

QUESTIONS AND SOLUTIONS**UNIT-1****INTRODUCTION**

- 1. What do you mean by thermodynamic equilibrium? How does it differ from thermal equilibrium? [05 Marks, June-2020]**

Equilibrium state:

A system is said to be in thermodynamic equilibrium if it satisfies the condition for thermal equilibrium, mechanical equilibrium and also chemical equilibrium. If it is in equilibrium, there are no changes occurring or there is no process taking place.

Thermal equilibrium:

There should not be any temperature difference between different regions or locations within the system. If there are, then there is no way a process of heat transfer does not take place. Uniformity of temperature throughout the system is the requirement for a system to be in thermal equilibrium.

- 2. State Zeroth law of thermodynamics? Write its importance in thermodynamics.**

[04 Marks, June-2019]

Zeroth law of thermodynamics" states that if two systems are each equal in temperature to a third, they are equal in temperature to each other.

It helps to measure temperature.

- 3. Consider a particular Celsius scale assigned the value of 0°C to steam point and 100°C to ice point.**

- i) Using ideal gas as the thermometer medium, setup a relationship between 0°C and pressure for a constant volume thermometer, proceed to derive the correction between the two Celsius scales. At what temperatures are the two scales are numerically equal?**
- ii) What is the numerical value of absolute zero for the particular scale? What is 200K in $^{\circ}\text{C}$? [07 Marks, June-2019]**

Let $T^{\circ}\text{C} = a + Pb$ be the Celsius scale

Then $0 = a + P_s b$ and $100 = a + P_i b$

On solving $b = 100 / (P_i - P_s)$

- 4. Two Celsius thermometers A and B with temperature readings T_A and T_B agree at ice point and steam point, but else where they are related by $T_A = p + qT_B + rT_B^2$, where p, q and r are constants. When the thermometers are immersed in an oil bath, A shows a temperature of 51°C , while B shows 50°C . Determine the temperature T_A , when T_B is 25°C . [04 Marks, June-2018]**

Solution. $t = a \ln p + b$
 ...(Given) On Celsius scale

:

Ice point = 0°C ,
 and Steam point
 = 100°C

From given conditions, we
 have $0 = a \ln 1.5 + b$... (i)

and $100 = a \ln 7.5 + b$
 ... (ii) i.e., $0 = a \times 0.4054 +$

b ... (iii) and $100 = a \times$
 $2.015 + b$... (iv)

Subtracting (iii) from (iv),
 we get $100 = 1.61a$

$$\begin{aligned} & 5. \\ & \text{or } a = 62.112 \end{aligned}$$

Substituting this value in eqn. (iii),
 we get $b = -0.4054 \times 62.112 = -$
 25.18

- 6. Explain what you mean by thermodynamic equilibrium.**

[06 Marks, Jan-2020]

Equilibrium state:

A system is said to be in thermodynamic equilibrium if it satisfies the condition for thermal equilibrium, mechanical equilibrium and also chemical equilibrium. If it is in equilibrium, there are no changes occurring or there is no process taking place.

Thermal equilibrium:

There should not be any temperature difference between different regions or locations within the system. If there are, then there is no way a process of heat transfer does not take place. Uniformity of temperature throughout the system is the requirement for a system to be in thermal

equilibrium.

Surroundings and the system may be at different temperatures and still system may be in thermal equilibrium.

Mechanical equilibrium:

There should not be any pressure difference between different regions or locations within the system. If there are, then there is no way a process of work transfer does not take place. Uniformity of pressure throughout the system is the requirement for a system to be in mechanical equilibrium. Surroundings and the system may be at pressures and still system may be in mechanical equilibrium.

Chemical equilibrium:

There should not be any chemical reaction taking place anywhere in the system, then it is said to be in chemical equilibrium. Uniformity of chemical potential throughout the system is the requirement for a system to be in chemical equilibrium.

Surroundings and the system may have different chemical potential and still system may be in chemical equilibrium.

7. Name a few measurements or quantities that can be conveniently used as thermometric properties in order to quantify the temperature. [04 Marks, Jan-2021]

They are

- i) Pressure
- ii) Volume
- iii) Resistance
- iv) Thermal emf
- v) Length

8. What are intensive and extensive properties? Give examples for each. [04 Marks, Jan-2018]

Intensive properties:

The properties that are independent of amount contained in the system are called extensive properties. For example, take temperature. We can have a substance with varying amount but still same temperature. Density is another example of intensive property because density of water is same no matter how much is the water. Other intensive properties are pressure, viscosity, surface tension.

Extensive properties:

The properties that depend upon amount contained in the system are called extensive properties. Mass depends upon how much substance a system has in it therefore mass is an extensive property.

9. In 1709, Sir Isaac Newton proposed a new temperature scale. On this scale, the temperature was a linear function on Celsius scale. The reading on this at ice point (0°C) and normal human body temperature (37°C) were 0°N and 12°N , respectively. Obtain the relation between the Newton scale and the Celsius scale. [06 Marks, Jan-2017]

10. Define the following:

i) Open system ii) closed system and iii) Isolated system and classify the following into open closed and isolated system and explain giving reasons.

i) Radiator of a car ii) Thermo flask iii) Water pump iv) Pressure cooker.

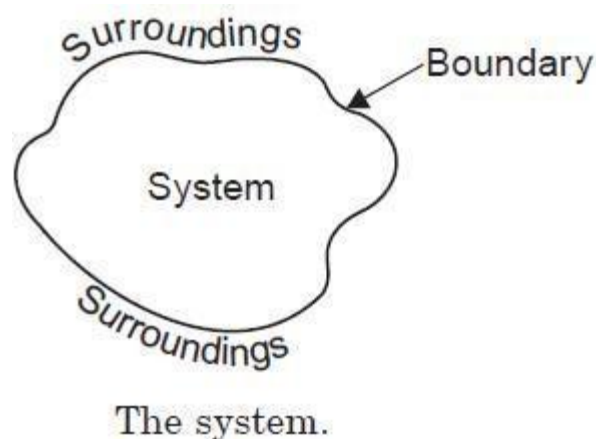
[07 Marks, Jun-2018]

System:

We need to fix our focus of attention in order to understand heat and work interaction. The body or assemblage or the space on which our attention is focused is called system. The system may be having real or imaginary boundaries across which the interaction occurs. The boundary may be rigid and sometimes take different shapes at different times. If the system has imaginary boundary then we must properly formulate the idea of system in our mind.

Surroundings:

Everything else apart from system constitutes surroundings. The idea of surroundings gets formulated the moment we define system. System and surroundings together form what is known as universe.



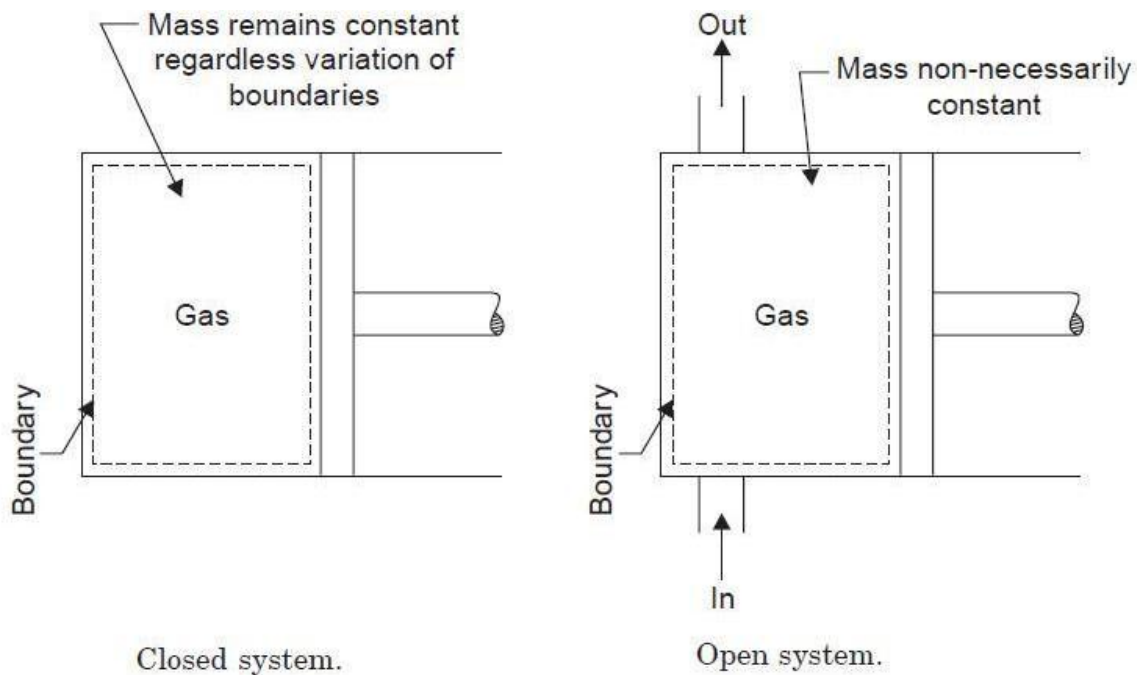
Closed system:

If the system has a boundary through which mass or material cannot be transferred, but only energy can be transferred is called closed system. In an actual system, there may not be energy transfer.

What is essential for the system to be closed is the inability of the boundary to transfer mass only.

Open system:

If the system has a boundary through which both energy and mass can transfer, then it is called open system.



Isolated System

An isolated system is that system which exchanges neither energy nor matter with any other system or with environment.

11. What are international fixed reference points? Name few of them. What is their importance?
[05 Marks, Jun-2019]
12. Define a new temperature scale N in which freezing point and boiling point of water are 100°N and 300°N respectively. Correlate this temperature scale with centigrade scale for which freezing and boiling points are 0°C and 100°C respectively.
[08 Marks, Jun-2018]
13. Distinguish between:
- Microscopic and macroscopic point of view
 - Temperature and thermal equilibrium and
 - Intensive and extensive properties.
- [06 Marks, Jan-2019]
14. Classify the following into open, closed and isolated systems:
- Evaporator
 - Passenger's train when stop at platform
 - Thermo flask
 - pressure cooker
 - I.C. engine during compression/expansion stroke
 - Refrigerant in a refrigerator
 - Boiler
 - Throttle valve.
- [08 Marks, Jan-2020]
15. Define a Quasi-static process. A platinum wire is used as a resistance thermometer. The wire resistance was found to be 10ohm and 16ohm at ice point and steam point respectively, and 30ohm at sulphur boiling point of 444.6°C . Find the resistance of the wire at 750°C , if the resistance varies with temperature by the relation. $R=R_0(1+\alpha T+\beta T^2)$.
[06 Marks, Jan-2014]
16. Classify the following as open / closed/ isolated systems:
- Tree; ii . Printer; iii . Baking of bread in an oven; iv. Fan
- [04 Marks, June-2018]
17. Define the following with examples:
- Property
 - Cycle;

- c. Path function
- d. Reference temperature
- e. Quasi static process;
- f. Thermodynamic equilibrium;
- g. Macroscopic approach
- h. State point;

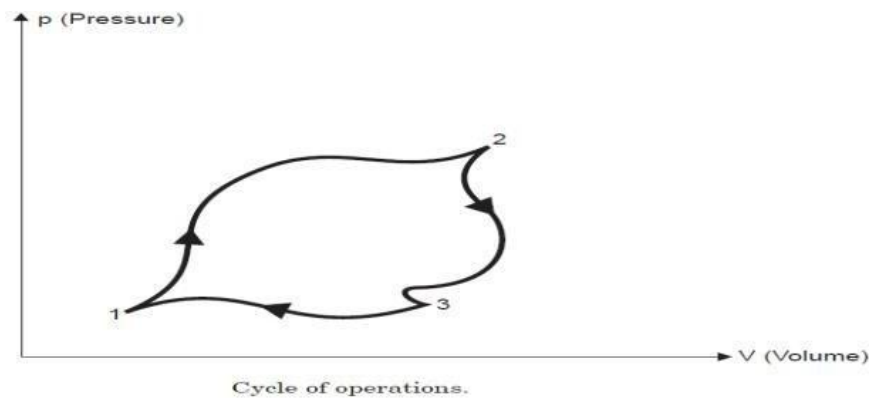
[08 Marks, June-2017]

Properties:

Variables such as pressure, temperature, volume and mass are properties. A system will have a single set of all these values.

CYCLE

Any process or series of processes whose end states are identical is termed a cycle.



Quasi-static process:

Quasi means „almost“. A quasi-static process is also called a reversible process. This process is a succession of equilibrium states and infinite slowness is its characteristic feature.

In the macroscopic approach, a certain quantity of matter is considered, without the events occurring at the molecular level being taken into account. From the microscopic point of view, matter is composed of myriads of molecules. If it is a gas, each molecule at a given instant has a certain position, velocity and energy and for each molecule these change very frequently as a result of collisions. The behavior of the gas is described by summing up the behavior of each molecule. Such a study is made in microscopic or statistical thermodynamics. Macroscopic thermodynamics

is only concerned with the effects of the action of many molecules, and these effects can be perceived by human senses. For example, the macroscopic quantity pressure is the average rate of change of momentum due to all the molecule collisions made on a unit area. The effects of pressure can be felt. The macroscopic point of view is not concerned with the action of individual molecules and the force on a given unit area can be measured by using a pressure gauge.

18. Develop a linear temperature scale 'B' where in ice and normal human body temperature are assumed as two fixed points and assigned the values 0°B and 50°B respectively. If the temperature of human body on Celsius scale is 36.7°C, obtain the relation between 'B' scale.

[08 Marks, June-2018]

Let $T = ax + b$

$$\text{At } 0^{\circ}\text{B}, 0 = ax_1 + b \text{----- (1)}$$

$$\text{At } 50^{\circ}\text{B}, 50 = ax_2 + b \text{----- (2)}$$

After solving 1 and 2, $a = 50 / (x_2 - x_1)$

And $b = -50x_1 / (x_2 - x_1)$

Substitute a and b in main equation we get,

$$T = 50 / (x_2 - x_1) \{ x - x_1 \}$$

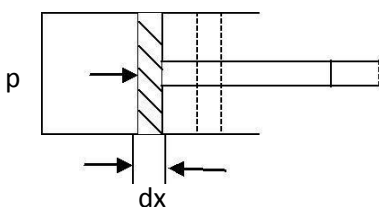
UNIT-2 WORK AND HEAT

1. Define work and heat. Write the similarities and dissimilarities between them. [06 Marks, July-2019]
2. State direction of heat transfer and work transfer in a viscous fluid is stirred by a paddle wheel in an insulated closed tank. [02 Marks, July-2019]
3. Show that work and heat are path functions and not properties of system. [06 Marks, Jan-2015]
4. Specify the most widely used sign convention for work and heat interaction. [04 Marks, Jan-2020]
5. List the differences between work and heat. [04 Marks, Jan-2018]
6. Show that work and heat are path functions. [04 Marks, Jun-2019]]
7. Define 'heat' and bring out dissimilarities between heat and work. [06 Marks, Jun-2019]]
8. Does heat transfer inevitably cause a temperature rise? What is the other cause for rise in temperature? [02 Marks, Jan-2018]
9. Define 'work' from thermodynamic point of view and derive an expression for flow work. [06 Marks, Jun-2019]

Thermodynamic definition of work: It is a kind of interaction that would occur at the system boundaries. It can be positive or negative.

Definition of Positive work is said to be done by a system when the „sole effect“ external to the system could be reduced to the raising of a weight.

Work done at the moving boundary of a system (Expression for displacement work)



Consider a piston-cylinder arrangement which contains certain working fluid undergoing quasi-static process.

Let p = Pressure exerted by the fluid on the piston

A = Area of c/s of the cylinder

dx = displacement of the piston when the system has undergone an infinitesimal change of state.

∴ Displacement work: $dw = \text{Force} \times \text{displacement}$

$$= p \cdot A \times dx$$

$$\text{i.e., } dw = p \cdot dV$$

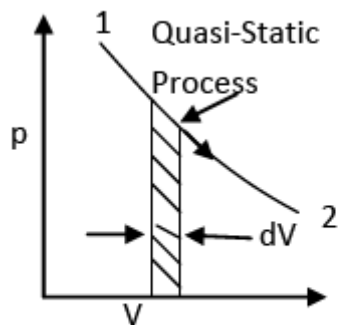
Where dv is the infinitesimal change in volume of the system. If the system undergoes a finite change of state from state (1) to state (2).

Then the displacement work is given by

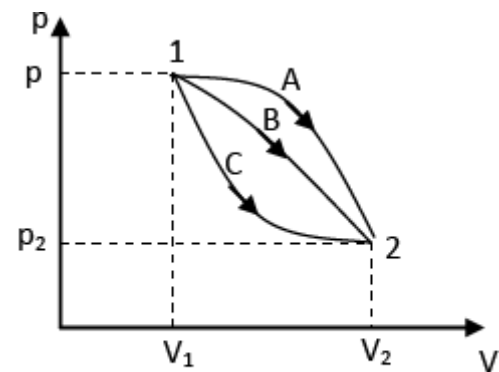
$$\int_1^2 dw = \int_1^2 p dv$$

The integration of above equation can be done only if the relationship between P and v during the process is known i.e., if the path of the process is well defined. Hence, work is a path function. As work depends on the path of the process which it follows, there will be different values of work for different process between two given states. Hence the differentials of the path functions are inexact differentials. The symbol δ will be used to designate inexact differentials. The magnitude of the work transfer by the system during the process from state (1) to state (2) containing unit mass of the fluid will be written as $\int_1^2 \delta w = W_{1-2} = 1W2$

The process can be represented by a full line on an appropriate thermodynamic coordinate system (in this case p - V diagram) and the area under the curve gives the work done by the system during the process.



Quasi-Static pdV work



Work-a path function

Inspection of the pV diagram above shows that just by specifying the end states 1 and 2 does not determine the area (or work); the nature of the curve needs to be known. The curve may be arched upwards or it may sag downwards, and the area under the curve will vary accordingly. For the same initial and final states, the work done by the system in following the paths A, B and C are different. Therefore the work is a path function and not a point function. Accordingly the work transfer across the system boundaries is not classified as a thermodynamic property.

The expression $\delta w = pdV$ holds good under the following restrictions

- i) The system is closed
- ii) There is no friction within the system
- iii) The pressure and all other properties are the same on all the boundaries of the system
- iv) The system is not influenced by motion, gravity, capillarity, electricity and magnetism

Heat: Heat is a mode of energy transfer that takes place between the system and the surroundings solely due to the temperature difference. Thus, heat is a transient phenomenon. It can be recognized only during a process. It is not a thermodynamic property of the system. Like work, heat is a path function i.e., the magnitude of heat transfer between the system and surroundings depends upon the type of process the system is undergoing.

Dissimilarities

- a. Heat is energy interaction due to temperature difference only; work is by reasons other than temperature difference.
- b. In a stable system, there cannot be work transfer; however there is no restriction for the transfer of heat.
- c. The sole effect external to the system could be reduced to rise of a weight but in the case of a heat transfer other effects are also observed.
- d. Heat is a low grade energy whereas work is a high grade energy.

- 10. An automobile vehicle of 1500 kg is running at a speed of 60km/hr. The brakes are suddenly applied and the vehicle is brought to rest. Calculate the rise in temperature of brake shoes, if their mass is 15 kg. Take the specific heat of brake shoe material as 0.46kJ/kg-K.**

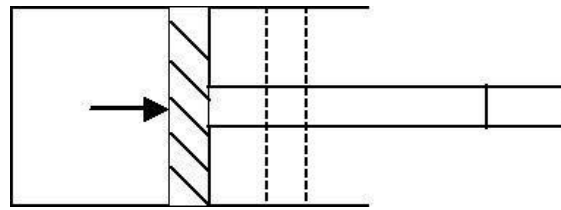
[06 Marks, July-2021]

- 11. The piston of an oil engine of area 0.0045m² moves downwards 75mm, drawing 0.00028m³ of fresh air from the atmosphere. The pressure in the cylinder is uniform during the process at 80kPa, while the atmosphere pressure is 101.375kPa, the difference being due to the flow resistance in the induction pipe and the inlet valve. Estimate the displacement work done by the air.**

[06 Marks, Jan-2021]

A piston device contains 0.05m³ of a gas initially at 200kPa. At this state, a linear spring having a spring constant of 150kN/m is touching the piston but exerting no force on it. Now heat is transferred to the gas, causing the piston to rise and to compress the spring until the volume inside the cylinder doubles. If the cross-sectional area of the piston is 0.25m², determine

- i) A final pressure inside the cylinder
- ii) The total work done by the gas
- iii) The fraction of work done against the spring to compress it.

Solution:

$$\therefore$$

$pV = C$ i.e., hyperbolic process or $p_1 V_1 = p_2 V_2$

$$5 \qquad \qquad \qquad 3 \qquad \qquad \qquad 5 \quad \text{Given, } p_1 = 3 \times 10^5 \text{ Pa} \quad V_1 = 0.015 \text{ m}^3$$

$$p_2 = 1.5 \times 10^5 \text{ Pa}$$

$$\therefore V_2 = ?$$

$$\int \qquad \qquad \qquad \int$$

$$W_{1-2} = ?$$

Positive sign indicates work is done by the system on the surroundings.

12. A quantity of gas is compressed in a piston cylinder from a volume of 0.8611 m^3 to a final volume of 0.17212 m^3 . The pressure (in bar) as a function of volume (m^3) is given by,

$$P = \frac{0.86110}{V} - \frac{8.60673 \times 10^{-5}}{V^2}$$

- i) Find the amount of work done in kJ.
 ii) If the atmospheric pressure, i.e 1 bar acting on the other side of piston is considered, find the network done in kJ. **[06 Marks, July-2018]**

Given $p_1=3\text{bar}$ and $v_1=0.015\text{m}^3$ $p_2=1.5\text{bar}$ $v_2=?$ And workdone=?

$$\text{ie } P/V = P_1/V = c = p_1/V_2$$

$$W = \int p dv = p_1/2v_1[v_2^2 - v_1^2]$$

$$W = -1.6885 \text{ kJ}$$

— -ve sign indicates that work is done on the system

Substituting the given values, we get $(W_d)_{1-2} = 1.316 \text{ kJ}$ +ve sign indicates that work is done by the system

- 13. To a closed system 150kJ of work is done on it. If the initial volume is 0.6m³ and pressure of system varies as follows: $P = (8-4V)$, where p is pressure in bar and V is volume m³. Determine the final volume and pressure of the system. [10 Marks, Jun-2020]**

Given $W = -150 \text{ kJ}$

$$V_1 = 0.6 \text{ m}^3$$

$$P = 8 - 4V$$

We know $W = \int p dv$

$$= \int 8 - 4V = 8[v_2 - v_1] - 2[v_2^2 - v_1^2]$$

$$-150 = 8[v_2 - v_1] - 2[v_2^2 - v_1^2]$$

After solving $v_2 = 0.3 \text{ m}^3$

$$p_2 = 5 \text{ bar}$$

- 14. With a neat p-V diagram, derive an expression for work done in each case of the following:**

- b. Isochoric process
- c. Isobaric process
- d. Isothermal process
- e. Polytrophic process

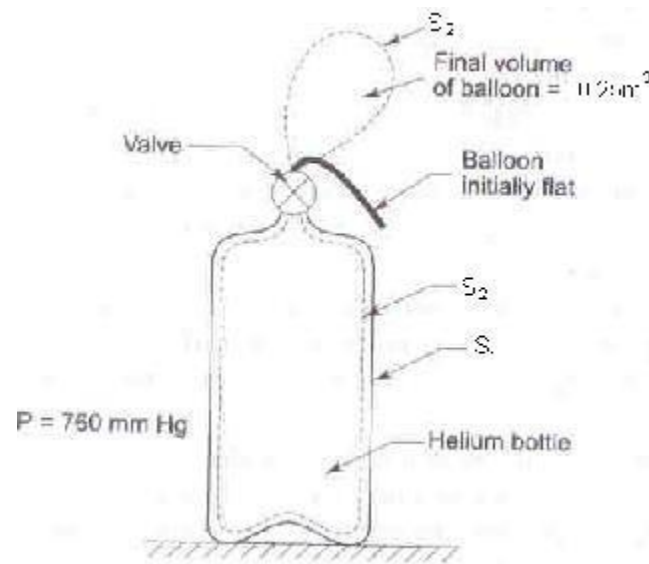
[10 Marks, Jan-2021]

- 15. Starting from a convenient common state point, on P-V diagram, show the four expansion processes for $n=0$, $n=1$, $n=\gamma$ (where γ is specific heat ∞ ratio) and $n=$, what are each processes called? Indicate their names adjacent to the processes on the diagram.**

[06 Marks, Jun-2019]

16. A gas contained in a cylinder fitted with a piston loaded with a small number of weights is at 1.3 bar pressure and 0.03m^3 volume. The gas is heated until the volume increases to 0.1m^3 . Calculate the work done by the gas in the following processes: pressure remains constant; temperature remains constant; $PV^{1.3} = C$ during the process. Show the process on P-V diagram.

[08 Marks, Jun-2020]



The firm line S_1 shows the boundary of the system before the process, and the dotted line S_2 shows the boundary after the process.

Total displacement work is given by

$$(Wd)_{1-2} = (Wd)_{\text{bottle portion of the system}} + (Wd)_{\text{Balloon portion of the system}}$$

Since there is no displacement of the bottle portion of the system boundary, it follows that

$$(Wd)_{\text{bottle}} = 0$$

$$= 0 + (Wd)_{\text{Balloon}}$$

The balloon is expanding against a constant atmosphere pressure of 760 mm of mercury,

$$\text{i.e., } p = \rho h$$

$$= 9810 (13.6) 0.76 = 1.01396 \times 10^5 \text{ N/m}^2 = 101.396 \text{ kPa}$$

$$\int (Wd)_{\text{balloon}} = \int p dV = p \int_1^2 dV$$

$$= p (V_2 - V_1)$$

$$= 101.396 (0.25 - 0)$$

$$= 25.349 \text{ kJ}$$

UNIT-3
FIRST LAW THERMODYNAMICS

1. What is a perpetual motion machine of first kind? Why is it impossible?

[03 Marks, Jun-2017]

2. Apply steady flow energy equation to each of the following:

a. Boiler

b. Nozzle

c. Centrifugal pump

[06 Marks, Jun-2015]

Joule's Experiment:

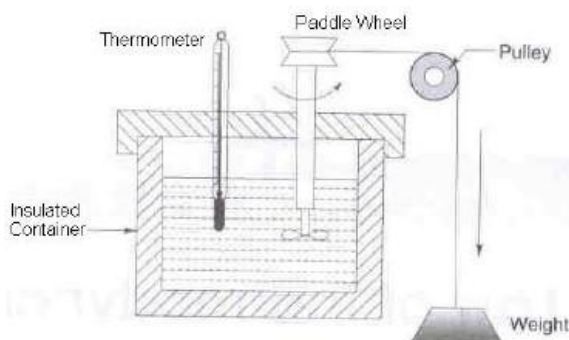


Figure: Joule's Experiment

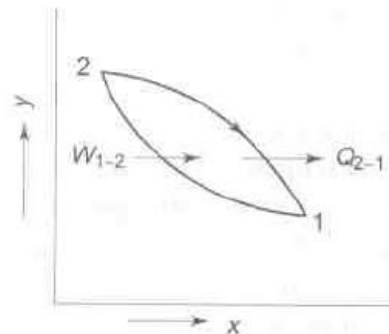


Figure: Cycle completed by a system with two energy interactions i.e., work transfer followed by heat transfer

Figure shows the experiment for checking the first law of thermodynamics. The work input to the paddle wheel is measured by the fall of weight, while the corresponding temperature rise of liquid in the insulated container is measured by the thermometer.

The process 1-2 undergone by the system is shown in figure i.e., W_{1-2} . Let the insulation be removed. The system and the surrounding interact by heat transfer till the system returns to its original temperature, attaining the condition of thermal equilibrium with the atmosphere. The

amount of heat transfer Q_{2-1} from the system during this process 2-1 is shown in figure. 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_{2-1} from the system.

Joule carried out many such experiments with different type of work interactions in a variety of systems, he found that the net work input the fluid system was always proportional to the net heat transferred from the system regardless of work interaction. Based on this experimental evidence Joule stated that,

“When a system (closed system) is undergoing a cyclic process, the net heat transfer to the system is directly proportional to the net work done by the system”. This statement is referred to as the first law for a closed system undergoing a cyclic process.

$$\oint Q \propto \oint W$$

If both heat transfer and work transfer are expressed in same units as in the S.I. units then the constant of proportionality in the above equation will be unity and hence the mathematical form of first law for a system undergoing a cyclic process can be written as

$$\oint Q = \oint W$$

3. 1200 kg car cruising steadily on a level road at 90km/hr. Now the car starts climbing a hill that is sloped 300 from the horizontal. If the velocity of the car is to remain constant during climbing, determine the additional power that must be delivered by the engine.

[04 Marks, Jun-2021]

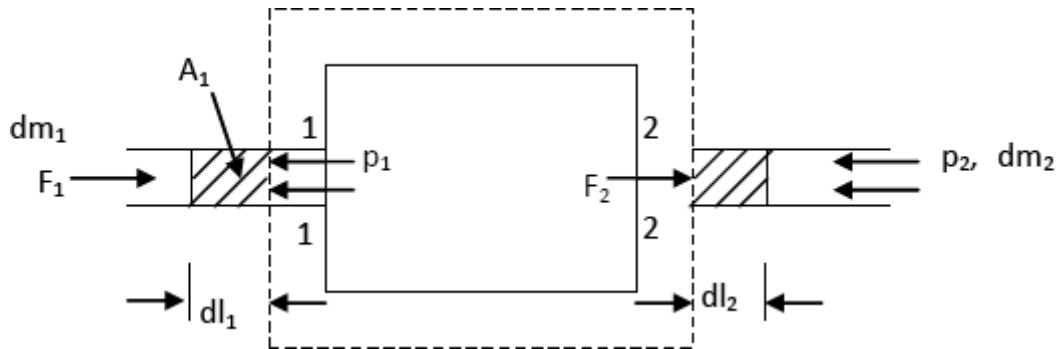
4. A centrifugal pump delivers 50 kg of water per second. The inlet and outlet pressure are 1 bar and 4.2 bar respectively. The suction is 2.2m below the centre of the pump and delivery is 8.5m above the centre of the pump. The suction and delivery pipe diameters are 200mm and 100mm respectively. Determine the capacity of electric motor to run the pump.

[07 Marks, Jun-2018]

5. Describe the classic paddle wheel experiment performed by Joule. What conclusions were drawn based on the experimental observations?

[10 Marks, Jan-2021]

Flow Work: Consider a flow process in which a fluid of mass dm_1 is pushed into the system at section 1 and a mass dm_2 is forced out of the system at section 2 as shown in fig.



In order to force the fluid to flow across the boundary of the system against a pressure p_1 , work is done on the boundary of the system. The amount of work done is $\delta W = - F_1 \cdot dl_1$,

Where F_1 is the force and dl_1 is the infinitesimal displacement, but $F_1 = p_1 A_1$

$$\therefore \delta W = - p_1 A_1 dl_1 = - p_1 dv_1$$

i.e., the flow work at section 1 = $- p_1 v_1$

Similarly, the work done by the system to force the fluid out of the system at section 2 = $+ p_2 v_2$

$$\text{Hence net flow work} = p_2 v_2 - p_1 v_1$$

For unit mass, the flow work is $(p_2 v_2 - p_1 v_1)$. Flow work is expressed entirely in terms properties of the system. The net flow work depends out on the end state of the fluid and it is a thermodynamics property. Also the fluid contains energies like internal energy, potential energy and due to the motion of the fluid, kinetic energy, in addition to the flow work. When a fluid enters an open system, these properties will be carried into the system. Similarly when the fluid leaves the system, it carries these energies out of the system. Thus in an open system, there is a change in energy of the system.

6. A turbo compressor delivers $2.33\text{m}^3/\text{s}$ at 0.276MPa , 43°C which is heated at this pressure to 430°C and finally expanded in a turbine which delivers 1860kW . During the expansion there is a heat transfer of 0.09MJ/s to the surroundings. Calculate the turbine exhaust temperature if changes in kinetic and potential energy are negligible. Assume for air, $R=0.287\text{kJ/kg-K}$, $C_p=1.005\text{kJ/kg-K}$.

[10 Marks, Jan-2019]

7. Write the steady state flow energy equation for an open system and explain the terms involved in it, and simplify SFEE for the following systems:
- Steam turbine
 - Nozzle

[06 Marks, Jun-2017]

8. The properties of a certain fluid are related as follows:

$$u = 0.718t + 196$$

$$Pv = 0.287(t + 273)$$

Where u is specific internal energy (kJ/kg), t is temperature in $^{\circ}\text{C}$, P is pressure in kN/m^2 and v is specific volume in m^3/kg . For this fluid find C_p and C_v . If a system composed of 2 kg of this fluid expands in a frictionless piston and cylinder machine from an initial state of 1 MPa, 100°C to a temperature of 30°C . If there is no heat transfer, find the net work for the process.

[08 Marks, Jun-2018]

SFEE on the basis unit mass:

Energy entering to the system = energy leaving the system

Where Q = heat transfer across the C.V, W = shaft work across the C.V, h = Enthalpy,

V = velocity, Z = elevation and g = gravitational acceleration

9. A blower handles 1 kg/s of air at temperature of 20°C and consumes a power of 15kW. The inlet and outlet velocities of air are 100m/sec and 150m/sec respectively. Find the exit temperature of air, assuming adiabatic conditions. Take $C_p = 1.005 \text{ kJ/kg-K}$.

[06 Marks, Jun-2019]

10. For a non-flow system, show that the heat transferred is equal to the change in enthalpy of a system.

[04 Marks, Jan-2019]

11. A gas undergoes a thermodynamic cycle consisting of the following processes: i) process 1-2: constant pressure $p = 1.4 \text{ bar}$, $V_1 = 0.028 \text{ m}^3$, $W_{12} = 10.5 \text{ kJ}$; ii) process 2-3: compression with $PV = \text{constant}$, $U_3 = U_2$ and iii) process 3-1: constant volume, $U_1 - U_3 = -26.4 \text{ kJ}$. There are no

significance change in KE and PE. i) Calculate the net work for the cycle; ii) Calculate the heat transfer for the process 1-2; iii) Show that $\Sigma Q_{\text{cycle}} = \Sigma W_{\text{cycle}}$ and iv) Sketch the cycle on p-V diagram.

[08 Marks, Jan-2017]

In a certain steady flow process, 12 kg of fluid per minute enters at a pressure of 1.4 bar, density 25 kg/m^3 , velocity 120 m/s and internal energy 920 kJ/kg. The fluid properties at exit are 5.6 bar, density 5 kg/m^3 , velocity 180 m/s and internal energy 720 kJ/kg. During the process the fluid rejects 60 kJ/s of heat and rises through 60 m. Determine work done during the process in kW.

a) Along the path 1-2-3,

From 1st law of thermodynamics, $Q_{1-3} = U_3 - U_1$

+ W_{1-3} From the data given, $80 = (U_3 - U_1) + 30 (U_3 -$

$U_1) = 50 \text{ kJ}$ Along the path 1-4-3, we have

$$Q_{1-3} = U_3 - U_1 + W_{1-3}$$

From the data given, $Q_{1-3} = 50 + 10 = 60 \text{ kJ}$

i.e., Work is done by the system b) Along the path 3-A-1,

$$(U_1 - U_3) = Q_{3-1} - W_{3-1}$$

$$\text{Or } Q_{3-1} = (U_1 - U_3) + W_{3-1}$$

$$= -50 - 20 = -70 \text{ kJ}$$

Negative sign indicates that heat is liberated from the system. c) Along the path 1-4

$$Q_{1-4} = U_4 - U_1 + W_{1-4}$$

$$= 40 - 0 + 10 \text{ (since } W_{1-4-3} = W_{1-4} + W_{4-3} = 10 + 0 = 10)$$

$$= 50 \text{ kJ}$$

Positive sign indicates heat is absorbed by the system

Along the path 4-3

$$Q_{4-3} = U_3 - U_4 + W_{4-3}$$

$$= 50 - 40 + 0 = 10 \text{ kJ}$$

12. With a neat sketch, explain the famous ‘Joules experiment’ to show that energy transfer to an adiabatic system is a function of end states only.

[04 Marks, Jun-2018]

13. For iso therming non flow and steady flow processes show that $\int_1^2 p dv = - \int_1^2 v dp$.

[06 Marks, Jun-2017]

14. Simplify SFEE equation for a case of throttle valve.

[02 Marks, Jun-3021]

15. An ideal gas ($\gamma = 1.4$) expands reversibly in a turbine from 10bar to 1 bar. Assume that process law is $p = 12.5V$, where ‘P’ is in bar and ‘V’ is in m^3/kg . If the heat loss from the turbine is 200KJ/Kg, calculate the shaft work done.

[08 Marks, Jun-2020]

The firm line S_1 shows the boundary of the system before the process, and the dotted line S_2 shows the boundary after the process.

Total displacement work is given by

$$(Wd)_{1-2} = (Wd)_{\text{bottle portion of the system}} + (Wd)_{\text{Balloon portion of the system}}$$

Since there is no displacement of the bottle portion of the system boundary, it follows that

$$(Wd)_{\text{bottle}} = 0$$

$$= 0 + (Wd)_{\text{Balloon}}$$

The balloon is expanding against a constant atmosphere pressure of 760 mm of mercury,

$$\text{i.e., } p = \rho h$$

$$= 9810 (13.6) 0.76 = 1.01396 \times 10^5 \text{ N/m}^2 = 101.396 \text{ kPa}$$

$$\int (Wd)_{\text{balloon}} = \int p dV = p \Delta V$$

$$= \int dV$$

$$= p (V_2 - V_1)$$

$$= 101.396 (0.25 - 0)$$

$$= 25.349 \text{ kJ}$$

UNIT-4
SECOND LAW THERMODYNAMICS

1. **Prove that a reversible engine is more efficient than an irreversible engine operating between the same temperature limits. [06 Marks, June-2018]**
2. **A house hold refrigerator maintains a space at a temperature of 0°C . Every time the door is opened, warm material is placed inside, introducing an average 400kJ of heat, but making only a small change in temperature of the refrigerator. The door is opened 25 times a day and the refrigerator at 25% and ideal COP. The cost of work is 3.50per kWh. What is the monthly bill for this refrigerator? The atmospheric temperature is at 3°C . [06 Marks, June-2017]**
3. **Explain the second laws of thermodynamics with reference to Kelvin Planck's statement and Clausius statement hence prove that both the statements are equivalent to each other although they appear to be different. [08 Marks, June-2018]**
4. **What is thermal energy reservoir? Explain source and sink. [04 Marks, Jan-2016]**
5. **Establish equivalence of Kelvin Planck's statements. [06 Marks, Jan-2019]**

Kelvin – Planck statement

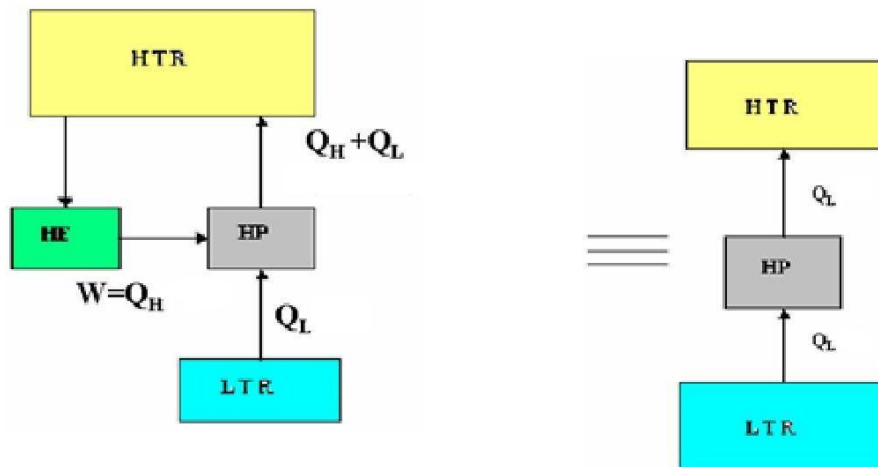
“It is impossible to construct a device which will operate in a cycle & produce no effect other than the raising of a weight and the exchange of heat with a single reservoir”

Clausius Statement

It is impossible to construct a heat pump which operating in a cycle will produce no effect other than the transfer of heat from a low temperature thermal reservoir to a higher temperature thermal reservoir.

That is in order to transfer heat from a low temperature thermal reservoir to a high temperature thermal reservoir work must be done on the system by the surroundings.

Proof of violation of the Kelvin – Plank statement results in violation of the Clausius statement.



Consider a heat engine that is operating in a cyclic process takes heat (Q_H) from a high temperature reservoir & converts completely into work (W), violating the Kelvin – Planck statement.

Let the work W , which is equal to Q_H , be utilized to drive a heat pump as shown. Let the heat pump take in Q_L amount of heat from a low temperature reservoir and pump ($Q_H + Q_L$) amount of heat to the high temperature reservoir.

From the diagrams we see that a part of heat Q_H , pumped to the high temperature reservoir is delivered to the heat engine, while there remains a heat flow Q_L , from the low temperature reservoir to the high temperature reservoir, which in fact violates the Clausius statement.

6. Two reversible heat engines A and B are arranged in series, A rejecting heat directly to B. Engine A receives 200kJ at a temperature of 4210C from a hot source, while engine B is in communication with a cold sink at a temperature of 4.40C. If the work output of A is twice that of B, Find;

- i) The intermediate temperature between A and B
- ii) The efficiency of each engine.
- iii) The heat rejected to the cold sink

[10 Marks, Jan-2015]

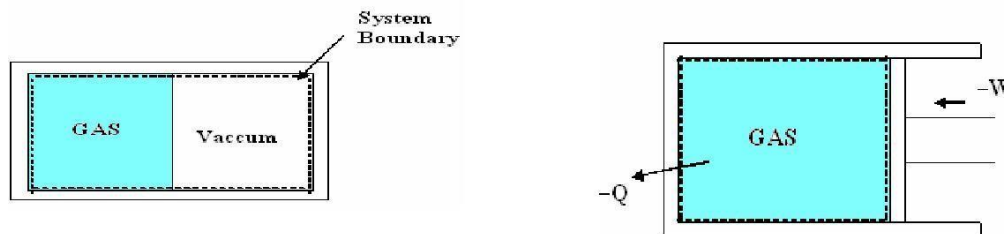
7.State and prove Carnot's theorem.

[10 Marks, July-2014]

8.A heat engine is used to drive a heat pump. The heat transfer from the engine and heat pump are used to heat water circulating through the radiators of a building. The efficiency of the heat engine is 27% and coefficient of performance of heat pump is 4. Evaluate ratio of the heat transfer to the radiator circulating water to the heat transfer to the engine.

[10 Marks, July-2014]

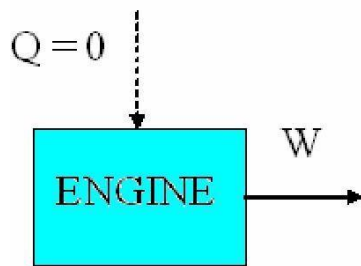
Proof that Unrestrained expansion makes process irreversible



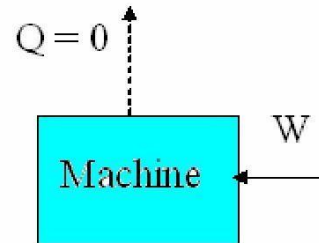
INITIAL STATE

PERPETUAL MOTION MACHINE OF FIRST KIND (PMMKI)

No machine can produce energy without corresponding expenditure of energy without corresponding expenditure of energy i.e., it is impossible to construct a PMMK of first kind. The machine violates the first law of thermodynamics. All attempts made so far to make PMMKI have failed, thus showing the validity of the first law.



A PMMK -I



The converse of A PMMK -I

9. State the limitations of first law thermodynamics. Illustrate with examples.

[04 Marks, Jan-2014]

10. Define Kelvin – plank statement, Clausius statement of II law of thermodynamics and show that they are equivalent.

[06 Marks, Jan-2014 & July-2014]

11. 17kJ/s from the 5°C reservoir, determine i) the rate of heat supply from the 840°C source and ii) the rate of heat rejection to the 60°C sink.

[10 Marks, Jan-2014]

12. Using Kelvin- plank statement show that free expansion process is irreversible.

[04 Marks, July-2013]

13. A heat pump working on a reversed Carnot cycle takes in energy from a reservoir maintained at 5°C and delivers it to another reservoir where temperature is 77°C. The heat pump derives power for its operation from a reversible heat engine operating within the higher and lower temperature of 1077°C and 77°C. For every 100kJ/kg of energy supplied to reservoir at 77°C, estimate the energy taken from it at 1077°C.

[08 Marks, July-2013]

Solution:

Temperature of source, $T_H = 1400 \text{ C} = 1673 \text{ K}$

Temperature of sink, $T_L = 350 \text{ C} = 673 \text{ K}$

We know that the thermal efficiency of the CARNOT cycle is the maximum between the specified temperature limits and is given as.

$$= 62.8\%$$

The thermal efficiency of the engine developed by the engineer is given as

$$\eta = 1 - Q_l/Q_h = W/Q = 3.4\text{kW}$$

Hence it is 62.23%

We have 3.4kW

And hence overall efficiency is 64.44%

UNIT-5
ENTROPY

1. Prove that for a system executing a cyclic process $\oint \frac{\delta Q}{T} \leq 0$, hence define entropy.

[08 Marks, Jul-2015]

2. In a certain heat exchanger 50kg of water is heated per minute from 50°C to 100°C by hot gases which enter the heat exchanger at 250°C. If the flow rate of gases is 100kg/min, estimate the net entropy. C_p (water) = 4.186 kJ/kg-K, C_p (gas) = 1 kJ/kg-K.

[06 Marks, Jul-2015]

Where δQ is an infinitesimal heat transfer, T is absolute temperature of the part of the system to which heat transfer δQ occurs.

PROOF:

For any reversible cycle from Clausius theorem,

$$\oint \frac{\delta Q}{T} = 0$$

From the Carnot's theorem we know that the efficiency of an irreversible engine is less than that of a reversible

$$\eta_{\text{engine, i.e.}} < \eta_{I \text{ (irreversible)}} < \eta_{R \text{ (reversible)}}$$

Where

η_{I} is efficiency of the irreversible engine and η_{R} is efficiency of the reversible engine.

$$\text{Hence, } 1 - \left(\frac{\delta Q_L}{\delta Q_H} \right)_I < 1 - \left(\frac{\delta Q_L}{\delta Q_H} \right)_R \text{ ----- (3)}$$

Where I and R represents irreversible and reversible processes respectively.

For a reversible engine, the ratio of the heat absorbed and heat rejected is equal to the ratio of the

absolute temperatures. Therefore

$$1 - \left(\frac{\delta Q_L}{\delta Q_H} \right)_I < 1 - \left(\frac{T_L}{T_H} \right) \text{----- (4)} \quad \text{i.e.} \quad \left(\frac{\delta Q_L}{\delta Q_H} \right)_I > \left(\frac{T_L}{T_H} \right)$$

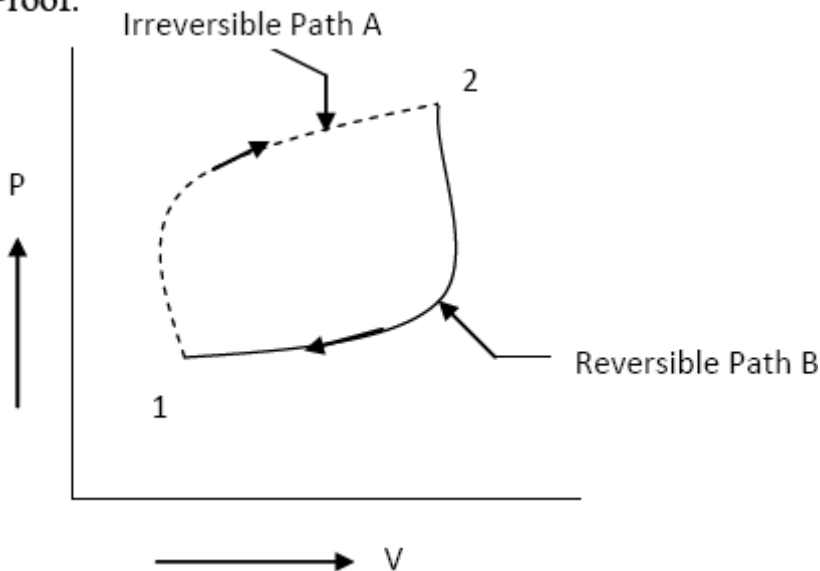
3. A piston-Cylinder arrangement contains 0.03m³ of nitrogen at 1 bar and 290K. The piston moves inwards and the gas is compressed exothermically and reversibly until the pressure becomes 4 bar. Determine change in entropy and work done. Assume nitrogen to be a perfect gas. [06 Marks, Jul-2015]

4. Establish the inequality of Clausius. [08 Marks, Jan-2015]

5. What is available and unavailable energy? [04 Marks, Jan-2015]

Entropy change in **IRREVERSIBLE** process: For a process that occurs irreversibly, the change in entropy is greater than the heat change divided by the absolute temperature. In symbols, $ds > \delta q/T$

Proof:



6. A lump of steel of mass 10 kg at 627⁰C is dropped in 100 kg of oil at 30⁰C. The specific heats of steel and oil are 0.5kJ/kg-K and 3.5 kJ/kg-K respectively. Calculate the entropy

change of steel, the oil and the universe.

[08 Marks, Jan-2015]

7.State and prove inequality of Clausius? What is the significance of inequality of Clausius?

[10 Marks, Jan-2015]

8.An adiabatic vessel contains 85 kg of oil at a temperature of 27⁰C. A spherical ball made of steel of 10 kg at 727⁰C is immersed in oil.Calculate the entropy change of the universe.The specific heats of steel of steel and oil are 0.5kJ/kg-K and 3.5 kJ/kg-K respectively.

[10 Marks, Jan-2015]

9.Prove that for a system executing a cyclic process $\oint \frac{\delta Q}{T} \leq 0$, hence prove that entropy is a property of the system.

[08 Marks,

Jan-2014]

Statement: For any system undergoing internally reversible cycle, the integral of

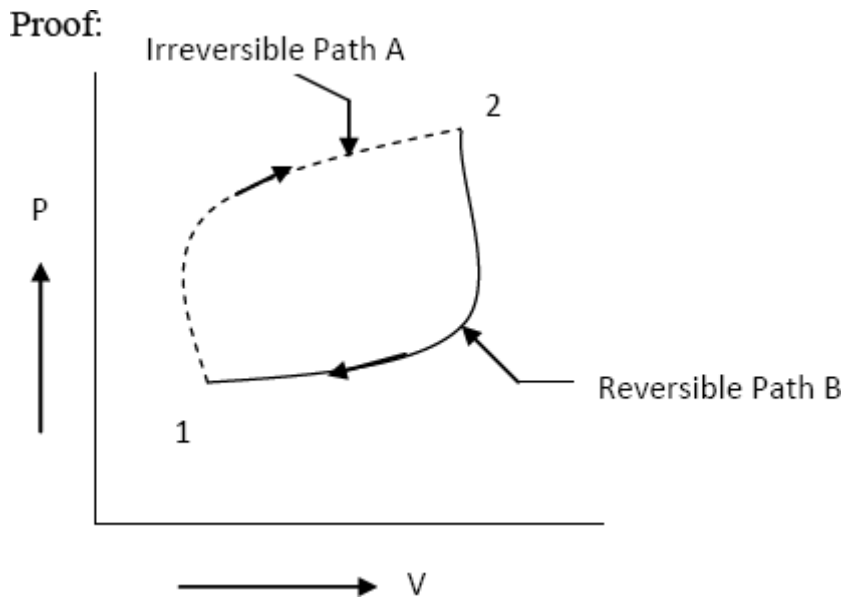
$$\frac{Q_R}{T}$$

is zero, in symbols,

$$\oint \frac{\delta Q_R}{T} = 0 \quad (1)$$

Let the system executes a cyclic process, starting at state 1, proceeding to state 2 along the reversible path A, and returning state 1 along a different path B.





From the Clausius inequality we have along path 1A2B1, _____ (2)

10. Explain the principle of increase of entropy. [06 Marks, Jan-2014]

11. In a shell and tube exchanger 45 kg of water per minute is heated from 30°C to 85°C by hot gases which enter the heat exchanger at 225°C. if the flow rate of gases is 90kg/min, find the net change of entropy of the universe. [06 Marks, Jan-2014]

Since the process is reversible, we may reverse it and thus cause the system to retrace its path precisely. Let the element of heat transfer corresponding to the system boundary at temperature T be $\delta Q'_R$, for this reversed process.

Then we have along path _____
1B2A1, _____

But, since the second cycle is simple the first one with the direction reversed, we have, Hence entropy a property of a system.

12. Derive Clausius inequality for a cycle.

[08 Marks, Jul-2013]

13. Using entropy principle show that mixing of two fluids is an irreversible process.

[06 Marks, Jul-2013]

Using equation (1), for an irreversible cycle,

$$\oint \frac{\delta Q}{T} = \int_A^B \left(\frac{\delta Q}{T} \right)_I + \int_B^A \left(\frac{\delta Q}{T} \right)_R < 0 \text{ ----- (5)}$$

Now subtracting equation (5) from equation (4), we get

$$\int_A^B dS_I > \int_A^B \left(\frac{\delta Q}{T} \right)_I \text{ ----- (6)}$$

THE CLAUSIUS INEQUALITY:

When any system undergoes a cyclic process, the integral around the cycle of $\frac{\delta Q}{T}$ is less than or equal to zero.

In symbols, $\oint \frac{\delta Q}{T} \leq 0 \text{ ----- (1)}$

Where δQ is an infinitesimal heat transfer, T is absolute temperature of the part of the system to which heat transfer δQ occurs.

PROOF:

For any reversible cycle from Clausius theorem,

$$\oint_R \frac{\delta Q}{T} = 0 \text{ ----- (2)}$$

From the Carnot's theorem we know that the efficiency of an irreversible engine is less than that of a reversible engine, i.e. $\eta_I < \eta_R$

14. One Kg of water at 273K is heated to 373k by first bringing it in contact with reservoir at 323K and then reservoir at 373k. What is the change in entropy of universe?

[06 Marks, Jul-2013]

Where η_I is efficiency of the irreversible engine and η_R is efficiency of the reversible engine.

$$\text{Hence, } 1 - \left(\frac{\delta Q_L}{\delta Q_H} \right)_I < 1 - \left(\frac{\delta Q_L}{\delta Q_H} \right)_R \text{ ----- (3)}$$

Where I and R represents irreversible and reversible processes respectively.

For a reversible engine, the ratio of the heat absorbed and heat rejected is equal to the ratio of the absolute temperatures. Therefore

$$1 - \left(\frac{\delta Q_L}{\delta Q_H} \right)_I < 1 - \left(\frac{T_L}{T_H} \right) \text{ ----- (4) \quad i.e. } \left(\frac{\delta Q_L}{\delta Q_H} \right)_I > \left(\frac{T_L}{T_H} \right)$$

$$\text{or } \left(\frac{\delta Q_H}{\delta Q_L} \right)_I < \left(\frac{T_H}{T_L} \right) \text{ i.e. } \left(\frac{\delta Q_H}{T_H} \right)_I - \left(\frac{\delta Q_L}{T_L} \right)_I < 0 \text{ ----- (5)}$$

Using sign conventions of +ve for absorption of heat and -ve for the rejection of heat , we get,

$$\left(\frac{\delta Q_H}{T_H} \right)_I + \left(\frac{\delta Q_L}{T_L} \right)_I < 0 \text{ ----- (6)}$$

From this we see that the algebraic sum of the ratios of the amounts of heat transferred to the absolute temperature for a cyclic irreversible process is always less than zero,

$$\oint_I \frac{\delta Q}{T} < 0 \text{ ----- (7)}$$

$$\text{Combining equations (2) and (7), we get } \oint \frac{\delta Q}{T} \leq 0 \text{ ----- (8)}$$

This is known as **CLAUSIUS INEQUALITY**.

If $\oint \frac{\delta Q}{T} = 0$, the cycle is reversible, $\oint \frac{\delta Q}{T} < 0$, the cycle is irreversible and possible and $\oint \frac{\delta Q}{T} > 0$, the cycle is impossible since it violates the second law of thermodynamics.

UNIT-6
PURE SUBSTANCE

1. Define the following

- a. Tripple point
- b. Critical temperature
- c. Dryness fraction
- d. Saturation temperature.

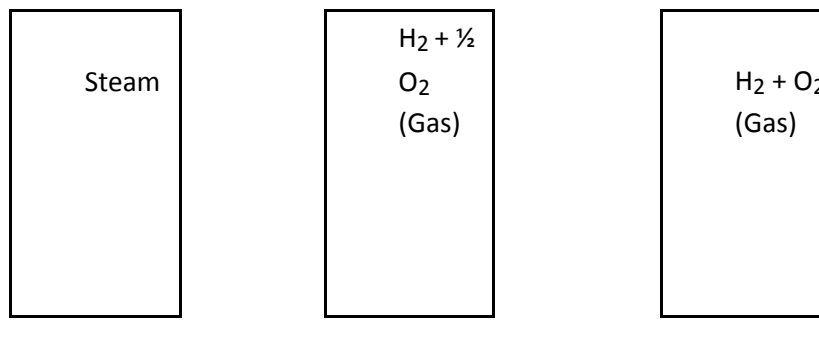
[04Marks, Jul-2015]

2. Sketch and explain the construction and working of a separating and throttling calorimeter used for determining the dryness fraction of steam in a boiler.

[08 Marks, Jul-2015]

A system is set to be a pure substance if it is (i) homogeneous in chemical composition, (ii) homogeneous in chemical aggregation and (iii) invariable in chemical aggregation.

Homogeneous in chemical composition means that the composition of each part of the system is same as the composition of any other part. Homogeneous in chemical aggregation implies that the chemical elements must be chemically combined in the same way in all parts of the system. Invariable in chemical aggregation means that the chemical aggregation should not vary with respect to time.



(i)
Satisfies condition
(i)

(ii)
Satisfies condition (i)

(iii)
Does not
satisfies
condition (i)

Satisfies condition (ii) Does not satisfies condition (ii)

Satisfies condition
Illustration of the definition of pure substance

Figure

In figure three systems are shown. The system (i) shown in the figure is a mixture of steam and water. It is homogeneous in chemical composition because in every part of the system we have, for every atom of oxygen we have two atoms of hydrogen, whether the sample is taken from steam or water. The same is through for system (ii) consisting of water and uncombined mixture of hydrogen and oxygen. System (iii) however is not homogeneous in chemical composition because in the upper part of the system hydrogen and oxygen are present in the ratio 1:1 where as in the bottom portion they are present in the ratio 2:1.

System (i) also satisfies condition (ii), because both hydrogen and oxygen have combined chemically in every part of the system. System (ii) on the other hand does not satisfies condition (ii) because the bottom part of the system has two elements namely hydrogen and oxygen have chemically combined where as in the upper part of the system the (ii) elements appear as a mixture of two individual gases.

Invariable in chemical aggregation means that the state of chemical combination of the system should not change with time. Thus the mixture of hydrogen and oxygen, if it is changing into steam during the time the system was under consideration, then the systems chemical aggregation is varying with time and hence this system is not a pure substance. Thus the system (i) is a pure substance where as the systems (ii) and (iii) is not pure substances.

3. Identify the type of steam in the following three cases, using the steam tables and giving necessary calculation supporting your claim.

- i) 2 kg of steam at 8 bar with an enthalpy of 5538kJ at a temperature of 170.40C.**
- ii) 1 kg of steam at 2550 kPa occupies a volume of 0.2742m³. also find the steam temperature.**
- iii) 1 kg and steam at 60 bar with an enthalpy of 2470.73kJ/kg. [08 Marks, Jul-2015]**

4. What is meant by pure substance? Can we treat air as a pure substance?

[06 Marks, Jan-2015]

5. Name the widely used thermodynamic diagrams for a pure substance.

[04 Marks, Jan-2015]

When interaction of heat takes place between a closed system and its surroundings, the internal

energy of the system changes. If δQ is the amount of heat transferred to raise the temperature of 1 kg of substance by dT , then, specific heat $C = \delta Q/dT$

As we know, the specific heat of gas depends not only on the temperature but also upon the type of the heating process. i.e., specific heat of a gas depends on whether the gas is heated under constant volume or under constant pressure process.

\therefore We have $dQ = m C_V \cdot dT$ for a rev. non-flow process at constant volume

and $dQ = m C_p \cdot dT$ for a rev. non-flow process at constant pressure

For a perfect gas, C_p & C_V are constant for any one gas at all pressure and temperatures. Hence, integrating above equations.

Flow of heat in a rev. constant pressure process = $m C_p (T_2 - T_1)$

Flow of heat in a rev. constant volume process = $m C_V (T_2 - T_1)$

The internal energy of a perfect gas is a function of temperature only. i.e, $u = f(T)$, to evaluate this function, let 1 kg of gas be heated at constant volume

From non-flow energy equation, $\delta Q = dU + \delta W$

$\delta W = 0$ since volume remains constant

$\therefore \delta Q = dU = C_V \cdot dT$

Int. $U = C_V T + k$ where k is a constant

For mass m , Int. energy = $m C_V T$

Any process between state 1 to state 2,

6. The following observations were recorded in an experiment with a combined separating and throttling calorimeter.

Pressure in the steam main 15 bar

Mass of water drained from the separator 0.55kg

Mass of steam condensed after throttle valve 4.2 kg

Pressure and temperature after throttling 1 bar, 1200C

Evaluate the dryness fraction of the steam in the main.

[10 Marks, Jan-2015]

7. Define dryness fraction? What are the methods used to measure dryness fraction? With neat sketch explain any one method? [10 Marks, Jun-2014]

A system is set to be a pure substance if it is (i) homogeneous in chemical composition, (ii) homogeneous in chemical aggregation and (iii) invariable in chemical aggregation.

Homogeneous in chemical composition means that the composition of each part of the system is same as the composition of any other part. Homogeneous in chemical aggregation implies that the chemical elements must be chemically combined in the same way in all parts of the system. Invariable in chemical aggregation means that the chemical aggregation should not vary with respect to time.

8. A rigid vessel of 2m^3 volume is filled with superheated steam at 20 bar and 350°C . the vessel is cooled until the steam is just dry saturated. Calculate the mass of steam in the vessel; the final pressure of steam and amount of energy transferred as heat to the surroundings.

[10 Marks, Jun-2014]

9. Draw the phase equilibrium diagram for a pure substance on T-S plot with relevant constant property lines. [05 Marks, Jan-2014]

10. What is the main objective of quality measurement? With a neat sketch, explain throttling calorimeter. [07 Marks, Jan-2014]

a) Reversible adiabatic process ($pV^\gamma = \text{constant}$)
Applying 1st law of thermodynamics to the process,

$$Q_{1-2} = U_2 - U_1 + W_{1-2}$$

The above equation is true for an adiabatic process whether the process is reversible or not. In an adiabatic experiment, the work done W_{1-2} by the fluid is at the expense of a reduction in the internal energy of the fluid. Similarly in an adiabatic composition process, all the work done on the fluid goes to increase the internal energy of the fluid.

To derive $pV^\gamma = C$: For a reversible adiabatic process

We have $\delta q = du + \delta u$

For a reversible process, $\delta w = p dV$ $\delta q = du + p dV$

= 0

For an adiabatic process $\delta q = 0$

Also for a perfect gas, $pV = RT$ or $p = \frac{RT}{V}$

$$dU + RT \frac{dV}{V}$$

Also, $u = C_V T$ or $du = C_V dT$

$$C_V dT + RT \frac{dV}{V} = 0$$

$$\therefore C_V \ln T + R \ln V = \text{constant}$$

$$\text{Sub. } T = \frac{pV}{R}$$

$$\text{or } \ln \frac{pV^\gamma}{R} = \text{constant}$$

$$\text{i.e., } \ln \frac{pV^\gamma}{R} = \text{constant}$$

$$\text{or } \frac{pV^\gamma}{R} = e^{\text{constant}} = \text{constant}$$

$$\text{i.e., } pV^\gamma = \text{constant}$$

we have $pV = RT$

$$\text{or } p = \frac{RT}{V}$$

sub. This value of p in $pV^\gamma = C$

Also, $V = \frac{RT}{P}$ sub. This in equation pressure $^\gamma = C$

$$p = \text{constant} \left(\frac{RT}{p} \right)^\gamma$$

11. What do you understand by degree of superheat? Steam initially at 1.5MPa, 300°C expands reversibly and adiabatically in a steam turbine to 40°C. Determine the ideal work output of the turbine per kg of steam. [08 Marks, Jan-2014]
12. With a neat sketch indicate various parameters on typical T-S and H-S diagrams. [06 Marks, Jun-2013]
13. With a neat sketch, explain how throttling calorimeter can be used to measure the dryness fraction of wet vapour. [06 Marks, Jun-2013]
14. Steam at 1Mpa and 250°C enters a nozzle with a velocity of 60m/s and leaves the nozzle at 10kPa Assuming the flow process to be isentropic and the flow rate to be 1Kg/s determine: the exit velocity and exit diameter of the nozzle. [08 Marks, Jun-2013]

Solution: Total initial energy $E_1 = KE_1 + PE_1 + U_1$

$$85 = 17 + 5 + U_1 \quad U_1 = 63 \text{ kJ}$$

$$\text{Initial sp. i.e.,} = \frac{63}{4.17} = 15.108 \text{ kJ/kg}$$

$$\text{Final state: } E_2 = KE_2 + PE_2 + U_2 = 1.9 + 1.1 + 4.17(150) = 628.5 \text{ kJ}$$

From 1st law, $\delta Q = E_2 - E_1 + W$

$$0 = 628.5 - 63 + W = \therefore 565.5 \text{ kJ}$$

A mass of 0.2 kg of a pure substance at a pressure of 1 bar and a temperature of 313 k occupies a volume of 0.15 m³. Given that the int. energy of the substance is 31.5 kJ, evaluate the sp. Enthalpy of the substance.

Solution: $m = 0.2 \text{ kg}$ $P = 1 \times 10^5 \text{ N/m}^2$ $T = 313 \text{ k}$ $v = 0.15$ $u = 31.5 \text{ kJ}$

We have, enthalpy = $U + Pv$

$$= 31.5 \times 10^3 + 1 \times 10^5 \times 0.15$$

$$= 46.5 \text{ kJ}$$

sp. Enthalpy $= 46.5/0.2 = 232.5 \text{ kJ/kg}$

UNIT-7
THERMODYNAMIC RELATIONS

1. Write notes on the following:
 - i) Clausius Clapeyron equation.
 - ii) Maxwell's equations. [08 Marks, July-2015]
2. Derive an expression for change in entropy for an ideal gas undergoing
 - a. An isobaric process
 - b. A polytropic process [06 Marks, July-2015]
3. One kg of air undergoes a cycle composed of the following three reversible processes:
 - a. Constant pressure expansion from 0.1MPa and 300K to 400K.
 - b. Constant volume cooling to 300K.
 - c. An isothermal compression to restore the gas to 0.1MPa.

Sketch the P-V diagram for the above cycle and estimate the entropy changes for the three processes.

[06 Marks, July-2015]

From the first law of TD,

$$\delta q = du + \delta w$$

For an adiabatic process, $\delta q = 0$

Hence the work done by a unit mass of a perfect gas on a piston during an adiabatic expansion process is equal to the decrease in internal energy, i.e., $\delta w = -du$

Whereas, for an adiabatic compression process, the internal energy of the gas will increase with a consequent increase in temperature.

For a perfect gas, $du = c_v dT$

Hence the work done during an adiabatic non-flow process between states 1 and 2 is given by

For the closed system, the work done during a polytropic expansion process is given by,

The work done for a steady flow system during a polytropic expansion process is given by,

It may be noted that the work done for a steady flow system is n times that for a closed system.

4. Show that the internal energy of an ideal gas is a function of temperature only.

[08 Marks, Jan-2015]

5. A gas of mass 1.5kg undergoes a quasistatic expansion which follows a relationship $p=a+bV$, where a and b are constants. The initial and final pressures are 1000kPa and 200kPa respectively and the corresponding volumes are 0.2m^3 and 1.2m^3 . The specific internal energy of the gas is given by the relation $u=1.5PV-85$ kJ/kg, where P is in kPa and V in m^3/kg . Calculate the net heat transfer and the max internal energy of the gas attained during expansion.

[12 Marks, Jan-2015]

The polytropic process of a perfect gas:

A Polytropic process is one for which the pressure volume relation is given by $p v^n = \text{constant}$, where the exponent n for the given process is a constant and may have any numerical value ranging from plus infinity to minus infinity.

From the above equation, it is evident that the properties at the end states of the reversible or irreversible polytropic process of a perfect gas may be written in the form

$$\frac{P_2}{P_1} = \left(\frac{v_1}{v_2} \right)^n$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} = \left(\frac{v_2}{v_1} \right)^{n-1}$$

There are four values of the exponent n that indicate processes of particular interest. When

- $n = 0$, constant pressure or isobaric process
- $n = \pm \infty$, constant volume or isovolumic process
- $n = 1$, constant temperature or isothermal process and
- $n = \gamma$, constant entropy or isentropic process

These processes are shown in the fig. on p-v and T-s diagrams.

3. Write Maxwell's equations and explain the terms involved. [04 Marks, Jun-2014]

4. Show that the change in entropy when a perfect gas undergoes a polytropic change

$PV^n = \text{constant}$ is given by the expression $(S_2 - S_1) = C_v \left(\frac{\gamma - n}{n} \right) \ln \left(\frac{P_1}{P_2} \right)$ [06 Marks, Jun-2014]

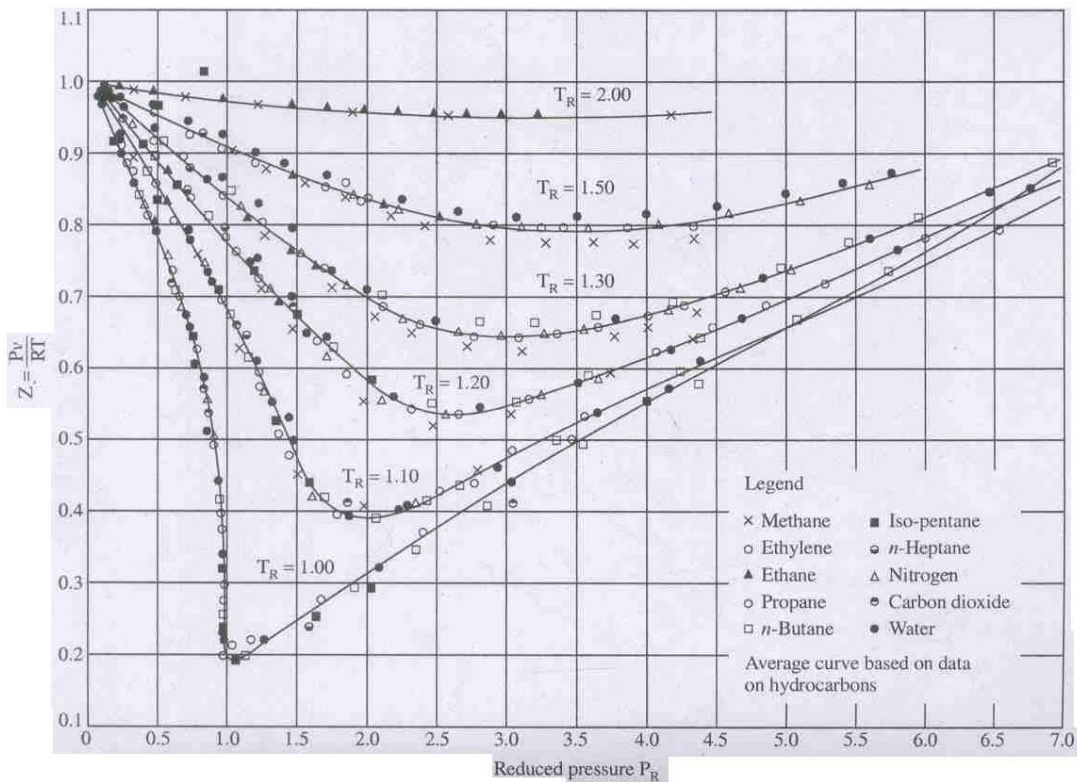
The following observations can be made from the generalized compressibility chart:

- At very low pressures ($P_R \ll 1$), the gases behave as an ideal gas regardless of temperature.
- At high temperature ($T_R > 2$), ideal gas behaviour can be assumed with good accuracy regardless of pressure except when ($P_R \gg 1$).
- The deviation of a gas from ideal gas behaviour is greatest in the vicinity of the critical point.

5. 0.2 kg of air with pressure 1.5 bar and temperature 27°C is compressed to a pressure of 15 bar according to the law $PV^{1.25} = \text{constant}$. Determine i) Work done on or by the air. ii) Heat flow to or from the air iii) Change of entropy stating whether it is an increase or decrease in entropy. For air $R = 0.287 \text{ kJ/kg-K}$, $\gamma = 1.4$, $C_v = 0.718 \text{ kJ/kg-K}$. [10 Marks, Jun-2014]

6. Obtain Clausius-Clapeyron relation involving the saturation temperature and pressure.

[10 Marks, Jan-2014]



7. Determine the enthalpy of vaporization of water at 200°C using Clapeyron equation.

[10 Marks, Jan-2014]

8. Obtain four Maxwell relations for a simple compressible system in the form $\left\{\frac{\partial M}{\partial y}\right\}_x = \left\{\frac{\partial N}{\partial x}\right\}_y$

[08 Marks, Jun-2013]

9. Obtain Clausius-Clapeyron relation involving the saturation temperature and pressure.

[06 Marks, Jun-2013]

10. Determine the enthalpy of vaporization of water at 200°C using Clapeyron equation.

[06 Marks, Jun-2013]

The compressibility factor can also be obtained from v-T or v-P data. Since the critical volume may not be consistent with the generalized chart, the pseudo critical specific volume v_c^1 is used in the definition

**UNIT-8
GAS MIXTURE**

1. Write notes on the following:

- a. Compressibility factor.
- b. Compressibility chart.
- c. Law of corresponding states.

[09 Marks, July-2015]

2. A volume analysis of a gaseous mixture yields the following results.

CO₂=12%, O₂=4%, N₂=82%, CO=2%. Determine the analysis on a mass basis and molecular weight and the gas constant on a mass basis for the mixture. Assume ideal gas behavior.

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[08 Marks, July-2015]

3. Define the terms partial pressure mole fraction, volume fraction of gas constituent in a mixture.

[03 Marks, July-2015]

4. Write notes on the following:

- a. Dalton's law of partial pressures.
- b. Vander waal's equation of states.
- c. Generalized compressibility chart.

[12 Marks, July-2014]

From the critical point data of gases, we have $T_c = 132.8 \text{ K}$, $P_c = 37.7 \text{ bar}$

$$= 0.0366 \text{ m}^3 / \text{kg-mole}$$

Substituting the constants a and b in the Van der Waals' equation of state, we get

1.364

$$P = 0.87 \frac{0.0366}{0.083143} \times 3000.87^2$$

Noting $v = 0.03 \text{ m}^3/\text{kg}$, $\approx 0.03 \times 29 = 0.87 \text{ m}^3/\text{kg mole}$

5. Determine the pressure exerted by carbon dioxide in a container of 1.5 m^3 capacity when it contains 5kg at 27°C by using.

i) Ideal gas equation

ii) Vander waal's equation

Take the Vander waal's constant $a=365.6 \text{ kN}\cdot\text{m}^4/(\text{kgmol})^2$; $b=0.0428 \text{ m}^3/\text{kgmol}$; universal gas constant $=R_u=8.314 \text{ kJ/kgmol}\cdot\text{K}$. [08 Marks, July-2014]

6. Explain the following:

a. Generalized compressibility chart.

b. Law of corresponding states.

c. Compressibility factor.

[06 Marks, Jan-2014]

The real gases follow closely the ideal gas equation only at low pressures and high temperatures. The pressures and temperatures depend on the critical pressure and critical temperature of the real gases. For example – 100°C is a low temperature for most of the gases, but not for air or nitrogen. Air or nitrogen can be treated as ideal gas at this temperature and atmospheric pressure with an error which is $<1\%$. This is because nitrogen is well over its critical temperature of -147°C and away from the saturation region. At this temperature and pressure most of the substances would exist in solid phase. Hence, the pressure and temperature of a substance is high or low relative to its critical pressure or temperature.

Gases behave differently at a given pressure and temperature, but they behave very much the same at temperatures and pressures normalized with respect to their critical temperatures and pressures. The ratios of pressure, temperature and specific volume of a real gas to the corresponding critical values are called the reduced properties.

7. Derive Vander Waal's constants in terms of critical properties. [08 Marks, Jan-2014]

8. Determine the pressure exerted by carbon dioxide in a container of 1.5 m^3 capacity when it contains 5kg at 27°C by using.

i) Ideal gas equation

ii) Vander waal's equation.**[06 Marks, Jan-2021]**

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Gases behave differently at a given pressure and temperature, but they behave very much the same at temperatures and pressures normalized with respect to their critical temperatures and pressures. The ratios of pressure, temperature and specific volume of a real gas to the corresponding critical values are called the reduced properties.

9. State and explain Amagat's law.**[06 Marks, Jun-2019]****10. State and explain law of corresponding states.****[06 Marks, Jun-2020]****11. A mixture of methane with, just enough oxygen to permit combustion is burned.**

The temperature and pressure of the final mixture are 27°C and 101.3 Kpa respectively,

Calculate:

- a. Mass fraction of the reactants,**
- b. the volume fraction of products,**
- c. the partial pressure of water vapour in the products of combustion and**
- d. volume of products.**
- e.**

[08 Marks, Jun-2018]

Compressibility Factor and Compressibility Chart:

The specific volume of a gas becomes very large when the pressure is low or temperature is high. Thus it is not possible to conveniently represent the behaviour of real gases at low pressure and high temperature.

For a perfect gas, the equation of state is $Pv = RT$. But, for a real gas, a correction factor has to be introduced in the perfect gas to take into account the deviation of the real gas from the perfect gas equation. This factor is known as the compressibility factor, Z and is defined as,

$$Z = RT/PV$$

$Z = 1$ for a perfect gas. For real gases the value of Z is finite and it may be less or more than

unity depending on the temperature and pressure of the gas.

Reduced Properties:

The real gases follow closely the ideal gas equation only at low pressures and high temperatures. The pressures and temperatures depend on the critical pressure and critical temperature of the real gases. For example – 100 C is a low temperature for most of the gases, but not for air or nitrogen. Air or nitrogen can be treated as ideal gas at this temperature and atmospheric pressure with an error which is <1%. This is because nitrogen is well over its critical temperature of -147 C and away from the saturation region. At this temperature and pressure most of the substances would exist in solid phase. Hence, the pressure and temperature of a substance is high or low relative to its critical pressure or temperature.

Gases behave differently at a given pressure and temperature, but they behave very much the same at temperatures and pressures normalized with respect to their critical temperatures and pressures. The ratios of pressure, temperature and specific volume of a real gas to the corresponding critical values are called the reduced properties.