# UNIT – 08 HEAT AND THERMODYNAMICS

## TWO MARKS AND THREE MARKS:

**01. 'An object contains more heat'- is it a right statement? If not why?**

Heat is not a quantity. Heat is energy in transit which flows from higher temperature object to lower temperature object. Once the heating process is stopped we cannot use the word heat. When we use the word 'heat', it is the energy in transit but not energy stored in the body. An Object has more heat is wrong, instead object is hot will be appropriate.

**02. Obtain an ideal gas law from Boyle's and Charles' law.**

1) Acceleration to Boyle's law P $\alpha \frac{1}{V}$

2) Acceleration to Charle's law V $\alpha$ T. By combining these two equations we have PV = CT. Here C is a positive constant.

3) So we can write the constant C as k times the number of particles N. Here k is the Boltzmann constant ($1.381\times10^{-23}$ $JK^{-1}$) and it is found to be a universal constant. So the ideal gas law can be stated as follows PV = NkT



**03. Define one mole.**

One mole of any substance is the amount of that substance which contains Avogadro number ($N_A$) of particles (such as atoms or molecules).

**04. Define specific heat capacity and give its unit.**

Specific heat capacity of a substance is defined as the amount of heat energy required to raise the temperature of 1kg of a substance by 1 Kelvin or 1°C

$\Delta Q$ = ms $\Delta T$

Therefore, s = $\frac{1}{m}\frac{\Delta Q}{\Delta T}$

Where s – Specific heat capacity of a substance and its value depends only on the nature of the substance not amount of substance.

$\Delta Q$ - Amount of heat energy ; $\Delta T$ - Change in temperature ;
m – Mass of the substance ; The SI unit for specific heat capacity is $Jkg^{-1}K^{-1}$

**05. Define molar specific heat capacity.**

Molar specific heat capacity is defined as heat energy required to increase the temperature of one mole of substance by 1K or 1°C. C = $\frac{1}{\mu}\frac{\Delta Q}{\Delta T}$

Here C is known as molar specific heat capacity of a substance and μ is number of moles in the substance.

The SI unit for molar specific heat capacity is J $mol^{-1}$ $K^{-1}$ .

06. What is a thermal expansion?

Thermal expansion is the tendency of matter to change in shape, area, and volume due to a change in temperature.
All three states of matter (solid, liquid and gas) expand when heated. When a solid is heated, its atoms vibrate with higher amplitude about their fixed points. The relative change in the size of solids is small.

07. Give the expressions for linear, area and volume thermal expansions.

Linear Expansion:

$\alpha_L = \frac{\Delta L}{L \Delta T}$ ; Where, $\alpha L$ = coefficient of linear expansion.

$\Delta L$ = Change in length; L = Original length ; $\Delta T$ = Change in temperature.

Area Expansion:

$\alpha_A = \frac{\Delta A}{A \Delta T}$ ; Where, $\alpha A$ = coefficient of area expansion.

$\Delta A$ = Change in area; A = Original area ; $\Delta T$ = Change in temperature

Volume Expansion:

$\alpha_V = \frac{\Delta V}{V \Delta T}$ Where, $\alpha V$ = coefficient of volume expansion;

$\Delta V$ = Change in volume; V = Original volume ; $\Delta T$ = Change in temperature. Unit of coefficient of linear, area and volumetric expansion of solids is $^\circ C^{-1}$ or $K^{-1}$



08. Define latent heat capacity. Give its unit.

Latent heat capacity of a substance is defined as the amount of heat energy required to change the state of a unit mass of the material.

$Q = m \times L$ ; $L = \frac{Q}{m}$

Where L = Latent heat capacity of the substance; Q = Amount of heat; m = mass of the substance. The SI unit for Latent heat capacity is J $kg^{-1}$ .

09. State Stefan-Boltzmann law.

Stefan Boltzmann law states that, the total amount of heat radiated per second per unit area of a black body is directly proportional to the fourth power of its absolute temperature.

$E \alpha T^4$ or $E = \sigma T^4$ ; Where, $\sigma$ is known as Stefan's constant. Its value is $5.67 \times 10^{-8}$ W $m^{-2}$ $k^{-4}$

10. What is Wien's law?

Wien's law states that, the wavelength of maximum intensity of emission of a black body radiation is inversely proportional to the absolute temperature of the black body. $\lambda_m \, \alpha \, \frac{1}{T}$ or $\lambda_m = \frac{b}{T}$. Where, b is known as Wien's constant. Its value is $2.898 \times 10^{-3}$ m K

11. Define thermal conductivity. Give its unit.

The quantity of heat transferred through a unit length of a material in a direction normal to unit surface area due to a unit temperature difference under steady state conditions is known as thermal conductivity of a material.

$\frac{Q}{L} = \frac{KA\Delta T}{L}$ ; Where, K is known as the coefficient of thermal conductivity.

The SI unit of thermal conductivity is J $s^{-1}$ $m^{-1}$ $K^{-1}$ or W $m^{-1}$ $K^{-1}$.

12. What is a black body?

A black body is an object that absorbs all electromagnetic radiations. It is a perfect absorber and radiator of energy with no reflecting power.

13. What is a thermodynamic system? Give examples.

Thermodynamic system:

A thermodynamic system is a finite part of the universe. It is a collection of large number of particles (atoms and molecules) specified by certain parameters called pressure (P), Volume (V) and Temperature (T). The remaining part of the universe is called surrounding. Both are separated by a boundary.

Examples: A thermodynamic system can be liquid, solid, gas and radiation. Bucket of water, Air molecules in the room, Human body, Fish in the sea.



14. What are the different types of thermodynamic systems?

Open system can exchange both matter and energy with the environment.
Closed system exchange energy, but not matter with the environment.
Isolated system can exchange neither energy nor matter with the environment.

15. What is meant by 'thermal equilibrium'?

Two systems are said to be in thermal equilibrium with each other if they are at the same temperature, which will not change with time.

16. What is mean by state variable? Give example.

In thermodynamics, the state of a thermodynamic system is represented by a set of variables called thermodynamic variables.

Examples: Pressure, temperature, volume and internal energy etc.

The values of these variables completely describe the equilibrium state of a thermodynamic system.

**17. What are intensive and extensive variables? Give examples.**

**Extensive variable** depends on the size or mass of the system.
**Example:** Volume, total mass, entropy, internal energy, heat capacity etc.
**Intensive variables** do not depend on the size or mass of the system.
**Example:** Temperature, pressure, specific heat capacity, density etc.

**18. What is an equation of state? Give an example.**

Equation of state:

The equation which connects the state variables in a specific manner is called equation of state. A thermodynamic equilibrium is completely specified by these state variables by the equation of state. If the system is not in thermodynamic equilibrium then these equations cannot specify the state of the system.

Example of equation of state called vander Waals equation. Real gases obey this equation at thermodynamic equilibrium. The air molecules in the room truly obey vander Waals equation of state. But at room temperature with low density we can approximate it into an ideal gas.



**19. State Zeroth law of thermodynamics.**

The zeroth law of thermodynamics states that if two systems, A and B, are in thermal equilibrium with a third system, C, then A and B are in thermal equilibrium with each other.

**20. Define the internal energy of the system.**

The internal energy of a thermodynamic system is the sum of kinetic and potential energies of all the molecules of the system with respect to the center of mass of the system.

The energy due to molecular motion including translational, rotational and vibrational motion is called internal kinetic energy ($E_K$) The energy due to molecular interaction is called internal potential energy ($E_P$).

Example: Bond energy. $U = E_K + E_P$

**21. Are internal energy and heat energy the same? Explain.**

No, but they are related. If heat energy is added to substance, its internal energy will increase. Internal energy is a means are of the amount of kinetic and potential energy possessed by particles in a substation.

Heat energy concerns only transfer of internal energy from the hotter to a colder body.

**22. Define one calorie.**

The amount of heat required at a pressure of standard atmosphere to raise the temperature of 1g of water $1^0C$.

**23. Did joule converted mechanical energy to heat energy? Explain.**

1) Yes, In his experiment, two masses were attached with a rope and a paddle wheel. When these masses fall through a distance h due to gravity, both the masses lose potential energy equal to 2mgh.

2) When the masses fall, the paddle wheel turns. Due to the turning of wheel inside water, frictional force comes in between the water and the paddle wheel.

3) This causes a rise in temperature of the water. This implies that gravitational potential energy is converted to internal energy of water.

4) The temperature of water increases due to the work done by the masses. In fact, Joule was able to show that the mechanical work has the same effect as giving heat.



**24. State the first law of thermodynamics.**

Change in internal energy ($\Delta U$) of the system is equal to heat supplied to the system (Q) minus the work done by the system (W) on the surroundings.

**25. Can we measure the temperature of the object by touching it?**

1) No, When you stand bare feet with one foot on the carpet and the other on the tiled floor, your foot on tiled floor feels cooler than the foot on the carpet even though both the tiled floor and carpet are at the same room temperature.

2) It is because the tiled floor transfers the heat energy to your skin at higher rate than the carpet. So the skin is not measuring the actual temperature of the object; instead it measures the rate of heat energy transfer.

3) But if we place a thermometer on the tiled floor or carpet it will show the same temperature.

**26. Give the sign convention for Q and W.**

| | | |
|---|---|---|
| System gains heat | - | Q is positive |
| System loses heat | - | Q is negative |
| Work done on the system | - | W is negative |
| Work done by the system | - | W is positive |

**27. Define the quasi-static process.**

A quasi-static process is an infinitely slow process in which the system changes its variables (P,V,T) so slowly such that it remains in thermal, mechanical and chemical equilibrium with its surroundings throughout. By this infinite slow variation, the system is always almost close to equilibrium state.

**28. Give the expression for work done by the gas.**

In general the work done by the gas by increasing the volume from $V_i$ to $V_f$ is given by $W = \int_{V_f}^{V_i} PdV$

**29. What is PV diagram?**

PV diagram is a graph between pressure P and volume V of the system. The P-V diagram is used to calculate the amount of work done by the gas during expansion or on the gas during compression.

**30. Explain why the specific heat capacity at constant pressure is greater than the specific heat capacity at constant volume.**

Because when heat is added at constant pressure the substance, expands and work. i.e. more amount of energy has to be supplied to a constant pressure to increase the system's temperature by the same amount. Some of this energy is lost due to expansion work done by the system.



**31. Give the equation of state for an isothermal process.**

The equation of state for isothermal process is given by PV = Constant

**32. Give an expression for work done in an isothermal process.**

$$W = \mu RT \text{ in } \left(\frac{V_f}{V_i}\right)$$

**33. Express the change in internal energy in terms of molar specific heat capacity.**

If Q is the heat supplied to mole of a gas at constant volume and if the temperature changes by an amount $\Delta T$ , we have $Q = \mu C_v \Delta T$ -------------1

By applying the first law of thermodynamics for this constant volume process (W=0, since dV=0), we have $Q = \Delta U - 0$ ------------2

By comparing the equations (1) and (2), $\Delta U = \mu C_v \Delta T$ or $C_v = \frac{1}{\mu}\frac{\Delta U}{\Delta T}$

If the limit $\Delta T$ goes to zero, we can write $C_v = \frac{1}{\mu}\frac{dU}{dT}$

Since the temperature and internal energy are state variables, the above relation holds true for any process.

**34. Apply first law for (a) an isothermal (b) adiabatic (c) isobaric processes.**

Isothermal : Q = W ; Q – Heat ; W – Wire

Adiabatic : ΔU = W Change internal Energy; Isobaric: ΔU = Q – PΔU

**35. Give the equation of state for an adiabatic process.**

The equation of state for an adiabatic process is given by $PV^{\gamma}$ = Constant. Here $\gamma$ is called adiabatic exponent $\left(\gamma = \frac{C_p}{C_v}\right)$ which depends on the nature of the gas. The equation implies that if the gas goes from an equilibrium state ($P_i$,$V_i$) to another equilibrium state ($P_f$ ,$V_f$) adiabatically then it satisfies the relation.

**36. Give an equation state for an isochoric process.**

The equation of state for an isochoric process is given by P= $\left(\frac{\mu R}{V}\right)$T,

Where, $\left(\frac{\mu R}{V}\right)$ = Constant

**37. If the piston of a container is pushed fast inward. Will the ideal gas equation be valid in the intermediate stage? If not, why?**

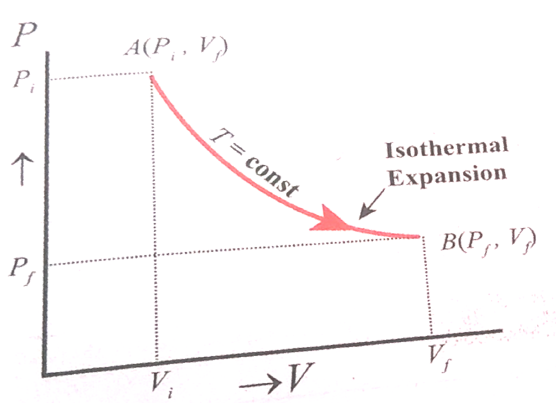
Decrease in volume leading to increase in temperature work is done on the gas. Ideal gas equation PV = RT. When piston be pushed further the parameters V and R are taken as constant. The equation becomes

P = kT. i.e P $\alpha$ T



**38. Draw the PV diagram for ;**

a. Isothermal process

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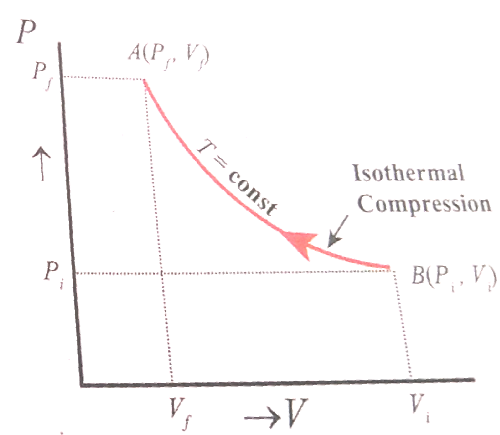


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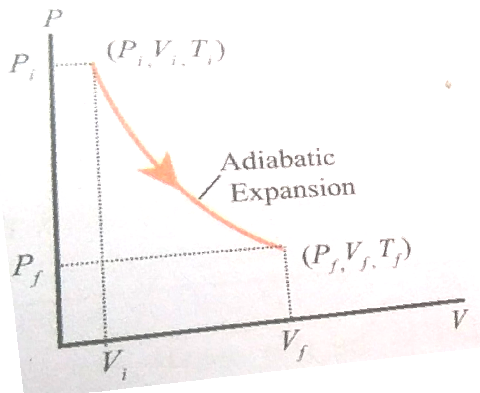
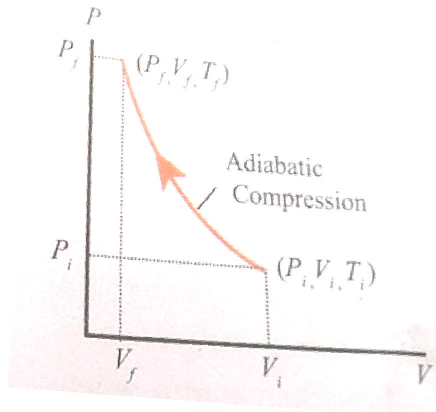
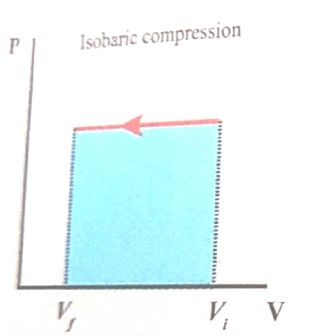
b. Adiabatic process




c. isobaric process

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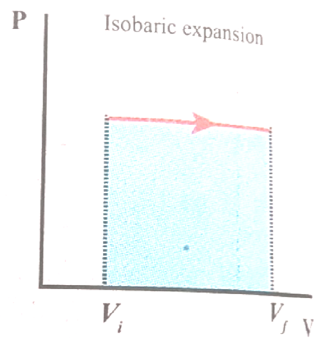
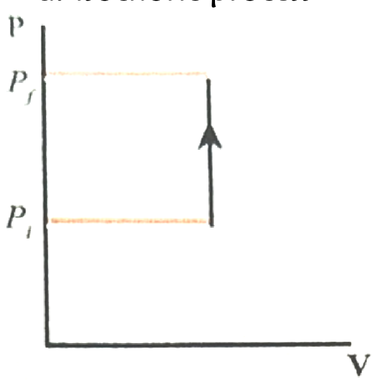
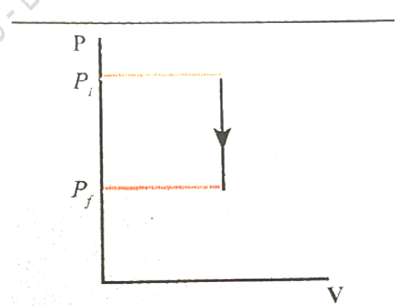



(b)

d. Isochoric process




39. What is a cyclic process?

This is a thermodynamic process in which the thermodynamic system returns to its initial state after undergoing a series of changes. Since the system comes back to the initial state, the change in the internal energy is zero. In cyclic process, heat can flow in to system and heat flow out of the system.

**40. What is meant by reversible and irreversible processes?**

**Reversible process:** A thermodynamic process can be considered reversible only if it possible to retrace the path in the opposite direction in such a way that the system and surroundings pass through the same states as in the initial, direct process. Example: A quasi–static isothermal expansion of gas, slow compression and expansion of a spring.

**Irreversible process:** All natural processes are irreversible. Irreversible process cannot be plotted in a PV diagram, because these processes cannot have unique values of pressure, temperature at every stage of the process.

**41. State Clausius form of the second law of thermodynamics**

"Heat always flows from hotter object to colder object spontaneously". This is known as the Clausius form of second law of thermodynamics.

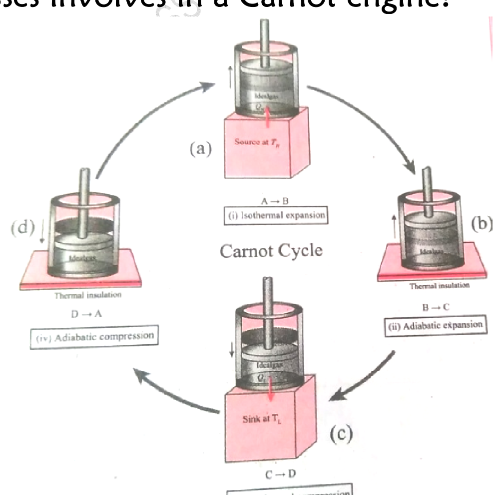
**42. State Kelvin-Planck statement of second law of thermodynamics.**

**Kelvin-Planck statement:** It is impossible to construct a heat engine that operates in a cycle, whose sole effect is to convert the heat completely into work. This implies that no heat engine in the universe can have 100% efficiency.

**43. Define heat engine.**

Heat engine is a device which takes heat as input and converts this heat in to work by undergoing a cyclic process.

**44. What are processes involves in a Carnot engine?**




**45. Can the given heat energy be completely converted to work in a cyclic process? If not, when can, the heat can completely converted to work?**

1) No, In a cyclic process, the complete heat energy is not completely converted to work. The whole heat cannot be converted into work, as it will violate second law of thermodynamics.

2) In an Isothermal process the whole heat can be converted into work. For an isothermal process dQ = dT, which shows that whole heat can be converted into work.

**46. State the second law of thermodynamics in terms of entropy.**

"For all the processes that occur in nature (irreversible process), the entropy always increases. For reversible process entropy will not change". Entropy determines the direction in which natural process should occur.

**47. Why does heat flow from a hot object to a cold object?**

Because entropy increases when heat flows from hot object to cold object.

**48. Define the coefficient of performance.**

COP is a measure of the efficiency of a refrigerator. It is defined as the ratio of heat extracted from the cold body (sink) to the external work done by the compressor W. COP $= \beta = \frac{Q_L}{W}$

**49. Can water be boiled without heating?**

Yes, at low pressure, the water boils fast at low temperature below the room temperature, when the pressure is made low, the water starts boiling without supplying any heat.

**50. As air is a bad conductor of heat, why do we not feel warm without clothes?**

This is conductor when we are without clothes air carries away heat from our body due to convection and hence we feel cold.

**51. Why is it hotter at the same distance over the top of a fire than in front of it?**

At a point in front of fire, heat is received due to the process of radiation only, while at a point above the fire, heat reaches both due to radiation and convection.

**52. Define Triple point.**

Triple point the triple point of a substance is the temperature and pressure at which the three phases (gas, liquid and solid) of that substance coexist in thermodynamic equilibrium. The triple point of water is at 273.1 K

**53. Write the applications of thermal conversion.**

1) Boiling water in a cooking pot is an example of convection. Water at the bottom of the pot receives more heat. Due to heating, the water expands and the density of water decreases at the bottom.

2) Due to this decrease in density, molecules rise to the top. At the same time the molecules at the top receive less heat and become denser and come to the bottom of the pot.

3) This process goes on continuously. The back and forth movement of molecules is called convection current.

4) To keep the room warm, we use room heater. The air molecules near the heater will heat up and expand.

5) As they expand, the density of air molecules will decrease and rise up while the higher density cold air will come down. This circulation of air molecules is called convection current.

54. Write the main features of prevost theory?

1) Every object emits heat radiations at all finite temperatures (except 0 K) as well as it absorbs radiations from the surroundings. For example, if you touch someone, they might feel your skin as either hot or cold.

2) A body at high temperature radiates more heat to the surroundings than it receives from it. Similarly, a body at a lower temperature receives more heat from the surroundings than it loses to it.

3) Prevost applied the idea of 'thermal equilibrium' to radiation. He suggested that all bodies radiate energy but hot bodies radiate more heat than the cooler bodies. At one point of time the rate of exchange of heat from both the bodies will become the same. Now the bodies are said to be in 'thermal equilibrium'. Only at absolute zero temperature a body will stop emitting.



55. Draw and explain the distribution of radiation intensity.

1) It implies that if temperature of the body increases, maximal intensity wavelength ($\lambda m$) shift s towards lower wavelength (higher frequency) of electromagnetic spectrum.

2) From the graph it is clear that the peak of the wavelengths is inversely proportional to temperature. The curve is known as 'black body radiation curve'.

## FIVE MARKS:

01. Explain the meaning of heat and work with suitable examples.

Meaning of work:

1) When you rub your hands against each other the temperature of the hands increases. You have done some work on your hands by rubbing. The temperature of the hands increases due to this work. Now if you place your hands on the chin, the temperature of the chin increases.

2) This is because the hands are at higher temperature than the chin. In the above example, the temperature of hands is increased due to work and temperature of the chin is increased due to heat transfer from the hands to the chin.

3) By doing work on the system, the temperature in the system will increase and sometimes may not. Like heat, work is also not a quantity and

through the work energy is transferred to the system . So we cannot use the word 'the object contains more work' or 'less work'.

4) Either the system can transfer energy to the surrounding by doing work on surrounding or the surrounding may transfer energy to the system by doing work on the system. For the transfer of energy from one body to another body through the process of work, they need not be at different temperatures.

## 02. Discuss the ideal gas laws.

### Boyle's law, Charles' law and ideal gas law:

1) For a given gas at low pressure (density) kept in a container of volume V, experiments revealed the following information.
When the gas is kept at constant temperature, the pressure of the gas is inversely proportional to the volume.

$P \; \alpha \; \frac{1}{V}$ It was discovered by Robert Boyle (1627-1691) and is known as Boyle's law.

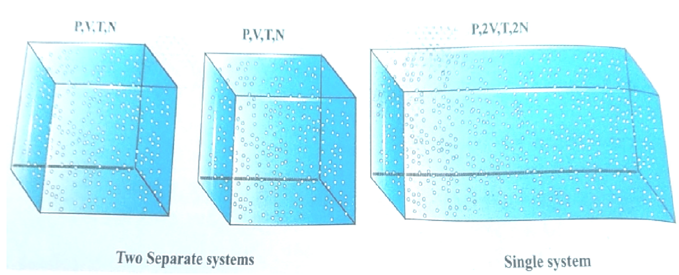
2) When the gas is kept at constant pressure, the volume of the gas is directly proportional to absolute temperature. $V \, \alpha \, T$ . It was discovered by Jacques Charles (1743-1823) and is known as Charles' law.
By combining these two equations we have PV = CT. Here C is a positive constant.

3) C is proportional to the number of particles in the gas container by considering the following argument.

4) If we take two containers of same type of gas with same volume V, same pressure P and same temperature T, then the gas in each container obeys the above equation. PV = CT.

5) If the two containers of gas is considered as a single system, then the pressure and temperature of this combined system will be same but volume will be twice and number of particles will also be double as shown in figure.






For this combined system, V becomes 2V, so C should also double to match with the ideal gas equation $\frac{P(2V)}{T}$ = 2C.

6) It implies that C must depend on the number of particles in the gas and also should have the dimension of $\left[\frac{PV}{T}\right]$ = $JK^{-1}$.

7) we can write the constant C as k times the number of particles N.

Here k is the Boltzmann constant ($1.381\times10^{-23}$ $JK^{-1}$) and it is found to be a universal constant. So the ideal gas law can be stated as follows PV = NkT

03. Explain in detail the thermal expansion.

1) Thermal expansion is the tendency of matter to change in shape, area, and volume due to a change in temperature.

2) All three states of matter (solid, liquid and gas) expand when heated. When a solid is heated, its atoms vibrate with higher amplitude about their fixed points. The relative change in the size of solids is small. Railway tracks are given small gaps so that in the summer, the tracks expand and do not buckle. Railroad tracks and bridges have expansion joints to allow them to expand and contract freely with temperature changes.

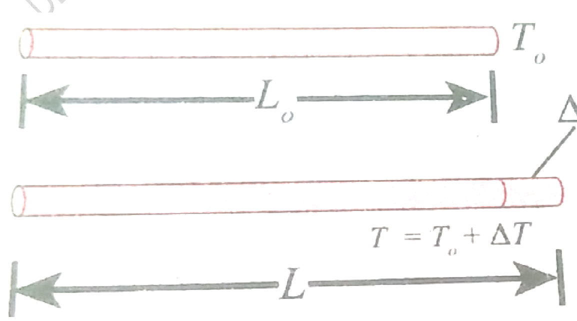
**3) Liquids**, have less intermolecular forces than solids and hence they expand more than solids. This is the principle behind the mercury thermometers.

4) In the case of **gas** molecules, the intermolecular forces are almost negligible and hence they expand much more than solids. For example in hot air balloons when gas particles get heated, they expand and take up more space.

5) The increase in dimension of a body due to the increase in its temperature is called thermal expansion.

6) The expansion in length is called **linear expansion**. Similarly the expansion in area is termed as **area expansion** and the expansion in volume is termed as **volume expansion**.

Linear Expansion:



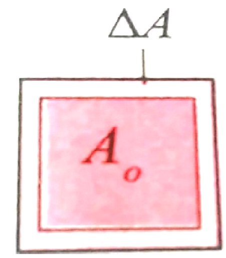

In solids, for a small change in temperature ΔT, the fractional change in length $\left(\frac{\Delta L}{L}\right)$ is directly proportional to ΔT. $\frac{\Delta L}{L} = a_L \Delta T$

Therefore, $\alpha_L = \frac{\Delta L}{L\Delta T}$ ; Where, αL = coefficient of linear expansion.

ΔL = Change in length; L = Original length ; ΔT = Change in temperature.

### Area Expansion:

For a small change in temperature $\Delta T$ the fractional change in area $\left(\frac{\Delta A}{A}\right)$ of a substance is directly proportional to $\Delta T$ and it can be written as




$$\frac{\Delta A}{A} = \alpha_A \Delta T$$

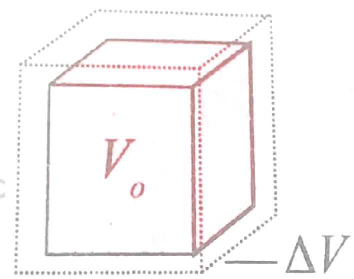
Therefore,

$\alpha_A = \frac{\Delta A}{A\Delta T}$ ; Where, $\alpha_A$ = coefficient of area expansion.

$\Delta A$ = Change in area; A = Original area ; $\Delta T$ = Change in temperature

### Volume Expansion:

For a small change in temperature $\Delta T$ the fractional change in volume$\left(\frac{\Delta V}{V}\right)$ of a substance is directly proportional to $\Delta T$.




$\frac{\Delta V}{V} = \alpha_V \Delta T$ , Therefore, $\alpha_V = \frac{\Delta V}{V\Delta T}$

Where, $\alpha_V$ = coefficient of volume expansion;

$\Delta V$ = Change in volume; V = Original volume ; $\Delta T$ = Change in temperature. Unit of coefficient of linear, area and volumetric expansion of solids is $°C^{-1}$ or $K^{-1}$

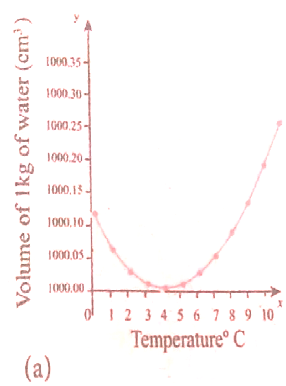


04. Describe the anomalous expansion of water. How is it helpful in our lives?

### Anomalous expansion of water:

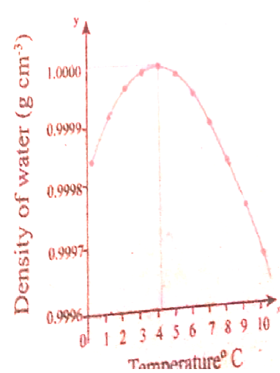
1) Liquids expand on heating and contract on cooling at moderate temperatures. But water exhibits an anomalous behavior. It contracts on heating between 0°C and 4°C.

2) The volume of the given amount of water decreases as it is cooled from room temperature, until it reach 4°C .




(a)

3) Below 4°C the volume increases and so the density decreases. This means that the water has a maximum density at 4°C . This behavior of water is called anomalous expansion of water.




4) In cold countries during the winter season, the surface of the lakes will be at lower temperature than the bottom.

5) Since the solid water (ice) has lower density than its liquid

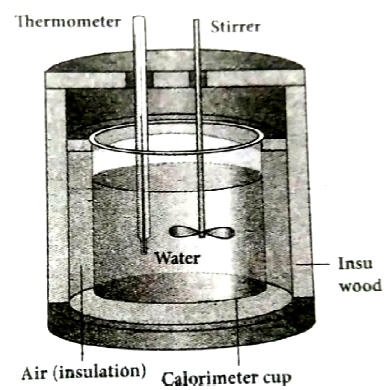
form, below 4°C, the frozen water will be on the top surface above the liquid water (ice fl oats).

6) This is due to the anomalous expansion of water. As the water in lakes and ponds freeze only at the top the species living in the lakes will be safe at the bottom.

**05. Explain Calorimetry and derive an expression for final temperature when two thermodynamic systems are mixed.**

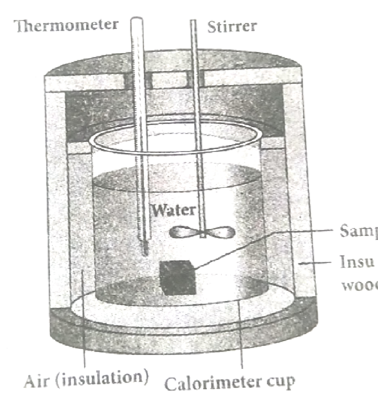
**Calorimetry :**

1) Calorimetry means the measurement of the amount of heat released or absorbed by thermodynamic system during the heating process. When a body at higher temperature is brought in contact with another body at lower temperature, the heat lost by the hot body is equal to the heat gained by the cold body. No heat is allowed to escape to the surroundings. It can be mathematically expressed as $Q_{gain} = - Q_{lost}$ ; $Q_{gain} + Q_{lost} = 0$




2) Heat gained or lost is measured with a calorimeter. Usually the calorimeter is an insulated container of water as shown in Figure.

3) A sample is heated at high temperature ($T_1$) and immersed into water at room temperature ($T_2$) in the calorimeter. After some time both sample and water reach a final equilibrium temperature $T_f$ . Since the calorimeter is insulated, heat given by the hot sample is equal to heat gained by the water. It is shown in the Figure.




$Q_{gain} = - Q_{lost}$

Note the sign convention. The heat lost is denoted by negative sign and heat gained is denoted as positive.

From the definition of specific heat capacity

$$Q_{gain} = m_2 s_2 (T_f - T_2)$$
$$Q_{lost} = m_1 s_1 (T_f - T_1)$$

Here $s_1$ and $s_2$ specific heat capacity of hot sample and water respectively. So we can write

$$m_2 s_2 (T_f - T_2) = - m_1 s_1 (T_f - T_1)$$
$$m_2 s_2 T_f - m_2 s_2 T_2 = - m_1 s_1 T_f + m_1 s_1 T_1$$
$$m_2 s_2 T_f + m_1 s_1 T_f = m_2 s_2 T_2 + m_1 s_1 T_1$$

The final temperature $T_f = \frac{m_1 S_1 T_1 + m_2 S_2 T_2}{m_1 S_1 + m_2 S_2}$

06. Discuss various modes of heat transfer.

Conduction:

Conduction is the process of direct transfer of heat through matter due to temperature difference. When two objects are in direct contact with one another, heat will be transferred from the hotter object to the colder one. Thermal conductivity depends on the nature of the material.

Convection:

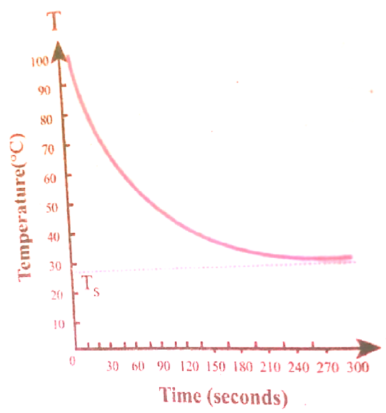
Convection is the process in which heat transfer is by actual movement of molecules in fluids such as liquids and gases. In convection, molecules move freely from one place to another.

Radiation:

Radiation is a form of energy transfer from one body to another by electromagnetic waves. Radiation which requires no medium to transfer energy from one object to another.

**Example:** 1. Solar energy from the Sun. 2. Radiation from room heater.

07. Explain in detail Newton's law of cooling.




Newton's law of cooling:

1) Newton's law of cooling states that the rate of loss of heat of a body is directly proportional to the difference in the temperature between that body and its surroundings .

$\frac{dQ}{dt}\ \alpha\ -(T - T)$ ------------- 1

2) The negative sign indicates that the quantity of heat lost by liquid goes on decreasing with time. Where, T = Temperature of the object

$T_s$ = Temperature of the surrounding.

From the graph in Figure , it is clear that the rate of cooling is high initially and decreases with falling temperature.

3) Let us consider an object of mass m and specific heat capacity s at temperature T. Let Ts be the temperature of the surroundings. If the temperature falls by a small amount dT in time dt, then the amount of heat lost is, dQ = msdT ---------------- 2

4) Dividing both sides of equation (2) by $\frac{dQ}{dt} = \frac{msdT}{dt}$ -------------3

From Newton's law of cooling $\frac{dQ}{dt}\ \alpha\ -(T - T_S)$

$\frac{dQ}{dt} = -a\,(T - T_S)$ ---------- 4

Where a is some positive constant. From equation (2) and (4)

$-a\,(T - T_S) = ms\frac{dT}{dt}$

$\frac{dT}{(T - T_S)} = -\frac{a}{ms}dt$ --------------------- 5

Integrating equation (5) on both sides,

$$\int_0^{\infty} \frac{dT}{(\mathrm{T-TS})} = -\int_0^{t} \frac{a}{ms} \mathrm{dt}$$

$$\ln (T - T_S) = \frac{a}{ms} t + b_1$$

Where $b_1$ is the constant of integration. taking exponential both sides, we get,

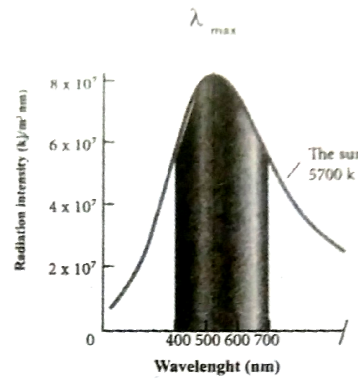
$$T = T_S + b_{2\,e}\,\frac{a}{ms} t \text{ . Here } b_2 = eb_1 = \text{Constant}$$

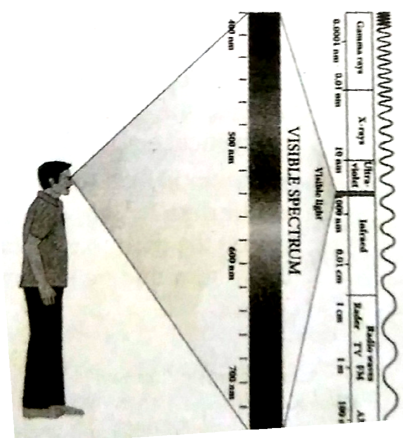
## 08. Explain Wien's law and why our eyes are sensitive only to visible rays?

1) Wien's law states that, the wavelength of maximum intensity of emission of a black body radiation is inversely proportional to the absolute temperature of the black body.

$$\lambda_m \,\alpha\, \frac{1}{T} \text{ or } \lambda_m = \frac{b}{T} \text{ ---------1}$$

Where, b is known as Wien's constant.
Its value is $2.898\times 10^{-3}$ m K




2) The Sun is approximately taken as a black body. Since any object above 0 K will emit radiation, Sun also emits radiation. Its surface temperature is about 5700 K. By substituting this value in the equation (1).

$$\lambda_m = \frac{b}{T} = \frac{2.898 \text{ x } 10^{-8}}{5700} \approx 508\text{nm}$$

3) It is the wavelength at which maximum intensity is 508nm. Since the Sun's temperature is around 5700K, the spectrum of radiations emitted by Sun lie between 400 nm to 700 nm which is the visible part of the spectrum.

4) The humans evolved under the Sun by receiving its radiations. The human eye is sensitive only in the visible not in infrared or X-ray ranges in the spectrum.

5) Suppose if humans had evolved in a planet near the star Sirius (9940K), then they would have had the ability to see the Ultraviolet rays!

## 09. Discuss the

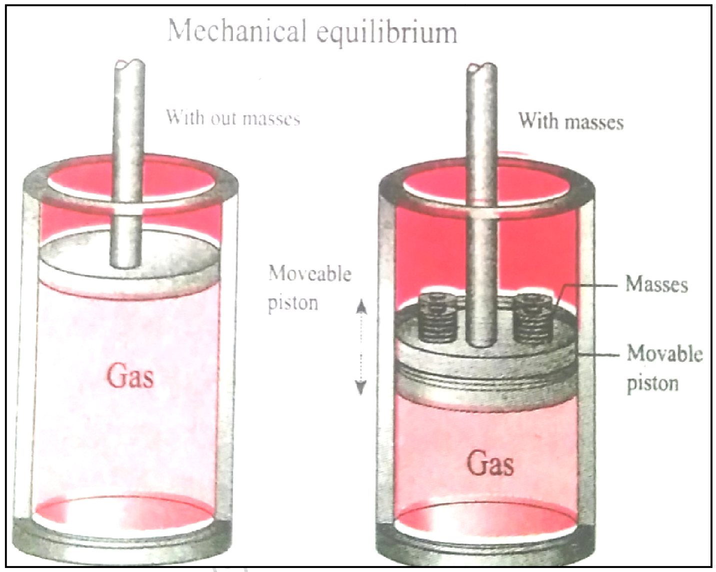
a. Thermal equilibrium
b. Mechanical equilibrium
c. Chemical equilibrium
d. Thermodynamic equilibrium.

### a. Thermal equilibrium:

Two systems are said to be in thermal equilibrium with each other if they are at the same temperature, which will not change with time.

b. Mechanical equilibrium:

Consider a gas container with piston as shown in Figure. When some mass is placed on the piston, it will move downward due to downward gravitational force and after certain humps and jumps the piston will come to rest at a new position. When the downward gravitational force given by the piston is balanced by the upward force exerted by the gas, the system is said to be in mechanical equilibrium. A system is said to be in mechanical equilibrium if no unbalanced force acts on the thermo dynamic system or on the surrounding by thermodynamic system.




c. Chemical equilibrium:

If there is no net chemical reaction between two thermodynamic systems in contact with each other then it is said to be in chemical equilibrium.

d. Thermodynamic equilibrium:

If two systems are set to be in thermodynamic equilibrium, then the systems are at thermal, mechanical and chemical equilibrium with each other. In a state of thermodynamic equilibrium the macroscopic variables such as pressure, volume and temperature will have fixed values and do not change with time.

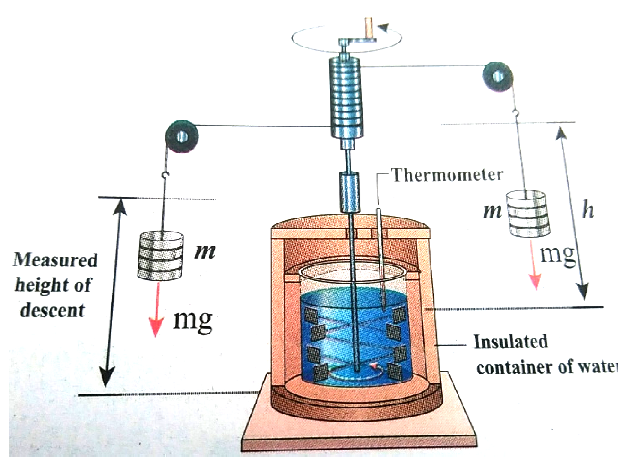


**10. Explain Joule's Experiment of the mechanical equivalent of heat.**

1) Joule showed that mechanical energy can be converted into internal energy and vice versa. In his experiment, two masses were attached with a rope and a paddle wheel.

2) When these masses fall through a distance h due to gravity, both the masses lose potential energy equal to 2mgh.

3) When the masses fall, the paddle wheel turns. Due to the



turning of wheel inside water, frictional force comes in between the water and the paddle wheel.

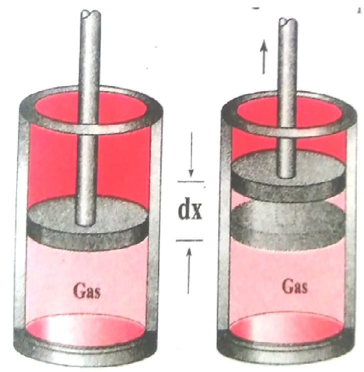
4) This causes a rise in temperature of the water. This implies that gravitational potential energy is converted to internal energy of water.

5) The temperature of water increases due to the work done by the masses. In fact, Joule was able to show that the mechanical work has the same effect as giving heat.

6) He found that to raise 1 g of an object by 1°C , 4.186 J of energy is required. In earlier days the heat was measured in calorie. 1 cal = 4.186 J This is called Joule's mechanical equivalent of heat.

**11. Derive the expression for the work done in a volume change in a thermodynamic system.**

Work done in volume changes




1) Consider a gas contained in the cylinder fitted with a movable piston. Suppose the gas is expanded quasi-statically by pushing the piston by a small distance dx.

2) Since the expansion occurs quasi-statically the pressure, temperature and internal energy will have unique values at every instant. The small work done by the gas on the piston. dW = Fdx ------------ 1

3) The force exerted by the gas on the piston F = PA. Here A is area of the piston and P is pressure exerted by the gas on the piston.

Equation (1) can be rewritten as dW = PA dx ------------ 2

4) But Adx = dV= change in volume during this expansion process. So the small work done by the gas during the expansion is given by
dW = PdV

5) Note here that is positive since the volume is increased. Here, is positive. In general the work done by the gas by increasing the volume from $V_i$ to $V_f$ is given by $W = \int_{V_i}^{V_f} PdV$ ------------- 4

Suppose if the work is done on the system, then $V_i > V_f$ . Then, W is negative.

6) Note here the pressure P is inside the integral in equation (4). It implies that while the system is doing work, the pressure need not be constant.

7) To evaluate the integration we need to first express the pressure as a function of volume and temperature using the equation of state.

**12. Derive Mayer's relation for an ideal gas.**

**Meyer's relation**

1) Consider μ mole of an ideal gas in a container with volume V, pressure P and temperature T.

2) When the gas is heated at constant volume the temperature increases by dT. As no work is done by the gas, the heat that flows into the system will increase only the internal energy. Let the change in internal energy be dU.

If Cv is the molar specific heat capacity at constant volume,

$$dU = \mu C_v dT \text{ -------------- } 1$$

3) Suppose the gas is heated at constant pressure so that the temperature increases by dT. If 'Q' is the heat supplied in this process and 'dV' the change in volume of the gas. $Q = \mu C_p dT$ ------------ 2

4) If W is the work done by the gas in this process, then

$$W = PdV \text{ -------------}3$$

But from the first law of thermodynamics, $Q = dU + W$ ---------4

Substituting equations (1), (2) and (3) in (4), we get,

$$\mu C_p dT = \mu C_v\, dT + PdV \text{ ------------}5$$

5) For mole of ideal gas, the equation of state is given by

$$PV = \mu RT \Rightarrow PdV + VdP = \mu RdT \text{ ----------- } 6$$

Since the pressure is constant, dP=0

$$\therefore C_p dT = C_v dT + RdT$$

$$\therefore C_P = C_v + R \text{ (or) } C_p - C_v = R \text{ ------------ } 7$$

This relation is called Meyer's relation



**13. Explain in detail the isothermal process.**

**Isothermal process**

1) It is a process in which the temperature remains constant but the pressure and volume of a thermodynamic system will change. The ideal gas equation is

$PV = \mu RT$, Here, T is constant for this process

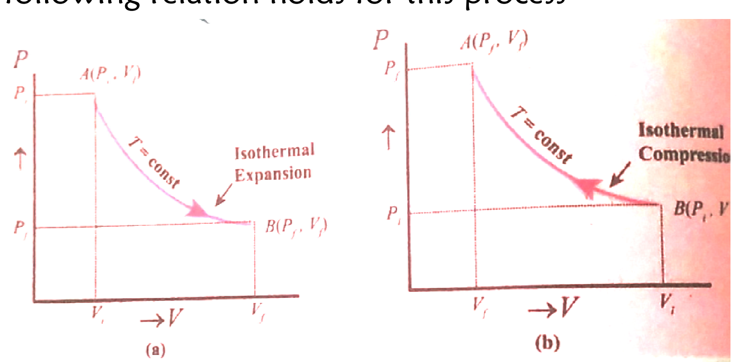
So the equation of state for isothermal process is given by $PV = constant$ ------ 1

2) This implies that if the gas goes from one equilibrium state ($P_1$,$V_1$) to another equilibrium state ($P_2$,$V_2$) the following relation holds for this process

$P_1V_1 = P_2V_2$ --------------2

3)Since PV = constant, P is inversely proportional to P α $\frac{1}{V}$.

This implies that PV graph is a hyperbola. The pressure-volume graph for constant temperature is also



called isotherm. PV diagram for quasi-static isothermal expansion and quasi-static isothermal compression.

4) We know that for an ideal gas the internal energy is a function of temperature only. For an isothermal process since temperature is constant, the internal energy is also constant. This implies that dU or ΔU = 0.

For an isothermal process, the first law of thermodynamics can be written as follows, Q = W ------------ 3

5) From equation (3), we infer that the heat supplied to a gas is used to do only external work.

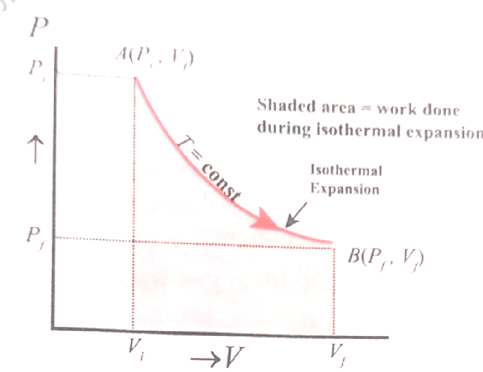
6) The isothermal compression takes place when the piston of the cylinder is pushed. This will increase the internal energy which will flow out of the system through thermal contact.

14. Derive the work done in an isothermal process

Work done in an isothermal process:

1) Consider an ideal gas which is allowed to expand quasi-statically at constant temperature from initial state ($P_i$,$V_i$) to the final state ($P_f$ , $V_f$). We can calculate the work done by the gas during this process. From equation the work done by the gas,

$$W = \int_{V_i}^{V_f} PdV \text{ -------------- } 1$$



(a)

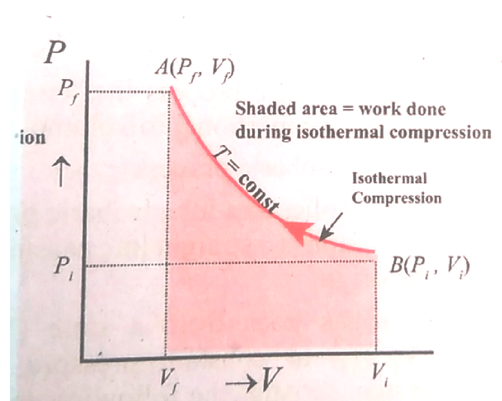
2) As the process occurs quasi-statically, at every stage the gas is at equilibrium with the surroundings. Since it is in equilibrium at every stage the ideal gas law is valid. Writing pressure in terms of volume and temperature,

$$P = \frac{\mu RT}{V} \text{ ---------------------} 2$$

Substituting equation (2) in (1) we get,

$$W = \int_{V_i}^{V_f} \frac{\mu RT}{V} dV$$

$$W = \mu RT \int_{V_i}^{V_f} \frac{dV}{V} \text{ -------------- } 3$$



(b)

In equation (3), we take μRT out of the integral, since it is constant throughout the isothermal process.

By performing the integration in equation (3),

we get $W = \mu RT \ln\left(\frac{V_f}{V_i}\right)$ ---------------- 4

3) Since we have an isothermal expansion, $\frac{V_f}{V_i} > 1$, So $\ln\left(\frac{V_f}{V_i}\right) > 0$.

As a result the work done by the gas during an isothermal expansion is positive.

The above result in equation (4) is true for isothermal compression also. But in an isothermal compression $\frac{V_f}{V_i}$ <1, So ln $\left(\frac{V_f}{V_i}\right)$ <0. As a result the work done on the gas in an isothermal compression is negative.

4) In the PV diagram the work done during the isothermal expansion is equal to the area under the graph. Similarly for an isothermal compression, the area under the PV graph is equal to the work done on the gas which turns out to be the area with a negative sign.

15. Explain in detail an adiabatic process.

Adiabatic process

1) This is a process in which no heat flows into or out of the system (Q=0). But the gas can expand by spending its internal energy or gas can be compressed through some external work. So the pressure, volume and temperature of the system may change in an adiabatic process.

2) The equation of state for an adiabatic process is given by

$PV^{\gamma}$ = Constant--------------1

Here $\gamma$ is called adiabatic exponent $\left(\gamma = \frac{C_p}{C_v}\right)$ which depends on the nature of the gas.

3) The equation (8.35) implies that if the gas goes from an equilibrium state ($P_i$,$V_i$) to another equilibrium state ($P_f$ ,$V_f$) adiabatically then it satisfies the relation

$P_iV_i^{\gamma} = P_fV_f^{\gamma}$ ------------- 2

4) The PV diagram of an adiabatic expansion and adiabatic compression process. The PV diagram for an adiabatic process is also called adiabat.

5) Note that the PV diagram for isothermal and adiabatic processes look similar. But actually the adiabatic curve is steeper than isothermal curve.

6) To rewrite the equation (1) in terms of T and V. From ideal gas equation, the pressure P = $\frac{\mu RT}{V}$. Substituting this equation in the equation (1), we have $\frac{\mu RT}{V}V^{\gamma}$ = Constant or $\frac{T}{V}$ $V^{\gamma} = \frac{Constant}{\mu R}$

7) Note here that is another constant. So it can be written as

$T V^{\gamma-1}$ = Constant ------------3

The equation (3) implies that if the gas goes from an initial equilibrium state ($T_i$, $V_i$) to final equilibrium state ($T_f$, $V_f$) adiabatically then it satisfies the relation $T_iV_i^{\gamma-1} = T_fV_f^{\gamma-1}$ --------------- 4

The equation of state for adiabatic process can also be written in terms of T and P as $T^{\gamma}P^{1-\gamma}$ = constant.

**16. Derive the work done in an adiabatic process**

Work done in an adiabatic process:

1) Consider μ moles of an ideal gas enclosed in a cylinder having perfectly non conducting walls and base. A frictionless and insulating piston of cross sectional area A is fitted in the cylinder. Let W be the work done when the system goes from the initial state ($P_i$,$V_i$,$T_i$) to the final state ($P_f$,$V_f$,$T_f$) adiabatically. $W = \int_{V_i}^{V_f} PdV$ ---------------- 1

2) By assuming that the adiabatic process occurs quasi-statically, at every stage the ideal gas law is valid. Under this condition, the adiabatic equation of state is $PV^{\gamma}$ = constant (or) $P = \frac{Constant}{V^{\gamma}}$ can be substituted in the equation (1), we get $W_{adia} = \int_{V_i}^{V_f} \frac{Constant}{V^{\gamma}} d\,V$

$$= \text{Constant} \int_{V_i}^{V_f} V^{\gamma} dV$$

$$= \text{Constant} \left[\frac{V^{-\gamma+1}}{-\gamma+1}\right]_{V_i}^{V_f}$$

$$= \frac{\text{Constant}}{1-\gamma}\left[\frac{\text{Constant}}{V_f^{\gamma-1}} - \frac{\text{Constant}}{V_i^{\gamma-1}}\right]$$

But, $P_iV_i^{\gamma} = P_fV_f^{\gamma}$ = constant.

$$W_{adia} = \frac{1}{1-\gamma}\left[\frac{P_fV_f^{\gamma}}{V_f^{\gamma-1}} - \frac{P_iV_i^{\gamma}}{V_i^{\gamma-1}}\right]$$

$$W_{adia} = \frac{1}{1-\gamma}[P_fV_f - P_iV_i] \text{ -------- } 2$$

From ideal gas law, $P_fV_f = \mu RT_f$ and $P_iV_i = \mu RT_i$

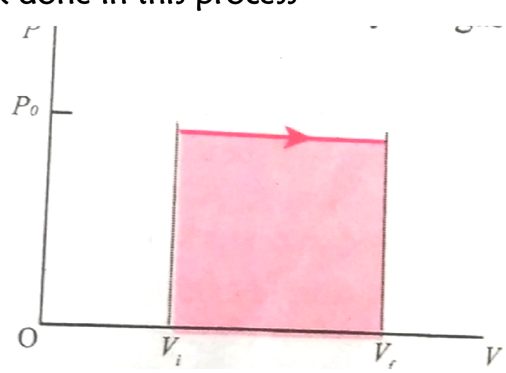
Substituting in equation (2), we get, $W_{adia} = \frac{\mu R}{\gamma-1}[T_i - T_f]$

3) In adiabatic expansion, work is done by the gas. i.e., $W_{adia}$ is positive. As $T_i>T_f$ , the gas cools during adiabatic expansion. In adiabatic compression, work is done on the gas. i.e., $W_{adia}$ is negative. As $T_i<T_f$, the temperature of the gas increases during adiabatic compression.



**17. Explain the isobaric process and derive the work done in this process**

Isobaric process




1) This is a thermodynamic process that occurs at constant pressure. Even though pressure is constant in this process, temperature, volume and internal energy are not constant. From the ideal gas equation, we have

$V = \left(\frac{\mu R}{P}\right)T$ ----------1 Here $\frac{\mu R}{P}$ = Constant

2) In an isobaric process the temperature is directly proportional to volume. $V \propto T$ (Isobaric process) ---- (2)

This implies that for a isobaric process, the V-T graph is a straight line passing through the origin.

3) If a gas goes from a state ($V_i$ ,$T_i$) to ($V_f$ ,$T_f$) at constant pressure, then the system satisfies the following equation $\frac{T_f}{V_f} = \frac{T_i}{V_i}$

The work done in an isobaric process: Work done by the gas $W = \int_{V_i}^{V_f} PdV$

In an isobaric process, the pressure is constant, so P comes out of the integral,

$W = P\int_{V_i}^{V_f} dV$ $W = P\,[V_f - V_i] = P\Delta V$ -----------3

4) Where ΔV denotes change in the volume. If ΔV is negative, W is also negative. This implies that the work is done on the gas. If ΔV is positive, W is also positive, implying that work is done by the gas.

5) The equation (3) can also be rewritten using the ideal gas equation.

From ideal gas equation PV = μRT and $V = \frac{\mu RT}{P}$

Substituting this in equation (3) we get, $W = \mu RT_f\left(1 - \frac{T_i}{T_f}\right)$

6) In the PV diagram, area under the isobaric curve is equal to the work done in isobaric process. The shaded area in the following Figure is equal to the work done by the gas.

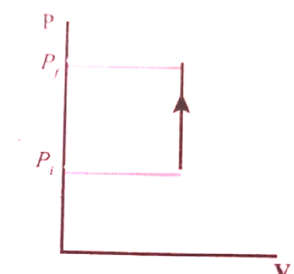
7) The first law of thermodynamics for isobaric process is given by

$\Delta U = Q - P\Delta V$

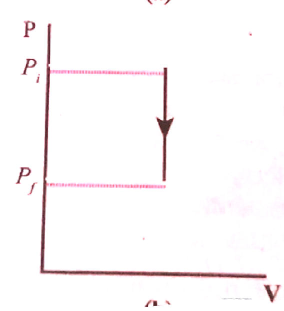


## 18. Explain in detail the isochoric process.

### Isochoric process



(a)



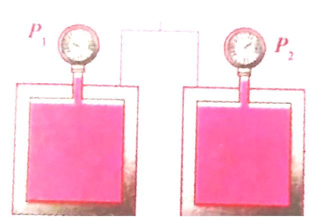

1) This is a thermodynamic process in which the volume of the system is kept constant. But pressure, temperature and internal energy continue to be variables. The pressure - volume graph for an isochoric process is a vertical line parallel to pressure axis.

2) The equation of state for an isochoric process is given by $P = \left(\frac{\mu R}{V}\right)$

Where, $\left(\frac{\mu R}{V}\right)$ = Constant

It that the pressure is directly proportional to temperature. This implies that the P-T graph for an isochoric process is a straight line passing through origin. If a gas goes from state ($P_i$,$T_i$) to ($P_f$,$T_f$) at constant volume, then the system satisfies the following equation $\frac{P_i}{T_i} = \frac{P_f}{T_f}$

Constant volume




For an isochoric processes, ΔV=0 and W=0. Then the first law becomes

$\Delta U = Q$

3) Implying that the heat supplied is used to increase only the internal energy. As a result the temperature increases and pressure also increases.

4) Suppose a system loses heat to the surroundings through conducting walls by keeping the volume constant, then its internal energy decreases. As a result the temperature decreases; the pressure also decreases.

**19. What are the limitations of the first law of thermodynamics?**

Limitations of first law of thermodynamics

The first law of thermodynamics explains well the inter convertibility of heat and work. But it does not indicate the direction of change.

For example,

a. When a hot object is in contact with a cold object, heat always flows from the hot object to cold object but not in the reverse direction. According to first law, it is possible for the energy to flow from hot object to cold object or from cold object to hot object. But in nature the direction of heat flow is always from higher temperature to lower temperature.

b. When brakes are applied, a car stops due to friction and the work done against friction is converted into heat. But this heat is not reconverted to the kinetic energy of the car. So the first law is not sufficient to explain many of natural phenomena.



**20. Explain the heat engine and obtain its efficiency.**

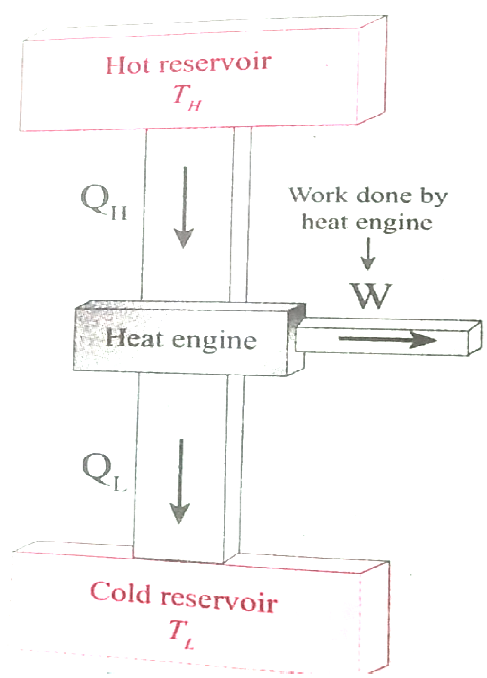
Heat engine is a device which takes heat as input and converts this heat in to work by undergoing a cyclic process.

A heat engine has three parts:

(a) Hot reservoir (b) Working substance

(c) Cold reservoir

A Schematic diagram for heat engine is given below in the figure




1) Hot reservoir (or) Source: It supplies heat to the engine. It is always maintained at a high temperature $T_H$

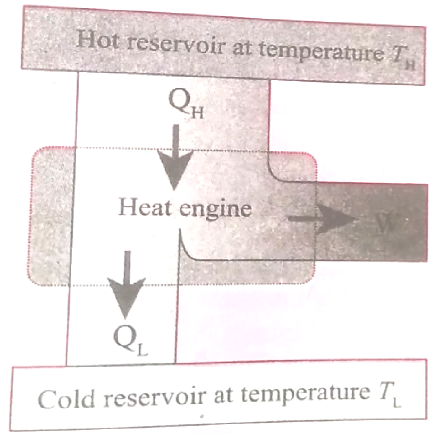
2) Working substance: It is a substance like gas or water, which converts the heat supplied into work.

i) A simple example of a heat engine is a steam engine. In olden days steam engines were used to drive trains. The working substance in these is water which absorbs heat from the burning of coal.

ii) The heat converts the water into steam. This steam is does work by rotating the wheels of the train, thus making the train move.

3) Cold reservoir (or) Sink: The heat engine ejects some amount of heat ($Q_L$) in to cold reservoir after it doing work. It is always maintained at a low temperature $T_L$.

**For example,** in the automobile engine, the cold reservoir is the surroundings at room temperature. The automobile ejects heat to these surroundings through a silencer.




4) The heat engine works in a cyclic process. After a cyclic process it returns to the same state. Since the heat engine returns to the same state after it ejects heat, the change in the internal energy of the heat engine is zero.

5) The efficiency of the heat engine is defined as the ratio of the work done (output) to the heat absorbed (input) in one cyclic process. Let the working substance absorb heat $Q_H$ units from the source and reject $Q_L$ units to the sink after doing work W units

We can write Input heat = Work done + ejected heat

$$Q_H = W + Q_L$$
$$W = Q_H - Q_L$$

Then the efficiency of heat engine $\eta = \frac{Output}{Input} = \frac{W}{Q_H} = \frac{Q_H - Q_L}{Q_H}$

$$\eta = \frac{Output}{Input} = \frac{W}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

6) Note here that $Q_H$, $Q_L$ and W all are taken as positive, a sign convention followed in this expression.

Since $Q_L < Q_H$, the efficiency (η) always less than 1. This implies that heat absorbed is not completely converted into work. The second law of thermodynamics placed fundamental restrictions on converting heat completely into work.



**21. Explain in detail Carnot heat engine.**

A reversible heat engine operating in a cycle between two temperatures in a particular way is called a Carnot Engine. The Carnot engine has four parts which are given below.

1) Source: It is the source of heat maintained at constant high temperature TH. Any amount of heat can be extracted from it, without changing its temperature.

2) Sink: It is a cold body maintained at a constant low temperature TL. It can absorb any amount of heat.

3) Insulating stand: It is made of perfectly non-conducting material. Heat is not conducted through this stand.

4) Working substance: It is an ideal gas enclosed in a cylinder with perfectly non-conducting walls and perfectly conducting bottom. A non-conducting and frictionless piston is fitted in it.

**Carnot's cycle:**

i) The working substance is subjected to four successive reversible processes forming what is called Carnot's cycle.

ii) Let the initial pressure, volume of the working substance be $P_1, V_1$.

**Step A to B:** Quasi-static isothermal expansion from $(P_1, V_1, T_H)$ to $(P_2, V_2, T_H)$:

5) The cylinder is placed on the source. The heat ($Q_H$) flows from source to the working substance (ideal gas) through the bottom of the cylinder. Since the process is isothermal, the internal energy of the working substance will not change. The input heat increases the volume of the gas. The piston is allowed to move out very slowly (quasi-statically).

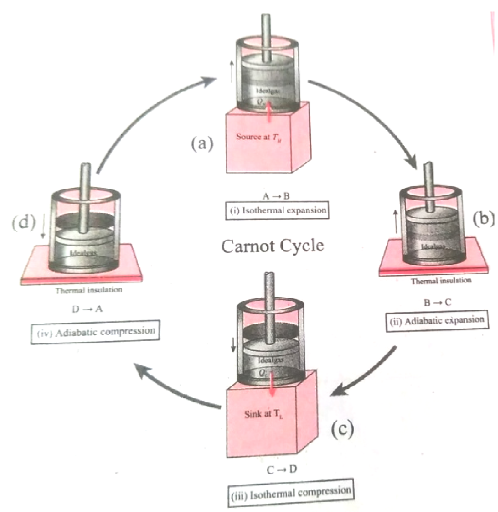
6) $W_1$ is the work done by the gas in expanding from volume $V_1$ to volume $V_2$ with a decrease of pressure from $P_1$ to $P_2$. This is represented by the P-V diagram along the path AB.

7) Then the work done by the gas (working substance) is given by

$$\therefore Q_H = W_{A\to B} = \int_{V_1}^{V_2} P\,dV$$

Since the process occurs quasi-statically, the gas is in equilibrium with the source till it reaches the final state. The work done in the isothermal expansion is given by the equation.

**Step B to C:** Quasi-static adiabatic expansion from $(P_2, V_2, T_H)$ to $(P_3, V_3, T_L)$




1) The cylinder is placed on the insulating stand and the piston is allowed to move out. As the gas expands adiabatically from volume $V_2$ to volume $V_3$ the pressure falls from $P_2$ to $P_3$.
2) The temperature falls to $T_L$. This adiabatic expansion is represented by curve BC in the P-V diagram. This adiabatic process also occurs quasi-statically and implying that this process is reversible and the ideal gas is in equilibrium throughout the process. The work done by the gas in an adiabatic expansion is given by,

$$W_{B\to C} = \int_{V_2}^{V_3} P\,dV = \frac{\mu R}{\gamma-1}[T_H - T_L] = \text{Area under the curve BC}$$

**Step C → D:** Quasi-static isothermal compression from $(P_3, V_3, T_L)$ to $(P_4, V_4, T_L)$:

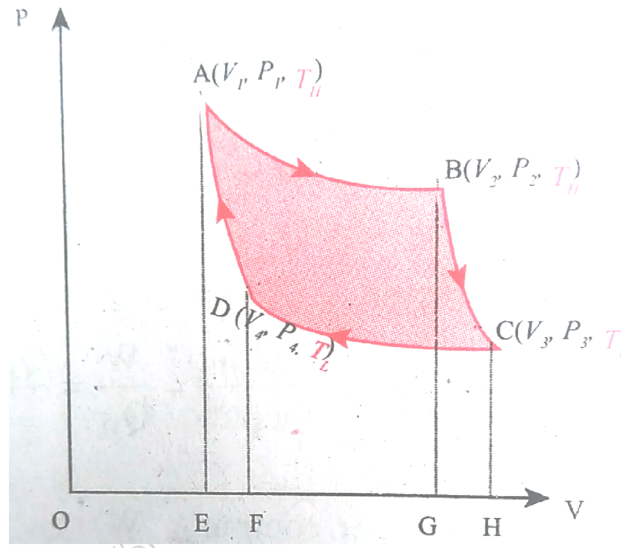
1) The cylinder is placed on the sink and the gas is isothermally compressed until the pressure and volume become $P_4$ and $V_4$ respectively. This is

represented by the curve CD in the PV diagram. Let $W_{C\rightarrow D}$ be the work done on the gas. According to first law of thermodynamics

$$W_{C\rightarrow D} = \int_{V_3}^{V_4} PdV = \mu RT_L \ln = \frac{V_4}{V_3} = -\mu RT_L \ln = \frac{V_3}{V_4}$$

= – Area under the curve CD

Here $V_3$ is greater than $V_4$. So the work done is negative, implying work is done on the gas.




**Step D→A:** Quasi-static adiabatic compression from ($P_4$,$V_4$,$T_L$) to ($P_1$,$V_1$,$T_H$):

1) The cylinder is placed on the insulating stand again and the gas is compressed adiabatically till it attains the initial pressure $P_1$, volume $V_1$ and temperature $T_H$. This is shown by the curve DA in the P-V diagram.

   $W_{D\rightarrow A} = \int_{V_4}^{V_1} PdV = \frac{\mu R}{\gamma-1}[T_L - T_H]$ = Area under the curve DA

2) In the adiabatic compression also work is done on the gas so it is negative. Let 'W' be the net work done by the working substance in one cycle

   ∴W=Work done by the gas – work done on the gas

   $= W_{A\rightarrow B} + W_{B\rightarrow C} - W_{C\rightarrow D} - W_{D\rightarrow A}$ since $W_{B\rightarrow C} = W_{D\rightarrow A}$

   $= W_{A\rightarrow B} - W_{C\rightarrow D}$

   The net work done by the Carnot engine in one cycle

   $W = W_{A\rightarrow B} - W_{C\rightarrow D}$ ---------------1

   Equation (1) shows that the net work done by the working substance in one cycle is equal to the area (enclosed by ABCD) of the P-V diagram.

3) It is very important to note that after one cycle the working substance returns to the initial temperature $T_H$. This implies that the change in internal energy of the working substance after one cycle is zero.



## 22. Derive the expression for Carnot engine efficiency.

**Efficiency of a Carnot engine**

1) Efficiency is defined as the ratio of work done by the working substance in one cycle to the amount of heat extracted from the source.

$$\eta = \frac{Work\ done}{Heat\ extracted} = \frac{W}{Q_H} \text{ ---------- } 1$$

From the first law of thermodynamics, $W = Q_H - Q_L$

$$\eta = \frac{QH - QL}{Q_H} = 1 - \frac{Q_L}{Q_H} \text{ -------------- } 2$$

Applying isothermal conditions, we get,
$Q_H = \mu RT_H \ln \frac{V_2}{V_4}$ ; $Q_L = \mu RT_L \ln \frac{V_3}{V_4}$ ------------ 3

Here we omit the negative sign. Since we are interested in only the amount of heat ($Q_L$) ejected into the sink, we have, $\frac{Q_L}{Q_H} = \frac{T_L \, In \frac{V_3}{V_4}}{T_H \, In \frac{V_2}{V_1}}$ ---------4

By applying adiabatic conditions, we get, $T_H V_2^{\gamma-1} = T_L V_3^{\gamma-1}$
By dividing the above two equations, we get, $T_H V_1^{\gamma-1} = T_L V_4^{\gamma-1}$
By dividing the above two equations, we get, $\left(\frac{V_2}{V_1}\right)^{\gamma-1} = \left(\frac{V_3}{V_4}\right)^{\gamma-1}$

Which implies that, $\frac{V_2}{V_1} = \frac{V_3}{V_4}$ ---------------5

Substituting equation (5) in (4), we get, $\frac{Q_L}{Q_H} = \frac{T_L}{T_H}$

The efficiency $\eta$ - $1 - \frac{T_L}{T_H}$

Note : $T_L$ and $T_H$ should be expressed in Kelvin scale.

**23. Explain the second law of thermodynamics in terms of entropy.**

**Entropy and second law of thermodynamics**

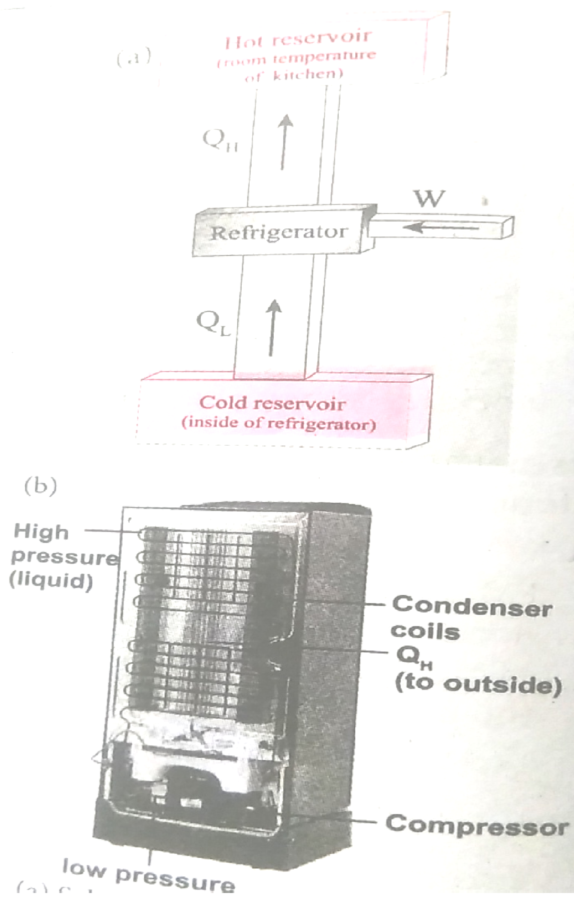
1) We have seen in the equation that the quantity $\frac{Q_H}{T_H}$. Is equal to $\frac{Q_L}{T_L}$ the quantity $\frac{Q}{T}$ is called entropy. It is a very important thermodynamic property of a system.
2) It is also a state variable. $\frac{Q_H}{T_H}$ is the entropy received by the Carnot engine from hot reservoir and $\frac{Q_L}{T_L}$ is entropy given out by the Carnot engine to the cold reservoir. For reversible engines (Carnot Engine) both entropies should be same, so that the change in entropy of the Carnot engine in one cycle is zero. But for all practical engines like diesel and petrol engines which are not reversible engines, they satisfy the relation $\frac{Q_L}{T_L} > \frac{Q_H}{T_H}$.
3) In fact we can reformulate the second law of thermodynamics as follows "For all the processes that occur in nature (irreversible process), the entropy always increases. For reversible process entropy will not change". Entropy determines the direction in which natural process should occur.
4) Because entropy increases when heat flows from hot object to cold object. If heat were to flow from a cold to a hot object, entropy will decrease leading to violation of second law thermodynamics.
5) Entropy is also called 'measure of disorder'. All natural process occur such that the disorder should always increases.
6) Consider a bottle with a gas inside. When the gas molecules are inside the bottle it has less disorder. Once it spreads into the entire room it leads to more disorder.

7) In other words when the gas is inside the bottle the entropy is less and once the gas spreads into entire room, the entropy increases. From the second law of thermodynamics, entropy always increases.
8) If the air molecules go back in to the bottle, the entropy should decrease, which is not allowed by the second law of thermodynamics.
9) The same explanation applies to a drop of ink diffusing into water. Once the drop of ink spreads, its entropy is increased. The diffused ink can never become a drop again. So the natural processes occur in such a way that entropy should increase for all irreversible process.

**24. Explain in detail the working of a refrigerator.**

REFRIGERATOR

A refrigerator is a Carnot's engine working in the reverse order.




Working Principle:

The working substance (gas) absorbs a quantity of heat $Q_L$ from the cold body (sink) at a lower temperature $T_L$. A certain amount of work W is done on the working substance by the compressor and a quantity of heat $Q_H$ is rejected to the hot body (source) ie, the atmosphere at $T_H$. When you stand beneath of refrigerator, you can feel warmth air.

From the first law of thermodynamics ,

we have $Q_L + W = Q_H$

As a result the cold reservoir (refrigerator) further cools down and the surroundings (kitchen or atmosphere) gets hotter.