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Department of Physics
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Thermal Physics

I B.Sc Physics Course

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UNIT – I Thermodynamics

Zeroth law of thermodynamics – First law of thermodynamics –Heat engines – Reversible and irreversible process – Carnot's theorem – Second law of thermodynamics, thermodynamic scale of temperature - entropy – change of entropy in reversible and irreversible processes – Temp – entropy diagram (T.S.) – law of increase of entropy.

Thermodynamics

One excellent definition n of thermodynamics is that is the science of energy and entropy. Alternate definition is thermodynamics is the science that deals wirh heat and workand those properties of substances that bear a elation to heat and work.

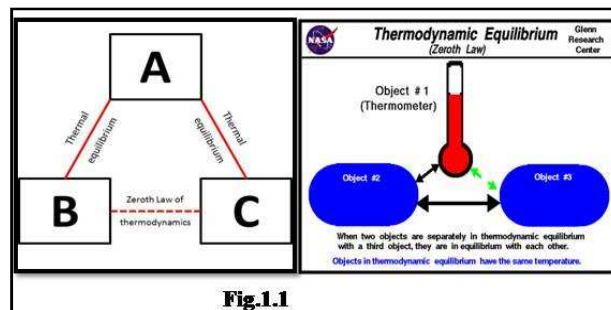## Thermodynamic system and Thermodynamic Coordinates

Thermodynamic system -   A system that depends on thermodynamic   quantities like pressure, volume and temperature, (eg) Gas enclosed I a cylinder

Thermodynamic coordinates - Quantities required for complete knowledge of thermodynamic state of a system (eg) pressure, volume and temperature

Zeroth law of thermodynamics

Statement

The Zeroth law of thermodynamics states that if two bodies A and B are each separately in thermal equilibrium with a third body C, then A and B are also in thermal equilibrium with each other as shown in Fig.1.1

Fig.1.1

First Law of Thermodynamics

Statement

When a certain amount of heat Q is applied to a system which does external work W in passing from state 1 to state 2, the amount of heat is equal to sum of the increase in the internal energy of the system and the external work done by the system [Fig.1.2].

The law is expressed as   **Q= (U$_2$-U$_1$) + W**

Note: For very small change in state of the system, the law is expressed as
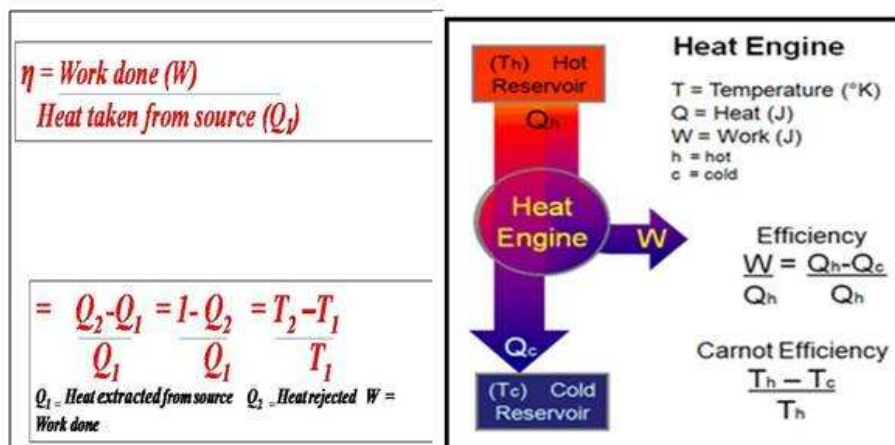
$$\delta Q = dU + \delta W$$

(all quantities expressed in unit of energy)

Fig.1.2
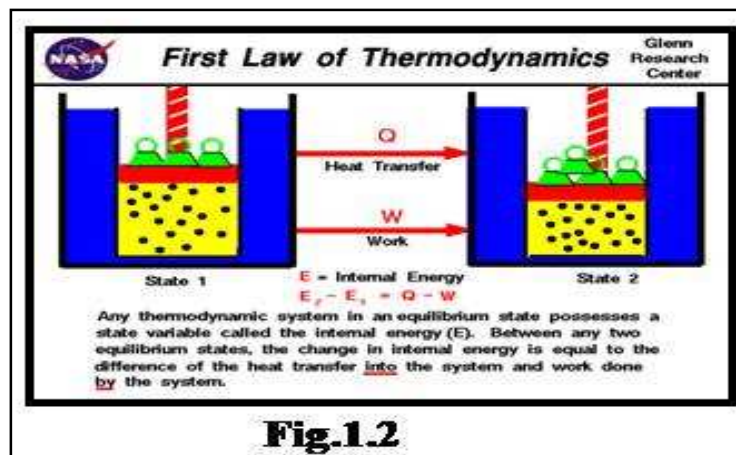
Heat Engine

Heat Engine is a device which converts heat into work. It consists of three parts [Fig.1.3]
[a]   Source (high temperature reservoir) at temperature T1
[b]   Sink (low temperature reservoir) at temperature T2
[c]   Working substance

Fig.1.3

Reversible and Irreversible Processes

Reversible Process:

It is a process in which an infinitesimally small changes in the external condition will result in al changes taking place in the direct process being exactly repeated in the reverse order and opposite sense.

Example: Place a piece of metal on a hot plate at temperature T. It the temperature of the hot plate is increased by small step dT, a small amount of heat dQ is transferred to metal and we decrease the temperature of hot plate by dT, an equal amount of heat dQ is transferred back to hot plate. In this way, the metal and hot plate are restored to their original condition

Irreversible Process:

The process which is not exactly reversible

Example: A cup of hot coffee left on a table gradually cools down and never gets hotter by itself. All natural processes proceed in one direction only.

The Carnot's Engine

It consists of the following parts [Fig.1.4]:

    (a)   **Source** : hot body at T_1. The heat engine draws heat from it.
    (b)   **Sink :** Cold body at T_2. Any amount of heat is rejected to it.
    (c)   **Working substance** : Ideal gas enclosed in cylinder-piston arrangement.
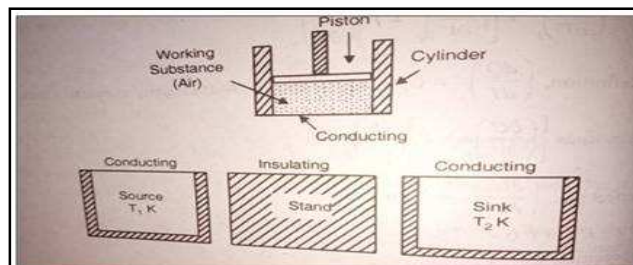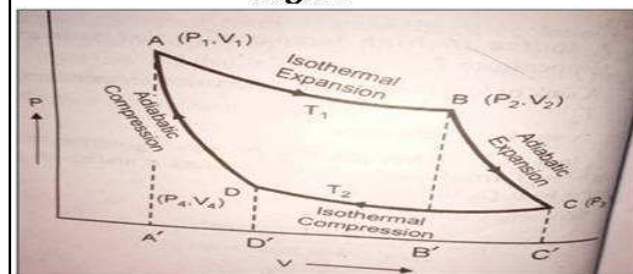   (d)   **Non-conducting stand** is provided for adiabatic operation.

Fig.1.4

Fig.1.5

Carnot cycle

(1) *Isothermal expansion AB*: The piston is moved upward so that gas expands isothermally represented by curve AB as shown in Fig.1.5

Consider one gram molecule of the gas. LET Q_1 be the quantity of heat absorbed from the source which is equal to the amount of works done W_1 by the gas in expansion from initial curve (P_1,V_1) to (P_2,V_2)

$$Q_1 = W1= \int_{V_1}^{V_2} PdV- RT_1\int_{V_1}^{V_2} dV/V=RT_1 \log_e[V_2/V_1]$$

(2) *Adiabatic expansion BC:* Place the cylinder on the insulating stand. Allow the as to expand adiabatically till the temperature falls to T2 which is represented by adiabatic BC.

$$W_2 =\int_{V_2}^{V_3} PdV=\int_{V_2}^{V_3} KdV/V\gamma= [KV3^{\gamma-1} – KV2^{\gamma-1}]/1-\gamma$$
$$= [P_3V_3-P_2V_2 / KV_3^{\gamma-1}]$$
$$W_2= R(T_1-T_2)/(\gamma-1)$$

(3) *Isothermal compression* CD: Place the cylinder on sink at temperature T2. The gas is compressed isothermally till it attains the state D. This is equal to the work done W3 on the gas.

$$Q_2 = W_3 = \int_{V_3}^{V_4} PdV= RT_2 \log_e [V_3/V_4]$$

(4) *Adiabatic compression DA*: Place the cylinder in insulting stand. The gas is compressed adiabatically until the temperature rises to T_1 represented by adiabatic DA.

Work done from D to A : $W_4= \int_{V_4}^{V_1} PdV= R(T_1-T_2)/(\gamma-1)$
The net work done by the gas is $W=W_1+W_2+W_3+W_4$

$$W= RT_1 \log_e[V_2/V_1]- RT_2 \log_e [V_3/V_4]$$

The points A and D are on the same adiabatic
$T_1V_1^{\gamma-1} = T_2V_4^{\gamma-1}$ or $T_2/T_1 = [V_1/V_4]^{\gamma-1}$

The points B and C are on the same adiabatic
$T_1V_2^{\gamma-1} = T_2V3^{\gamma-1}$ or $T_2/T_1 = [V_2/V_3]^{\gamma-1}$

So $[V_1/V_4]^{\gamma-1} = [V_2/V_3]^{\gamma-1}$
or $V_2/V_1= V_3/V_4$

$$W = Q_1-Q_2 = R(T_1-T_2) \log V_2/V_1$$

Efficiency (η) of the engine is defined as

$$\eta = \frac{\text{Amount of heat converted into work}}{\text{Total heat absorbed from the source}}$$

$$\eta = \frac{Q_1 - Q_2}{Q_1} = \frac{R(T_1 - T_2) \log \frac{V_2}{V_1}}{RT_1 \log \frac{V_2}{V_1}}$$

$$\text{Efficiency } \eta = \frac{T_1 - T_2}{T_1} = 1 + \frac{T2}{T_1}$$

Carnot's theorem

The theorem consists of two parts and can be stated as follows:

Statement 1

No engine can be more efficient   than a perfectly reversible engine working between the same two temperatures
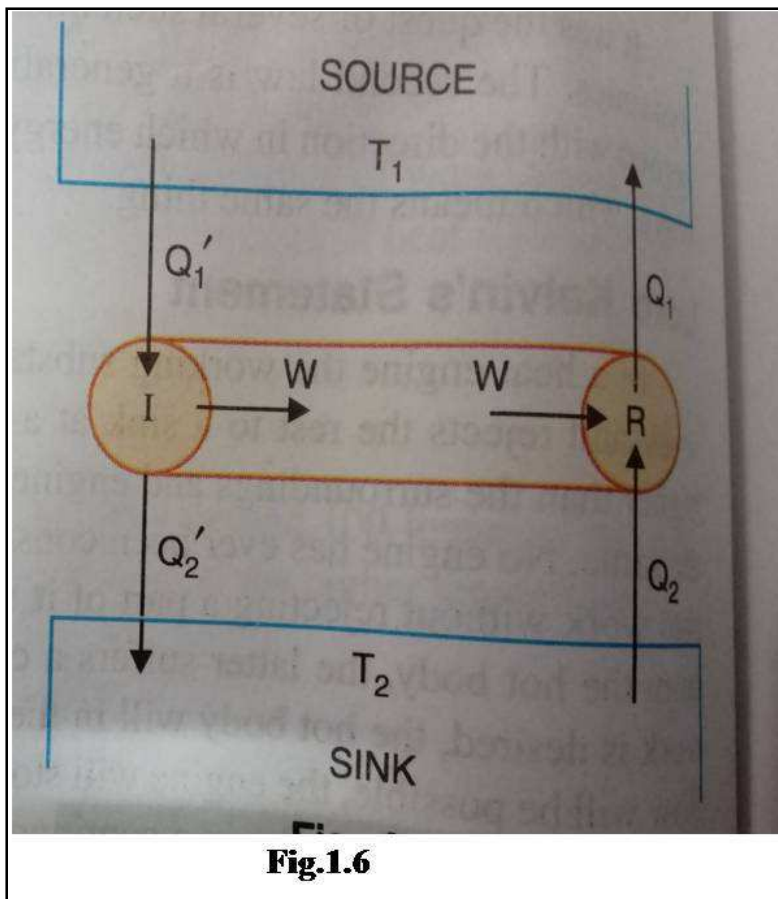
Statement 2

The efficiency of all reversible engines working between the same two temperatures is the same, whatever is the working substance.

Proof:

First Part:

To prove the first part of the theorem, we consider two engines R and I working between the temperatures T_1 and T_2 as shown in Fig.1.6. Of these two engines, R is reversible and I is irreversible

Fig.1.6

Suppose I is more efficient than R. Suppose in each cycle, R absorbs the quantity of heat Q1 from the source at T_1 and rejects the quantity of heat Q_2 to the sink at temperature T_2. Suppose in ach cycle, I absorbs the quantity of heat Q_1' from the source at the temperature T_1 and give the quantity of heat Q_2' to the sink at the temperature T_2. Let the two engines do the same amount of work W in each cycle. According to the assumption I is more efficient than R.

$$\frac{Q_1' - Q_2'}{Q_1'} = \frac{Q_1 - Q_2}{Q_1}$$

or $$\frac{W}{Q_1'} > \frac{W}{Q_1}$$

Or $$Q_1 > Q_1'$$

and $$Q_1' - Q_2' = Q_1 - Q_2 ,$$

or $$Q_2 - Q_2' = Q_1 - Q_1'$$

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Now because $$Q_1 > Q_1',$$

Therefore, $$Q_2 > Q_2'$$

Now, suppose the two engines are coupled together so that I drives R backwards and suppose they use the same source and sink. The combination forms a self-acting machine in which I supports external work W and R absorbs this amount of work in its reverse cycle. I to its cycle absorbs heat Q_1' from the source and gives up heat Q_2' to the sink. R in its reverse cycle, absorbs heat Q_2 *from the sink and gives up* Q_1 *to the source.*

The net result of the completer cycle of the coupled engines is given by :

Gain of heat by the source at T1 = $Q_1 - Q_1'$

Loss of heat by the sink T2 = Q2 – Q2'

External work done on the system = 0.

Thus, the coupled engines forming a self acting machine unaided by any external agency transfer heat continuously from a body at a low temperature to a body at a higher temperature.

This conclusion is contrary to the second law of thermodynamics, according to which in a cycle process heat cannot ne transferred from one body to another at a higher temperature by a self –acting machine. Hence, our assumption is incorrect, and we conclude that no engine can be more efficient than a perfectly reversible engine working between the same temperature.

Second Part:
The second part of the theorem may be proved by the same arguments as before. For this purpose, we consider two reversible engines R_1 and R_2 and assume that R_2 is more efficient than R_1. Proceeding in the same way, we can show that R_2 cannot be more efficient than R_1. Therefore, all reversible engines working between the same two temperatures have the same efficiency.

Thus, the efficiency of a perfectly reversible engine depends only on the temperatures between which the engine works and is independent of the nature of the working substance.

Second law of thermodynamics

Lord Kelvin statement

It is impossible to get a continuous supply of work from a body by cooling it to a temperature lower than that of its surroundings.

Planck' s statement

It is impossible to construct an engine which, working in a completer cycle, will produce no effect other than the raising of a weight and the cooling of a heat reservoir.

Kelvin-Planck Statement

It is impossible to construct an engine which operating in a cycle, has the sole effect of extracting heat from a reservoir and performing an equivalent amount of work.

Clausius's Statement

It is impossible for a self acting machine working in a cyclic process unaided by external agency to transfer heat from a body at a lower temperature to a body at a higher temperature.

Thermodynamic (or absolute or Work) scale of temperature

The efficiency of a reversible engine is independent of the working substance and depends only on the two temperatures between which the engine works. Since $\eta = 1 - \frac{Q_2}{Q_1}$, $\frac{Q_2}{Q_1}$ can depend only on the temperatures. This led Kelvin to suggest a new scale of temperature . It we let q_1 and q_2 represent these two temperatures, his defining equation is $\frac{\theta_1}{\theta_2} = \frac{Q_1}{Q_2}$.

That is the ratio of any temperatures on this scale is equal to the ratio of the heats absorbed and rejected by a Carnot reservoir working between these two temperatures. Such temperature scale is called the thermodynamic (or Kelvin)temperature scale,. This temperature scale does not depend upon the property of the working substance. Hence it is called absolute temperature scale

To determine the size of the degree on the thermodynamic scale

Consider a Carnot reversible engine working between the temperature of boiling water and melting ice at normal pressure. The Carnot cycle is represented by ABCD. Here AB and CD are respectively the isothermals for steam point and ice point [Fig. 1.7]

. The work done by the engine is numerically equal to the area ABCD. Let this area be divided into 100 equal parts by drawing isothermals parallel to CD or Ab. Then any isothermal will be at a temperature 1° lower than the isothermal just above it.Then the area of each point represents one degree on the thermodynamic scale. Thus, 1 K on thermodynamic scale may be defines as follows:

"1K is the temperature difference of source and sink between which a Carnot's engine operates to deliver work equal to one hundredth of the work delivered by the same engine working between steam and ice point".

Absolute Zero on thermodynamic scale

If we draw isothermals below the ice point, an isothermal representing the zero of the scale can be obtained. [Fig.1.7]. The isothermal GK represents absolute Zero.

Consider an engine working between the steam point and absolute zero ($\theta_0 = 0$)
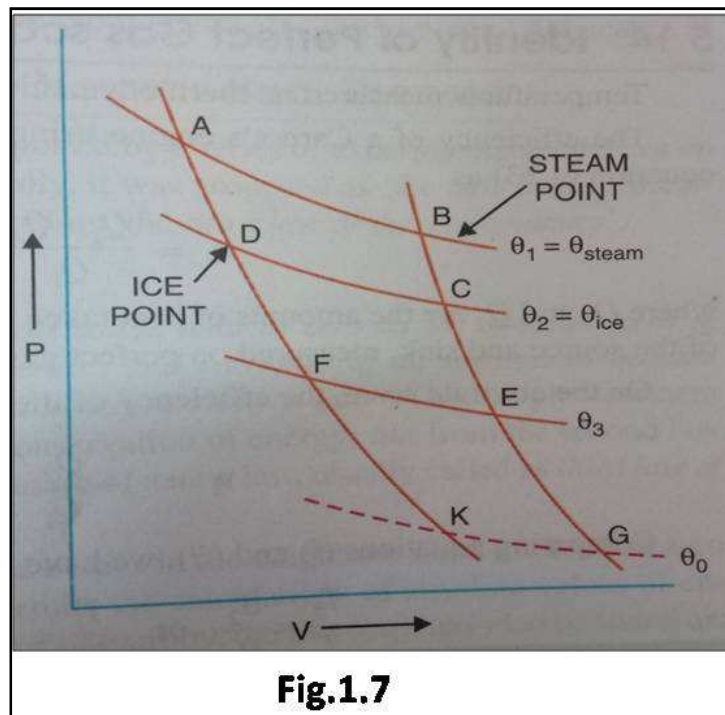
The efficiency of such an engine is

$$\eta = 1 - \frac{\theta_0}{\theta_{max}} = 1$$

Again, consider an engine working between ice point and absolute zero. Its efficiency is

$$\eta' = 1 - \frac{\theta_0}{\theta_{ice}} = 1$$

But efficiency is given by $\eta = 1 - \frac{Q_2}{Q_1}$

Fig.1.7

$$\eta = 1 - \frac{Q_2}{Q_1} = 1 \text{ or } \frac{Q_2}{Q_1} = 0$$

That is $\quad Q_2 = 0$

and $\qquad\qquad\qquad\qquad\qquad \eta = 1.$

Thus, the zero of the absolute scale is that temperature of the sink at which no heat is rejected to it., the efficiency of the engine being unity. Thus, a negative temperature is not possible on this scale.

Identity of perfect scale and thermodynamic scale.

The efficiency of a Carnot engine using a perfect gas as the working substance is

$$\eta = 1 - \frac{Q_2}{Q_1} = 1 - \frac{T_2}{T_1} \quad \text{-----(1)}$$

On the absolute scale, the efficiency of the engine is

$$\eta = 1 - \frac{Q_2}{Q_1} = 1 - \frac{\theta_2}{\theta_1} \quad \text{-------(2)}$$

Comparing (1) and (2)

$$\frac{T_2}{T_1} = \frac{\theta_2}{\theta_1} \quad \text{-----(3)}$$

Let the engine work between steam and ice points. Then

$$\frac{T_s}{T_i} = \frac{\theta_s}{\theta_i} = \frac{T_s - T_i}{T_i} = \frac{\theta_s - \theta_i}{\theta_i}$$

There are 100 degrees between the ice point and steam point on the two scales. Hence

$$\frac{100}{T_i} = \frac{100}{\theta_i}$$

Or $$T_i = \theta_i.$$

Similarly, $$T_s = \theta_s$$

(ie). The ice point and steam point on the two scales are identical.

Now consider a Carnot engine working between the steam point and another general temperature T

Then from eqn (1)

$$\frac{T_s}{T} = \frac{\theta_s}{\theta}$$

But $$T_s = \theta_s$$

Hence $$T = \theta$$

Thus, the thermodynamic temperature (θ) and perfect gas temperature (T) are numerically equal to each other. Hence a thermodynamic scale can be reduced by realizing a perfect gas scale. In practice, the scale furnished by a constant volume hydrogen thermometer is taken as standard. The temperature measured on it are corrected to obtain the corresponding temperatures on the perfect gas scale.

Thermodynamic Scale of temperature

The efficiency of reversible Carnot 's engine depends only upon the two temperatures between which it works and is independent of the properties (nature) of working substance. Using this property of Carnot's reversible engine which solely depends on temperature,. Lord Kelvin in 1848, suggested a new scale of temperature known as absolute scale of temperature. Lord Kelvin worked out the theory of such as absolute scale called the Kelvin's work or thermodynamic scale and showed that it agrees with the ideal gas scale.

Theory:

Suppose a reversible engine absorbs heat Q_1 at temperature θ_1 and rejects heat Q_2 at temperature θ_2 (measures on any arbitrary scale), then since the efficiency if the engine is a function of these two temperatures,

$$\eta = \frac{Q_1 - Q_2}{Q_1} = f(\theta_1, \theta_2)$$

$$1 - \frac{Q_2}{Q_1} = f(\theta_1, \theta_2)$$

$$\frac{Q_1}{Q_2} = \frac{1}{1 - f(\theta_1, \theta_2)} = F(\theta_1, \theta_2) \quad \text{---------(1)}$$

Similarly, if the reversible engine works between a pair of temperatures θ_2 and θ_3 ($\theta_2 > \theta_3$), absorbing heat Q_2 and rejecting Q_3, we can write,

$$\frac{Q_2}{Q_3} = F(\theta_2, \theta_3) \quad \text{------------(2)}$$

Also, it is works between Q_1 *and* Q_3 ($\theta_1 > \theta_3$), then

$$\frac{Q_1}{Q_3} = F(\theta_1, \theta_3) \quad \text{------------(3)}$$

Multiply Eqn (1) and (2) we have

$$\frac{Q_1}{Q_2} \times \frac{Q_2}{Q_3} = \frac{Q_1}{Q_3} = F(\theta_1, \theta_2) \times F(\theta_2, \theta_3)$$

Now, Comparing with Equation (3), we have

$$F\left(\theta_1, \theta_3\right) = F\left(\theta_1, \theta_2\right) \times F\left(\theta_2, \theta_3\right) \quad \text{---------(4)}$$

This is called the functional equation. It does not contain θ_2 on the left hand side.

Therefore, function F should be so chosen that θ_2 disappears from the right hand side. This is possible if

$$F\left(\theta_1, \theta_2\right) = \frac{\emptyset(\theta_1)}{\emptyset(\theta_2)} \times \frac{\emptyset(\theta_2)}{\emptyset(\theta_3)} = \frac{\emptyset(\theta_1)}{\emptyset(\theta_3)}$$

Equation (1) can be written as,

$$\frac{Q_1}{Q_2} = F\left(\theta_1, \theta_2\right) = \frac{\emptyset(\theta_1)}{\emptyset(\theta_2)}$$

Since $\theta_1 > \Theta_2$ *and* $Q_1 > Q_2$, *the function* $\emptyset(\theta_1) > \emptyset(\theta_2)$. Thus, function $\emptyset(\theta)$ is a linear function of θ and can be used to measure temperature. Thus, Lord Kelvin suggested $\emptyset(\theta)$ should be taken proportional to θ, ie. $\emptyset(\theta_1) = \theta_1$ and $\emptyset(\theta_2) = \theta_2$, we have

$$\frac{Q_1}{Q_2} = \frac{\theta_1}{\theta_2}$$

or

$$\frac{\theta_1}{\theta_2} = \frac{Q_1}{Q_2}$$

This equation shows that the ratio of the two temperatures on this scale is equal to the ratio of the heat absorbed to the heat rejected. This temperature scale is called Kelvin's thermodynamic (or absolute or work) scale of temperature.

Entropy

Definition: The entropy of a substance is that physical quantity which remain constant when the substance undergoes a reversible adiabatic process.

Explanation:

Consider two adiabatic AF and BE as shown in figure crossed by a number of isothermals at temperature T_1, T_2, T_3. Consider the Carnot cycle ABCD. Let Q1 be the heat absorbed from A to B at Temperature T_1. Let Q2 be the het rejected from C to D at Temperature T_2.[Fig.1.8]

From theory of Carnot engine, $Q_1/T_1 = Q_2/T_2$

Similarly for Carnot cycle, DCEF, $Q_1/T_1 = Q_3/T_3$

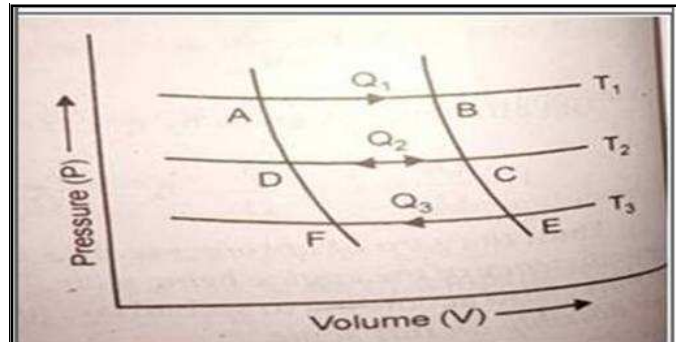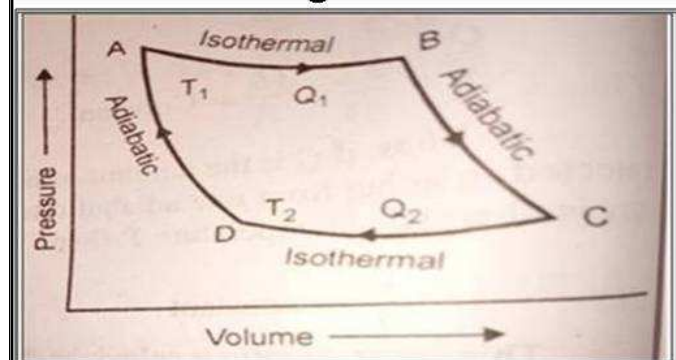$Q_1/T_1 = Q_2/T_2 = Q_3/T_3 =$ Constant.

Fig.1.8

Fig.1.9

Thus if Q is the amount of heat absorbed or rejected in going from one adiabatic to another adiabatic along any isothermal at temperature T , then $Q / T =$ Constant. This constant ratio is called the change in entropy in going from adiabatic AF to the adiabatic BE.

If a system absorbs a quantity of heat dQ at constant temperature T during a reversible process, the entropy increases by dS =dQ/T.

If a substance gives out a a quantity of heat dQ at constant temperature T during a reversible process, the entropy decreases by dS =dQ/T. Unit of entropy is JK^{-1}.

For an adiabatic change dQ=), dS=0.

Thus, no change of entropy during a reversible adiabatic process.

Change of entropy in a reversible process

Consider a reversible Carnot cycle [Fig.1.9]

(i)   The working substance absorbs an amount of heat Q_1 at a constant temperature T_1 in the isothermal expansion :

Increase in entropy from A to B = Q_1/T_1

(ii)   During the adiabatic expansion from B to C, there is no change in entropy.

(iii)   During the isothermal compression from C to D, the working substance gives out a quantity of heat Q2 at constant temperature T_2.

Decrease in entropy from A to B = Q_1/T_1

(iv)   During the adiabatic compression from D to A, there is no change in entropy.

The net change in entropy of working substance
during the cycle ABCD   = Q_1/T_1 - $Q_1/T1$

For a reversible cycle, Q_1/T_1 = Q_1/T_1 (or) Q_1/T_1 - Q_1/T_1 = 0.

Thus, the total change of entropy is zero during a Carnot's cycle.

Entropy change in a reversible cycle is zero.

Change of entropy in a Irreversible process

Consider an irreversible process like conduction and radiation of heat . Suppose a body at a higher temperature T_1 conduct away a small quantity of heat dQ to another body at a lower temperature T_2, then

Decrease in entropy of the hot body = dQ/T_2

Increase in entropy of the cold body = dQ/T_1

The net increase in entropy of the system = dS = dQ/T_1 - dQ/T_1

dS is always positive since $T_2 > T_1$.

Hence, the entropy of a system increases in all irreversible processes.

Law of increase of entropy

Consider the natural processes of conduction of heat from a body A at temperature T_1 to another body at lower temperature T_2. This process is irreversible. Since heat always flows from higher to a lower temperature, the quantity of heat transmitted be Q, then

Decrease in entropy of a hotter body = Q/T_1

Increase in entropy of colder body = Q/T_2

Net increase in entropy of the system $dS = Q/T_1 - Q/T_2 = $ +ve quantity as $T_i > T_2$.

Thus the entropy increases in all irreversible processes. This is known as law of principle of increase of entropy.

Temperature – Entropy diagram

The state of a substance may be represented by points plotted with temperature as ordinates and entropies as abscissa. This is T-S diagram [Fig.1.10]. The isothermals ae horizontal straight line and adiabatic are vertical lines.

(i)   From A to B, heat energy Q1 is absorbed at temperature T1, Increase in entropy from A to B = $S_1 = Q_1/T_1$.

(ii)   From B to C, No change in entropy.

(iii) From C to D, the decrease in entropy at constant temperature T2 is $S_2 = Q_2/T_2$.
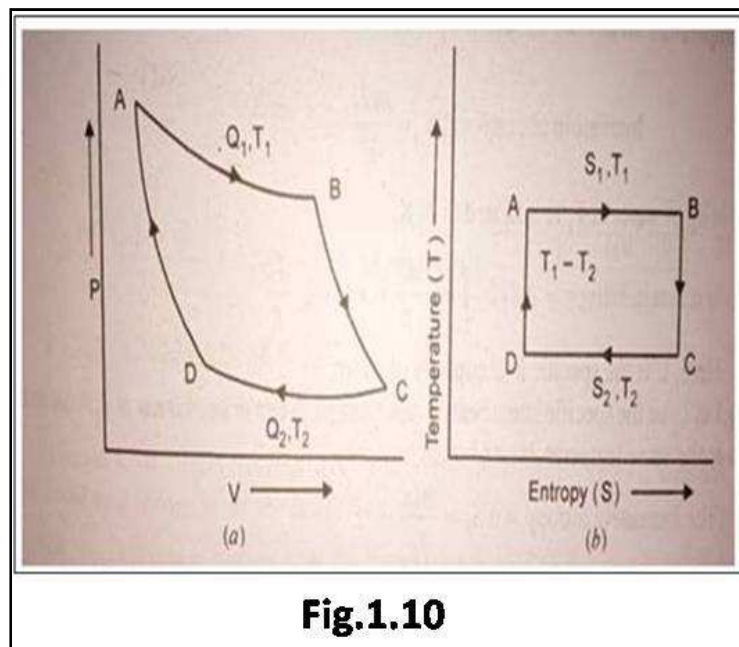
(iv)   From D to A, no change in entropy.

Fig.1.10

The area ABCD in T-S diagram $S_1(T_1-T_2) = S_2(T_1-T_2)$
$S_1/S_2 = Q_1/T_1 - Q_2/T_2 = Q_1 - Q_2/T_1 - T_2$

Area of figure ABCD in T-S diagram = $Q_1 - Q_2/T_1 - T_2 (T_1 - T_2) = Q_1 - Q_2$.

The area ABCD represents the energy converted into work.

The efficiency of the engine, = Heat energy converted into work / total heat absorbed

$$\eta = \frac{S_1(T_1 - T_2)}{T_1 S_1} = \frac{T_1 - T_2}{T_1}$$

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The TdS Equations

1. **. First TdS Equaion: The entropy S of a pure substance can be taken as a function o temperature and volume.**

   $dS = (\partial S|\partial T)_V \, dT + (\partial S|\partial T)_T \, dV$

   Multiplying both sides by T

   $T \, dS = T \, (\partial S|\partial T)_v \, dT + T \, (\partial S|\partial T)_T \, dV$ ----- Eqn (1)

   But $C_V = T \, (\partial S|\partial T)_v$

   and from Maxwell's relations

   $(\partial S|\partial T)_T = (\partial P|\partial T)_V$

   Substituting these values in above equation (1) we get,

   $\mathbf{T \, dS = C_V \, dT + \mathit{T} \, (\partial P|\partial T)_V \, dV.}$ -----------Eqn **(2)**

   Eqn.(2) is called as the First T dS equation.

2. **Second TdS Equaion: The entropy S of a pure substance can be taken as a function of temperature and pressure.**

   $dS = (\partial S|\partial T)_P \, dT + (\partial S|\partial T)_T \, dP$

   Multiplying both sides by T

   $T \, dS = T \, (\partial S|\partial T)_P \, dT + T \, (\partial S|\partial T)_T \, dP$ ----- Eqn (3)

   But $C_P = - T \, (\partial S|\partial T)_P$

   and from Maxwell's relations

   $(\partial S|\partial T)_T = (\partial V|\partial T)_P$

   Substituting these values in above equation (1) we get,

   $\mathbf{T \, dS = C_P \, dT - \mathit{T} \, (\partial V|\partial T)_P \, dP.}$ -----------Eqn (4)

   Eqn.(4) is called as the Second T dS equation

Review Questions

PART A

1. State Zeroth law of thermodynamics.
2. State first law of thermodynamics.
3. State second law of thermodynamics.
4. Distinguish between reversible and irreversible process giving examples.
5. State different statements of second law of thermodynamics.
6. Find the efficiency of the Carnot engine working between the steam point and the ice point.
7. Define and explain entropy.
8. Obtain an expression for change in entropy in an irreversible process.
9. What is meant by thermodynamic scale of temperature?
10. Explain what is T-S diagram. What information does it provide?

PART B

1. Derive an expression for the efficiency of a Carnot's engine in terms of temperature of the source and sink.
2. State and prove Carnot's theorem.
3. Define entropy.hat is its physical significance. Show that the entropy of a perfect gas remains constant in a reversible process but increases in an irreversible process.
4. A Carnot's engine is operated between two reservoirs at temperatures of 450K and 350K. If the engine receives 1000 calories if heat from the sources in each cycle, calculate the amount of heat rejected to the sink in each cycle. Calculate the efficiency of the engine and the work done by the engine in each cycle. (1 calorie =4.2 joules).
5. Define Kelvin's absolute scale of temperature. Show that this scale agrees with that of a perfect gas scale.

Book referred

[1] Fundamentals of Thermodynamics   by Richard E.Sonntag, Claus Borgnakke, Gordan J.Van Wylen, 5th edition.
[2] An Introduction to Thermodynamics and Statistical Mechanics   by A.K.Saxena
[3] Thermal Physics by R.Murugeshan and Er.Kiruthiga Sivaprasath -, S.Chand and Co Ltd- Revised Edition 2007
[4] Heat Thermodynamics and Statistical Mechanics by BrijLal, N.Subrahmanyam and P.S Hemne-, S.Chand and Co Ltd- Revised Edition 2007.

UNIT – II   Low Temperature Physics

Joule – Thomson's effect - porous plug expt. – liquefaction of gases – Adiabatic expansion process – adiabatic demagnetization – Accessories employed in dealing with liquefied gases – Practical applications of low temp – Refrigerating mechanism – Electrolux refrigerator – Frigidaire – Air conditioning machines.

Joule – Thomson's effect

Statement

If a gas initially at constant high pressure is allowed to suffer throttle expansion through the porous plug of silk, wool or cotton wool having a number of fine pores, to a region of constant low pressure adiabatically, a change in temperature of gas (either cooling or heating) is observed. This effect is called as Joule –Thomson or Joule-Kelvin effect.

Porous Plug experiment

Joule in collaboration with Thomson [Lord Kelvin] devised a very sensitive technique known as Porous Plug experiment. The experiment set up of porous plug experiment to study the Joule-Thomson effect is shown in Fig.2.1. It consists of the following main parts:

(a) A Porous plug having two perforated -brass discs D & D1.
(b) The space between D & D1 is placed with cotton wool or silk fibers.
(c) The porous plug is fitted ina cylindrical box-wood W which is surrounded by a vessel containing cotton wool. This is to avoid loss or gain of heat from the surroundings.
(d) T1 &T2 are two sensitive platinum resistance thermometers and they measure the temperatures of the incoming and outgoing gas.
(e) The gas is compressed to a high pressure with the help of piston P and it is placed through a spiral tube immersed in water bath maintained at a constant temperature. If there is any heating of the gas due to compression, this heat is absorbed by the circulating water in the water bath.

Experimental Procedure

The experimental gas is compressed by Pump P and is passed slowly and uniformly through the porous plug keeping the high pressure constant read by pressure gauge. During the passage through the porous plug, the gas is throttled. The separation between the molecules

Fig.2.1
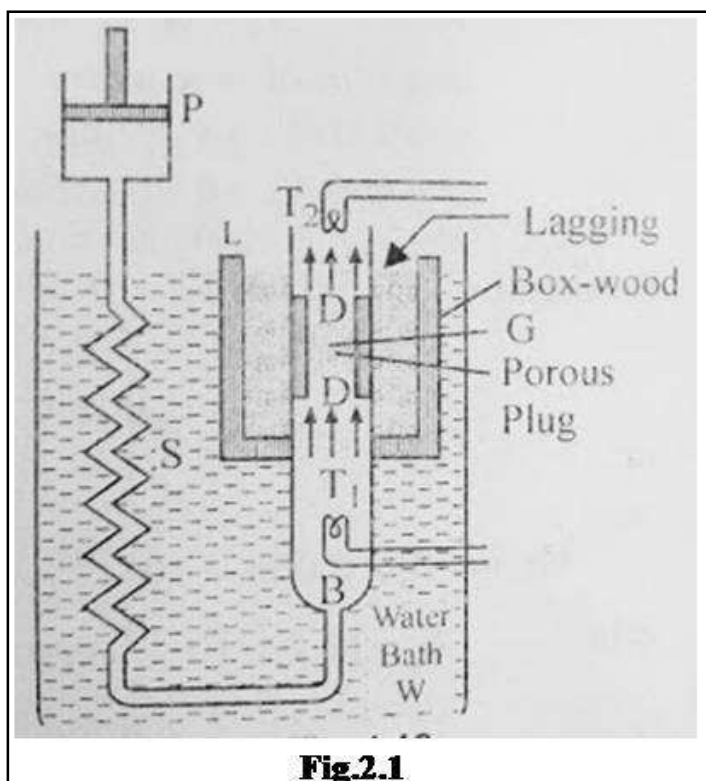
increases. On passing through the porous plug, the volume of the gas increases against the atmospheric pressure. As there is no loss or gain of heat during the whole process, the expansion of the gas takes place adiabatically. The initial and final temperatures are noted by platinum resistance thermometers T1 & T2.

Experimental Results

A simple arrangement of porous plug experiment is shown in Fig.2.2 .The behavior of large number of gases was studied at various inlet temperatures of the gas and the results are as follows:

(1) At sufficiently low temperatures, all gases show a cooling effect.
(2) At ordinary temperatures, all gases except hydrogen and helium show cooling effect. Hydrogen and Helium show heating effect.
(3) The fall in temperature is directly proportional to the difference in pressure on the two sides of porous plug.
(4) The fall in temperature for a given difference with rise in the initial temperature of the gas. It was found that the cooling effect decreased with the increase of initial temperature and becomes zero at a certain temperature and at a temperature higher than the temperature instead of cooling heating was observed. This particular temperature at which the Joule –Thomson effect changes sign is called temperature of inversion.

Fig.2.2
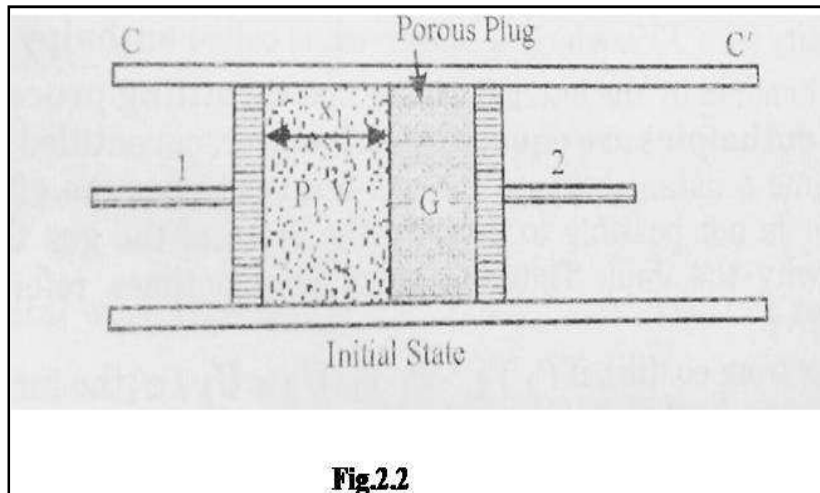
Theory of Porous Plug experiment

The arrangement of the porous plug experiment is shown in Fig. The gas passes through the porous plug from the high pressure side to the low pressure side. Consider one mole of the gas. Let P_1, V_1 and P_2, V_2 represent the pressure and volume of the two sides of the porous plug.

Let dx be the distance through which each piston moves to the right.

The work done on the gas by the piston $A = P_1A_1dx = P_1V_1$

The work done by the gas on the piston $B = P_2A_2dx = P_2V_2$

Net external work done by the gas $= P_2V_2 - P_1V_1$

Let w be the work done by the gas in separating the molecules against their inter-molecular attraction.

Total amount of work done by the gas $= (P_2V_2 - P_1V_1 + w$

There are three cases depending upon the initial temperature of gas.

(i)   Below the Boyle temperature: $P_2V_2 < P_1V_1$
       $P_2V_2 - P_1V_1$ is +ve and w must be either positive or zero.
       Thus, a net +ve work is done by the gas.
       Hence, there must be a cooling effect.

(ii)   At the Boyle temperature: $P_2V_2 = P_1V_1$
        $P_2V_2 - P_1V_1 = 0$.
        The total work done by the gas in this case is w. Therefore, cooling effect at this temperature is only due to the work done by the gas in overcoming inter-molecular attraction.

(iii)   Above the Boyle temperature: $P_2V_2 > P_1V_1$
        $P_2V_2 - P_1V_1$ is –ve.

Thus, the observed effect will depend upon whether $(P_2V_2 - P_1V_1)$ is greater than or less than w.

If $w > (P_2V_2 - P_1V_{1,})$, cooling will be observed.

I   f $w < (P_2V_2 - P_1V_{1,})$, heating will be observed.

Thus, the cooling or heating of a gas depends on

(i)   The deviation from Boyle's law
(ii)   Work done in overcoming inter-molecular attraction.

Definition of temperature of inversion : The temperature at which the Joule-Thomson effect change sign (ie. The cooling effect becomes the heating effect) is called the temperature of inversion. (T_i). A this temperature (T_i), there is neither cooling nor heating.

Relation between temperature of inversion (T_i) and critical temperature (T_c).

Let (T_i) be the critical temperature of a gas. Then,

Its temperature of inversion $\mathbf{T_i}$ is $= 6.75 \, T_c$

Thus, the temperature of inversion of a gas is much higher than its critical temperature.

Expression for the Joule Thomson cooling produced in a vander Waals gas.

Suppose that one mole of gas is allowed to expand through a porous plug from a pressure P_1 and volume V_1 to a pressure P_2 and volume V_2. Let the temperature change from T_1 to T_2 due to Joule-Thomson effect.

Net external work done by the gas $= P_2V_2 - P_1V_{1,}$ -----(1)

Now, an internal work is also done by the gas in overcoming the forces of molecular attraction. For a van der Waals gas, the attractive forces between the molecules are equivalent to an internal pressure $\frac{a}{V^2}$.

Internal work done by the gas when the gas expands from a volume V_1 to V_2 is

$$\int_{V_1}^{V_2} P \, dV = \int_{V_1}^{V_2} \frac{a}{V^2} \cdot dV = \frac{a}{V_1} - \frac{a}{V_2} \text{-------(2)}$$

Total work done by the gas = external work +internal work

$$W = P_2V_2 - P_1V_1, \; +\frac{a}{V_1} - \frac{a}{V_2} \text{-------(3)}$$

Now, van der Waals equation of state for a gas is

$$(P +\frac{a}{V^2}) \, (V - b) = RT$$

or $\;\; PV = RT + Pb - \frac{a}{V} \;\;$ (neglecting $\frac{ab}{V^2}$)

$$P_1V_1 = RT_1 + bP_1 - -\frac{a}{V_1} \qquad\qquad \text{and} \;\; P_2V_2 = RT_2 + b\,P_1 - \frac{a}{V_2}$$

Substituting these values for P_1V_1 and P_2V_2 -in eqn (3) we get,

$$W = R(T_1 - T_1) - b(P_1 - P_2) + \frac{2a}{V_1} - \frac{2a}{V_2} \text{-----(4)}$$

Since a and b are very small, PV=RT or V=RT/P.

Hence, $V_1 = RT_1/P_1 \;\;$ and $V_2 = RT_2/P_2$.

Also, T_1 and T_2 are vry nearly equal. Hence we may write T for T_1 or T_2.

$$W \;\;\; = R(T_2 - T_1) - b(P_1 - P_2) + \frac{2a}{RT} (P_1 - P_2)$$

Let $T_1 - T_2 = \partial T$. Then

$$W = -R \, \partial T - b(P_1 - P_2) + \frac{2a}{RT} (P_1 - P_2)$$

$$W = (P_1 - P_2) \, (\frac{2a}{RT} - b) - R \, \partial T. \text{ \_-------(5)}$$

Since the gas is thermally insulated , the energy necessary for doing this work is drawn from the K.E. of the molecules. Hence, the K.E. decreases resulting in a fall of temperature by ∂T.

Heat lost by the gas = $C_V \, \partial T$

$$C_V \, \partial T \;\; = \;\; (P_1 - P_2) \, (\frac{2a}{RT} - b) - R \, \partial T.$$

Or $\partial T (C_v + R) = (P_1 - P_2) (\frac{2a}{RT} - b)$

Or $\partial T = \dfrac{(P_1 - P_2) (\frac{2a}{RT} - b)}{C_P}$-------(6)

Eqn (6) gives the fall in temperature or the cooling produced in a van der Waals gas when subjected to throttling process.

(i)   If $\frac{2a}{RT} > b$, then ∂T is positive. Hence there will be a cooling effect.

(ii)   If $\frac{2a}{RT} < b$, then ∂T is negative. Hence there will be a heating effect.

(iii)   If If $\frac{2a}{RT} = b$, then $\partial T = 0$. Hence there will be neither a heating nor a cooling effect.

(iv)   The temperature at which the Joule –Thomson effect changes sign is called the temperature of Inversion. (Ti).

(v)   At this temperature, $\dfrac{2a}{RTi} = b$,

$$Ti = \frac{2a}{Rb}.$$

Thus, above the temperature of inversion, Joule- Thomson effect will be a heating effect and below it a cooling effect.

Relation between

Boyle temperature (T_B), temperature of inversion (T_I) and critical temperature(T_C)

We have

$$\mathbf{T_B} = \frac{a}{R\mathbf{b}} \quad T_i = \frac{2a}{R\mathbf{b}} \quad \text{and } T_c = \frac{8a}{27R\mathbf{b}}$$

$T_i = 2\,\mathbf{T_B}$ **and** $T_i = 6.75\,T_c$

Thus, the temperature of inversion of a gas is much higher than its critical temperature

Liquefaction of Gases

Introduction

A gas goes into liquid and solid forms as the temperature is reduced. Thus the processes of liquefaction of gases and solidification of liquids are involved in the production of low temperatures. Andrews experiments showed that if a gas is to be liquefied by merely applying pressure on it, it has to be cooled below its critical temperature. Since the critical temperatures of carbon dioxide and sulphur dioxide and ammonia are higher than room temperature, these gases can be liquefied at room temperature without precooking simply by increasing the pressure.

Joule Thomson experiment is a very important technique to liquefy gases. The cooling produced depends on the difference of pressure on the two sides of the porous plug and the initial temperature.

Liquefaction of Gases

The systematic study of liquefaction of gases started in 1823 when faraday successfully liquefied chlorine, CO2, hydrogen sulphide etc, only by cooling them and applying pressure. However, gases like oxygen, hydrogen and helium etc could not be liquefied even by applying very high pressure. Hence, they were termed as permanent gases. Andrew's e experiments on CO_2, in 1862 showed that a gas must be cooled below the critical temperature before being liquefied under pressure   Real success was obtained when Joule-Thomson effect is coupled with regenerative cooling.

## *Principle of Regenerative Cooling*

The cooling produced in Joule-Thomson experiment of a gas depends on the difference of pressure on the sides of the porous plug and the initial temperature for most of the gases, the joule-Thomson cooling is very small. For example, at a temperature of 20℃ when the pressure on the two sides are 50 atmospheres and 1 atmospheres respectively, the air cools only by 11.7℃ . In order to increase to cooling, the pressure difference was increased , but the cooling did not increase very much. For example, at a temperature of 20℃ when the pressure on two sides were kept at 210 atmospheres and 1 atmosphere the air was cooled only by 42℃. However, the cooling effect can be intensified by employing the process called the regenerative cooling.

Principle

In this process, a portion of the gas which suffers Joule-Thomson expansion and becomes cooled is employed to cool other portion of the incoming gas below the later reaches the nozzle to suffer Joule-Thomson expansion. After suffering the Joule-Thomson expansion at the nozzle, the incoming gas becomes further cooled. By continuous repetition of this process, the temperature of the gas coming out of the nozzle falls continuously till the gas starts liquefying on the low pressure side. The continuous process used to cool the gas continuously is called the regenerative cooling.

Experimental Arrangement: The schematic arrangement of regenerative principle is shown in Fig.2.3 The gas is compressed to a high pressure in the compressor. The heat of compression evolved is removed by passing the gas through spiral contained in the water cooled jacket A. The gas next enters the inner side of the regenerator R and suffers Joule-Thomson expansion at the nozzle V so that it cools by a small amount. This cooled gas returns by the outer tube and absorbs heat

From the incoming high pressure gas before it reaches the compressor at the same temperature as the incoming gas at R. The gas is again compressed, cooled by A and re-enters at R. As time passes, the gas approaching V becomes more and more cooled till the joule-Thomson cooling at V sufficient to liquefy the gas. A portion of the escaping gas, then condenses inside the Dewar flask F. At this stage, the temperature of the whole apparatus becomes steady and the temperature of the low pressure gas in R which is less than the temperature of the adjacent high pressure gas at every part of the inner tube. Thus, the low pressure gas extracts heat from the incoming gas.

Fig.2.3
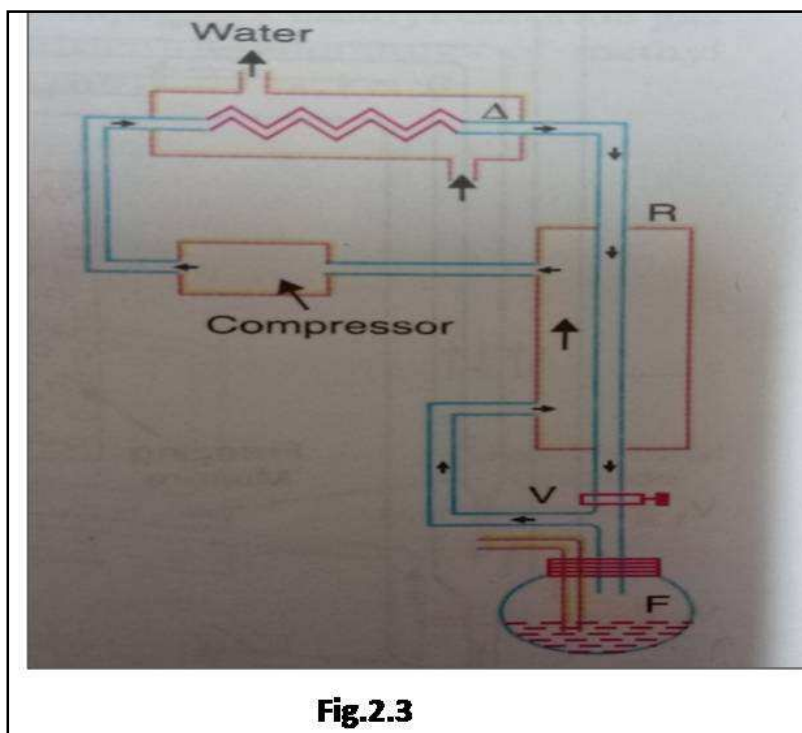
Adiabatic process

An adiabatic process is a process in which change in volume and pressure of a given gas takes place in completer thermal isolation. During an adiabatic process, no heat enters or leaves the system, but the temperature changes.
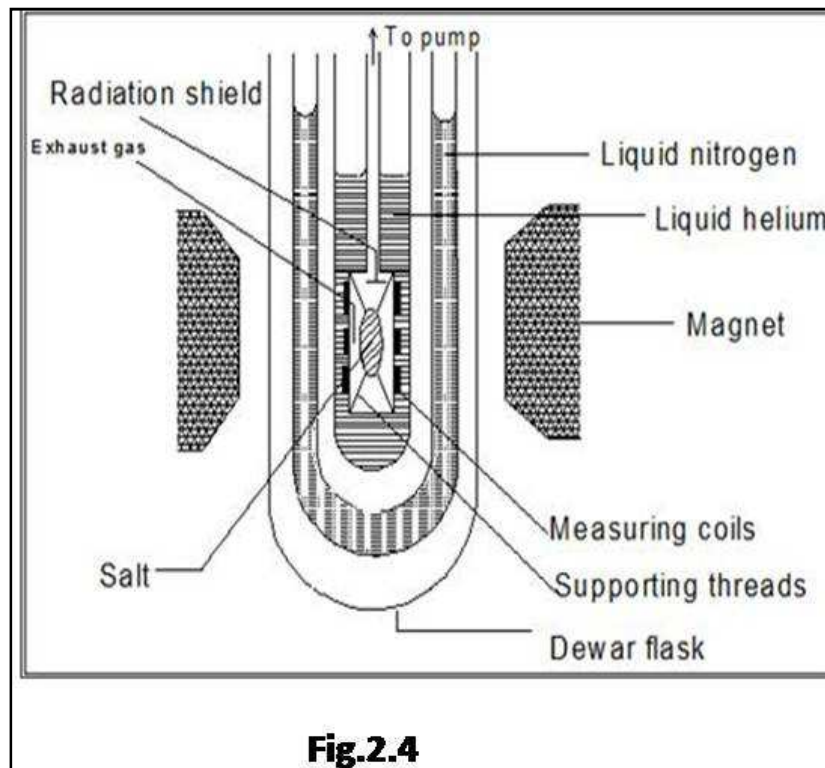
Adiabatic Demagnetization

Principle

When a paramagnetic substance is magnetized, external work is done on it and its temperature rises. When the substance is demagnetized, work is done by the substance. Hence, if the substance is demagnetized adiabatically, its temperature falls. This is called Adiabatic Demagnetization. Maximum cooling can be produced by applying strong magnetic field and low initial temperatures.

Experimental setup

The paramagnetic salt (gadolinium sulphate) is suspended inside a glass bulb B. Bulb B is surrounded by Dewar flasks D1 and D2 containing liquid helium and liquid hydrogen. respectively. The whole setup is placed between the pole-pieces of a strong electromagnet as shown in Fig.2.4.

(a) The magnetic field is switched on and the specimen gets magnetized.
(b) The heat due to magnetization is removed by first introducing hydrogen gas into B and then passing it off with a high vacuum pump. Now the cold magnetized specimen is thermally insulated from D1 and D2.
(c) The magnetic field is switched off now.

Fig.2.4

Adiabatic demagnetization of the specimen takes place and the temperature falls. The final temperature of the specimen(T1) is determined by measuring the susceptibility of the substance at the beginning and at the end of the experiment by using a solenoid coil CC.

Let χ_1 and χ_2 be the susceptibilities of the specimen salt at the initial and final T_1 and T_2.

According to Curie's law, $\mathbf{T_2} = \dfrac{\chi_1}{\chi_2} \ \mathbf{T_1}$

Expression for the fall in temperature due to adiabatic demagnetization

According to first law of thermodynamics

$$dQ = dU + P \, dV \text{-----------(1)}$$

The thermo dynamical behavior of a paramagnetic crystal, placed in a magnetic field depends on the strength of the magnetizing field in addition to pressure and volume.

Let the paramagnetic substance be placed in the magnetic field of magnetic flux density B_i. The elementary magnetic dipoles of the paramagnetic salt become aligned parallel to the field direction.

Work done by the sample = -B dI

Here, dI = change in the intensity of magnetization per gram molecule.

Eqn (1) becomes,

$$dQ = dU + PdV - B \, dI \text{-------------(2)}$$

According to second law of thermodynamics, we have

$$dQ = T \, dS \text{------------(3)}$$

$$T \, dS = dU + P \, dV - B \, dI$$

or $\qquad dU = T \, dS + B \, dI - P \, dV \quad \text{-------(4)}$

Let x and y be a pair of independent thermo dynamical variables

Then, from the condition

$$\frac{\partial 2U}{\partial x \, \partial y} = \frac{\partial 2U}{\partial y \, \partial x}, \qquad \text{we get}$$

$$\frac{\partial\ (T,S)}{\partial(x,y)}\ +\ \frac{\partial\ (B,I\ )}{\partial(x,y)}\ =\ \frac{\partial\ (P,V)}{\partial(x,y)}\quad\text{--------(5)}$$

In the adiabatic demagnetization experiments, the change in volume is negligible. It means $\partial V = 0\ (ie)V = constant$

$$\frac{\partial\ (T,S)}{\partial(x,y)}\ =\ -\ \frac{\partial\ (B,I\ )}{\partial(x,y)}\quad\text{--------------(6)}$$

This is the general equation connecting T,S,B and I.

The various thermodynamical relation can be derived by choosing any two out of these four variables, T,S,B and I.

(1) Taking x=B and y=T
$$(\partial S|\partial B)T\ \ =\ (\partial I|\partial T)B\quad\text{----(7)}$$

(2) Taking x = B and y =S
$$(\partial T|\partial B)S\ \ =\ -\ (\partial I|\partial S)B\quad\text{----(8)}$$

From Eqn (8)
$$(\partial T|\partial B)S\ \ =\ -\ (\partial I|\partial S)B\ \ =\ -\frac{(\partial I|\partial T)B}{(\partial S|\partial T)B}$$

$T(\partial S|\partial T)\ B\ = C_B$, the specific heat capacity of the substance at constant volume.
$$(\partial T|\partial B)S\ \ =\ \frac{-\ T}{C_B}\ \ (\partial I|\partial T)S\quad\text{------(9)}$$

Eqn.(9) gives the change in temperature during adiabatic demagnetization.

This phenomenon where there is change in temperature due to adiabatic demagnetization is called magneto calorie effect.

Let T_i and T_f be the initial and final temperatures of the specimen corresponding to the initial and final magnetic flux densities B_i and B_f respectively. Then,

$$T_f - T_i = \int_{Bi}^{Bf}\frac{T}{C_B}(\partial I|\partial T)_B\ dB\ \text{------(10)}$$

But $I = \chi BV$ and $\chi\ =\frac{C}{T}$ (from Curie Law)

Here, χ is the susceptibility per unit volume

$$T_f - T_i = - \int_{Bi}^{Bf} \frac{T}{C_B} \frac{d}{dT} (\chi BV) \, dB = - \int_{Bi}^{Bf} \frac{TBV}{C_B} \frac{d}{dT} \left(\frac{C}{T}\right) dB$$

$$= - \int_{Bi}^{Bf} \frac{TBVC}{C_B} \frac{d}{dT} (1/(-T^2)) \, dB$$

$$T_f - T_i = \frac{C V}{C_B \ T} \frac{(B_i^2 - B_f^2)}{2} \qquad \text{------------(11)}$$

When the magnetic field is cut off, $B_f = 0$,

$$T_f - T_i = - \frac{CVB_i^2}{2 C_B \ T_i} \qquad \text{------------(12)}$$

The negative sign in Eqn (12) indicates a fall in temperature in adiabatic demagnetization.

Therefore, fall in temperature,

$$\Delta T = \frac{CVB_i^2}{2 C_B \ T_i} \qquad \text{------------(13)}$$

From Eqn.(13) it is evident that the fall in temperature is greater for large values of the magnetizing field and low values of initial temperature

Fall in temperature due to adiabatic demagnetization,

$$\mathbf{\Delta T = CVB_i^2 / 2C_B T_i}$$

$$\Delta T = - \frac{CV \ B_{i2}}{2C_B \ Ti}$$

Conclusions: (a) The temperature of the paramagnetic substance decreases on decreasing the magnetizing field B indicated by the negative sign ΔT and

(b) Greater is the initial field B and lower is the initial temperature T, greater is the temperature fall ΔT.

It should be noted that the quantity CV is the Curie constant per mole. It 1 gm of paramagnetic substance (salt) is taken, then CV would stand for Curie constant per gm.

T-S Diagram

The cooling produced by adiabatic demagnetization is explained by using T-S (ie) Temperature entropy diagram as shown in Fig. 2.5

In the diagram,, the entropy of the substance is represented as a function of temperature for two different magnetizing fields constants. (ie) $H_2 = 0$ and $H_1 = H$. The arrow AB represents the change in entropy during isothermal magnetization (at constant temperature). This arrow shows the decrease in entropy of the substance during magnetization form H=0 to H). Now if the field is switched off, the substance demagnetize adiabatically, so that the temperature falls while during the process entropy remains constant as represented by an arrow BC. During the process, ie adiabatic demagnetization the temperature of the order of 10^{-4} can be reached. The main hurdle in this method is the measurement of such a low temperature . This problem is resolved by using the Curie law. Assuming the validity of Curie law, and if the susceptibility of the sample is measures, the Curie temperature $T_c = \dfrac{C}{\varphi}$ (also known as magnetic temperature) can be calculated. Knowing the Curie temperature, the thermo dynamical temperature T can be calculated. The temperature measures by this method is of the order of 10^{-4} K. We can still go sown to the order of 10^{-6} by making use of nuclear magnetism. But it should be remembered that absolute zero never be attained in actual practice.
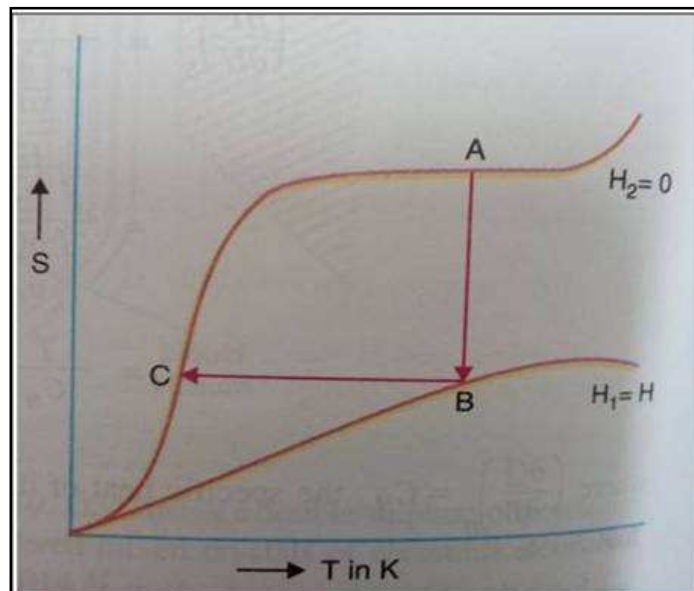

Fig.2.5

Accessories employed in dealing with liquefied gases

Cryogenic liquids are liquefied gases that are kept in their liquid state at very low temperatures. Cryogenics is the science of ultra low temperatures. Low temperatures are achieved by the liquefaction of gases. The gases which are most widely used in industry and research are helium, hydrogen, nitrogen, fluorine, argon, oxygen and methane.

Cryogenic fluids are stored in well insulated containers to minimize loss due to boil off.
• The most commonly used container for handling cryogenic fluids is the Dewar flask.
• Dewar flasks are non pressurized, vacuum jacketed vessels.

Liquid Dewar Flasks

Liquid dewar flasks are non-pressurized, vacuum-jacketed vessels which should have a loose fitting cap or plug that prevents air and moisture from entering, yet allows excess pressure to vent. Flasks containing helium, hydrogen and other low- boiling liquids have an outer vessel of liquid nitrogen for insulation.

Laboratory Liquid Dewar Flasks

Laboratory liquid Dewar has wide-mouthed openings and do not have lids or covers. These small containers are primarily used in laboratories for temporary storage.

The tank has regulators, vent valves, inner and outer tank rupture disks, pressure gauges, pressure relief valves and vaporizers to assure proper containment of the cryogenic material during storage and dispensing. Cryo flask for handling liquid nitrogen. Portable trolleys must be used for moving large containers of cryogens.

Liquid Cylinders

Liquid cylinders are pressurized containers specifically designed for cryogenic liquids. This type of container has valves for filling and dispensing the cryogenic liquid, and a pressure-control valve with a frangible (bursting) disk as backup protection. There are three major types of liquid cylinders which are designed for dispensing liquid or gas, only gas or only liquid.

Cryogenic liquid containers, also referred to as liquid cylinders, are double-walled vacuum vessels with multilayer insulation in the annular space. They are designed for the reliable and economic transportation and storage of liquefied gases at cryogenic temperatures, typically colder than –130°F (–90°C).

Cryo hand gloves must be worn when handling cryogenic liquids. The gloves must be loose fit so that they can be quickly removed in case any liquid splashes into them. Tongs must be used to withdraw objects immersed in liquid. Liquefied gases must be transported only in suitably insulated containers that provide means for the escape of gas as liquid evaporates. Never plug the outlet of such containers.

Practical applications of low temperatures

Applications in pure sciences

(a) Separation of the constituents of air
(b) Production of high vacuum
(c) Calorimetric work
(d) Study of properties of the upper atmosphere
(e) Study of properties of substances at low temperatures
(f) Applications in pure sciences

Applications in Industry

(a) Liquid oxygen stored in cylinders are used In hospitals for artificial respiration.
(b) Liquid oxygen is used in the manufacture of explosives.
(c) Argon is used in 'gas filled' electric lamps.
(d) Neon is employed in discharge tube required for illumination and advertising sign boards.
(e) Liquid air is importance in separation and purification o gases.
(f) The most important application of liquefied gases is in the working of refrigerating and air conditioning machines.

Refrigerating mechanism – Electrolux refrigerator

Definition

Refrigeration is defined as the production of temperature lower than that of the surroundings and maintains that temperature within the boundary of s given space.

Principle

The principle used in the production of low temperature is by the evaporation of a suitable liquid under reduced pressure.The liquids used for this purpose are called refrigerants. (Eg) ammonia, sulphurdiooxide, carbondioxide, Freon, amd methyl chloride. In large refrigerating plants, ammonia is used and for domestic purposes, freons and sulphur dioxide are used.

The gas is compressed to a high pressure by the compressor P. It is cooled down by the water circulating through the spiral pipe at C. The gas then gets liquefied. This high pressure liquid passes through a throttle valve T towards a low pressure side. It comes out as a mixture of liquid and vapour and its temperature gets lowered. At D this liquid vapour mixture takes heat from its surroundings material thus cooling this stuff. In this process, the remaining liquid also turns into vapour. This vapour is finally sucked by the pump P. It is shown in Fig.2.6.
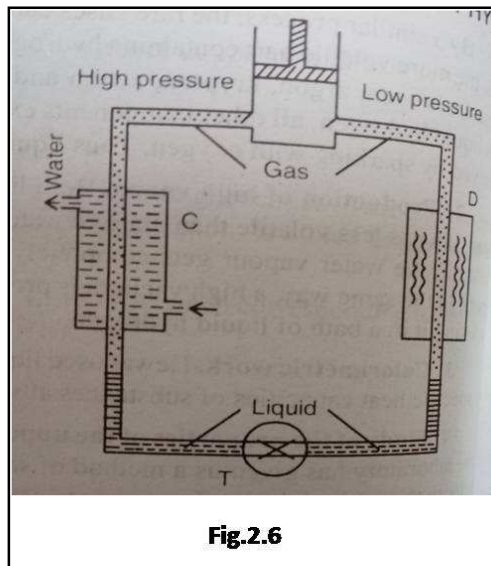
Fig.2.6

Electrolux refrigerator

Principle

The principle used in the production of low temperature is by the evaporation of a suitable liquid under reduced pressure. The liquid ammonia is made to evaporate under reduced pressure in an atmosphere of hydrogen. Fig.2.7 shows the schematic diagram of an Electrolux refrigerator

Construction and Working: It consists of four essential parts

   (a) *Generator* : Ammonia gas is generated by heating the strong aqueous solution of ammonia in it by means of a heater H.
   (b) *Condenser*: It is cooled by water circulating round it. So the gaseous ammonia condenses to the liquid form
   (c) *Evaporator:* The evaporator is inside the space desired to be cooled. Here the liquid ammonia gets evaporated.
   (d) *Absorber*: The absorber is surrounded by a cold water jacket. Here, the gaseous ammonia from the evaporator gets absorbed by the weak aqueous solution from the generator.

Fig.2.7
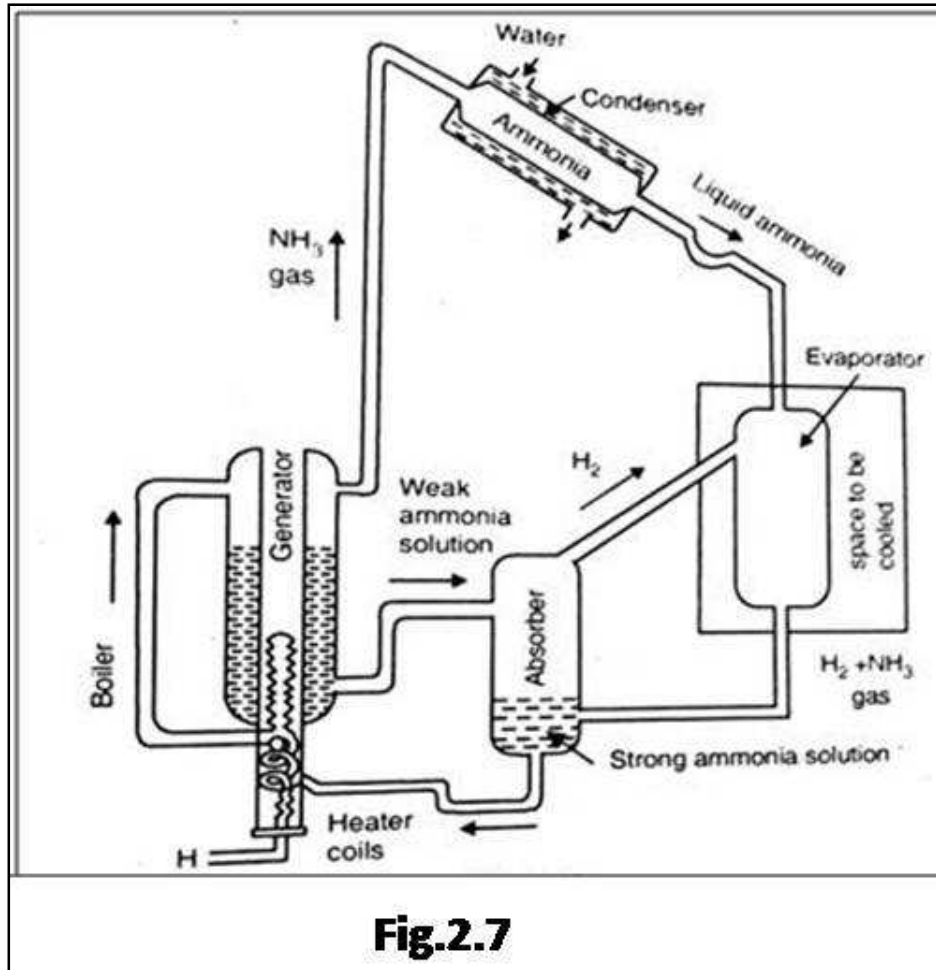
Working:

The weak ammonia solution from the forced into absorber. The strong ammonia solution goes into boiler. The gaseous ammonia enters the condenser and it is cooled and condensed. Liquid ammonia enter the evaporator and is mixed with hydrogen. Hydrogen reduces the partial pressure of ammonia below its saturation point and causes evaporation. The evaporator is surrounded by the compartment to be cooled. When ammonia evaporates under reduced pressure, the latent heat of vapourisation is taken from surrounding compartment. In this way, the compressor is cooled. Hydrogen and gaseous ammonia leave the evaporator and enters the absorber. The meet the weak ammonia solution. The ammonia gas is dissolved and hydrogen gas rises through the absorber and enters the evaporator. The strong ammonia solution is forced up into the boiler again. The process continues and a sufficiently low temperature is produced in the compartment to be cooled.

*Advantages***:** No compressor is required and the circulation of liquid and gas is automatic.

Frigidaire

It consists of an adiabatic enclosure at a low temperature. The principle used in the production of low temperature is by the evaporation of a suitable liquid under reduced pressure and circulating the evaporating liquid around the enclosure.   The refrigerant used nowadays is Freon or CFCs were replaced by hydrochlorofluorocarbon HCFCs which are a mixture of hydrogen, chlorine, fluorine and carbon Another popular refrigerant gas is HFC, which contains no chlorine and is thought to have absolutely no negative effect on the ozone. Modern refrigerators use a refrigerant called hydro fluorocarbon (HFC).Fig.2.8 shows the schematic diagram of Frigidaire.

Fig.2.8
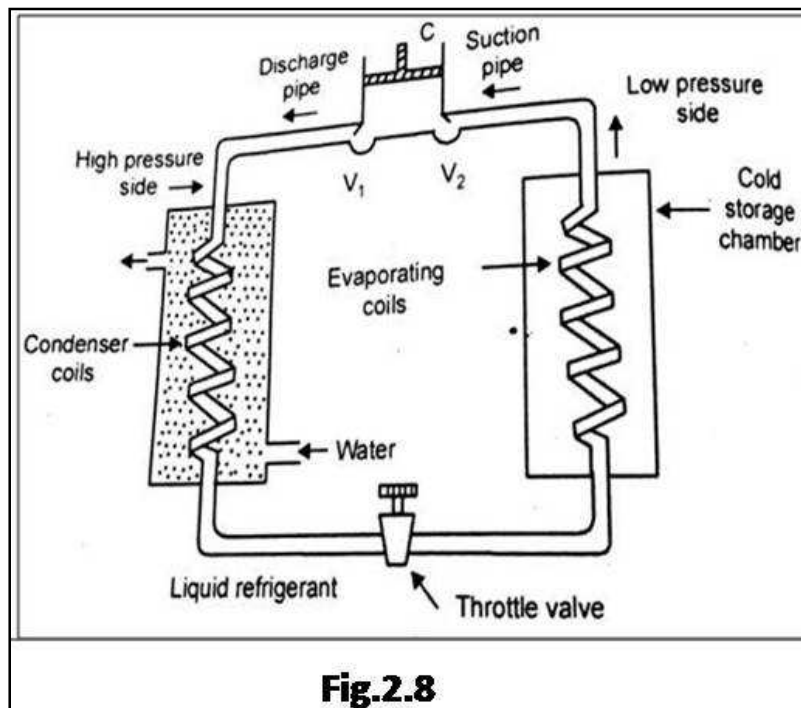
Construction:

It is a electric motor driven   compressor. It is fitted with two spring loaded vales V_1 and V_2 in its bottom. During the downstroke of the piston, when the pressure on the gas or vapour in it increases, V_1 is thrown open, V_2 remaining closed. During the upstroke of the piston, when the pressure falls, V_1 gets opened and V_2 is closed.

A steady steam of cold water is kept circulating round the condenser coils. The evaporator cells are surrounded by the space or the chamber to be cooled. The throttle valve has a small orifice in it. The pressure on the liquid passing through it from the condenser coils on the high pressure side   can be reduced to be equal to that prevailing in the evaporator coils on the low pressure side.

Working:

To start with, some vapour of the refrigerant is introduced into the compressor. The vapour is compressed by the compressor during its downward stroke. The valve V_1 opens V_2 closed. Now the vapour under high pressure enters into the condenser coils. The condenser cell is surrounded by an enclosure in which cold water is circulating. Here, the heat of the compressor is reduced by the cold water. So the vapour under high pressure and low temperature liquefies in the condenser coils. The liquid refrigerant passes through the regulator valve V into the evaporator coils. The regulator valve reduces the pressure of liquid from high valve (inside condenser) to low valve (inside evaporator). Due to low pressure, the liquid evaporates in the evaporator coils. Here, when the liquid evaporates, it absorbs latent heat of vapourisation from surrounding cold storage space. The space or the chamber thus goes cooled. The low pressure vapour from the evaporator coils is then drawn into the compressor during the upstroke of its piston through valve V_2. Now V_1 is opened and V_2 is closed. The same cycle of operation is repeated again. After some time, the temperature of the space around the evaporator coils gets cooled to the desired temperature.

Uses of refrigeration are :

(a) Preservation of perishable products during storage of transportation,
(b) The manufacture of ice and solid carbon dioxide (dry ice)
(c) The control of temperature and humidity in air conditioning systems.

Air conditioning

Definition

Air conditioning may be defined as a method of controlling the weather conditions within the limited space of a room, or a hall, so that one may have the maximum comfort.

Air conditioner

Air conditioner cools the air, remove the dust and controls the humidity of the atmosphere. The important actions involved in the operation of air conditioning system are: (a) Temperature control (b)Humidity control (c) Air filtering, cleaning and purification. (d) Air movement and circulation.

Window air conditioner (room air conditioner)

This is suitable for cooling rooms in summer. It consists of three parts

Construction:

It consists of two units (1) indoor unit   (2) outdoor unit.[Fig.2.9] An indoor unit consists of an evaporator, fan, air filter, control panel, trays etc. The outdoor unit consists of a motor driven compressor, condenser, fan, trays, etc.
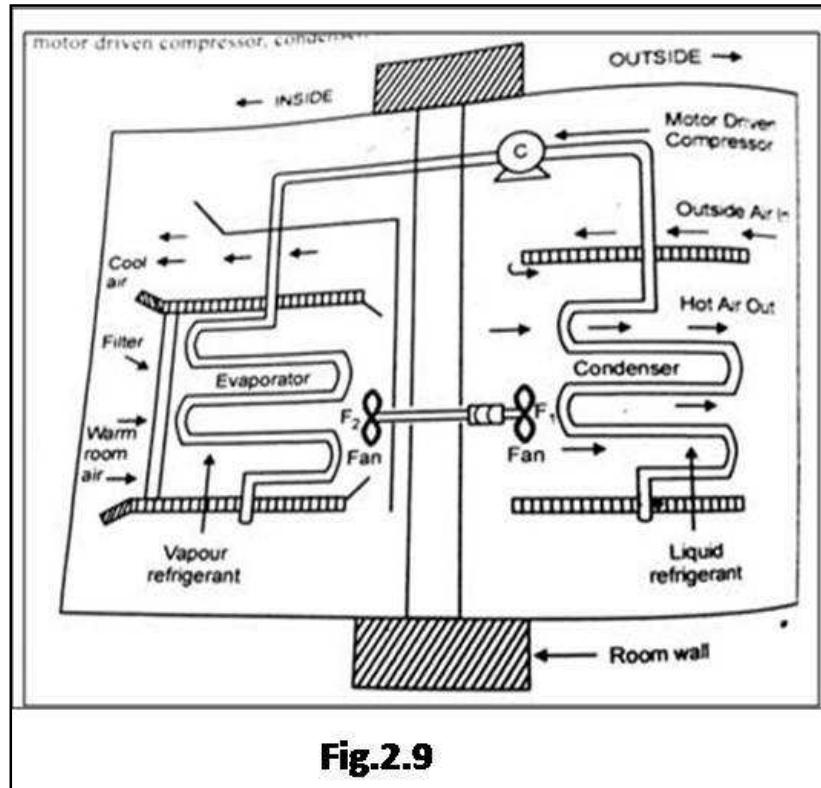

Fig.2.9

Working:

The condenser and evaporator are connected through capillary tube. The liquid refrigerant collects in the lower half of the condenser and from there flows via capillary tube into the evaporator. Pressure inside the evaporator is very low. So, the liquid refrigerant evaporates rapidly by picking up hear fro evaporator surface which is consequently cooled. The motor driven fan F2 draws air from inside the room through a suitable filter and force it to flow over the evaporator. The air so cooled goes back to the room. An adjustable thermostat mounted on the control panel provides the necessary temperature control. The low pressure refrigerant is sucked back into the compressor. From the compressor, the refrigerant is forced into the conditioner to be cooled and condensed into a liquid. The cycle is repeated. Compressor and condenser are connected to fan F1 that drives air in from outside, circulates it over the condenser where it is heated up and hen discharge it so outside, The moisture which collects on the evaporator is drained into a drip pan kept under the evaporator.

Review Questions

PART A

1. **What is Joule Thomson effect?**
2. **What do you mean by adiabatic expansion?**
3. **What is temperature of inversion?**
4. **Explain the principle involved in liquefaction of gases.**
5. **Explain the principle of cooling by adiabatic demagnetization.**
6. **Calculate the cooling produced by adiabatic demagnetization of a paramagnetic salt as the field is reduced from 10,000 oersted to zero at initial temperature of 2K. (Given: Curie constant per gm mol per cc = 0.042 erg degree/gm oersted-2 and C_H= 0.42 Joule gm $^{-1}$ deg $^{-1}$.**
7. **Explain the principle of refrigeration.**
8. **Name two refrigerants normally used.**
9. **Describe briefly the principles and practice of air-conditioning.**
10. **What are the effects of CF_2Cl_2 on ozone layer?**

PART B

1. **Explain in detail about adiabatic demagnetization.**
2. **Explain the liquefaction of gas with a suitable mechanism.**
3. **Describe Porous Plug experiment. What are the inferences from the experiment?**
4. **Obtain an expression for fall in temperature due to adiabatic demagnetization in a paramagnetic gas obeying Curie' Law.**
5. **Explain in detail, the working of the Frigidaire.**
6. **Explain refrigeration cycle. How it is used to obtain low temperatures in Electrolux refrigerator.**
7. **With the help of neat sketch, explain the working of air conditioner.**
8. **Write an essay on the applications of "Low temperatures".**

Books referred:

[1] Thermal Physics by R.Murugeshan and Er.Kiruthiga Sivaprasath -, S.Chand and Co Ltd- Revised Edition 2007
[2] Heat Thermodynamics and Statistical Mechanics by BrijLal, N.Subrahmanyam and P.S Hemne-, S.Chand and Co Ltd- Revised Edition 2007
[3] Accessories employed in dealing with liquefied gases
http://www.ccohs.ca/Oshanswers/chemicals/cryogenic/cryogen1.html?=undefined&wbdisable=true
file:///C:/Users/home/Downloads/Cryogenics%20Safety_0.pdf

UNIT – III   Quantum Physics

Radiation – Stefan's Law – Boltzmann law – Black body radiation – Rayleigh – Jean's law – Planck's law – Stefan's fourth power law – Pyrometry – Solar constant Specific Heat: Specific heat of solids – Dulong and Petits' law – Einstein's theory of specific heat – Debye's theory - specific heat of gases – Variations of specific heat of Diatomic gases –Specific heat of diatomic gases – (Quantum theory).

Radiation

Radiation is the process in which heat is transferred from one place to another directly without the aid of intervening medium.

Example:

(a) *Heat from the sun reaches earth due to radiation without affecting the intervening medium.*
(b) *Experience of feeling hot when we stand near a furnace.*

Stefan's Law – Boltzmann law

Stefan's law:

It states that the rate of emission of radiant energy by unit area of a perfectly black body is directly proportional to the fourth power of its absolute temperature. Thus

$$E = \sigma T^4$$

where σ is a constant called stefan's constant. The value of σ is 5.67×10^{-8} W m^{-2} K^{-4} . If the body is not perfectly black and its relative emissivity is e, then $E = e\sigma T^4$ where E varies between 0 and 1 depending on the nature of the surface. For a perfectly black body e=1.

Boltzmann gave a theoretical proof of stefan's law on the basis of thermodynamics. Therefore, this law is also called as Stefan's – Boltzmann law.If a black body at absolute temperature T is surrounded by another black body at absolute temperature T_0, the net rate of loss of heat energy per unit area of the surface is $E = \sigma (T^4 - T_0,4)$. If the body has emissivity e, then the total energy radiated is $E = e\sigma (T^4 - T_0,4)$

Black body

A perfect black body is one that absorbs all the heat radiations, of whatever wavelengths incident on it. When such a body is heated, it emits radiations of all possible wavelengths.

Black Body Radiation

When a black body is placed inside a uniform temperature enclosure, it emits full radiation of the enclosure after it attains equilibrium with it. These radiations are independent of the nature of the substance, nature of the walls and presence of any other body in the enclosure but depends only on the temperature. Since a perfect black body absorbs all radiation that fall on it, whatever wavelength they may be, the radiation emitted by it will possess a character purely dependent on temperature to which it is raised and not the property of any particular substance. Hence it is solely temperature dependent. Such radiation in a uniform temperature enclosure are known as *black body radiation.*

Energy distribution in black body radiation

If the radiation emitted by a black body at a fixed temperature is analyzed by means of a suitable spectroscopic arrangement, it is found to spread into a continuous spectrum. The total energy is not distributed uniformly over the entire range of the spectrum.

The distribution of energy in black body radiation for different wavelength ad at various temperatures was determined experimentally by Lummer and Pringsheim. The experiment is shown in Fig 3.1..

The radiation from the black body is rendered into a parallel beam by the concave mirror M_1. It is then allowed to fall on a fluorspar prism to resolve it into a spectrum. The spectrum is brought to focus by another concave mirror M_2 and to a linear bolometer. The bolometer is connected to a galvanometer. The deflections in the galvanometer corresponding to different are noted by rotating the prism table. Then curves are plotted for E_λ versus λ. The experiment is done with the black body at different temperatures. The curves obtained are shown in Fig.3.1.

Results.

(a) At any given temperatures, E_λ first increases with λ, first increases with λ reaching a maximum value corresponding to a particular wavelength λ_m and then decreases for longer wavelengths.

(b) The value of E_λ for any λ increases as the temperature increases.

(c) The wavelength corresponding to the maximum energy shifts to shorter wavelength side as the temperature increases. This confirms Wien's displacement law $\lambda_m T = $ constant.

(d) Total energy emitted per unit area of the source per second at a given temperature $\int_0^\infty E_\lambda \, d\lambda$. It is represented by the total area between the curve for that temperature and the λ axis. This area is found to be proportional to the fourth power of the absolute temperature, This verifies Stefan's law.
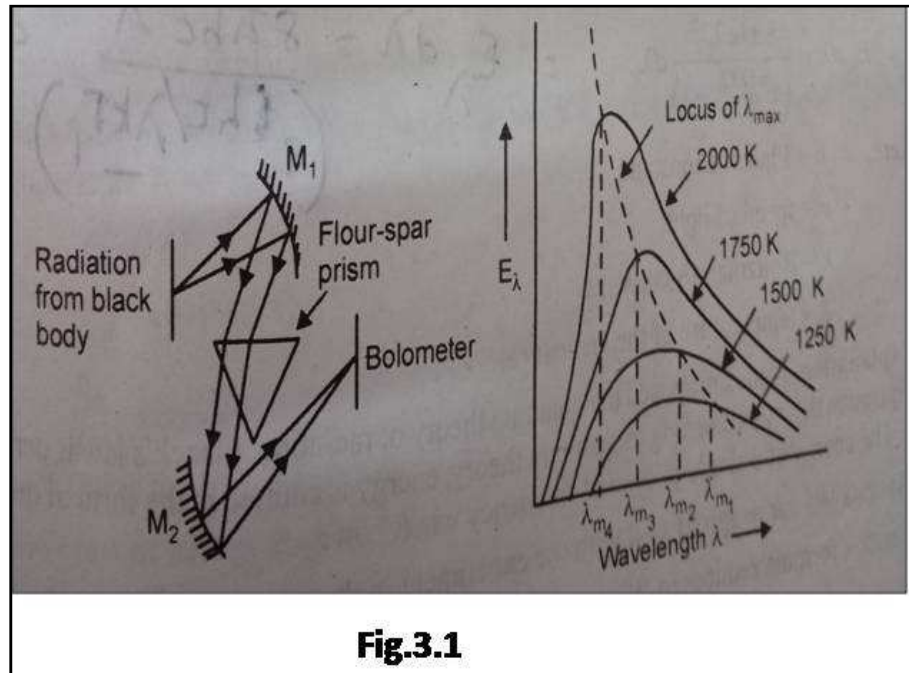
Fig.3.1

Planck's law

Planck in 1901 derived an empirical formula to explain the experimentally observed energy distribution in the spectrum of black body on the basis of quantum theory of radiation. According to this theory, the energy distribution is given by
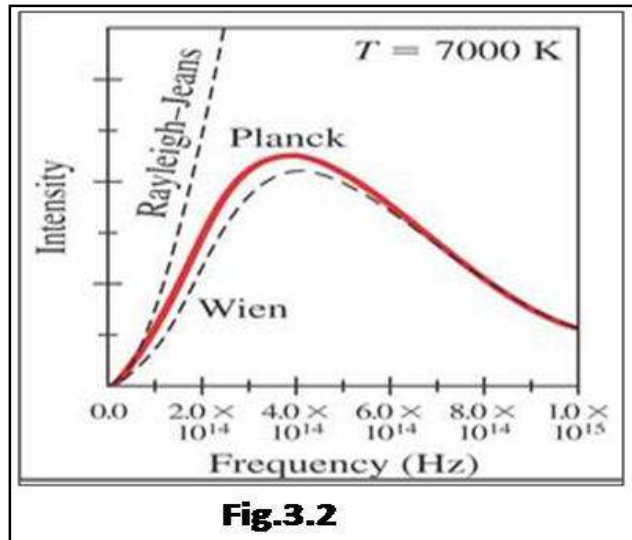
$$E_\lambda \, d\lambda = \frac{8\pi hc \, \lambda^{-5} \, d\lambda}{e^{(-hc/\lambda kT)} - 1}$$

where h –Planck's constant, c-speed of light, k-Boltzmann constant T-temperature of the enclosure.

Explanation

Planck's law is derived on the basis of quantum throy. According to this theory, energy is emitted in the form of quanta called photons.The energy of single photon of frequency γ is E = hγ. Planck's law curve agree well with the experiment for entire range of wavelengths.

Planck's formula reduces to Wien's formula fro small wavelengths and Rayleigh Jean's formula for longer wavelengths as shown in Fig 3.2.

Fig.3.2

Wien's law of energy distribution

Statement

The energy density of radiation in an enclosure at temperature T having wavelength λ to $\lambda+d\lambda$ is

$$E_\lambda \, d\lambda = 8\pi hc \; \lambda^{-5} \; e^{-hc/\lambda kT} \; d\lambda$$

where h –Planck's constant, c-speed of light, k-Boltzmann constant T-temperature of the enclosure.

Derivation of Wien's law from Planck's law

Planck's radiation law is
$$E_\lambda \, d\lambda = \frac{8\pi hc \; \lambda^{-5} \; d\lambda}{e^{(-hc/\lambda kT)} - 1}$$

when λ is small, $e^{-hc/\lambda kT}$ is large when compared to 1. ***Hence*** $e^{-hc/\lambda kT} - 1 = e^{-hc/\lambda kT}$
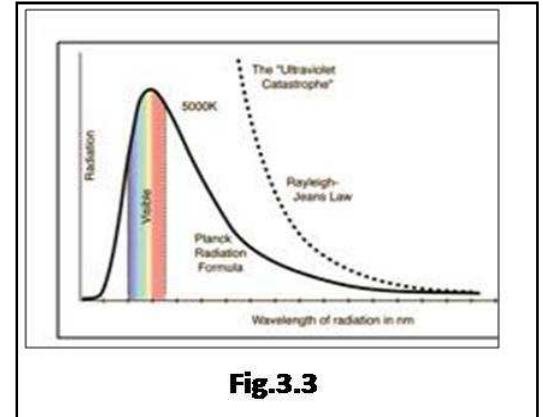
Hence Planck's law reduces to

$$E_\lambda \, d\lambda = 8\pi hc \; \lambda^{-5} \; e^{-hc/\lambda kT} \; d\lambda$$

This is Wien's law. Thus, Planck's law reduces to Wien's law for shorter wavelengths.

Rayleigh – Jean's law

Lord Rayleigh and SirJ. Jean assumed that the electromagnetic radiation spectrum emitted by a black body continuously vary in wavelengths from zero to infinity and tried to establish a relation between spectral energy density and wavelengths and the graph is shown in the Graph 3.3 and The energy distribution is given by the formula ,

$$E_\lambda d\lambda = \frac{8\pi KT \, d\lambda}{\lambda^4}$$

Fig.3.3

The energy density of radiation in an enclosure at temperature T having wavelength λ to $\lambda+d\lambda$ is

$$E_\lambda \, d\lambda = 8\pi kT \, \lambda^{-4} \, d\lambda$$

Planck's radiation law is

$$E_\lambda \, d\lambda = \frac{8\pi hc \, \lambda^{-5} \, d\lambda}{e^{(-hc/\lambda kT)} - 1}$$

when λ is large, $e^{-hc/\lambda kT} - 1 = [1 + hc/.\,\lambda kT - 1]$, **_Hence_** $e^{-hc/\lambda kT} - 1 = e^{-hc/\lambda kT}$

Planck's law reduces to Rayleigh –Jean's law**.**

$$E_\lambda \, d\lambda = 8\pi kT \, \lambda^{-4} \, d\lambda$$

Thus, Planck's law reduces to Rayleigh –Jean's law for longer wavelengths.

Stefan's fourth power law

In 1879, Austrian physicist Josef Stefan formulated a law as a result of his experimental studies and the same law was derived by Austrian physicist Ludwig Boltzmann in 1884 from thermodynamic considerations:

Statement

The total radiant heat energy emitted from a surface is proportional to the fourth power of its absolute temperature. If *E* is the radiant heat energy emitted from a unit area in one second

and T is the absolute temperature (in degrees Kelvin), then $E = \sigma\, T^4$, where (σ) representing the constant of proportionality, called the Stefan-Boltzmann constant. This constant has the value 5.670367×10^{-8} watt per metre^2 per K^4. The law applies only to blackbodies, theoretical surfaces that absorb all incident heat radiation.

Pyrometry

Pyrometers are instruments used to measure high temperatures. The physics of measurement of very high temperature above 1600^0 C is called   pyrometry. The fact that the radiation emitted by a black body depends solely upon its temperature provides radiation methods for measuring high temperatures. Both Stefan's law and Planck's law are used for the determination of temperature. The pyrometers based on the principle of radiation are termed as radiation pyrometers.

Types of radiation pyrometers :

(a) **Total radiation pyrometers**: *In this instrument, t*he energy of radiation emitted by the body is measured. The temperature is determined by applying Stefan's law assuming that the body is black.
(b) **Optical or Spectral pyrometers**: In this instrument, the intensity of radiation of a certain wavelength emitted by the body is compared with that of the radiation of same wavelength emitted by a black body at a known temperature. The temperature is deduced from Wien's distribution la or more accurately from Planck' law.

Solar constant

Statement

It is the amount of heat energy (radiation) absorbed per minute by the sq.cm. of a perfectly black body surface placed at a mean distance of the earth from the sun, in the absence of the atmosphere, the surface being held perpendicular to the sun's rays.

Explanation

The sun is the source of heat radiation and it emits radiations in all directions. The earth receives only a fraction of the energy emitted by the sun. The atmosphere absorbs a part of the heat radiation and air, clouds, dust particles etc, in the atmosphere scatter the heat and light radiations falling on them. It is possible to calculate the temperature of the sun from the quantity of heat radiation received by the earth. For this purpose, a constant called Solar Constant has to be defined.

To calculate the true value of solar constant S_o

The instruments used to measure the solar constant are called pyrheliometers. The experiment is performed several times on the same day under constant sky conditions for different elevations of the sun. The observed value of the solar constant S and the true value of

solar constant S_0 are connected by the relation $S = S_0\ t^{sec\ z}$ *where* t is the transmission coefficient of the atmosphere and z is the zenith diameter of the sun or angular altitude.

Taking logarithm, **we get log S = log S_0 + *sec z log t***

From the experimental values, a Graph [Fig.3.4(a)] is drawn between log S(on Y-axis) and sex z(on X-axis). We get a straight line as shown in Figure above. The value if intercept of the straight line on Y-axis gives the value of log S_0. From this, the value of S_0 can be calculated.

Temperature of the Sun

The surface temperature of the Sun may be estimated by assuming that the Sun radiant energy like a black body. The temperature so estimated is known as the black body temperature of the Sun. Let R be the radius of the sun Refer [Fig.3.4(b)] Then its surface area is $4\pi R^2$. Let T be the absolute temperature of the sun.

According to Stefan's law, total energy emitted by the sun per second= $4\pi R^2 \times \sigma T^4$
Here σ is Stefan's constant.
This energy is spread in all directions. Let us consider a sphere of radius r concentric with the sun. r is the mean distance of the earth from the sun. Then , this radiated energy will spread over the surface area $4\pi r^2$.

Let S be the value of the solar constant.
Total energy received by the surface $4\pi r^2$ per second $= 4\pi r^2 S$.

$4\pi R^2 \times \sigma T^4 = 4\pi r^2 \times S$.

$T^4 = \dfrac{Sr^2}{R^2\sigma}$ or $T = [(\dfrac{r}{R})^2 \times \dfrac{S}{\sigma}]^{1/4}$.
Thus temperature of the sun can be calculated by detreining values of S,r,R and σ.

Temperature of the Sun from the following data
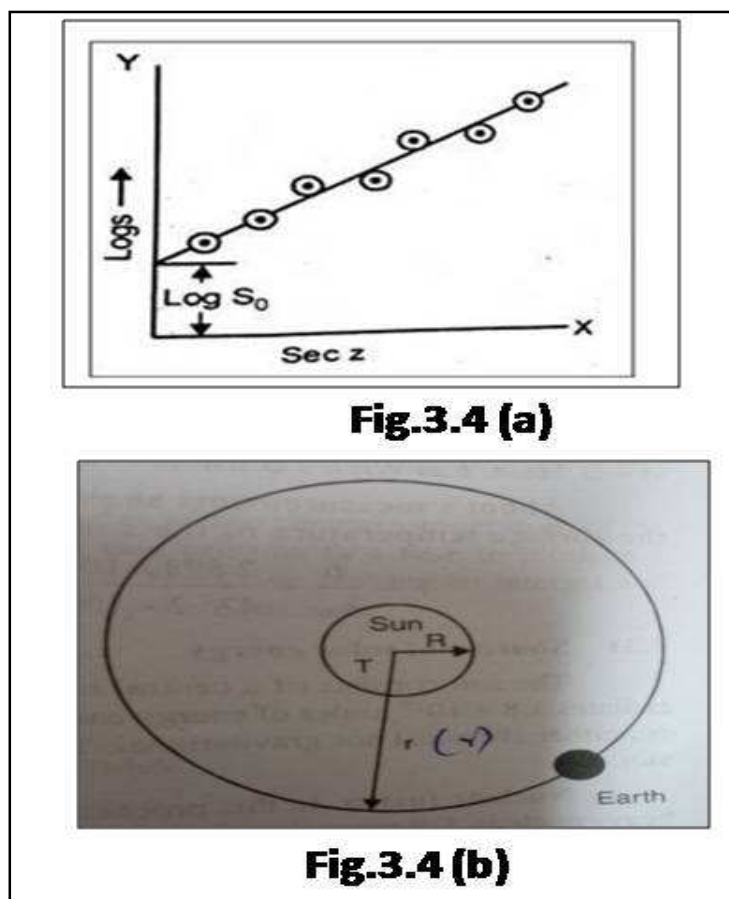Solar constant S = 1400 W m^{-2} , Radius of the sun R = 6.96 X10^8 m
Distance of the sun from the earth r = 1.496 X10^{11} m
Stefan's constant σ = 5.6697X 10^{-8} W m^{-2} K^{-4}

The black body temperature of the sun is given by

$$T = [(\dfrac{r}{R})^2 \times \dfrac{S}{\sigma}]^{1/4}$$
$$= [\ (\dfrac{r1.496\ X10^{11}}{R6.96\ X10^8})^2 \quad \times \dfrac{1400}{5.6697X\ 10^{-8}}\ ]^{1/4}$$

$T = 5812$ K.

Fig.3.4 (a)

Fig.3.4 (b)

Dulong and Petits' law

Dulong and Petit in the year 1819, studied the specific heat if various elements in solid state and enunciated a law called Dulong and Petit's law.

Statement

The product of the specific heat and the atomic weight (ie) atomic heat of all elements in the solid state is a constant. The value of this constant was fixed at 6.4 and taken as 6. The exact value is 5.96 which also agrees with the value derived from kinetic theory of matter. This law agrees with experiment at ordinary temperatures but experiments show that the specific heat of solids decreases rapidly with decrease in temperature at very low temperatures.

Derivation of Dulong and Petits' law

All solids are made up of atoms or molecules closely packed together. The atoms are arranged in a crystalline array by strong electro-magnetic forces exerted by every atom on each other. At absolute zero, the energy of solid is assumed to be zero as atoms are at rest. But when

the temperature is raised, the atoms starts vibrating about their mean position and the vibrations are transmitted from one end to another atom. At low temperatures, the displacement of atoms about their mean positions is very small as compared to interatomic distances. Thus, the vibrations of atoms are simple harmonic in nature.

The justification of this law was obtained from Boltzmann's consideration of law of equipartition of energy. Accordingly, the energy associated with one gram atom of a substance for each atom of freedom at temperature T=1/2 RT where R is the Universal gas constant.If the atom is considered to be vibrating about the mean position, the mean kinetic energy will be equal to its mean potential energy.

Each atom has three degree of freedom

Total average energy of each atom $=3kT$

Total thermal energy of one mole of solid $=3NkT = 3RT$ [N=Avogadro's number and Nk=R (gas constant)]   Thus, E=3RT

Therefore, the specific heat at constant volume is
$$C_V = dE/dT = 3R$$
where C_V is the atomic heat of the substance.
$$C_V = 3 \times 8.31 \times 10^7 / 4.18 \times 10^7 \text{ cals/g-atom-K}$$
$$C_V = 5.96 \text{ cals/g-atom-K}$$

Therefore, the total energy associated with one gram atom of a substance at a temperature
$$T=3RT.$$

Einstein's theory of specific heat – Debye's theory

It was experimentally found that the specific heat capacity of a substance decreases with decrease in temperature and tends to zero at absolute zero. Similarly, it increases with increase in temperature and reaches a maximum value at higher temperatures. The variation of atomic heat capacity with temperatures of diamond, aluminium and silver is shown in Graph 3.5. The first attempt to explain the variation of specific heat capacity with temperature was made by Einstein in 1907 on the basis of quantum theory.
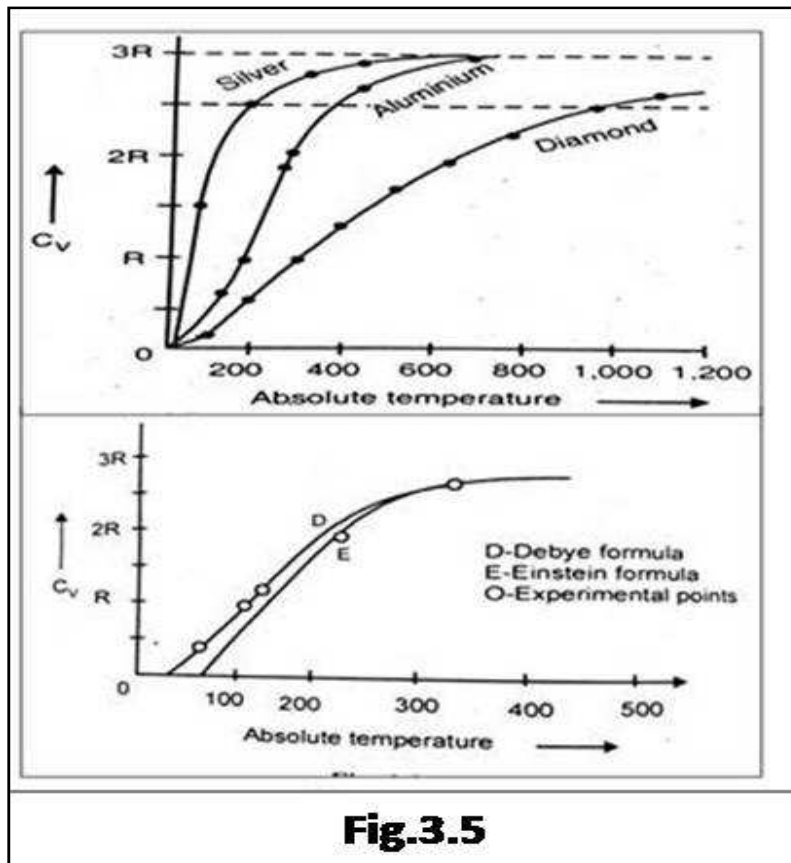
Fig.3.5

Quantum theory

Dulong and Petit's law has been explained on the basis of quantum theory of heat radiation. According to quantum theory, heat is radiated in the form of discrete particles called photons. Each particle has energy equal to $h\upsilon$ where h is the Planck's constant and υ is the frequency of heat radiation. Einstein also explained Dulong and Petit's law on the basis of quantum theory and said that the atomic heat is equal to 6 only at higher temperatures and this is the maximum value. The atomic heat of the elements decreases with the decrease in temperature. Most of the substances reach the maximum value of six at room temperature but carbon silicon are below the maximum value of six at room temperature. Their atomic heat also tends to the maximum value of 6 at higher temperatures.

Debye also modified Einstein's theory and concluded that in some substances like copper, aluminium. Iron etc, the atomic heat at low temperature decreases more slowly than explained by Einstein.

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Fig.3.6
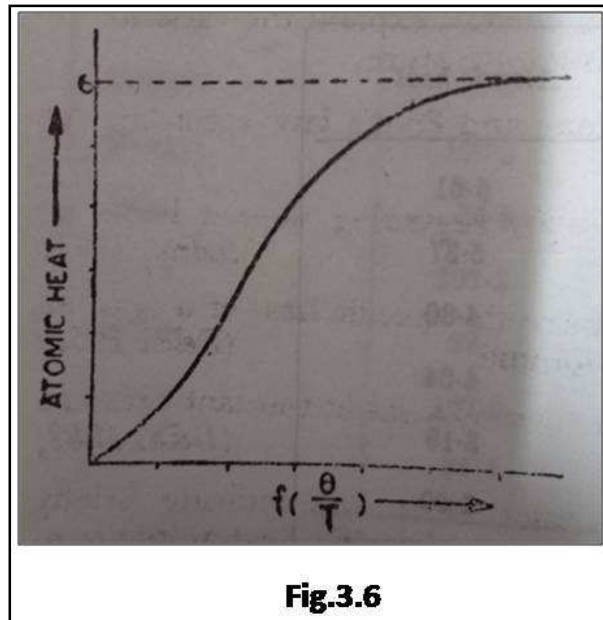
According to Debye-Einstein theory

(1) The atomic heat of all the substances tends to the maximum value of six.
(2) The atomic heat of all the elements decreases with the fall of temperatures.
(3) The atomic heat tends to the value zero, near about absolute zero.
(4) At low temperatures, the atomic heat varies as the cube of the absolute temperature.

$$Atomic\ heat\ \propto\ T^3$$

It is known as Debye's T^3 law.

(5) The graph between atomic heats and absolute temperature of all the elements will coincide if the temperature scale is suitable modified according to the expression

$A = f\left(\dfrac{\theta}{T}\right)$

Here A is the atomic heat of the element at absolute temperature T and θ is the parameter called Debye temperature. Debye temperature is a constant for a particular element but it is different for different elements. The value $f\left(\dfrac{\theta}{T}\right)$ is the same for all the elements at absolute temperature T.

Thus , according to this theory a single graph between A and $f\left(\dfrac{\theta}{T}\right)$ for all the elements is obtained and shown in Fig.3.6.

Specific heat of diatomic gases

A diatomic gas molecule has two atoms. Such a molecule at ordinary temperatures has three degree of freedom of translation and two degrees of freedom of rotation.

Energy associated with each degree of freedom = ½ kT
Energy associated with 5 degrees of freedom = 5/2 kT
Consider one gram molecule of gas
Energy associated with 1 gram molecule of a diatomic gas

$$E = 5/2 \ kT, \qquad C_v = dE/dT = 5/2 \ R$$

But $C_p - C_v = R$ (or) $C_p = C_v + R$ = 5/2 R+R = 7/2 R

Therefore, the ratio of specific heats $\gamma = C_p / C_v = 7/2 \ R \ /5/2 \ R = 1.40$

Variation of specific heat of diatomic gas

A diatomic gas molecule has a dumb-bell structure. For Example, a hydrogen molecule

[1] *At high temperature*:

Beyond 750K, the collision causes the atoms in the nucleus to vibrate. In addition to translational and rotational motion, vibrational motion also takes place and the molecule has 7 degrees of freedom. [3 rotational+ 2 rotational+2 vibrational]. The theory predicts

$C_v = 7/2 \ R = 3.5 \ R$ and $\gamma = 9/7 = 1.29.$

These values are in good agreement with experimental values.

[2] *At room temperature*:

The molecule has rotational motion in addition ot translational motion. Thus, it has 5 degrees of freedom [3 translational+2 rotational]. The theory predicts

$C_v = 5/2 \ R = 2.5R$ and $\gamma = 7/5 = 1.40.$

These values are in good agreement with experimental values.

[3] *At low temperatures*:

At low temperatures, say 20K, the specific heat capacities of hydrogen decreases to

$C_v = 3/2 \ R = 1.5 \ R$ and $\gamma = 5/3 = 1.67.$

That is the value predicted by theory to a monoatomic gas.

Review Questions

PART A

1. What is a black body? What are the salient features of black body radiation?
2. Explain the distribution of energy in a black body spectrum
3. State Stefan's law.
4. Calculate the radiant emittance of a black body at a temperature of (1) 400 K (ii) 4000 K   [σ is 5.672×10^{-8} M.K.S.units]
5. State Dulong and Petit's law.
6. State the three formulas of radiation viz., Rayleigh-Jeans, Wien's and Planck's.
7. Stat Planck's law, Wien's displacement and Rayleigh-Jeans la of radiation.
8. Define specific heat of solids.
9. What is Pyromter?
10. Define Solar Constant.

Part B

1. Derie an expression for Planck's law for black body radiation.
2. Discuss the Einstein's theory of specific heat of solids.
3. Define Solar Constant. Explain how the solar constant is determined experimentally..
4. Show that Planck's law reduces to Wien's law for shorter wavelebgths and Rayleigh-Jean's law for longer wavelengths.
5. An aluminum foil of relative emittance 0.1 is placed in between two concentric spheres at temperatures 30 K and 200 K respectively. Calculate the temperature of the foil after the steady state is reached. Assume that the spheres are perfectly black body radiators/ Also calculate the rate of energy transfer between one of the spheres and the foil. [σ is 5.672×10^{-8} M.K.S.units]

Books referred:

[1] Thermal Physics by R.Murugeshan and Er.Kiruthiga Sivaprasath -, S.Chand and Co Ltd- Revised Edition 2007
[2] Heat and Thermodynamics by Anandamoy Manna,Dorling Kindersley, 2011. ISBN, 8131754006..
[3] Heat Thermodynamics and Statistical Mechanics by BrijLal, N.Subrahmanyam and P.S Hemne-, S.Chand and Co Ltd- Revised Edition 2007
[4] Physics for B.Sc Students by C.L.Arora and Dr.P.S.Hemne, S.Chand and Co Ltd.

Course: I Year B.Sc Physics
Sub.Code: UPH214P2
Subject: Mechanics and Thermal Physics

Short Questions

1. State the Zeroth law of thermodynamics.
2. State the First law of thermodynamics.
3. State the Second law of thermodynamics.
4. What is a Heat engine?
5. State Carnot,s theorem.
6. What do you mean by entropy of a substance?
7. Mention some differences between reversible and irreversible processes.
8. Write down the expression for efficiency of a Carnot engine.
9. What is the difference between first and second of thermodynamics.
10. What is Joule-Thomson effect?
11. What do you meant by adiabatic expansion?
12. What is meant by liquefaction of gases?
13. Write a note on production of low temperatures.
14. What is adiabatic demagnetization?
15. Distinguish between adiabatic process and Joule-Thomson effect.
16. List some practical applications of low temperatures.
17. Define Dulong and Petit law.
18. Define Solar Constant.
19. Define Stefan's fourth power law.
20. State Rayleigh – Jeans law.
21. State Planck's law.
22. What is meant by radiation?
23. What is black body?
24. Define specific heat.
25. What is pyrometry?
26. State Stefan's-Boltmanz law.
27. Write a note on black body radiation?

Review questions

1. Describe the working of Carnot engine and derive its efficiency.
2. Discuss the change in entropy in reversible and irreversible processes.
3. Explain porous plug experiment in detail.
4. Explain adiabatic demagnetization.
5. What are accessories employed in liquefied gases?
6. Explain the working of Electrolux refrigerator.
7. Explain the working of Frigidaire with a neat sketch.
8. Explain the refrigerating mechanism of a refrigerator with a neat sketch.
9. Explain the working of Air conditioning machines.
10. State Stefan's law and explain the experimental determination of Solar Constant.
11. Explain Einstein theory of Specific heat of solids.
12. Derive Planck's equation for black body radiation.