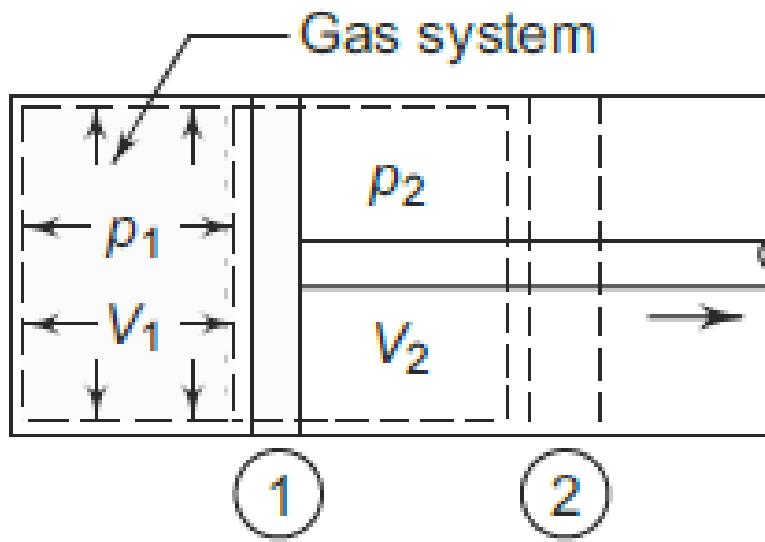
# ENERGY TRANSFER BY WORK



# ENERGY TRANSFER BY WORK



# Work Done at the Moving Boundary of a System in a Quasi-Equilibrium Process / Displacement Work



(21)

- Q- The readings  $T_A$  and  $T_B$  of two thermometers A & B agree at ice point and steam point and are related by the equation

$$T_A = l + m T_B + n T_B^2$$

between those points, where  $l, m, n$  are const. When both are immersed in oil A reads  $51^\circ\text{C}$  and B reads  $50^\circ\text{C}$ . Determine the reading on A when B reads  $25^\circ\text{C}$ .

$$\text{At } 0^\circ\text{C}, 0 = l + m \times 0 + n \times 0 \Rightarrow l = 0$$

$$T_A = m T_B + n T_B^2$$

$$\text{At } 100^\circ\text{C}, 100 = m \times 100 + n \times 100^2$$

$$1 = m + 100n \quad \dots (1)$$

$$51 = 50m + 2500n \quad \dots (2)$$

Solving eqn (1) and (2)

$$m = 1.04, n = -4 \times 10^{-4}$$

$$T_A = 1.04 T_B - 4 \times 10^{-4} T_B^2$$

$$\text{at } T_B = 25^\circ\text{C}$$

$$T_A = 1.04 \times 25 - 4 \times 10^{-4} \times 25^2 = 25.75^\circ\text{C} \quad \underline{\text{Ans}}$$

- Q- In a new temp. scale  ${}^\circ N$ , the boiling and freezing points are  $400 {}^\circ N$  and  $100 {}^\circ N$ , respectively. What will be the reading on new scale corresponding to  $60^\circ\text{C}$ :  ${}^\circ N = ax^\circ\text{C} + b$

$$100 = ax + b \quad \dots (1), \quad 400 = ax \times 100 + b \quad \dots (2)$$

$$\text{Solving (1) and (2)} \Rightarrow a = 3, b = 100$$

$$\text{when } \cancel{x} = T = 60^\circ\text{C}$$

$${}^\circ N = 3 \times 60 + 100$$

$$= 280 {}^\circ N \quad \underline{\text{Ans}}$$

## ENERGY

Energy can exist in numerous forms such as thermal, mechanical, kinetic, potential, electric, magnetic, chemical etc. and their ~~sum~~ sum constitutes the total energy  $E$  of a system.

Thermodynamics provides no information about the absolute value of the total energy. It deals only with the change of the total energy.

In thermodynamic analysis, it is often helpful to consider the various forms of energy that make up the total energy of a system in two groups: macroscopic and microscopic.

The macroscopic form of energy are those a system possesses as a whole w.r.t. some outside reference frame, such as kinetic and potential energy.

The microscopic forms of energy are those related to the molecular structure of a system and the degree of the molecular activity. They are independent of outside reference frames. The sum of all the microscopic forms of energy is called the internal energy of a system.

$$\begin{aligned} \text{Microscopic Energy} &= \text{Sensible Energy} + \text{Latent Energy} \\ (\text{Internal Energy}) & \\ &\quad \text{Temp.} \end{aligned}$$

(K.E + Rotational  
spin + vibration)

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Page No.

## Some Physical Insight to Internal Energy

Let us examine a system at molecular level. The molecules of a gas move through space with some velocity and thus possess some kinetic energy. This is known as the translational energy.

The atoms of polyatomic molecules rotate about an axis, and the energy associated with this rotation is the rotational kinetic energy. The atoms of a polyatomic molecule may also vibrate about their common center of mass and the energy associated with this back and forth motion is the vibrational kinetic energy.

The portion of the internal energy of a system associated with the kinetic energies of the molecules is called the sensible energy.

The avg. velocity and the degree of activity of the molecules are proportional to the temperature of the gas. Therefore at higher temp. the molecules possess higher kinetic energies and as a result, the system has a higher internal energy.

The internal energy is also associated with various binding forces between the molecules of a substance, between the atoms within a molecule and between the particles within an atom and its nucleus. This force is strongest in solid and weakest in gas.

If sufficient energy is added to the molecules of a solid or liquid, the molecules overcome these molecular forces and break away, turning the substance into a gas.

Because of this added energy, a system in the gas phase is at a higher internal energy level than it is in the solid or the liquid phase. The internal energy associated with the phase of a system is called the latent energy. The phase change process can occur without a change in the chemical composition of a system.

An atom consists of neutrons and positively charged protons bounded together by a very strong nuclear force ~~or~~ in the nucleus and negatively charged electrons orbiting around it. The internal energy associated with the atomic bonds in the molecule is called chemical energy.

## Energy Transfer by heat

Energy can cross the boundary of a closed system in two distinct forms: heat and work.

We know from experience that a can of cold soft drink on a table eventually warms up and that a hot baked potato on the same table cools down.

When a body is left in a medium that is at diff temp., energy transfer takes place between the body and the surrounding medium until thermal equilibrium is established. The direction of energy transfer is always from the body at higher temp to the lower temp one. Once the temp. equality is established, energy transfer stops. In the process described above, energy is said to be transferred in the form of heat.

"Heat is defined as the form of energy that is transferred across the boundary of a system at a given temp. to another system (or surrounding) at a lower temp. by virtue of the temp. difference between the two systems".

That is:

- heat is transferred from the system of higher temp. to the system at lower temp.
- heat transfer occurs solely bcz of the temperature diff. between the two systems.

Another aspect of this definition of heat is that a body never contains heat. Rather, heat can be identified only as it crosses the boundary. Thus heat is a transient phenomenon.

If we consider the hot block of copper as one system and the cold water in the beaker as another system, we recognize that originally neither system contains any heat (they do contain energy, of course).

When the copper block is placed in the water and the two are in thermal communication, heat is transferred from the copper to the water until equilibrium of temp is established.

At this point, we no longer have heat transfer, because there is no temp difference. Neither of the systems contains heat at the conclusion of the process.

*Convention*  
Heat transfer to a system is considered positive and heat transfer from a system is negative.  
Heat is a path function and is recognized as an exact differential.

A process during which there is no heat transfer is called an adiabatic process.

There are two ways a process can be adiabatic: either the system is well insulated so that only a negligible amount of heat can pass through the boundary or

both the system and the surrounding are at the same temp. and therefore there is no driving

for heat transfer.

Heat is transferred by three mechanisms:

- 1) Conduction: is the transfer of energy from the more energetic particles of a substance to the adjacent less energetic ones as a result of interaction between particles.
- 2) Convection: is the transfer of energy between a solid surface and the adjacent fluid that is in motion and it involves the combined effect of conduction and fluid motion.
- 3) Radiation: is the transfer of energy due to the emission of electromagnetic waves (as photons).

### Specific Heat

It is the amount of heat required to raise the temperature of unit mass of a substance to a unit degree of temperature difference.

If  $C_n = SP$  heat of the substance,  $dT = \Delta T$  rise in temp.  
 $Q =$  heat added to unit mass.

We have  $C_n = \lim_{\Delta T \rightarrow 0} \frac{\Delta Q}{\Delta T} = \frac{Q}{dT}$

$$Q = C_n dT$$

$$\text{or } Q = m C_n dT$$

4 36  
22 39  
37 54

Thus  $C_v$  is the sp. heat when heat is transferred to the system undergoing a general process or polytropic process.

$$\text{SP. heat } C_p = \left( \frac{\delta Q}{\delta T} \right)_P \text{ at constant pressure}$$

$$C_v = \left( \frac{\delta Q}{\delta T} \right)_V \text{ at constant volume}$$

### Energy Transfer by Work

Work is usually defined as a force  $F$  acting through a displacement  $x$ , the displacement being in the direction of the force. That is

$$W = \int F dx$$

This is a very useful relationship because it enables us to find the work required to raise a weight, to stretch a wire etc.

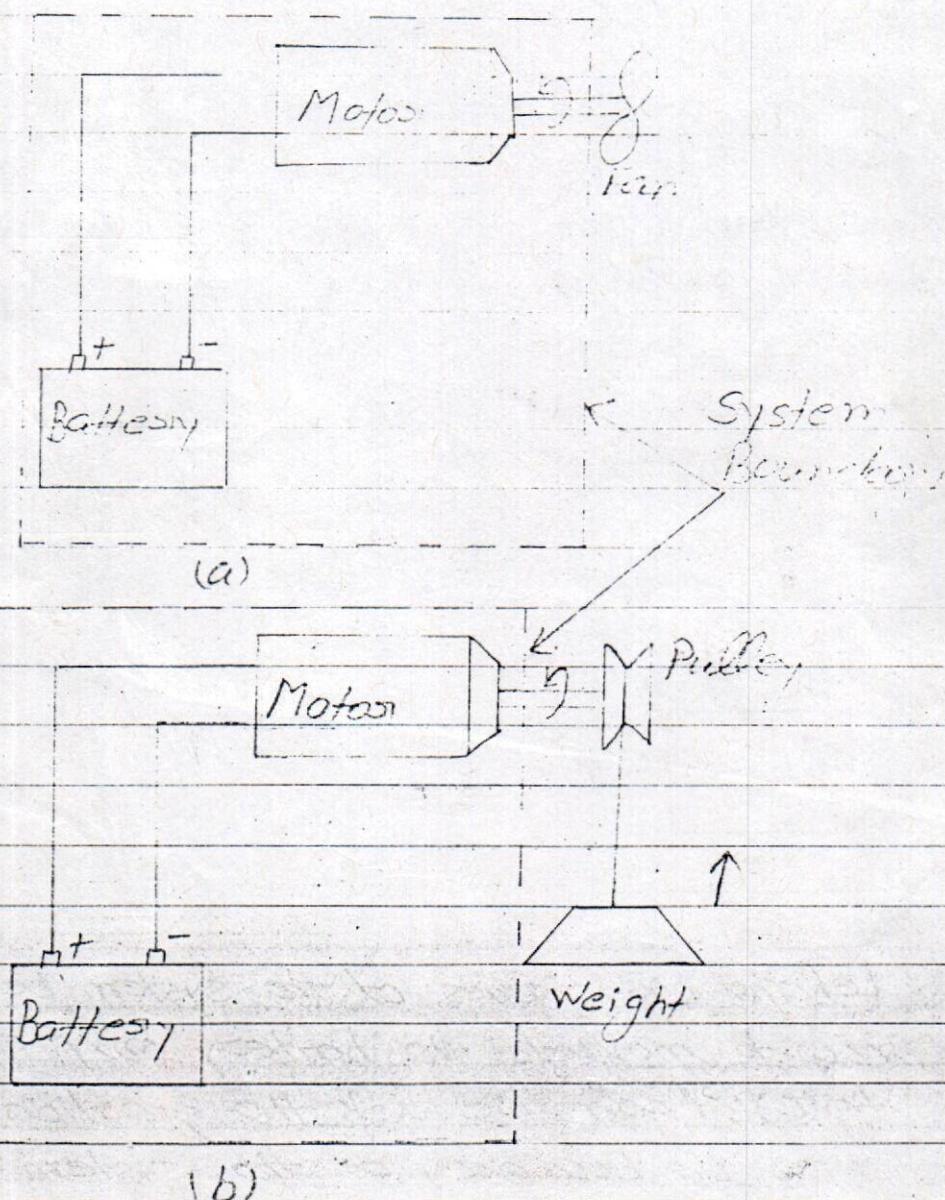
However when treating thermodynamics from a macroscopic point of view, it is advantageous to tie in the definition of work with the concepts of systems, properties and processes. We therefore define the work as follows:

"Work is done by a system if the sole effect of the surroundings (everything external to the system) could be the raising of a weight".

Notice that the raising of a weight is in effect

a force acting through a distance. Notice also that our definition does not state that a weight was actually raised.

Let us illustrate this definition of work with few examples.

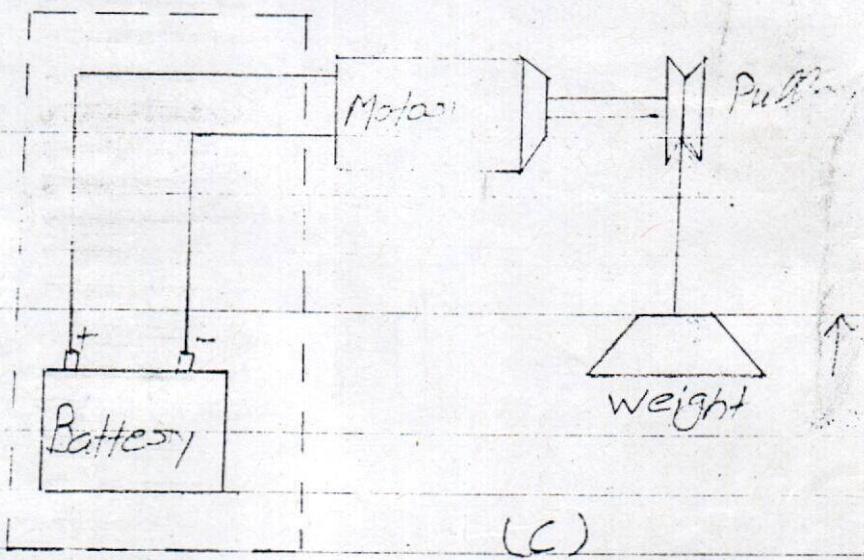


Consider as a system the battery and motor of fig (a) and let the motor drive a fan. Does work cross the boundary of the system?

To answer this question using the definition of work given earlier, replace the fan with the pulley and weight arrangement shown in fig (b).

As the motor turns, the weight is raised, and the sole effect external to the system is the raising of a weight.

Thus for our original system of fig (a), we conclude that work is crossing the boundary of the system since the sole effect external to the system could be the raising of a weight.



Let the boundaries of the system be changed now to include the battery only as shown in fig (c). Again we ask the question does work cross the boundary of the system?

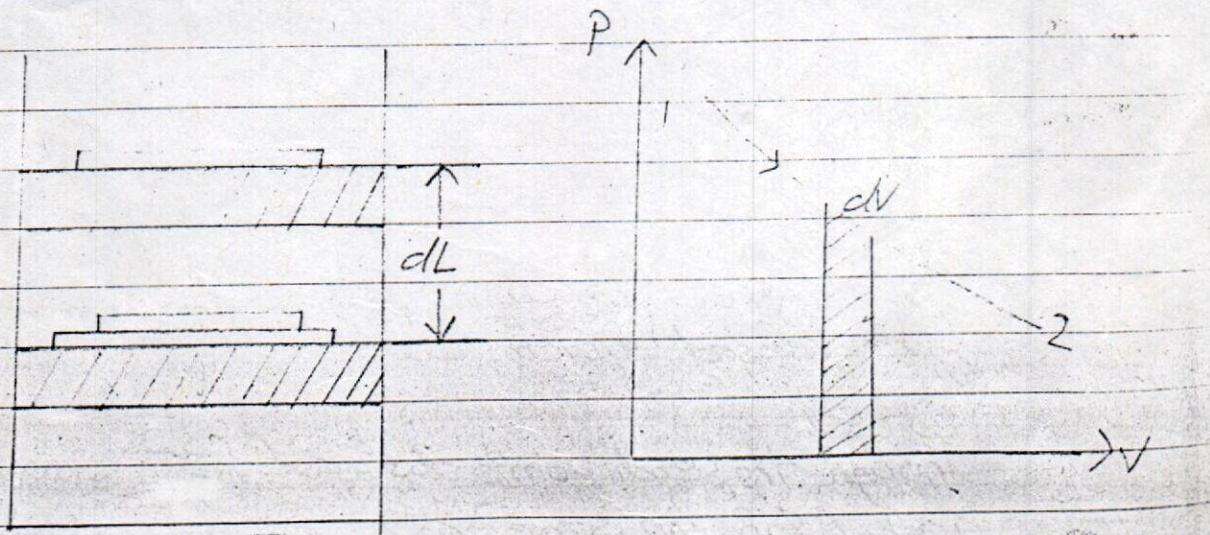
To answer this question, we need to ask a more general question. Does the flow of electrical energy across the boundary of a system constitute work?

The only limiting factor in having the sole external effect be the raising of a weight is the inefficiency of the motor.

However as we design a more efficient motor, with lower bearing and electrical losses, we recognize that we can approach a certain limit that meets the requirement of having the only external effect be the raising of a weight.

Therefore we can conclude that when there is a flow of electricity across the boundary of a system, as in fig (C).

Work done of the moving boundary of a system in a quasi-equilibrium process / Displacement work



Consider as a system the gas contained in a cylinder and piston as shown in fig. Let one of the small weights be removed from the piston, which will cause the piston to move upward a distance  $dL$ .

We can consider this quasi-equilibrium process. During the process system passed through the states shown by the line connecting states 1 and 2 on the P-V diagram.

The assumption of quasi-equilibrium is essential here because each point on the line 1-2 represents a definite state and those states will correspond to the actual state of the system only if the deviation from equilibrium is infinitesimal.

Total force on the piston =  $P \cdot A$   
where  $P$  is the pressure of the gas and  $A$  is the area of the piston.

Therefore the work  $SW = P \cdot A \cdot dL = PdV$  — (1)

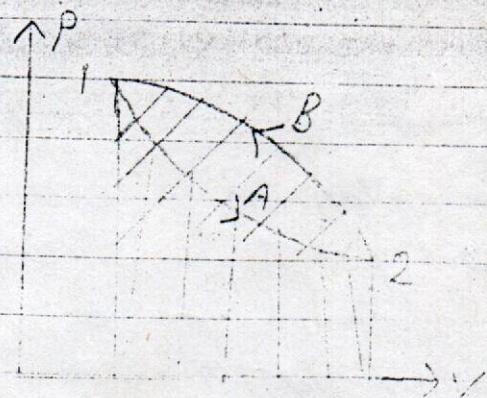
The work done at the moving boundary during a given quasi-equilibrium process can be found by integrating eqn. (1)

$$W_{1-2} = \int_1^2 PdV$$

Area under the curve projected on volume axis gives closed system work.

Though the end points for both A & B are same, as areas under them are diff., work transfer is also diff.

Hence work transfer is a path function and it is



not a property. Hence work transfer is an ~~inextensible~~  
differentiable.

Conditions for applying the eqn  $W = \int_1^2 P dV$

- The system must be a closed system.
- Work should cross the boundary.
- The process is reversible process.

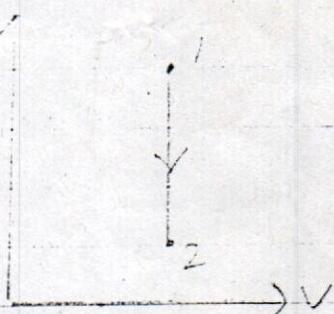
Work transfer for various processes in a closed system

a) Constant Volume Process:

$$W = \int_1^2 P dV$$

as  $V = \text{const}$ ,  $dV = 0$

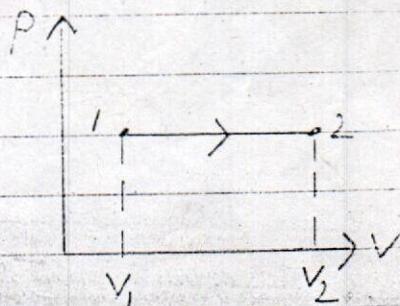
Hence  $\boxed{W=0}$



b) Constant Pressure Process:

$$W = \int_1^2 P dV = P \int_1^2 dV$$

$\boxed{W = P(V_2 - V_1)}$



c) Isothermal Process:

For ideal gas  $PV = mRT$

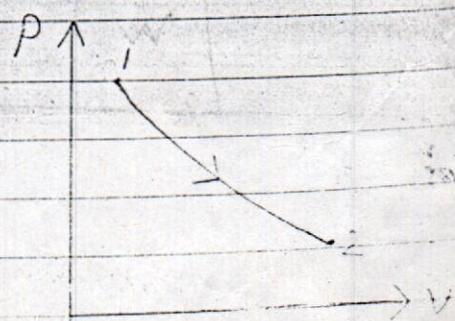
$m = \text{const}$ ,  $R = \text{const}$ ,  $T = \text{const}$ .

$PV = \text{constant}$

$$P_1 V_1 = P_2 V_2 = \text{constant}$$

As  $PV = C$

$$P = \frac{C}{V}$$



$$W = \int_1^2 P dV = \int_1^2 C/V dV$$

$$W = \cancel{C} [CnV]^2 = C [nV_2 - \cancel{nV_1}]$$

$$\boxed{W = P_1 V_1 \ln \frac{V_2}{V_1} = mRT \ln \frac{V_2}{V_1}}$$

as  $P_1 V_1 = P_2 V_2 \Rightarrow \frac{V_2}{V_1} = \frac{P_1}{P_2}$

$$\boxed{W = P_1 V_1 \ln \frac{P_1}{P_2} = mRT \ln \frac{P_1}{P_2}}$$

#### c) Adiabatic Process

For a reversible adiabatic

$$process PV^\gamma = C$$

where  $\gamma$  = adiabatic index

$$PV^\gamma = C \Rightarrow P = \frac{C}{V^\gamma} = CV^{-\gamma}$$

$$W = \int_1^2 P dV = \int_1^2 CV^{-\gamma} dV$$

$$= C \left[ \frac{V^{-\gamma+1}}{-\gamma+1} \right]_{V_1}^{V_2} = \frac{1}{-\gamma+1} \left[ C V_2^{-\gamma+1} - C V_1^{-\gamma+1} \right]$$

$$= \frac{1}{-\gamma+1} \left[ \frac{P_2 V_2^\gamma \cdot V_2}{V_2^\gamma} - \frac{P_1 V_1^\gamma \cdot V_1}{V_1^\gamma} \right]$$

$$= \frac{1}{-\gamma+1} \left[ P_2 V_2 - P_1 V_1 \right]$$

$$\boxed{W = \frac{P_1 V_1 - P_2 V_2}{\gamma-1}}$$

c) Polytropic Process: In polytropic process there are both heat and work transfer.  $PV^n = C$

$$W = \frac{P_1 V_1 - P_2 V_2}{n-1}, n = \text{Polytropic index}$$

on energy which enters the system as work  
leaves heat

41 m

steady flow means that the rates of flow of mass and energy across the  
control surface are constant

First Law of Thermodynamics

We are familiar with the conservation of energy principle, which is an expression of the first law of thermodynamics, back from our high school.

We are told repeatedly that energy can not be created or destroyed during a process; it only changes from one form to another. It's simple enough, but let's test ourselves to see if we understand and truly believe this principle.

Consider a room whose door and windows are tightly closed and whose walls are well insulated so that heat loss or gain through the walls are negligible.

Now let's place a refrigerator in the middle of the room with its door open and plug it into a wall outlet. You may even use a small fan to circulate the air in order to maintain temp. uniformity in the room.

Now what do you think will happen to the avg. temp. of air in the room? Will it be increasing or decreasing? or will it remain constant?

Probably the first thought that comes to mind is that the avg. air temp in the room will decrease as the warmer room air mixes with the air in the refrigerator.

Some may draw our attention to the heat generated by the motor of the refrigerator, and may argue that the avg. air temp. may rise if this heating effect is greater than the cooling effect.

But they will get confused if it is stated that the motor is made of superconducting materials, and thus there is ~~no~~<sup>very</sup> heat generation in the motor.

Heated discussions may continue until we sight until we remember the conservation of energy principle that we take for granted.

If we take the entire room including the air and the refrigerator as the system, which is an adiabatic closed system since the room is well sealed and well insulated, the only energy interaction involved is the electrical energy crossing the system boundary and entering the room.

The conservation of energy requires the energy content of the room to increase by an amount equal to the amount of the electrical energy drawn by the refrigerator. The refrigerator as motor does not store this energy.

Therefore this energy must now be in the room air and the conduction makes it will manifest itself as a rise in the air temperature. The

The temp. rise of air can be calculated on the basis of the conservation of energy principle using the properties of air and the amount of electrical energy consumed.

If energy is already conserved, then what are all those speeches on energy conservation and the measures taken to conserve energy?

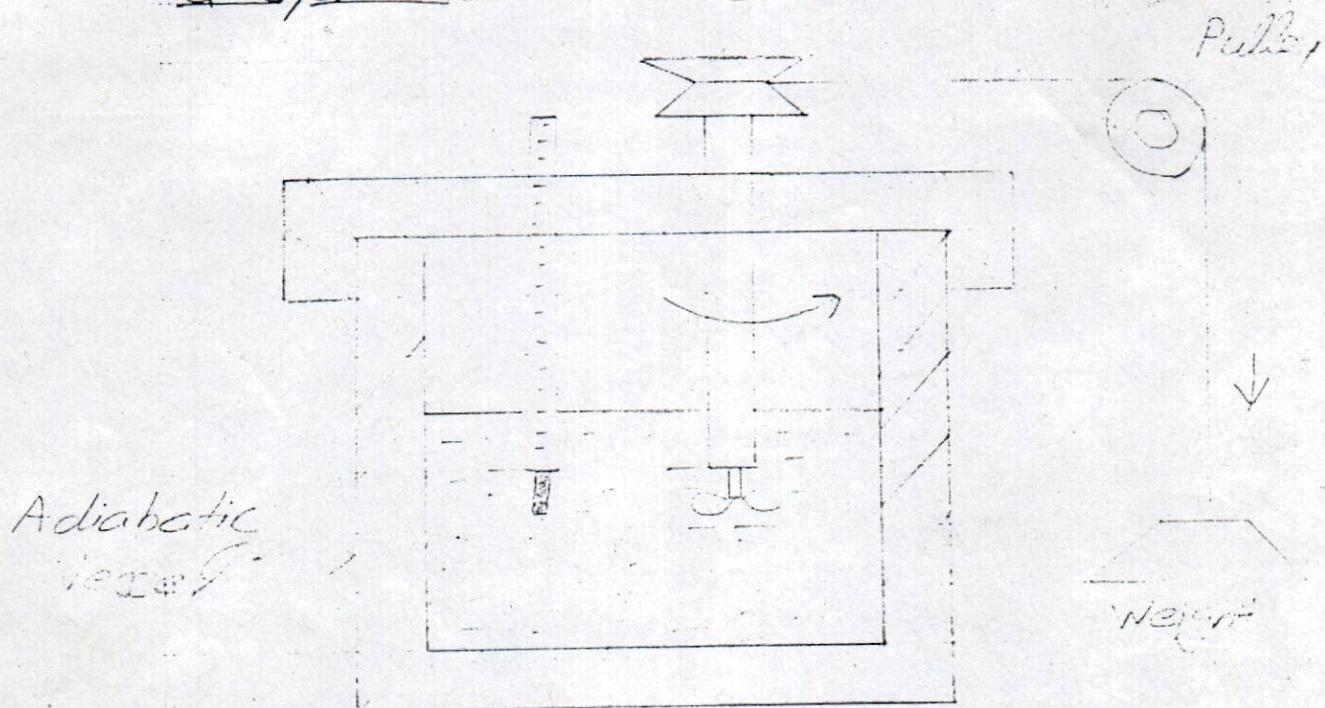
Actually, by energy conservation what is meant is the conservation of the quality of energy, not the quantity.

Electricity, which is of the highest quality of energy for example, can always be converted to an equal amount of thermal energy. But only a small fraction of thermal energy, which is the lowest quality of energy, can be converted back to electricity.

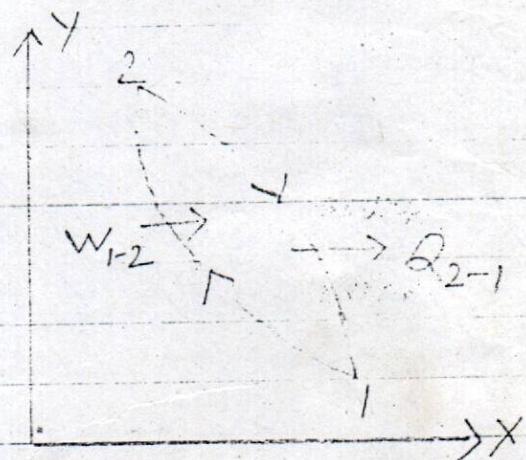
We all know that a rock at some elevation possesses some potential energy and part of this potential energy is converted to kinetic energy as the rock falls.

Experimental data show that decrease in potential energy is converted to kinetic energy as the rock falls exactly equals the increase in kinetic energy when the air resistance is negligible, thus confirming the conservation of energy principle.

## First law for a closed system undergoing a cycle



Energy which enters the system as heat may leave the system as work or energy which enters the system as work may leave as heat.



Let us consider a closed system which consists of a known mass of water contained in an adiabatic vessel having a thermometer and a paddle wheel as shown in fig.

Let a certain amount of work  $W_{1-2}$  be done upon the system by the paddle wheel. The quantity of work can be measured by the fall of the weight which drives the paddle-

wheel through a pulley.

The system was initially at temp  $T_1$ , same as that of atmosphere and after work transfer let the temp rise to  $T_2$ . The process is always 1 atm. The process 1-2 undergone by the system is shown in fig (b) in generalized thermodynamic coordinates  $X, Y$ .

Let the insulation now be removed. The system and the surroundings interact by heat transfer till the system returns to the original temp.  $T_1$ , attaining the condition of thermal equilibrium with the atmosphere. The amount of heat transfer  $Q_{21}$  from the system during the process 2-1, shown in fig. can be estimated.

The system thus executes a cycle, which consists of a definite amount of work input  $W_{1-2}$  to the system followed by the transfer of an amount of heat  $Q_{21}$  from the system.

It has been found that  $W_{1-2}$  is always proportional to the heat  $Q_{21}$ , and the constant of proportionality is called the joules equivalent or mechanical equivalent of heat.

$$\text{Algebraically: } (\sum W)_{\text{cycle}} = J(\sum Q)_{\text{cycle}}$$

In the S.I. system of units, both heat and work are measured in the derived unit of energy, the Joule. The constant of proportionality  $J$  is the above unity ( $J = 1 \text{ Nm}/\text{J}$ ).

Hence for a closed system undergoing a cycle net heat transfer is equal to zero and work transfer i.e.

$$\sum Q = \sum W$$

$$\sum (Q-W) = 0$$

### Consequences of 1st Law of thermodynamics

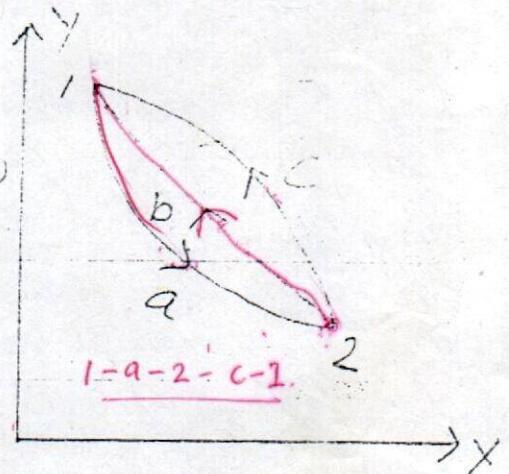
I<sup>st</sup> Heat transfer is a path function

For cycle 1-a-2-b-1

$$\delta Q_{1-a_2} + \delta Q_{2-b_1} \\ = \delta W_{1-a_2} + \delta W_{2-b_1} \quad (1)$$

For cycle 1-a-2-C-1

$$\delta Q_{1-a_2} + \delta Q_{2-C_1} \\ = \delta W_{1-a_2} + \delta W_{2-C_1} \quad (2)$$



Subtract eqn(2) from eqn(1)

$$\delta Q_{2-b_1} - \delta Q_{2-C_1} = \delta W_{2-b_1} - \delta W_{2-C_1} \quad (3)$$

As we already know work transfer is a path function, hence  $\delta W_{2-b_1} \neq \delta W_{2-C_1}$

$$\delta W_{2-b_1} - \delta W_{2-C_1} \neq 0$$

Then  $\delta Q_{2-b_1} - \delta Q_{2-C_1} \neq 0$

$$\delta Q_{2-b_1} \neq \delta Q_{2-C_1}$$

Though the end points for path b and c are same, heat transfer for path b and c are not same.

Hence heat transfer is a path function.

## II Energy is a property

From eqn(3):  $\delta Q_{2-b-1} - \delta Q_{2-c-1} = \delta W_{2-b-1} - \delta W_{2-c-1}$

$$\delta Q_{2-b-1} - \delta W_{2-b-1} = \delta Q_{2-c-1} - \delta W_{2-c-1}$$

$$[\delta Q - \delta W]_{2-b-1} = [\delta Q - \delta W]_{2-c-1} = dE$$

$$\delta Q - \delta W = dE \quad \Rightarrow \quad \boxed{\delta Q = dE + \delta W} \quad (4)$$

eqn(4) is valid for

Though the paths b and c are different, the quantity  $[\delta Q - \delta W]$  is same for both the paths as the end points are same. Hence  $[\delta Q - \delta W]$  must be a property.

Now Energy  $E = K.E. + P.E + I.E(U)$

$$dE = d(K.E.) + d(P.E) + dU$$

For a closed system kinetic and potential energy changes are negligible.

Hence  $dE = dU$

$$\text{so } \boxed{\delta Q = dU + \delta W} \quad (5)$$

## III Energy of an isolated system is always constant

From eqn(4):  $\delta Q = dE + \delta W$

for an isolated system, there is no heat  $\rightarrow$  and work transfer. So  $\delta Q = 0$  and  $\delta W = 0$

$$0 = dE + 0$$

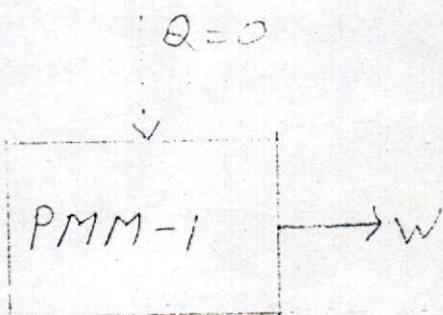
$$dE = 0 \Rightarrow E_2 - E_1 = 0$$

$$\boxed{E_2 = E_1 = E}$$

#### IV Perpetual motion machine of first kind (PMM) is impossible

There can be no machine which produce work continuously without absorbing some other form of energy.

PMM-1 is impossible because it violates 1<sup>st</sup> law of thermodynamics.



#### Ideal gas eqn for various processes

##### Constant Volume Process

$$PV = mRT \Rightarrow \text{As } V = \text{const} \quad \cancel{m \text{ and } R \text{ are also const}}$$

$m$  and  $R$  are also const.

$$P \propto T \Rightarrow \boxed{\frac{P_1}{T_1} = \frac{P_2}{T_2}}$$

##### Constant Pressure Process

As  $P = \text{const}$ ,  $m \& R$  are also const

$$V \propto T$$

$$\boxed{\frac{V_1}{T_1} = \frac{V_2}{T_2}}$$

## Isothermal Process

$T, m$  and  $R$  are const.

$$PV = C \Rightarrow P_1 V_1 = P_2 V_2$$

## Adiabatic Process

$$PV^\gamma = C \text{ and } PV = nRT \Rightarrow P = nRT/V$$

$$\text{so } \frac{mRT}{V} V^\gamma = C \Rightarrow TV^{\gamma-1} = \text{const.}$$

$$\left[ T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1} \right]$$

$$\frac{mRT}{V} \cdot V^{\gamma-1} = \text{const}$$

$$TV^{\gamma-1} = \text{const}$$

$$T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$$

$$\text{Also } \left[ P_1 V_1^\gamma = P_2 V_2^\gamma \right]$$

$$\frac{P_2}{P_1} = \left( \frac{V_1}{V_2} \right)^\gamma \Rightarrow \frac{V_1}{V_2} = \left( \frac{P_2}{P_1} \right)^{1/\gamma} \quad \frac{T_2}{T_1} = \left( \frac{V_1}{V_2} \right)$$

$$\left( \frac{T_2}{T_1} \right)^{1/\gamma-1} = \left( \frac{P_2}{P_1} \right)^{1/\gamma} \Rightarrow \left[ \frac{T_2}{T_1} = \left( \frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} \right]$$

## Polytropic Process

$$PV^n = C$$

$$\left[ T_1 V_1^{n-1} = T_2 V_2^{n-1} \right]$$

$$\left[ P_1 V_1^n = P_2 V_2^n \right]$$

$$\left[ \frac{T_2}{T_1} = \left( \frac{P_2}{P_1} \right)^{\frac{n-1}{n}} \right]$$

## Enthalpy (H)

Enthalpy is a property and is defined as the sum of the internal energy (U) and the product of Pressure Volume (PV)

$$H = U + PV$$

It is an extensive property.

## Heat transfer for various non-flow processes

### 1) Constant Volume Process

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

For a closed system, const. vol. reversible process  $\delta W = PdV = 0$

Hence  $\boxed{\delta Q_v = dU}$

Also we know that for const. vol. process

$$\delta Q_v = mC_v dT$$

so  $\boxed{dU = mC_v dT}$

This eqn is valid for any process.

### 2) Constant Pressure Process

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

As Pressure is constant

$$\delta Q_p = dU + d(PV) = d(U + PV) = dH$$

$$\boxed{\delta Q_p = dH}$$

Also  $\delta U = mC_v dT$

so  $\boxed{dH = mC_p dT}$

This eqn is valid for any process.

Note: The quantities  $U$ ,  $H$  and  $T$  are all properties of the system and thus are the function of the thermodynamic state of the system, not the manner in which we get there.

So the expression  $dU = mc_v dT$  and  $dH = mc_p dT$  are valid at any point in any ideal gas process as long as it is possible to define the state of the system.

### Isothermal Process

As we know that  $dU = mc_v dT$  and  $c_v$  are constants, so  $dU \propto dT$  or  $U \propto T$ , That means

Also  $dH = mc_p dT$ . similarly  $H \propto T$   
Hence The internal energy and Enthalpy of an ideal gas are function of temp. only.

For isothermal Process  $\cancel{T = \text{const.}} \Rightarrow dT = 0$   
so  $dU = 0$

$$dQ = dU + \delta W \Rightarrow dQ = \delta W$$

### Adiabatic Process

In an adiabatic process there is no heat transfer from the system or into the system.

$$\boxed{dQ = 0}$$

5) Polytropic Process

$$\delta Q = dU + \delta W = mC_V dT + \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$$

We know  $C_P - C_V = R \Rightarrow \gamma C_V = C_P + R$

$$C_V = \frac{R}{\gamma - 1}$$

$$\begin{aligned} \delta Q &= \frac{mR(T_2 - T_1)}{\gamma - 1} + \frac{P_1 V_1 - P_2 V_2}{\gamma - 1} \\ &= \frac{1}{\gamma - 1} (mRT_2 - mRT_1) + \frac{P_1 V_1 - P_2 V_2}{\gamma - 1} \\ &= \frac{1}{\gamma - 1} (P_2 V_2 - P_1 V_1) + \frac{P_1 V_1 - P_2 V_2}{\gamma - 1} \\ &= (P_1 V_1 - P_2 V_2) \left[ \frac{1}{\gamma - 1} - \frac{1}{\gamma - 1} \right]^{\gamma - 1} \\ &= P_1 V_1 - P_2 V_2 \times \frac{\gamma - n}{(n-1)(\gamma - 1)} \end{aligned}$$

$$\boxed{\delta Q = P \left( \frac{\gamma - n}{\gamma - 1} \right) \times \frac{P_1 V_1 - P_2 V_2}{n-1} = \frac{\gamma - n}{\gamma - 1} \times W_{P_1, V_1}}$$

To Prove that  $C_P - C_V = R$  for an ideal gas

$$H = U + PV \Rightarrow dH = dU + d(PV) = dU + d(mRT)$$

$$dH = dU + mRdT$$

$$mC_P dT = mC_V dT + mRdT$$

$$C_P = C_V + R$$

$$\boxed{C_P - C_V = R}$$

For air,  $C_P = 1.005 \text{ kJ/kg-K}$

$$C_V = 0.718 \text{ kJ/kg-K}$$

$$R = 0.287 \text{ kJ/kg-K}, \quad \gamma = 1.4$$

To show that for an adiabatic process  $PV^\gamma = C$

$$\delta Q = dU + \delta W \Rightarrow \delta Q = dU + PdV \quad (1)$$

$$H = U + PV \Rightarrow dH = dU + d(PV) = dU + PdV + VdP$$

$$dH = \delta Q + VdP \quad (2)$$

For an adiabatic process:  $\delta Q = 0$

$$dH = VdP \quad (3)$$

$$\text{Also from eqn (1)} \quad dU = -VdP \quad (4)$$

Divide eqn (3) by eqn (4)

$$\frac{dH}{dU} = -\frac{VdP}{PdV} \Rightarrow \frac{mc_pdT}{mc_vdT} = -\frac{VdP}{PdV}$$

$$\gamma = -\frac{VdP}{PdV} \Rightarrow \gamma \frac{dV}{V} + \frac{dP}{P} = 0$$

$$\gamma \ln V + \ln P = \ln C$$

$$\ln PV^\gamma = \ln C$$

$$\boxed{PV^\gamma = C}$$

$$\delta Q = dU + PdV$$

$$dU = -PdV \quad (1)$$

$$dH = dU + PdV + VdP$$

$$dH = \delta Q + VdP$$

$$dH = VdP \quad (2)$$

$$\frac{dH}{dU} = -\frac{VdP}{PdV}$$

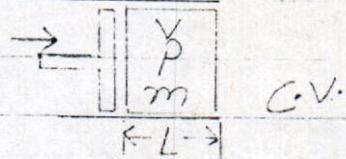
$$\frac{mc_pdT}{mc_vdT} = -\frac{VdP}{PdV}$$

$$\gamma = -\frac{VdP}{PdV} \quad \gamma \frac{dV}{V} + \frac{dP}{P} = 0$$

## Flow Work

The amount of work involved in causing the fluid element either to enter or leave the control volume is known as flow work.

Consider a fluid element of volume  $V$ , as shown in figure.



If the fluid pressure is  $p$  and the cross-sectional area of the fluid element is  $A$ , the force applied on the fluid element by the imaginary piston

$$F = P \times A$$

To push the entire fluid element into the control volume, the force must act through a distance  $L$ ; then

$$\frac{W_{flow}}{m} = F \times L = P \times A \times L$$

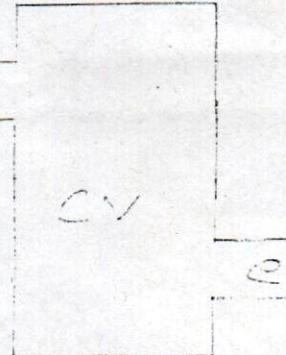
$$[W_{flow} = P V] \quad \frac{P}{P V} = P^2$$

$$\frac{dV}{m^3} = \rho \frac{dm}{kg}$$

$$\frac{m^3}{kg} \times$$

### Conservation of Mass

Let  $i$  and  $e$  be the state at the inlet and exit of the control volume.



$$m_i - m_e = \dot{m}_{cv}$$

$$\frac{dm_i}{dt} - \frac{dm_e}{dt} = \left(\frac{dm}{dt}\right)_{cv}$$

$$\boxed{\dot{m}_i - \dot{m}_e = \dot{m}_{cv}}$$

As there is no mass accumulation

$$\left(\frac{dm}{dt}\right)_{cv} = 0$$

$$\boxed{\dot{m}_i = \dot{m}_e}$$

$$\text{Mass flow rate } \dot{m} = \rho A C = \frac{AC}{v}$$

where  $v = \text{sp. volume}$ .

$$\boxed{\frac{A_1 C_1}{v_1} = \frac{A_2 C_2}{v_2}}$$

$$\frac{kg}{m^3} \times \frac{m^2}{s} \times \frac{m}{s}$$

$$\frac{m^2}{s} \times \frac{kg \times 10}{ms}$$

$$kg/s$$

## Conservation of Energy

$$\text{Energy at Inlet} = K.E. + P.E. + I.E + F.W. + \text{heat}$$

$$\left\{ \begin{aligned} &= \frac{1}{2} m_i c_i^2 + m_i g z_i + U_i + P_i V_i + Q \\ &= \frac{1}{2} m_i c_i^2 + m_i h_i + m_i g z_i + Q \end{aligned} \right.$$

$$\text{similarly Energy at outlet} = \frac{1}{2} m_e c_e^2 + m_e h_e + m_e g z_e + W_{cv}$$

$$\Delta E_{cv} = \text{Energy at inlet} - \text{Energy at outlet}$$

$$\left( \frac{dE}{dt} \right)_{cv} = \frac{d}{dt} \left[ m_i h_i + \frac{1}{2} m_i c_i^2 + m_i g z_i + Q \right] - \frac{d}{dt} \left[ m_e h_e + \frac{1}{2} m_e c_e^2 + m_e g z_e + W_{cv} \right]$$

for steady flow,  $m_i = m_e = m$

As there is no energy accumulation in the CV.

$\left( \frac{dE}{dt} \right)_{cv} = 0$ , and neglecting K.E. and P.E. changes

$$m_i h_i + Q = m_e h_e + W_{cv}$$

Note: It is assumed that  $h_i$  and  $h_e$  are not vary with time.

$$\frac{d}{dt} \left( \frac{m_i}{dm} \right) h_i + \frac{1}{2} m_i c_i^2 + m_i g z_i + Q = m_e h_e + \frac{1}{2} m_e c_e^2 + m_e g z_e$$

$$h_i + \frac{1}{2} m_i c_i^2 + g z_i + Q = + W_{cv}$$

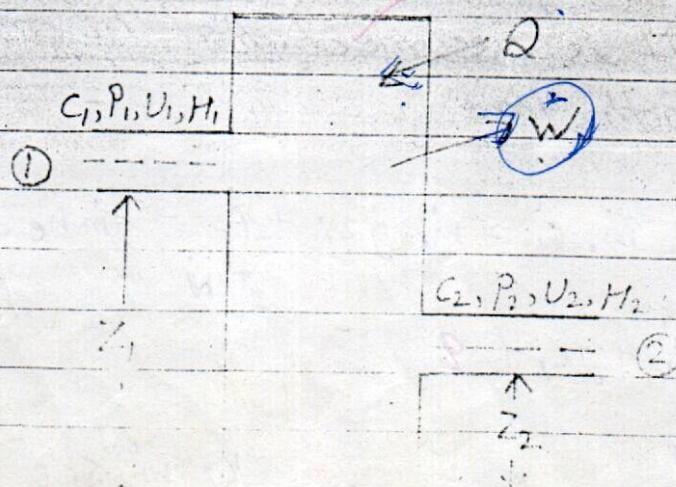
$$\frac{\text{kg}}{\text{kg}} \downarrow \quad \frac{\text{m/s}}{\text{scc}} \quad = \quad \frac{\text{kg m}^2 \text{scc}^{-2}}{\text{scc}} = \text{N.m}$$

## Steady Flow Energy Equation

The term steady implies no change with time. Steady flow process is defined as a process during which the fluid properties can change from point to point within the control volume, but at any fixed point, they remain the same during the entire process.

### Assumptions

- 1) The mass flow through the system remains const.
- 2) Fluid is uniform in composition.
- 3) The only interaction between system and surrounding are work and heat.
- 4) The state of fluid at any point remain constant with time.
- 5) In the ~~out~~ analysis, only potential, kinetic and flow energies are considered.



At state 1 and 2:

$c_1, c_2$  = Velocities of fluid at inlet and outlet

$P_1, P_2$  = Pressure " " " "

$U_1, U_2$  = Internal energy " " "

$H_1, H_2$  = Enthalpy " " "

$Z_1, Z_2$  = Height above the datum at inlet and outlet.

We know that  $\delta Q = \delta E + \delta W$

$$Q = \Delta E + W \quad (1)$$

Now total energy  $E = K.E. + P.E. - I.E.$

$$\Delta E = \Delta(K.E.) + \Delta(P.E.) + \Delta(I.E.)$$

$$= \frac{1}{2} m(c_2^2 - c_1^2) + mg(Z_2 - Z_1) + (U_2 - U_1) \quad (2)$$

Also  $W$  = Entropy displacement work + control volume work + Exit displacement work.

$$W = -P_1 V_1 + W_{cv} + P_2 V_2 \quad (3)$$

From eqn (1), (2) and (3)

$$Q = \frac{1}{2} m c_2^2 - \frac{1}{2} m c_1^2 + mg Z_2 - mg Z_1 + U_2 - U_1 - P_1 V_1 + W_{cv} + P_2 V_2$$

$$(U_1 + P_1 V_1) + \frac{1}{2} m c_1^2 + mg Z_1 + Q = (U_2 + P_2 V_2) + \frac{1}{2} m c_2^2 + mg Z_2 + W_{cv}$$

$$H_1 + \frac{1}{2} m c_1^2 + mg Z_1 + Q = H_2 + \frac{1}{2} m c_2^2 + mg Z_2 + W_{cv}$$

$$h_1 + \frac{c_1^2}{2} + g Z_1 + \dot{q} = h_2 + \frac{c_2^2}{2} + g Z_2 + W_{cv}$$

KJ/kg

$$\dot{m} \left[ h_1 + \frac{c_1^2}{2} + g Z_1 \right] + \dot{q} = \dot{m} \left[ h_2 + \frac{c_2^2}{2} + g Z_2 \right] + \dot{W}_{cv}$$

$$\frac{c_1^2}{2} = \frac{m \times m}{2 \text{ sec}^2} \times \frac{\text{kg}}{\text{kg}} = \frac{N \cdot m}{\text{kg}} = \frac{\text{J}}{\text{kg} \times 1000}$$

# Steady Flow Engineering Devices

## 1) Nozzles and Diffusers

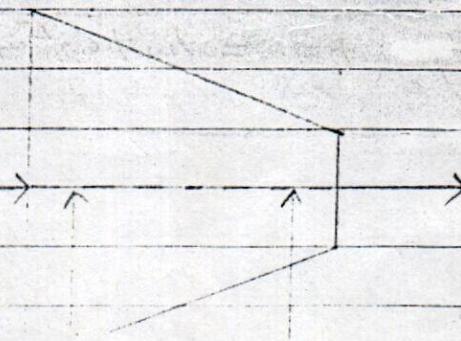
A nozzle is a device that increases the velocity of a fluid at the expense of ~~the~~ pressure.

A diffuser is a device that increases the pressure of a fluid by slowing it down.

The cross-sectional area of a nozzle decreases in the flow direction for subsonic flows and increases for super-sonic flow.

The rate of heat transfer between the fluid flowing through a nozzle or a diffuser and the surrounding is very small ( $Q \approx 0$ ) since the fluid has high velocities and thus it does not spend enough time in the device for any significant heat transfer to take place.

Nozzles and diffusers typically involve no work ( $W=0$ ) and change in potential energy is also negligible ( $\Delta PE \approx 0$ )



$$h_1 + \frac{c_1^2}{2} + g z_1 + g = h_2 + \frac{c_2^2}{2} + g z_2 + w_{cv}$$

applying above mention conditions  
 $g z_1 = g z_2$ ,  $g = 0$ ,  $w_{cv} = 0$

$$h_1 + \frac{c_1^2}{2} = h_2 + \frac{c_2^2}{2}$$

As  $c \ll c_2$ , for nozzle

$$h_1 = h_2 + \frac{c_2^2}{2}$$

## > Turbines and Compressors

In steam, gas or hydroelectric power plants, the device that drives the electric generator is the turbine.

Compressor is used to increase the pressure of a fluid. Work is supplied to this device from an external source through a rotating shaft.

Heat transfer from turbines is usually negligible ( $Q \approx 0$ ) since they are typically well insulated.

Heat transfer is also negligible for compressors unless there is intentional cooling.

Potential energy changes are negligible for all of those devices ( $\Delta PE \approx 0$ )

The velocities involved in those devices, with the exception of turbines are usually too low to

cause any significant change in its kinetic energy ( $\Delta KE \approx 0$ ).

The fluid velocity encountered in most turbines are very high and the fluid experiences a significant change in its kinetic energy. However this change is usually very small relative to the change in enthalpy and thus it is often disregarded.

$$h_1 + \frac{C_1^2}{2} + g z_1 + g = h_2 + \frac{C_2^2}{2} + g z_2 + w_{turb}$$

For turbine:  $z_1 = z_2$ ,  $g = 0$ ,  $\left(\frac{C_1^2 - C_2^2}{2}\right) \ll (h_1 - h_2)$

so  $h_1 + w_t = h_2 + w_t$

$$w_t = h_1 - h_2$$

For compressor:  $C_1 \approx C_2$ ,  $z_1 = z_2$ ,  $g = 0$

$$\text{so } h_1 = h_2 - w_c$$

$$w_c = h_2 - h_1$$

X

### 3) Throttling Valves

Throttling valves are any kind of flow-restricting devices that cause a significant pressure drop in the fluid. Some ex. are adjustable valves, capillary tubes and porous plug.

Unlike turbines, they produce a pressure drop without involving any work ( $w_{turb} = 0$ ).

The pressure drop in the fluid is often accompanied by a large drop in temperature

and for that reason throttling devices are commonly used in RAC application. The magnitude of temp. drop (or sometimes temp. rise) during a throttling process is governed by a property called the Joule - Thomson co-efficient.

Throttling valves are usually small devices, and the flow through them may be assumed to be adiabatic ( $Q \approx 0$ ) since there is neither sufficient time nor large enough area for any effective heat transfer to take place.

Also there is no work done ( $W_{cv} = 0$ ) and the change in potential energy, if any, is very small ( $\Delta PE \approx 0$ ).

Even though the exit velocity is often considerably higher than the inlet velocity, in many cases, the increase in kinetic energy is insignificant ( $\Delta KE \approx 0$ )

$$h_1 + \frac{c_1^2}{2} + g z_1 + g = h_2 + \frac{c_2^2}{2} + g z_2 + W_{cv}$$

Applying the above mentioned conditions

$$[h_1 \approx h_2]$$

$$u_1 + p_1 v_1 = u_2 + p_2 v_2$$

or Internal energy + Flow energy = constant.

Thus the final outcome of a throttling process depends on which of the two quantities increases

during the process.

If the flow energy increases during the process ( $P_2V_2 > P_1V_1$ ), it can do so at the expense of the internal energy. As a result internal energy decreases, which is usually accompanied by a drop in temp.

If the flow energy decreases ( $P_2V_2 < P_1V_1$ ), the internal energy and the temp of the fluid will increase during a throttling process.

In the case of an ideal gas  $h=f(T)$  and thus the temp has to remain constant during a throttling process.

#### 4) Heat Exchangers and Boilers

As the name implies, heat exchangers are devices where two moving fluid streams exchange heat without mixing.

Under steady operation, the mass flow rate of each fluid stream flowing through a heat exchanger remains constant.

Heat exchangers typically involve no work interactions ( $W_{cv}=0$ ) and negligible kinetic and potential energy changes ( $\Delta KE \approx 0, \Delta PE \approx 0$ ) for each fluid stream.

The heat transfer rate associated with heat exchangers depends on how the control volume is selected.

When the entire heat exchanger is selected as the control volume,  $\dot{Q}$  becomes zero, because no heat is crossing the boundary as the outer shell is usually well insulated to prevent any heat loss to the surrounding medium.

If however, only one of the fluid is selected as the control volume, then heat will cross this boundary ( $\dot{Q} \neq 0$ ).

Similarly in boiler, fuel is burnt and heat is generated, which is used to convert the water into steam. No work is supplied ( $W_{cv}=0$ ).

K.E and P.E. changes are also negligible.

$$\text{so } h_1 + \frac{C_1^2}{2} + g z_1 + g = h_2 + \frac{C_2^2}{2} + g z_2 + W_{cv}$$

applying above mention conditions

$$h_1 + g = h_2$$

$$[g = h_2 - h_1]$$

Q- A steam turbine operates under steady flow conditions. It receives 7200 kg/h of steam from the boiler. The steam enters the turbine at enthalpy of 2800 kJ/kg, a velocity of 4000 m/min and an elevation of 4m. The steam leaves the turbine at enthalpy of 2000 kJ/kg, a velocity of 8000 m/min and an elevation of 1m. Due to friction, heat losses from the turbine to surrounding amount to 1580 kJ/h. calculate the power output of the turbine.

Solution  $\dot{m} = 7200 \text{ kg/h} = 7200 / 3600 \text{ kg/sec} = 2 \text{ kg/sec}$   
 $h_1 = 2800 \text{ kJ/kg}$ ,  $c_1 = 4000 \text{ m/min} = 66.666 \text{ m/sec}$   
 $Z_1 = 4 \text{ m}$ ,  $h_2 = 2000 \text{ kJ/kg}$ ,  $c_2 = 8000 \text{ m/min} = 133.333 \text{ m/sec}$   
 $Z_2 = 1 \text{ m}$ ,  $\dot{q} = -1580 \text{ kJ/h} = 0.438 \text{ kW}$

According to SFEE

$$\dot{m} \left[ h_1 + \frac{c_1^2}{2000} + \frac{g z_1}{1000} \right] + \dot{q} = \dot{m} \left[ h_2 + \frac{c_2^2}{2000} + \frac{g z_2}{1000} \right] + \dot{W}$$

$$\begin{aligned} \dot{W} &= \dot{m} \left[ h_1 - h_2 + \frac{c_2^2 - c_1^2}{2000} + \frac{g(z_2 - z_1)}{1000} \right] + \dot{q} \\ &= 2 \left[ (2800 - 2000) + \frac{66.66^2 - 133.33^2}{2000} + \frac{9.81(4-1)}{1000} \right] - 0.438 \end{aligned}$$

$$\dot{W} = 1586.287 \text{ kW Ans}$$

Q- An axial flow compressor of a gas turbine plant receives air from atmosphere at a pressure 1 bar, temperature 300K and velocity 60 m/sec. At the discharge of compressor, the pressure is 5 bar and the velocity is 100 m/sec. The mass flow rate through the compressor is 20 kg/sec. Assuming adiabatic compression, calculate the power required to drive the compressor. Also calculate the inlet and outlet pipe diameters.

Given  $P_1 = 1 \text{ bar} = 10^5 \text{ Pa}$ ,  $T_1 = 300 \text{ K}$ ,  $C = 60 \text{ m/sec}$ ,  $P_2 = 5 \text{ bar} = 5 \times 10^5 \text{ Pa}$   
 $C_2 = 100 \text{ m/sec}$ ,  $\dot{m} = 20 \text{ kg/sec}$ ,  $Z_1 = Z_2$

As the compression is adiabatic  $\dot{Q} = 0$

$$\dot{m} \left[ \frac{h_1 + C_1^2}{2000} + \frac{g_2}{1000} \right] + \dot{Q} = \dot{m} \left[ \frac{h_2 + C_2^2}{2000} + \frac{g_2}{1000} \right] + \dot{W}$$

$$\dot{m} \left[ h_1 - h_2 + \frac{C_1^2 - C_2^2}{2000} \right] = \dot{W} \Rightarrow \dot{W} = \left[ C_p(T_2 - T_1) + \frac{C_1^2 - C_2^2}{2000} \right] \dot{m}$$

For adiabatic compression process

$$T_2 = T_1 \left( \frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} = 300 \left( \frac{5}{1} \right)^{\frac{0.4}{1.4}} = 475.145 \text{ K}$$

$$\text{so } \dot{W} = 20 \left[ 1.005 (300 - 475.145) + \frac{60^2 - 100^2}{2000} \right] = -3584.9 \text{ kW Ans}$$

Now mass flow rate  $\dot{m} = \rho_1 A_1 C_1 = \rho_2 A_2 C_2$

As we know  $PV = mRT \Rightarrow \frac{P}{RT} = \frac{m}{V} = \rho$

$$\text{so } \dot{m} = \frac{P_1 A_1 C_1}{RT_1}$$

$$20 = \frac{1 \times 10^5 \times A_1 \times 60}{287 \times 300} \Rightarrow A_1 = 0.287 \text{ m}^2$$

$$\frac{\pi D_1^2}{4} = 0.287 \Rightarrow D_1 = 0.604 \text{ m Ans}$$