HEAT

INTRODUCTION

Heat is defined as energy which is transferred from one place to another owing to a temperature difference between them. Without the heat which comes to us from the sun life on earth would be non-existent.

CHAPTER ONE: TEMPERATURE

The temperature of a substance is a number which expresses its degree of hotness on some chosen scale.

Measurement of temperature.

Temperature is measured by means of a thermometer.

There are different types of thermometers.

Most common thermometers depend on the expansion of a liquid when heated.

Thermometers have a scale on them called a temperature scale which we read to determine the temperature.

Temperature is measured by observing the change in some property of an object as it becomes hotter or cooler.

The changes include those of volume, pressure, electrical resistance.

Temperature scales

The fundamental scale in physics is called the **thermodynamic scale**.

The scale is sometimes called the **Kelvin scale** and its unit is the **Kelvin (K)**

From experiment;

(i) The temperature of pure melting ice at standard atmospheric pressure is 273.15K

(ii) the temperature of the steam from pure boiling water at standard atmospheric is 373.15K

The Celsius scale of the temperature is defined so that

(i) if we write ϑ (C) for the temperature value on the Celsius scale and T(K) for one on the thermodynamic scale then $T = \theta + 273$

(ii) the interval 1 degree Celsius equals the interval 1kelvin.

Fahrenheit scale

To convert from degrees celcuis to ^{0}F the formula below is used;

$$^{0}F = \frac{9}{5}C + 32$$

Common thermometric properties are:

(i) the volume of a liquid which may be made to expand into a narrow tube.

(ii) the e.m.f of a thermocouple.

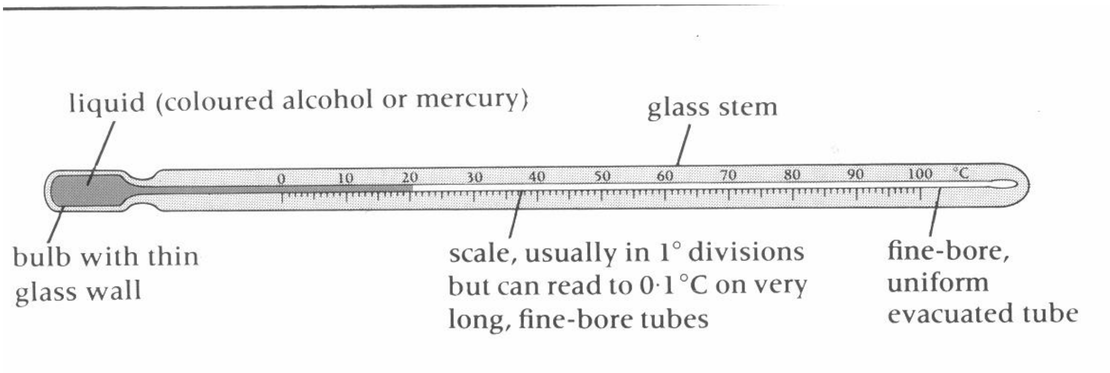
(iii) the pressure of a fixed mass of gas kept at constant volume.

(iv) the electrical resistance of a platinum coil.

Liquid in glass thermometers.

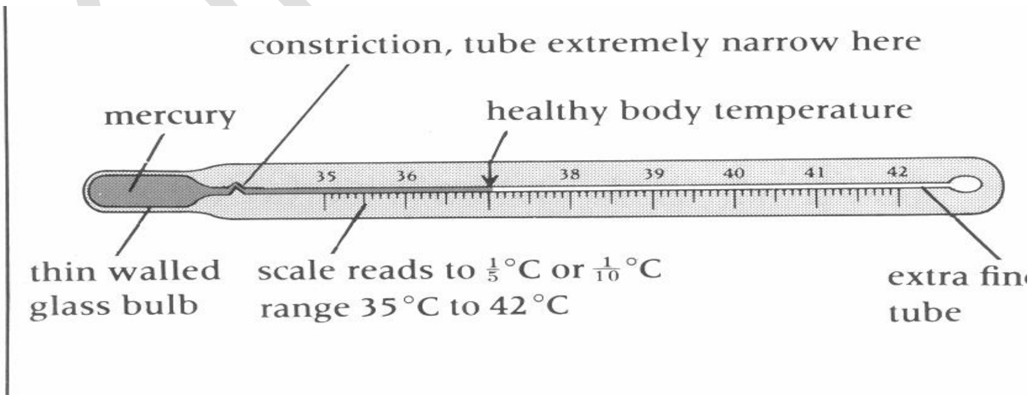
The mercury-in glass or alcohol-in-glass thermometers use the change in volume of liquid to measure temperature. They cover a range from -40^{o}C to 300^{o}C.

Note the following design details.
(a)The liquid is contained in a thin walled glass bulb to help conduction of heat through the glass to the liquid.
(b)The amount of liquid should be small in order to obtain a quick response because a small quantity takes less time to warm up.
(c) The fine tube should be uniform to give even expansion along it.
(d)The space above the liquid is evacuated during manufacture to prevent a high pressure of the trapped air when the liquid expands.



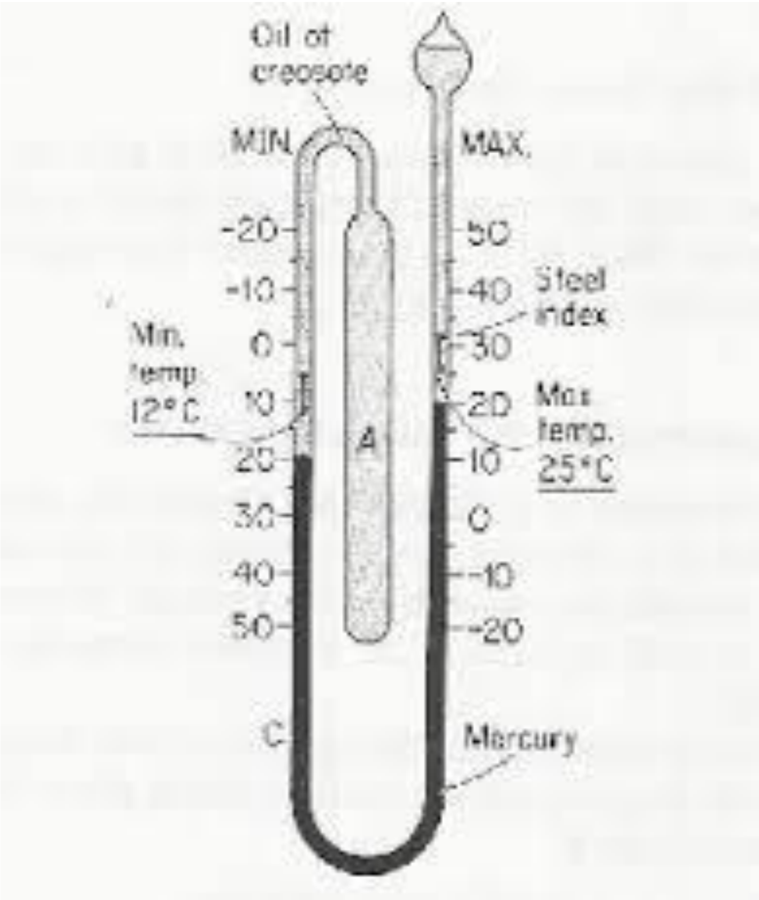
a) A standard liquid-in-glass thermometer

The Clinical thermometer.
It is designed to measure the temperature of the human body.
For this reason it has a small temperature range within which the body temperature can fluctuate.
The thermometer is placed beneath the patient's armpit and left there for about two minutes to ensure that it fully acquires the patient's body temperature. It is then withdrawn and the body temperature read off from the position of the mercury thread.
Before using it again the mercury in the stem must be returned to the bulb by shaking.

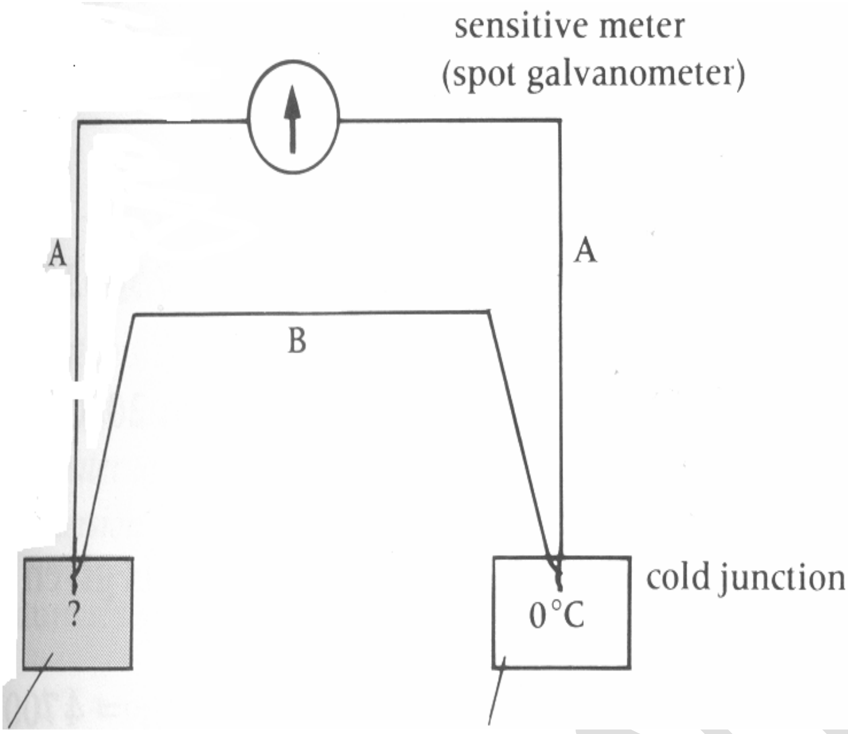


b) A clinical thermometer

(c) Six's maximum and minimum thermometer.
The purpose of this thermometer is to record the maximum and minimum temperatures attained in a day.
Generally a minimum temperature occurs during the night while a maximum temperature occurs during day.



Thermoelectric thermometer
Two different wires joined together at two points kept at different temperatures and connected to a sensitive galvanometer form a thermocouple. The meter shows that an emf is produced. Common metals used in this kind of thermometer are constantan and the other is nichrome or platinum and a platinum-rhodium alloy chosen because their melting points are very high.
One junction is kept at 0^oC and the other is used to record the temperature being measured. The meter is graduated so that it reads temperatures directly and not merely e.m.f's
Advantages of a thermoelectric meter are:
(i)It can measure very high temperatures such as those in furnaces of molten metals.
(ii)The junction is very small and therefore the thermometer can measure temperature at a point.
(iii)It can follow rapid changes of temperature.



Resistance thermometer
The change in electrical resistance of a wire as its temperature changes. Usually the wire is of platinum. The resistance of platinum increases as the temperature rises. Resistance thermometers are accurate, sensitive and can be used to measure both high and low temperatures.
The fixed temperature points.

(i) Upper fixed point.
The upper fixed point is the temperature of steam from water boiling under standard atmospheric pressure of 760mmHg.

(ii) Lower fixed point.
The lower fixed point is the temperature of pure melting ice. The ice must be pure since impurities lower the melting point.

Celsius temperature scale.
The difference in temperature between the fixed points is called the fundamental interval. This is divided into 100 equal divisions, the ice point being called 0^oC
And steam point 100^oC.This called the Celsius scale.
Temperatures on it are called 'degrees Celsius '
Determination of the upper fixed point.
A thermometer is pushed through a hole in a cork and placed inside a thermometer.
Water is heated in the lower part of the hypsometer.
The bulb of the thermometer should not touch the water surface.
The thermometer is adjusted so that the mercury thread is seen just above the top of the cork.
When the cork has remained steady for some time its level is marked on the stem by a light scratch.
The double walled vessel reduces heat loss and consequent cooling of the vapour surrounding the thermometer.
The manometer gives warming should the pressure inside differ from atmosphere pressure.

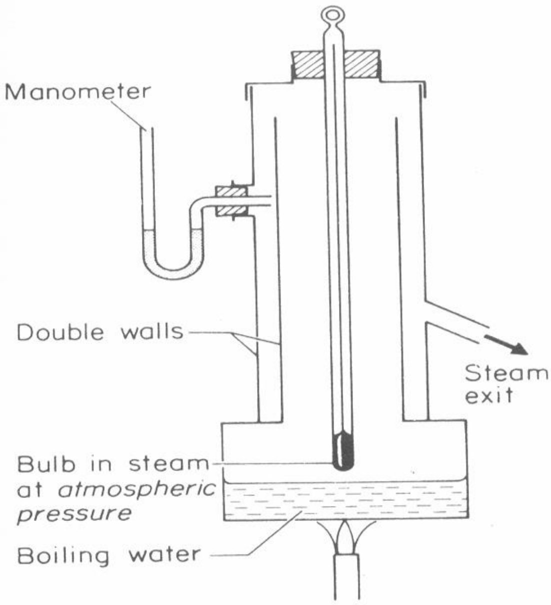


Fig. 14.2. Hypsometer (upper fixed point)

Determination of the lower fixed point.
The thermometer is placed in a glass funnel kept full of small pieces of pure ice blocks having a beaker underneath to catch the water.
The mercury thread is allowed to show just above the top of the ice.
When the level of the thread has remained steady for some time its position is marked. That indicates the lower fixed point.

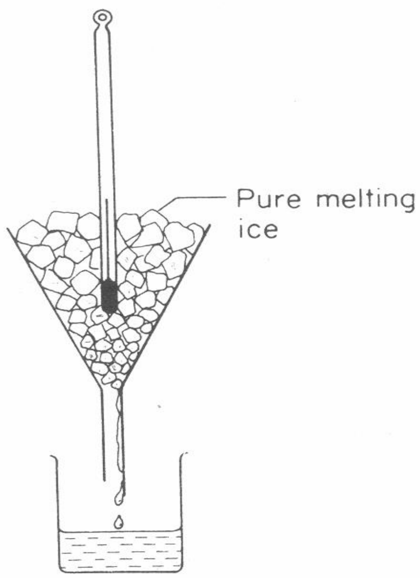


Fig. 14.3. Lower fixed point

To measure temperature with the thermometer.
If x is length of mercury thread above the lower fixed point and y is the length between the upper and lower fixed points the unknown temperature ϑ can be determined from the expression

$\vartheta = \frac{x}{y} x 100^0$C

for a thermometer with 100 equal parts, with a Celsius scale.

Choice of liquid for thermometers.

Mercury freezes at -39°C and boils at 357°C while alcohol freezes at -115°C.It is therefore essential to use alcohol thermometers in places where temperatures drop so low up to -40°C.Alcohol also possesses the advantage of having an expansivity of about six times that of mercury.

Advantages of mercury over alcohol.

(1)It does not wet glass. Alcohol tends to cling to the wall of the tube, this leads to errors in taking the reading.

(2) It does not vaporize like alcohol onto the upper part of the bore.

(3)It is opaque and easily seen, whereas alcohol has to be coloured.

(4) It is a better conductor of heat than alcohol and therefore responds more rapidly to changes of temperature.

Why water should not be used in thermometers

Water is unsuitable for use in thermometers because

(i)it freezes at 0°C,so it cannot read temperature below that.

(ii)It has an irregular expansion.

The thermodynamic temperature scale.

Various types of thermometer give different readings when used to measure the same temperature because the values obtained depends on the properties of the substance used in the thermometer.

Types of thermometer include ;

(i) mercury-in glass thermometers

(ii) platinum resistance thermometers

(iii) thermoelectric thermometer e.t.c

Lord Kelvin devised a scale called the thermodynamic scale which is independent of the properties of the substance used in thermometers.

Temperatures on this scale are measured in Kelvin.

They are denoted K.

On the thermodynamic scale the melting point of ice is 273K and the boiling point of water is 373K.

Revision Questions

1.a)List the advantages and disadvantages of mercury and alcohol as thermoelectric liquids.

b)Ice and steam *points* on an ungraduated thermometer are found to be 192mm apart. What temperature is recorded in °C when the length of mercury thread is 67.2mm above the ice point mark?

2a).Describe an experiment to determine the fixed points of a thermometer.

b)i)Mention any three reasons why water is not used a thermometric liquid.

ii)When a Celsius thermometer is inserted in a boiling liquid, the mercury thread rises above the lower fixed point by 19.5cm.Find the temperature of the boiling liquid if the fundamental interval is 25cm.

Chapter 2: EXPANSION OF SOLIDS AND LIQUIDS

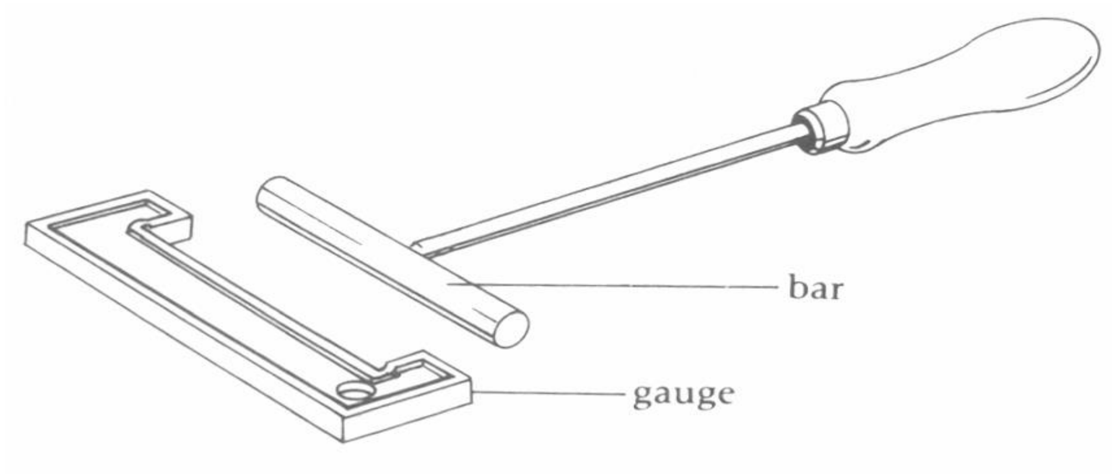
The increase in size of objects when they are heated is called expansion.

Demonstrating expansion of a solid.

The metal bar shown below is made such that it will just fit into the gap in the gauge when both the bar and the gauge are cold.

Heat the bar over a Bunsen flame and test the fit again. With the rise in temperature of the bar comes an increase in length.

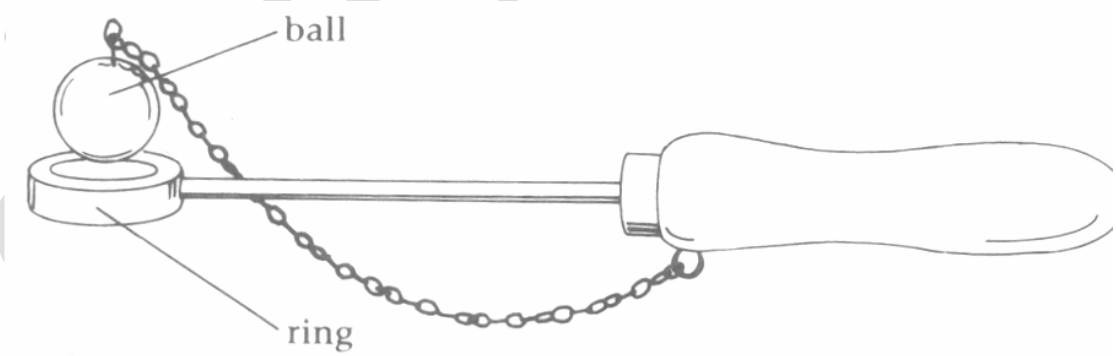
The gauge shows that the bar has increased in length which is called linear expansion, and cannot fit in the gauge.



A spherical metal ball will just pass through the ring when both are cold.

Heat the ball over a Bunsen flame, and the test the fit again. The ball expands when heated and will not go through the ring.

The diameter of the ball has increased in all directions. The expansion in area of a solid is known as superficial expansion and the expansion in volume is called cubical expansion.



Expansion and contraction-uses

Railway tracks are designed with gaps in between them to allow for expansion.

Railway tracks have been damaged during hot seasons where the gap allowed for expansion was too small.

Pipelines in the chemical industry which carry liquids and gases over long distances must have flexible expansion joints built in them at them at regular intervals.

Expansion and contraction is used in riveting to get a tight joint.

A hot rivet is pushed through a hole in the two plates to be joined.

Then the end of a hot rivet is hammered to form another head.

As the rivet cools it contracts and pulls the two plates together more tightly.

THE BIMETALLIC STRIP.A bimetallic strip is made of two strips of the same length and cross sectional of different metals joined together e.g iron and brass.

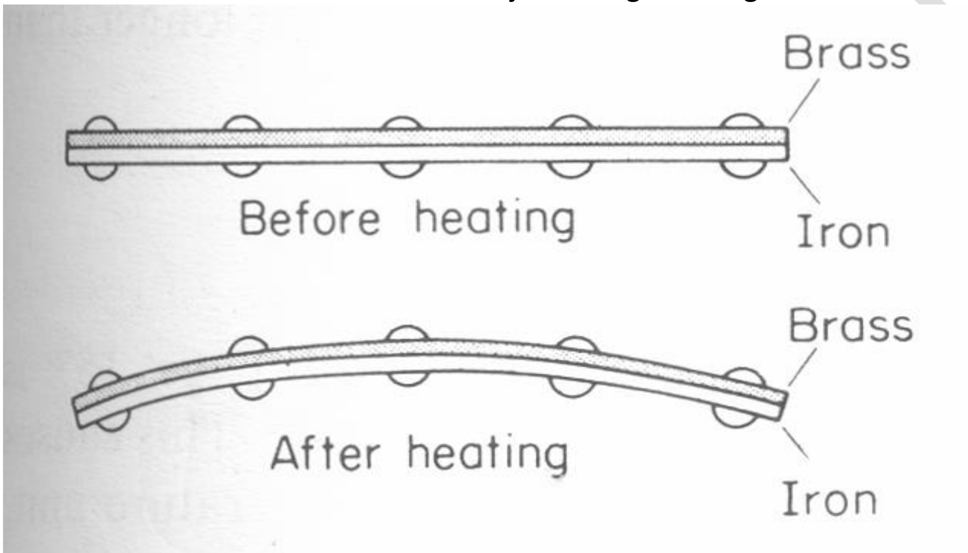


Fig. 15.5. Bimetallic strip

When cold the strips are straight ,but when heated the metals expand differently causing them to bend.
Since brass expands more than iron, the two will bend with brass on the outside.
Bimetallic strips are applied in
i)thermostats
ii)motor vehicle flashing direction indicators

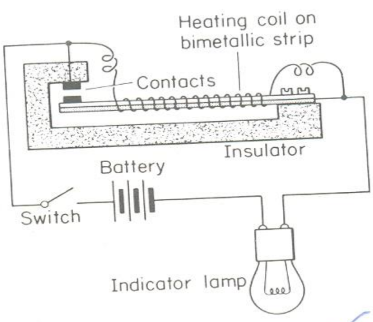
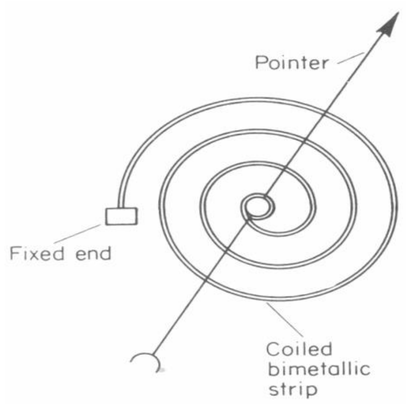


Fig. 15.7. Flasher unit

ii) fire alarms.
A thermostat is a devise used for maintaining steady temperature.
Thermostats are applied in
(i)hot water storage tanks
(ii) electric irons.



The figure above shows the principle of a bimetallic thermometer. One end of a thin bimetallic spiral is fixed, the other end being attached to the spindle of a pointer which moves over a scale of degrees.The metals used are brass and invar and the spiral tends to curl in a clockwise direction as the temperature rises.

Linear Expansivity

The measure of the tendency of a particular material to expand is called its expansivity. Brass expands more than iron when heated by the same amount, therefore brass has a higher expansivity than iron.

The linear expansivity of a substance is the fraction of its original length by which a rod of the substance expands per Kelvin rise in temperature.

Linear expansivity of a substance depends on

(i)the length of the substance.

(ii)the rise in temperature.

Linear expansivity of steel

$$\alpha = \frac{\Delta l}{l x \Delta\theta}$$

Where Δl is the change in length of steel.

$\Delta\theta$ is the rise in temperature.

l is the original length of steel.

Measuring Linear expansivity.

Measure the original length of the rod using a metre ruler.

Fit the rod inside a steam jacket and fit the thermometer in its socket.

Screw up the micrometer so that there is no gap at either end of the rod and take a reading of the micrometer scale x_1 .

Note the initial temperature of the rod θ_1.

Unscrew the micrometer to leave room for expansion of the rod and pass steam through the jacket for a few minutes.

Screw up the micrometer again and take a second reading of the micrometer scale x_2.

Note the final temperature of the rod θ_2.

Calculate the change in length$\Delta l = x_2 - x_1$ measured by the micrometer.

Calculate the rise in temperature $\Delta\theta = \theta_2 - \theta_1$.

(Both $l \; and \; \Delta l$ should be in the same units).

Calculate the linear expansivity from

$$\alpha = \frac{\Delta l}{l x \Delta\theta}$$

Hence new length =original length +expansion.

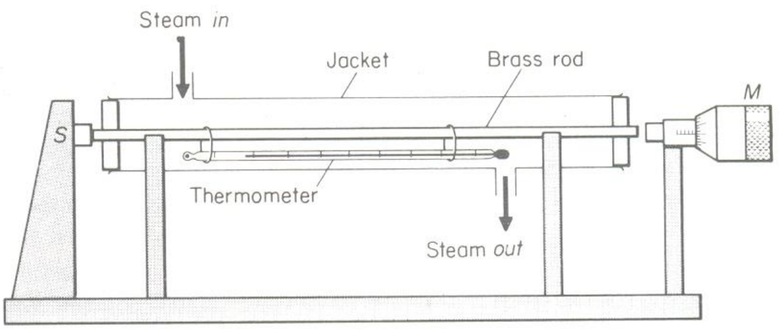


Fig. 15.9 Measurement of thermal expansion

Demonstrating expansion of liquids

Fill a glass flask with coloured water and fit a stopper with a long glass tube so that there is no air in the flask and water rises a short way up the tube.

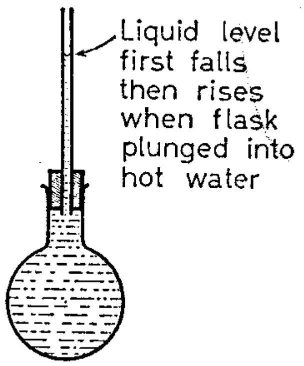
Heat the flask.

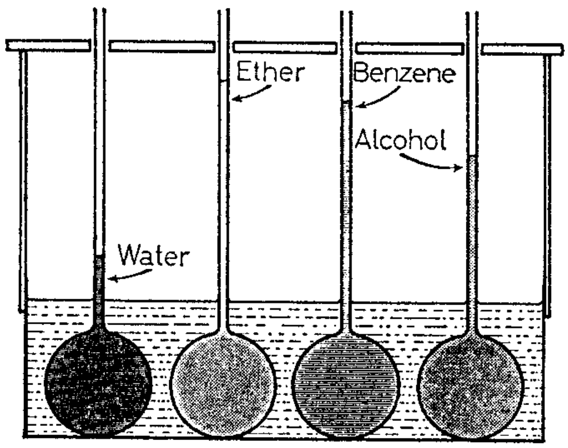
The water level drops first and then rises after heating. The drop is due to expansion of glass flask which increases in volume. This creates space inside and hence the drop.

Once heat reaches the liquid it expands rapidly up the tube and over the top. This shows that the volume expansion of a liquid is very large.

(Liquids expand much more in volume than solids).

Different liquids have different thermal expansions.





To demonstrate this, several fairly large glass bulbs with glass stems are filled to a short distance above the bulb with various liquids. In order to make a fair comparison, the bulbs and stems must be of the same size. The bulbs are immersed in a metal trough containing cold water and left until they have reached a steady temperature. A little extra liquid should then be added in case the levels are not the same anymore. The bath is heated and well stirred to ensure uniform temperature. When the bulbs and their contents have acquired the new temperature of the bath, it will be seen that the liquid levels have risen by different amounts.Thus,for a given rise in temperature equal volumes of different liquids show different expansions in volume.

The unusual expansion of water.

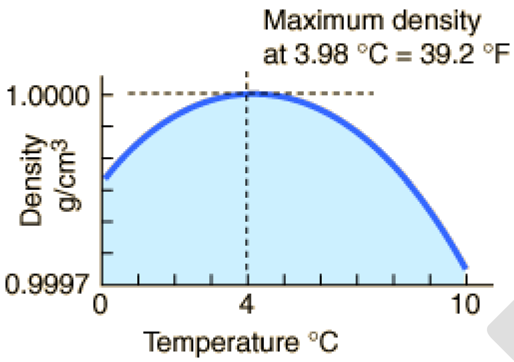
Some substances do not always expand when heated. Over certain temperature ranges they contract. Water is an outstanding example. If we start with ice at -10^{o} C And heat it expands until it reaches 0^{o}C.It then begins to melt while the temperature remains 0^{o}C.

This melting is accompanied by a contraction in volume. Between O and 4^{o}C.Hence water has its maximum density at 4^{o}C.

Beyond 4^{o}C water expands.

This behaviour is described as anomalous.

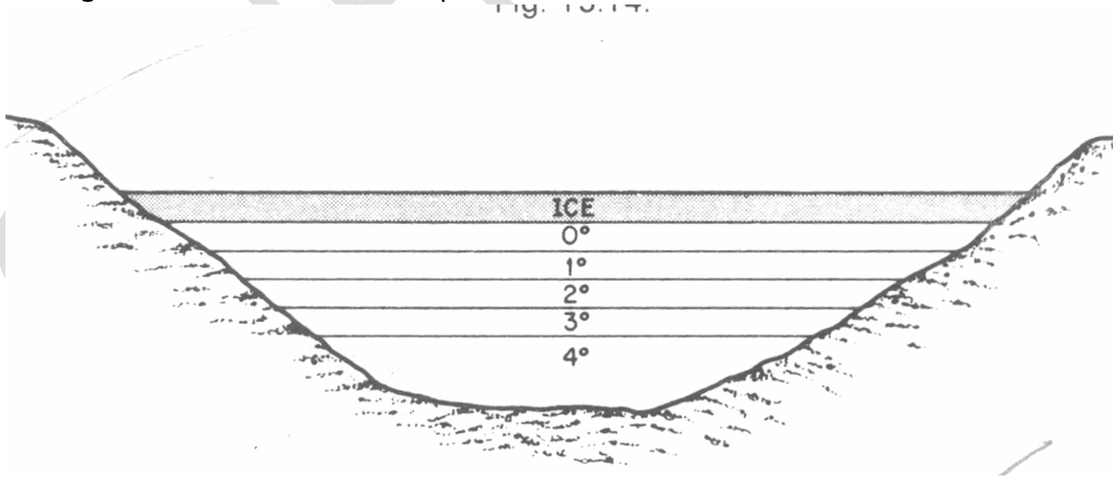
(irregular).The changes in water volume between -10^{o}C to 15^{o}C are shown graphically below.



Biological importance of the anomalous expansion of water.

It helps preserve aquatic life during very cold weather. As the temperature of a pond or lake falls the water contracts becomes denser and sinks.

At the bottom of the lake or pond is dense water whose temperature is slightly higher than for the layer above. The less dense water stays at the top. If further cooling occurs the water at the top freezes.



Fish can survive in the layers below where unfrozen water still exists.

CHAPTER 3:

HEAT CAPACITY AND SPECIFIC HEAT CAPACITY.

The heat capacity of an object depends on its mass.

The heat capacity is defined as the quantity of heat energy required to raise the temperature of a given mass of a material by one Kelvin. It is denoted by C.

SI unit of heat capacity is JK^{-1}

$Q = C\theta$

The specific heat capacity of a substance is the heat energy needed to raise the temperature of 1kg mass of the substance by 1K.It is denoted by c.

$Q = mc\theta$

$Heatcapacity = mass \times specificheatcapacity$

Below is a table showing specific heat capacities of different substances.

It can be noticed that water has an unusually high specific heat capacity of 4200J/kgK

Table of specific heat capacities in J/kgK.

Aluminium	**900**	**Lead**	**130**
Brass	380	Mercury	140
Copper	400	Methylated	2400
Glass	670	Water	4200
Iron	460	Zinc	380

Because of its high specific heat capacity water is most suitable liquid in the radiators of a vehicle to cool the engine because less amount of liquid is needed to draw heat energy from the engine as compared to other liquids.

i.e heat = mcθ.

The higher the value of c the greater the heat removed keeping m and θ Constant.

To measure the specific heat capacity of a metal by the electrical method.

This method is suitable for a metal which is a good conductor of heat.

A cylindrical block of metal is drilled with two holes one for an electric heater and the other a thermometer.

A little oil is used in the holes to ensure good thermal contact. Heat losses are reduced by standing the block on a slab and lagging the block.

The heater circuit is connected and rheostat is adjusted to obtain suitable current.

Before switching on the current note the temperature of the block. Switch on the current and simultaneously start a stop clock.

Take the readings of the voltmeter and ammeter. When the temperature has risen by about 10degrees.

Switch off current and stop the clock simultaneously.

Read the final temperature on the thermometer.

Energy received by block=energy supplied by heater.

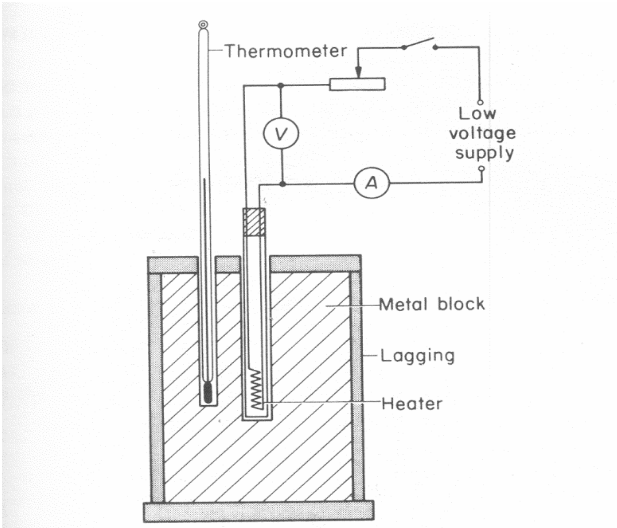


Fig. 42.1. Simple solid block calorimeter

$mc(\theta_2 - \theta_1) = VIt$

Specific heat capacity of metal

$$c = \frac{VIt}{m(\theta_2 - \theta_1)}$$

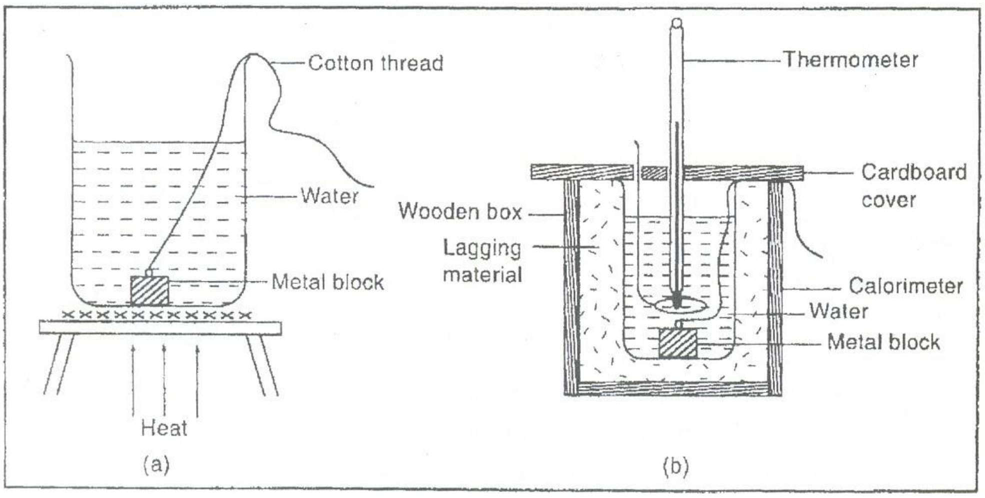
Precautions

(i)The metal block must be heavily lagged to prevent heat loss to the surroundings.

(ii)The two holes should be filled with a light oil to improve thermal contact with the heater and thermometer.

Determination of specific heat capacity of a solid by the method of mixtures.

Determination of specific heat capacity of a solid by the method of mixtures.



Procedure

Weigh the solid metal block and record it's mass m_s .Place the block in a beaker containing water and heat the water as shown above in (a).Allow the water to boil. Weigh the calorimeter together with the stirrer and record the their mass as m_c. Add water to the calorimeter. Determine the mass of calorimeter with water m_l .

Mass of water= $m_w = m_l - m_c$ .Place the calorimeter in the insulating jacket.
Measure the temperature of the cold water in the calorimeter and record it as θ_1.
When the water in the beaker has boiled for some time, quickly transfer the metal block from the beaker into the cold water in the calorimeter.
Place a thermometer in the beaker to measure the temperature of the boiling water as θ_2. Record the final temperature of the mixture in the calorimeter as θ_3.
Assuming no heat losses to the surroundings during the transfer of the metal block from the beaker to the calorimeter and thereafter, the specific heat capacity of the solid can be calculated as follows;

Heat lost by metal bock =
Heat gained by calorimeter with stirrer + Heat gained by water in calorimeter.

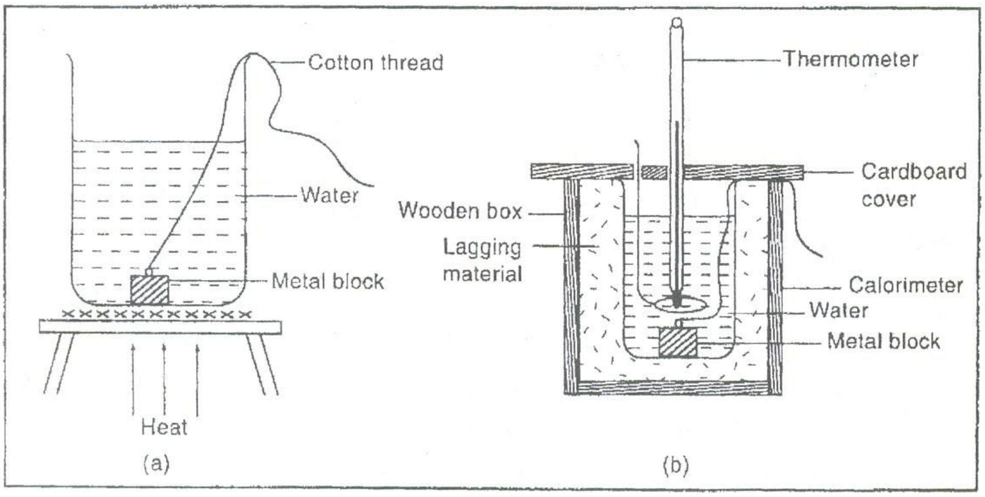
$$m_s c_s(\theta_2 - \theta_3) = m_c c_c(\theta_3 - \theta_1) + m_w c_w(\theta_3 - \theta_1)$$

Where c_c, c_s *and* c_w are specific heat capacities of the calorimeter, the solid and water respectively. The specific heat capacity of the material of the cube can therefore be calculated as

$$c_s = \frac{(\theta_3 - \theta_1)(m_c c_c + m_w c_w)}{m_s(\theta_2 - \theta_3)}.$$

Determination of the specific heat capacity of a liquid by the method of mixtures.
Procedure.

Determination of specific heat capacity of a solid by the method of mixtures.



Weigh the solid metal block and record it's mass as m_s.
Place a liquid in a beaker and immerse the block attached to a string into the liquid as shown in figure (a) below. With the beaker on a tripod stand heat the beaker and its contents until the liquid starts to boil. Record the temperature θ_1 of the boiling liquid.

Weigh the calorimeter and stirrer and then pour some liquid into it and again weigh the calorimeter with liquid. By subtraction determine the mass of the liquid m_l in the calorimeter alone. Place a thermometer in the calorimeter and take note of the temperature of the cold water θ_2 .
When the liquid in the beaker has boiled for some time ,transfer the block from the beaker into the cold liquid in the calorimeter.
Cover the calorimeter with a piece of cardboard as in figure (b) below.
Stir the mixture and record the final temperature θ_3
The specific heat capacity of the liquid can be calculated as follows;
Heat lost by the hot solid =
Heat gained by calorimeter and stirrer + Heat gained by liquid in the calorimeter.
$m_s c_s(\theta_1 - \theta_3) = m_c c_c(\theta_3 - \theta_2) + m_l c_l(\theta_3 - \theta_2)$
Where c_s , c_c and c_l are the specific heat capacities of the solid, calorimeter and liquid respectively.
Since all the other quantities are known the unknown quantity c_l can be determined.

Experiment to determine the specific heat capacity of a liquid by electrical method.

Diagrammatic set up of the apparatus:

Procedure

Weigh the calorimeter with the stirrer and record their mass as m_s .
Pour liquid into the calorimeter and determine the mass of liquid and that of the calorimeter. By subtraction of the mass obtained in the previous weighing, determine the mass of the liquid m_l in the calorimeter.
Place the calorimeter in an insulating jacket. Measure the initial temperature of the water θ_1.
Insert the heating coil into the liquid in the calorimeter as shown in figure above **.**
Switch on the heater current and simultaneously start timing. Record the ammeter and voltmeter readings I and V respectively.
After about five to ten minutes switch off the heater current and record the final temperature θ_2 of the calorimeter and its contents.
Record the duration of the heating t.
Assuming no heat is lost to the surroundings, the specific heat capacity of the liquid can be calculated as follows:

Heat supplied by electric heater =
Heat gained by liquid + Heat gained by calorimeter.
$IVt = m_l c_l(\theta_2 - \theta_1) + m_c c_c(\theta_2 - \theta_1)$ where c_l, c_c are the specific heat capacities of the liquid and calorimeter respectively.

Examples on heat capacity calculations:

Example 1

Calculate the quantity of heat required to raise the temperature of a metal block with a heat capacity of $460JK^{-1}$ from 15^oC to 45^oC.

Solution
Heat capacity ,C=$460JK^{-1}$
Temperature change , $\theta = (45 - 15)$
$= 30^0C$

$Q = C\theta$
$= 460 \times 30$
$= 13800J$

Example 2

A piece of copper of mass 60g and specific heat capacity $390JKg^{-1}K^{-1}$ cools from 90^oC to 40^oC .Find the quantity of heat given out.

Solution
$Q = mc\theta$
$= \frac{60}{1000} \times 390 \times (90 - 40)$
$= 1170J$

Example 3

How many joules of heat are given out when a piece of zinc of mass 50g and specific heat capacity 380J/kgK cools from 60°C to 20°C?

Q = mcθ
$= \frac{50}{1000} x380x(60 - 20).$
= 760Joules

Heat energy given out or received = mass x s.h.c x temperature change.
Heat energy in joules = m x c x $(\theta_2 - \theta_1)$
Where m is mass in kg
C specific heat capacity.
θ_1 is lower temperature.
$\theta_2$is higher temperature.

Example 4

What is the final temperature of the mixture if 100g of water at 70°C is added to 200g of cold water at 10°C and well stirred?(Neglect heat absorbed by container)
Heat given out by hot water = Heat received by cold water.

$0.1x4200x(70-\theta)=0.2x4200x(\theta-10)$

$7-0.1\theta=0.2\theta-2$

$9=0.3\theta$

$\theta=30^oC$

Example 5

The temperature of a piece of copper of mass 250g is raised to 100°C and it is then transferred to a well lagged aluminium can of mass 10.0g containing 120g of methylated spirit at 10.0°C.Calculate the final temperature after the spirit has been well stirred. Neglect the heat capacity of the stirrer and any losses from evaporation.

Solution.

Heat given out by copper =$0.25x400x(100-\theta)$.
Heat received by aluminium = $0.01x900x(\theta-10)$.
Heat received by spirit = $0.12x2400x(\theta-10)$.
Heat given out =heat received
$100x(100-\theta)=9x(\theta-10)+288x(\theta-10)$
$10{,}000-100\theta=297\theta-2970$
$12970=397\theta$

$\theta=32.7^o$C.

Example 6

Find the final temperature of water if a heater source rated 42W heats 50g water from 20°C in five minutes.(Specific heat capacity of water is $4200JKg^{-1}K^{-1}$)
Solution
Heat supplied by the heater = Heat gained by the water.
$42\times5\times60=mc\theta$
$42\times300=50\times10^{-3}\times4200\times\theta$
$\theta=60^o$
But $\theta=T-20$
$T=80^oC$

Example 7.

A block of metal of mass 1.5kg which is insulated is heated from 30^oC to 50^0C in 8minutes and 20 seconds by an electric heater coil rated 54W.Find:
(a)the quantity of heat supplied by the heater.
(b)the heat capacity of the block.
(c)its specific heat capacity.
Solution
(a)Quantity of heat supplied = power x time
$Q=54\times500$
$=27000J$
(b) $Heatcapacity, C=\frac{Q}{\theta}$
But $Q=27000J$ and $\theta=50\ -30\ =20$

$$C = \frac{27000}{20}$$
$$= 1350\,JK^{-1}$$

(c) Specific heat capacity, $c = \frac{C}{m}$

$$c = \frac{1350}{1.5} = 900\,JKg^{-1}K^{-1}.$$

EXERCISE

1. Calculate the heat given out when 50g of iron cools from 45^{o}C to 15^{o}C. (C for iron 460J/kgK).
2. Calculate the specific heat capacity of gold if 108J of heat raise the temperature of 9g of the metal from 0^{o}C to 100^{o}C.
3. A lady wanted to have a warm bath at 40^{o}C.She had 5kg of water in a basin at 85^{o}C.What mass of cold water at 25^{o}C must she have added to the hot water to obtain her choice of bath? Neglect heat losses and take specific heat capacity of water to be $4200\,Jkg^{-1}K^{-1}$.
4. A bath contains 100kg of water at 60^{o}C.Hot and cold taps are then turned on to deliver 20kg per minute each at temperatures of 70^{o}C and 10^{o}C respectively. How long will it be before the temperature in the bath has dropped to 45^{o}C?
5. The temperature of a brass cylinder of mass 100g was raised to 100^{o}C and transferred to a thin aluminium can of negligible heat capacity containing 150g of paraffin at 11^{o}C.
   If the final steady temperature after stirring was 20^{o}C,calculate the specific heat capacity of paraffin.(Neglect heat losses and assume specific heat capacity of brass=380J/kgK)
6. 0.2kg of iron at $100^o C$ is dropped into 0.09kg of water at $26^o C$ inside a calorimeter of mass 0.15kg and specific heat capacity $800\,Jkg^{-1}K^{-1}$ .Find the final temperature of the water(Specific heat capacity of iron is $460\,JKg^{-1}K^{-1}$ and that of water $4200\,JKg^{-1}K^{-1}$)

CHAPTER 4: LATENT HEAT

When water in a kettle is heated its temperature rises until it reaches 100^{o}C.The water starts to boil but the temperature remains constant at 100^{o}C,but at the same time heat is being steadily absorbed by the water from the gas flame or heating element.

This heat is the energy needed to convert the water from liquid state to the vapour state at the same temperature.

From experiment 2,260,000Joules are required to convert 1kg of water at its boiling point to steam at the same temperature. This is known as specific latent heat of steam.

‘Latent ‘means hidden or concealed.

Latent heat means hidden heat. The heat which melts ice is hidden in the sense that when ice melts its no hotter than before it was heated.

Latent heat of vaporization is the amount of heat required to change the state of a liquid to vapour without change in temperature.

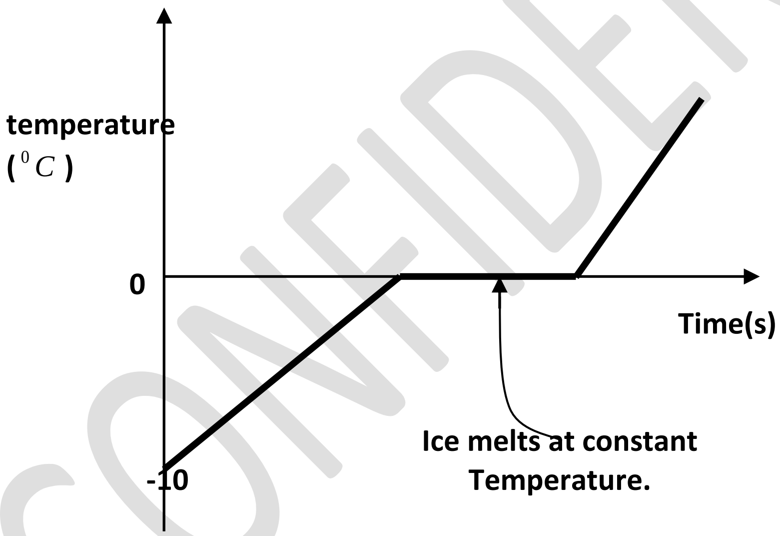
The specific latent heat of vaporization of a substance is the quantity of heat required to change 1kg mass of the substance from the liquid to the vapour state without change of temperature. SI Unit : joule per kilogram.(J/kg).
Latent heat of fusion is the amount of heat required to change the state of a material from solid to liquid without change in temperature. Conversely as a liquid changes to solid state, latent heat of fusion is given out.
The specific latent heat of fusion of a substance is the quantity of heat required to change 1kg mass of the substance from the solid to the liquid state without change of temperature. SI (Unit: J/kg).
CHANGE OF STATE.
Experiment: T*o investigate the effect of supplying heat to a solid*.
Procedure.

- Place crushed ice in a beaker and keep it in a freezer to ensure its temperature drops below $0^{o}C$,say, $-10^{0}C$.
- Heat the ice and record the temperature of the ice at intervals as you keep stirring.

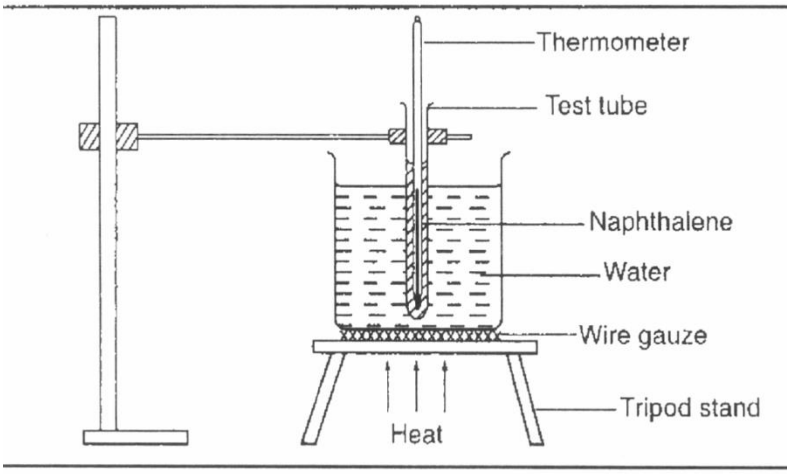
  Observation

  The thermometer records a temperature rise of the ice until it reaches $0^{0}C$.

On further heating, the temperature remains at $0^{0}C$ while the ice changes to water at $0^{0}C$. After all the ice has melted, the temperature rises again.



Explanation
When the ice at about $-10^{0}C$ is heated, the heat energy is used in raising its temperature to $0^{0}C$. The energy given to the ice at $0^{0}C$ is used to change ice from solid to liquid state.
Conclusion
The heat supplied to ice at $0^{0}C$ does not change the temperature of the ice, but changes its state from solid to liquid(melting).The heat absorbed as the ice melts is called latent heat.
EXPERIMENT:*To explore the change of state of naphthalene using the cooling curve* .



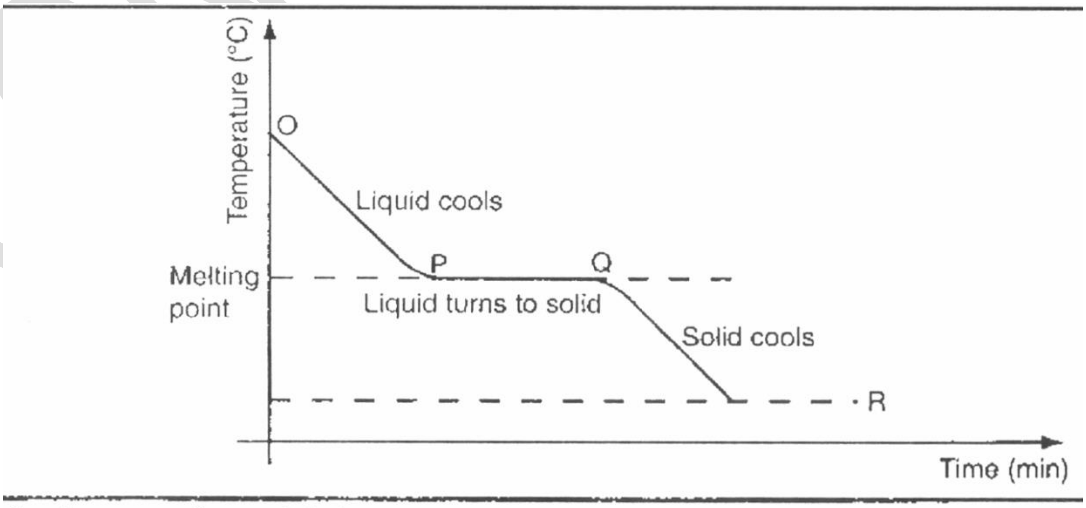
Procedure.

- **H**alf fill a test tube with naphthalene and support it in a water bath as shown in figure above.
- Heat the water bath until naphthalene just melts.
- Put a thermometer inside the liquid naphthalene and continue heating until a temperature of about 90^0C is reached.
- Remove the tube from the water bath and let it cool.
- Record the temperature reading every 30 seconds as naphthalene cools.
- Plot a graph of temperature against time.

  Observation

  During the cooling, the temperature of liquid naphthalene falls from about 90^0C to about 80^0C ,where it remains constant for some time. At this temperature ,all the naphthalene gradually changes to solid after which the temperature falls further to room temperature.

  The graph of temperature against time is as shown below.



Cooling curve for naphthalene

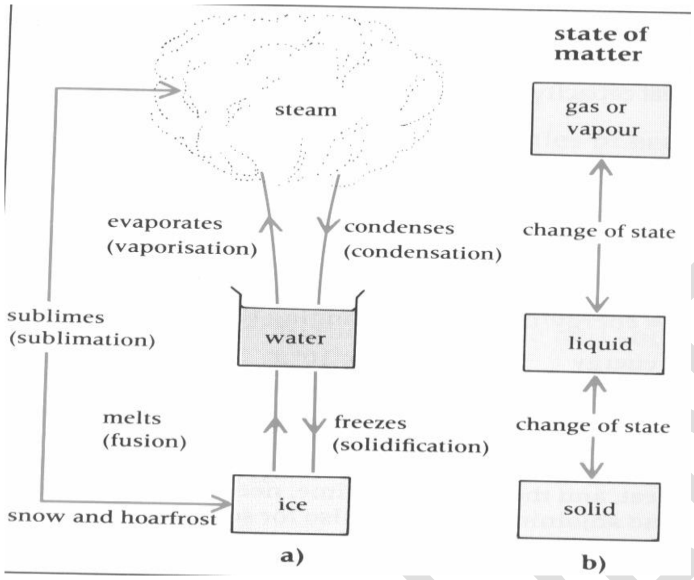
Explanation

The portion OP represents the liquid naphthalene cooling. PQ-Liquid naphthalene changes to solid without change in temperature. Point P is the freezing point where naphthalene is solidifying(and also the melting point).In portion QR ,solid naphthalane cools to room temperature at R.

During the period PQ ,the liquid naphthalene is losing latent heat of fusion as it solidifies.

changes of state for water.

The figure below illustrates the changes of state which are possible for water.



When ice melts to form water the change of state is called fusion. When water evaporates to form water vapour or steam the change of state is called vaporisation. When steam condenses to form water the change of state is called condensation. When water freezes to form ice the change of state is called solidification. It is also possible for a change to occur directly from water vapour to ice or from ice to water vapour. This change of state is called sublimation.

Latent heat calculation.

Example 1

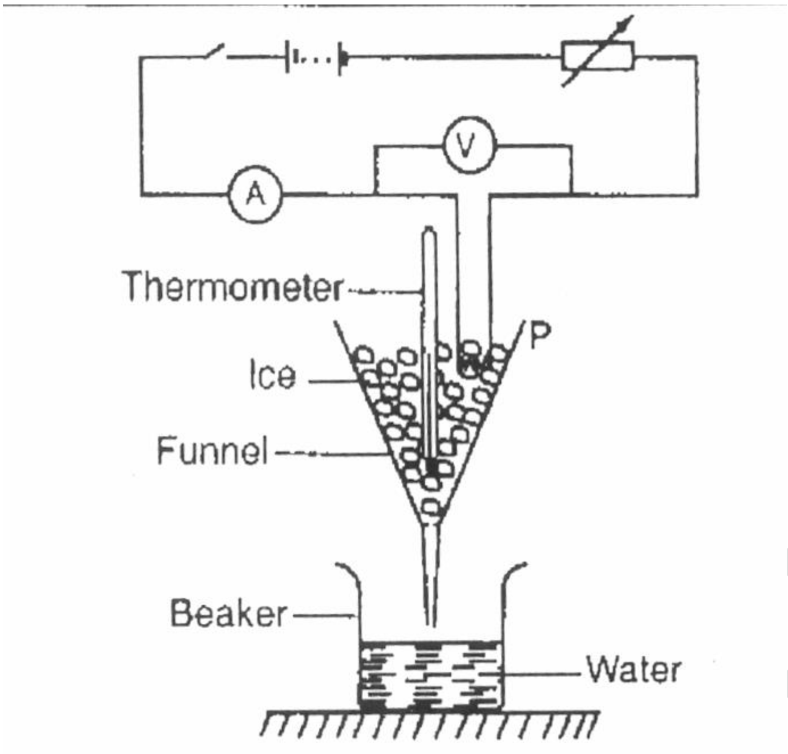
2 kg of ice in a beaker at $-10^{o}C$ is heated until it becomes steam at $100^{0}C$.

(i)Represent diagrammatically the various stages the ice goes through it becomes steam.

(ii)Calculate the amount heat supplied.

(specific heat capacity of ice = $2100Jkg^{-1}$,Specific latent heat of ice = $3.36\times10^{5}Jkg^{-1}$,Specific heat capacity of water = $4200Jkg^{-1}$.Specific latent heat of vaporization = $2{,}260{,}000Jkg^{-1}$.)

EXPERIMENT :***To determine specific latent heat of fusion of ice by the electrical method.***



Procedure

First determine the mass of an empty beaker, m_o .

- Put crushed ice into a filter funnel .
- Place an immersion heater connected to an ammeter, voltmeter and rheostat and make sure that it is completely covered with ice.
- Adjust the rheostat to a suitable value and close the switch. Start the clock once the switch is closed.
- Note the reading of the ammeter and voltmeter.
- When a reasonable amount of water has collected in the beaker under P, note the time, t, remove the beakers and switch off the heater.
- Weigh the beaker and the water in it, m_1 .
- Determine the mass of water, m ,from $m = m_1 - m_0$.

  Heat energy supplied by the heater = heat energy gained by melting the ice.

  $IVt = mL$

Where L is the specific latent heat of fusion of ice.

The table below gives values of specific latent heat of fusion of some common materials.

MATERIAL	Specific latent heat of fusion ($\times 10^5 Jkg^{-1}$).
Copper	4.0
aluminium	3.9
Water	3.34
Iron	2.7
wax	1.8
Naphthalene	1.5
Lead	0.026

Mercury	0.013

EXPERIMENT :To determine the specific latent heat of vaporization of water by electrical method.

source.

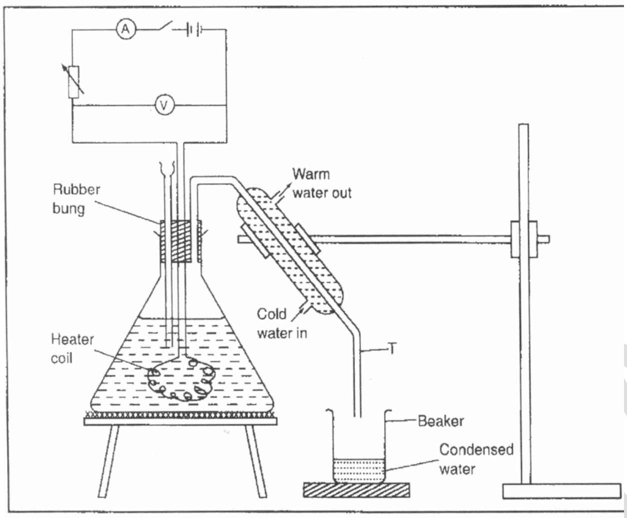


Fig. 9.13: Determining specific latent of vaporisation of water using electrical method

Procedure

- Set up the apparatus as shown.
- Switch on the heater and maintain a steady current using the variable resistor.
- Allow the heating to continue until the system reaches state where condensed water issues down the tube T at constant rate.
- Weigh the beaker and record its mass as m_0 and place it under the tube to collect the condensed water and simultaneously start timing.
- When a measurable quantity of water has collected in the beaker, remove the beaker as you stop the watch. Record the time t, taken and weigh the beaker with condensed water.
- Read and record the ammeter and voltmeter readings.

COOLING CAUSED BY EVAPORATION.

Ether and methylated spirit are examples of volatile liquids. A volatile liquid is one that has a low boiling point and easily changes from liquid to vapour state at ordinary temperatures.

If a little methylated spirit is spilt on the hand it evaporates rapidly and the hand feels very cold.

To change from liquid to vapour the spirit requires latent heat. This it obtains from the hand which thus loses heat and cools. The spirit has a low boiling point and so it evaporates more quickly at the temperature of the hand.

EVAPORATION

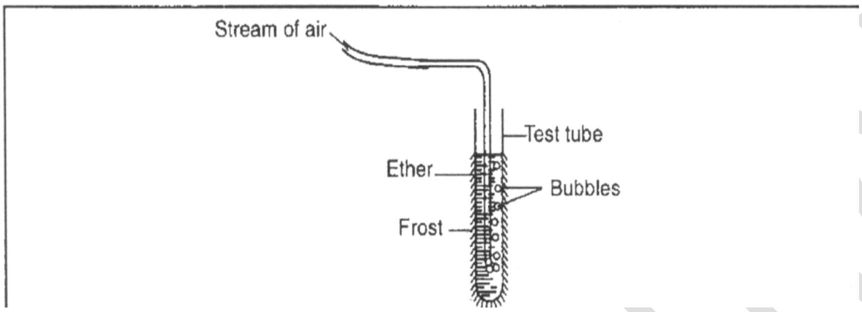
Molecules in a liquid are in continuous random motion with varying kinetic energy.A molecule at the surface of the liquid may acquire sufficient energy to overcome the attractive force from the neighbouring molecules in the liquid and thus escape.This process is known as evaporation and occurs at all temperatures even before boiling point.

Effects of evaporation

(i)Pour some methylated spirit on the back of your hand. The hand feels cold as the spirit evaporates from the skin. The hands feel cold as the spirit evaporates from the skin. The evaporating methylated spirit extracts latent heat from the skin,making it feel cold.

(ii)In a fume chamber pour ether into a test tube. Bubble air through the ether using a long rubber tubing as in figure below.

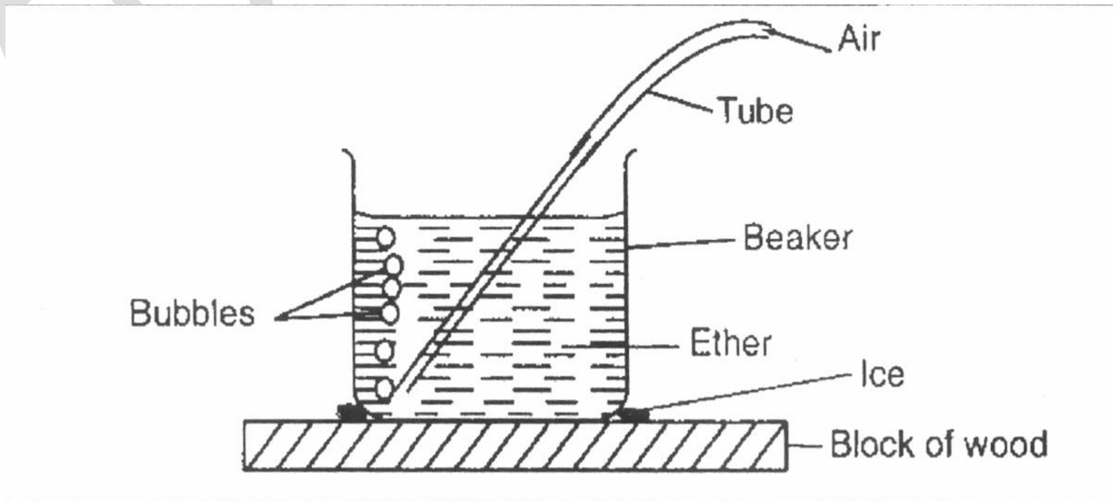
long rubber tubing, as in figure 9.18.



Frost forms on the outside surface of the tube. Evaporating ether draws latent heat of vaporarization from the liquid ether, the test tube and the surrounding space. The tube therefore cools so the frost forms around it. Bubbling increases the surface area of ether exposed to air.

(iii)A beaker about one –third full of ether is stood in a small pool of water on a flat piece of wood. A current of air is then bubbled through the ether by means of a rubber tube attached to bellows. The ether evaporates into the bubbles and the vapour is carried quickly away as the as the bubbles rise to the surface and burst, thus increasing the rate of evaporation. The rapid change from the liquid to the vapour state requires latent heat. This comes from the internal energy of the liquid ether itself, with the result that it soon cools well below 0^oC.

At the same time heat becomes conducted through the walls of the beaker from the pool of water below it and eventually the water cools to 0^oC.After this ,it begins to lose latent heat and freezes.



Evaporation and boiling.

Evaporation is the change of a liquid into a gas at any temperature.
Boiling is the change of a liquid into a gas a specific temperature.
Evaporation occurs at all temperatures at the surface of a liquid.

Factors which affect the rate of evaporation

(i) The temperature is higher since more molecules in the liquid are moving fast enough to escape from the surface.
(ii) The surface area of the liquid is large so giving more molecules a chance to escape because more are near the surface.
(iii) A wind is blowing over the surface carrying vapour molecules away from the surface thus stopping them from returning to the liquid and making it easier for more liquid molecules to break free.

Boiling

(i) Boiling occurs at definite temperature.
(ii) The temperature at which a liquid boils is called the boiling point.
(iii) Boiling is accompanied by formation of bubbles within the liquid.

Differences between evaporation and boiling

1.Evaporation takes place on the surface of the liquid while boiling takes place through out the liquid.
2.Evaporation is invisible while boiling is visible. i.e formation of bubbles can be visualised.
3.Evaporation occurs at any temperature while boiling occurs at a specific temperature called the boiling point.

KINETIC THEORY OF MATTER

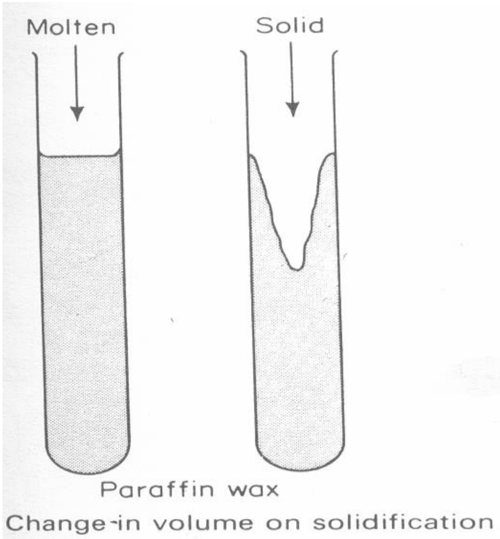
All matter is made up of small particles called molecules. The molecules are in constant motion or vibration. The movement of the molecules is increased with the rise in temperature.

Cooling by evaporation explained by the kinetic theory.

When a liquid is heated the molecules at the bottom gain energy and rise to the surface of the liquid. They either escape or fall back into the liquid.
Only the faster molecules escape because they have enough energy to escape from the attraction of liquid molecules. Some of these collide with other molecules above the liquid and so bounce back into it.
Others escape completely and do not return to the liquid.
In this way a liquid loses its most energetic molecules while the less energetic ones are left behind. The average kinetic energy of the remaining molecules is therefore reduced and this results in a fall in temperature.

CHANGE OF VOLUME ON SOLIDFICATION.

When water freezes to form ice expansion occurs and the ice takes up a bigger volume than the water. For this reason water pipes may burst during very cold weather.
A bottle placed in the freezing chamber should not be filled with water to allow for expansion.
Most substances however contract when they solidify. Paraffin wax is one such example.



EFFECT OF PRESSURE ON MELTING POINT.

If a substance expands on solidifying then the application of pressure lowers the melting point. Conversely substances which contract in volume on solidifying have their melting points raised by pressure.

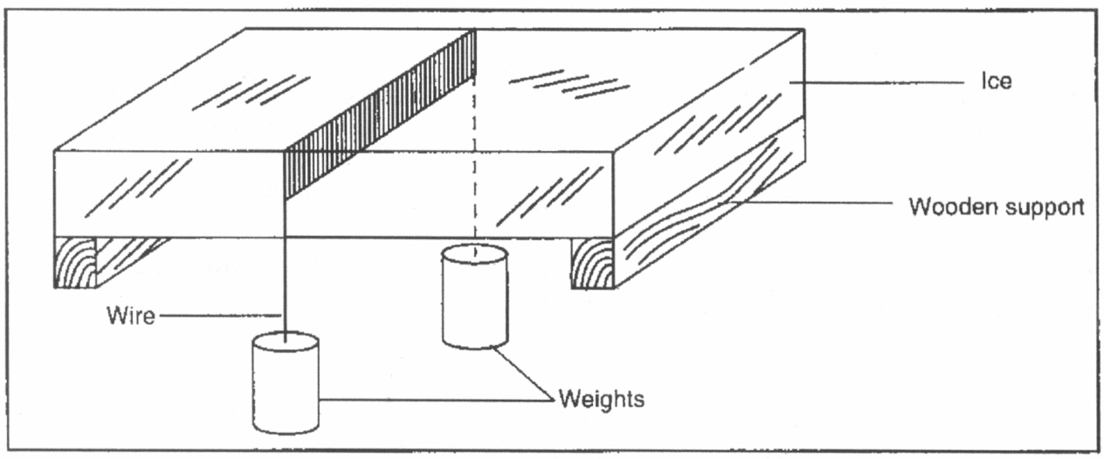


Fig. 9.14: Pressure affects melting point

MEASURING THE SPECIFIC LATENT HEAT OF STEAM.

We pass steam into a calorimeter with water. On its way the steam passes through vessel T ,which traps any water carried over by the steam. The mass of condensed steam is found by weighing. If θ_1 and θ_2 are the initial and final temperatures of the water the specific latent heat l is given by

Heat given by steam +heat given by condensed water=heat taken by water+ calorim condensing

$ml + mc_w$ (100-$\theta_2) = (m_1\, c_w + C)(\theta_2 - \theta_1)$ where m_1 is the mass of water in the calorimeter,c_w is the specific heat capacity of water and C is the heat capacity of the metal container.

Calorimeter, stirrer, water, thermometer, flask, delivery tube, heat source.

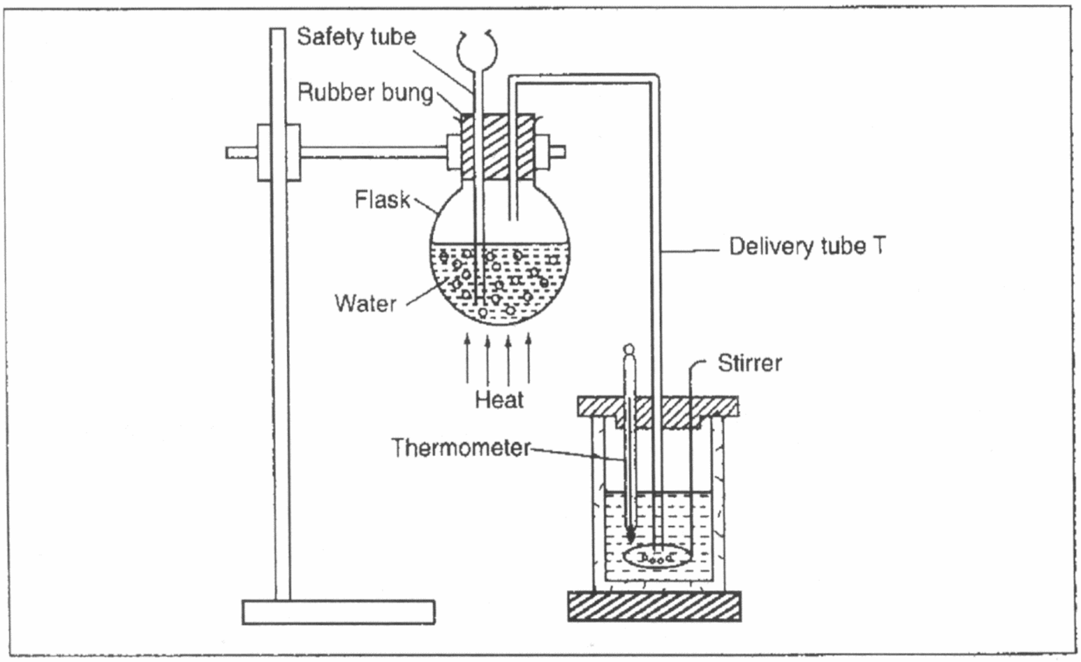


Fig. 9.12: Determination of pecific heat of vaporisation of water by the method of mixtures

Latent heat and the kinetic theory .

a) Fusion

The kinetic theory explains latent heat of fusion as being the energy which enables the molecules of a solid to overcome the intermolecular forces that hold them in place and when it exceeds a certain value they break free. Their vibrating motion about fixed positions changes to the slightly greater range of movement they have as liquid molecules.
Their p.e increases but not their average k.e as happens when heat causes a temperature rise.

b) Vaporisation.

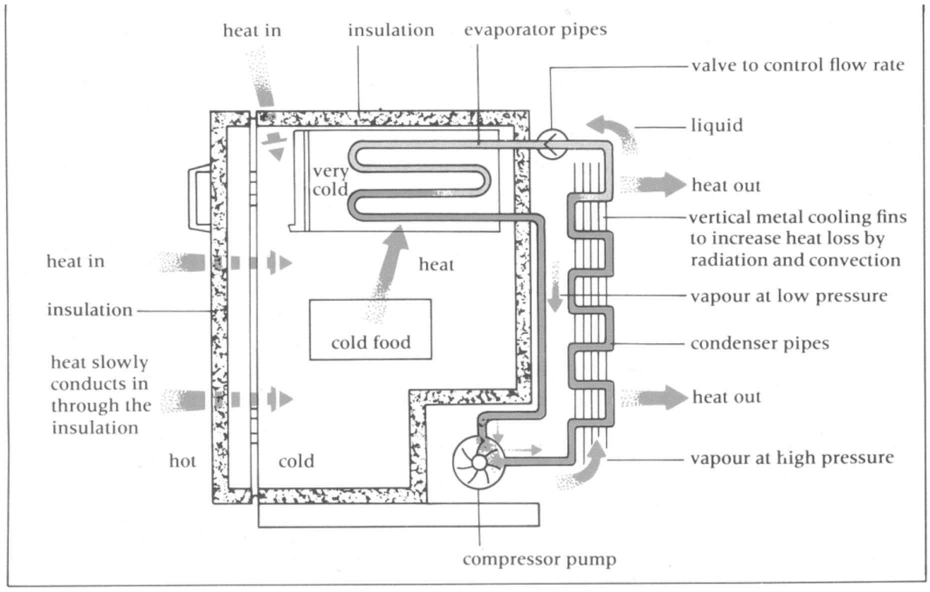
If liquid molecules are to overcome the forces holding them together and gain the freedom to move around independently as gas molecules, they need a large amount of energy. They receive this as latent heat of vaporisation which, increases the p.e of the molecules but not their k.e It also gives the molecules the energy required to push back the surrounding atmosphere in the large expansion that occurs when a liquid vaporises.

APPLICATIONS OF LATENT HEAT

How a refrigerator works

A refrigerator makes food cold by removing heat energy from it. The basic principle is to pump heat from food inside the refrigerator and give it to the air outside.
Cooling in the refrigerator takes place when a volatile liquid evaporates inside the copper coil surrounding the freezing box.As fast as the vapour is formed, it is removed by an electric pump and so under reduced pressure the liquid evaporates.
The vapour which has been pumped off passes into a second coil outside the cabinet where it is compressed by the pump and condenses back to liquid.

Here latent heat is given out, and to enable this heat to be dissipated quickly the condensing coil may be fitted with copper fins. Heat is removed by conduction into the fins and hence convection and radiation to the surroundings.



From the condensing coil the liquid is passed back into the evaporator coil round the freezing box. In this manner a continuous circulation of liquid and vapour is set up. The rate of vaporization and consequent degree of cooling is controlled by a thermostat switch which switches the pump motor on and off at intervals.

SWIMMING

If you stand in the wind in a wet swimming suit, you feel much colder than if your suit is dry. This is because the wind increases the evaporation of water from your skin. Evaporation requires latent heat. In this case latent heat comes from your body and so you feel colder.

QUESTIONS.

1.Calculations the quantity of heat required to melt 4kg of ice and to raise the temperature of the water formed to 50°C.Take the specific latent heat of ice to be$3.4x10^5 Jkg^{-1}$ and specific heat capacity of water to be $4.2x10^3 Jkg^{-1}K^{-1}$.

2.Calculate the heat required to convert 2kg of ice at -12°C to steam at 100°C.

3.An electric kettle contains 1.5litres of water at 20oC.Find
a)the heat required to bring it to boiling –point.
b) the additional heat required to boil half the water away ,assuming that all the heat from the element goes into the water. If the element is rated at 1000W, how long does it take the water to come to the boil?

4.Dry steam is passed into a well lagged copper can of mass 250g containing 400g of water and 50g of ice at $0^0 C$.The mixture is well stirred and the steam supply cut off when the temperature of the can and its contents reaches $20^0 C$.Neglecting heat losses, find the mass of steam condensed.(Specific heat capacities: water

$4200\,Jkg^{-1}K$, $0.4\,Jkg^{-1}K^{-1}$ (Specific latent heat of steam ,
$2{,}260{,}000\,Jkg^{-1}$, ice , $336{,}000\,Jkg^{-1}$)

CHAPTER 5: TRANSMISION OF HEAT

CONDUCTION

Conduction is the flow of heat through matter from places of higher temperature to places of lower temperature without movement of matter as a whole.

Conduction in solids

Various metals conduct heat at different rates. To demonstrate this attaches a match stick using melted wax at the end of each rod made of copper iron aluminium and brass. The rods should be of equal length and cross sectional area. The other end of the rods is placed in a flame at the same time. It is noticed that the match stick on copper falls off first followed by that on aluminium, then the one on brass and lastly that on iron. Hence copper is the best conductor of heat of these metals .

Good and bad conductors

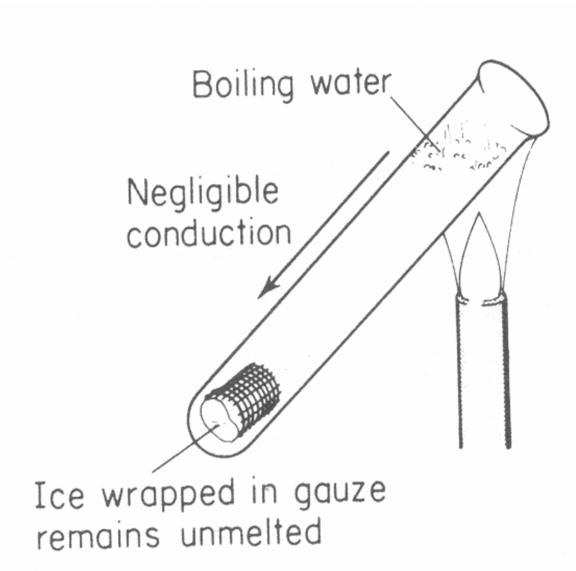
Most metals are good conductors of heat.
Materials such as wood, glass, cork, plastics and fabrics are bad conductors.
Metal objects below body temperature feel colder than those of bad conductors because they carry heat away faster from the hand-even if all the objects are at exactly the same temperature.

Conduction by liquids and gases.

Liquids and gases also conduct heat but only very slowly.
Water is a very poor conductor of heat.

To demonstrate that water is a poor conductor.

Wrap ice in a wire gauze and place it in a test tube. Pour water in a test tube and heat the water at the top as shown. Water will begin to boil at the top before the ice at the bottom melts.
This shows that little heat has been conducted to the bottom to melt the ice.



Good conductors.

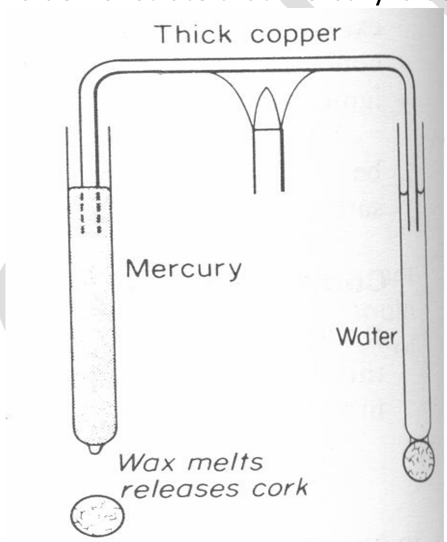
These are used whenever heat is required to travel quickly through something. Saucepans, boilers and radiators are made of metals such as aluminium, iron and copper.

Bad conductors (insulators)

The handles of some saucepans and frying pans are made of wood to prevent heat transfer by conduction.

Air is one of the worst conductors. This is why houses with cavity walls (two walls separated by an air space) keep warmer in cold seasons and cooler in hot seasons. Materials which trap air e.g wool, fur, polystyrene etc are also very bad conductors. Some of these are used as ‘lagging’.

To demonstrate that mercury is better conductor of heat than water.



A piece of thick copper wire bent twice at right angles is then placed in mercury and water at either end. The centre of the wire is heated with a Bunsen flame and heat is conducted through the metal equally into the water and mercury.

In a short time wax on the mercury filled tube melts and the cork falls off. With further heating the cork on the test tube with water will fall off.

Conduction and the kinetic theory.

Metals consist of free electrons. When one end of the metal is heated the electrons move faster their kinetic energy increases. They collide with atoms passing on their energy to them and as the metal is heated further the amplitude of vibration increases and hence the temperature of the metal rises.

CONVECTION

Convection is the flow of heat through a fluid from places of higher temperature to places of lower temperature by movement of the fluid itself.

Fluids are liquids and gases.

Convection in liquids.

To demonstrate convection currents fill a beaker with water and drop a single crystal of potassium permanganate at the bottom of it. Heat the bottom of the flask.An upward current of coloured water will ascend from the place where the heat is applied. This coloured stream reaches the top and spreads out. After a short time it circulates down the sides of the flask showing that a convection current has been set up.

Explanation

When a portion of liquid near the bottom of a vessel is heated it expands. Since its mass remains unaltered it becomes less dense and therefore rises.

142 **Thermal properties of matter**

Demonstrations of convection

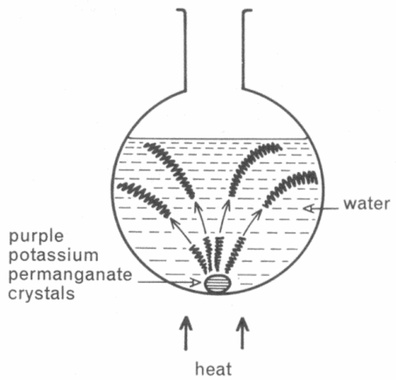


Fig. 5·24 Demonstrations of convection

Convection currents in air.

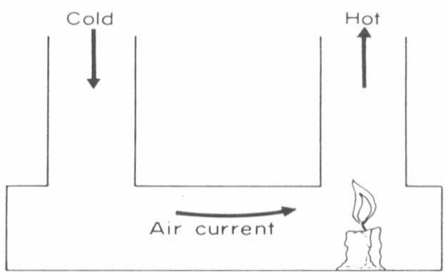


Fig. 17.12. Ventilation by convection

Position a lighted candle under one chimney and then stuff some card board into the top of the other chimney. The direction of the convection currents created by the candle is made visible by the smoke from the cardboard.

Convection currents are a flow of liquid or gas caused by a change in density in which the whole medium moves and carries heat energy with it.

Land and sea Breezes

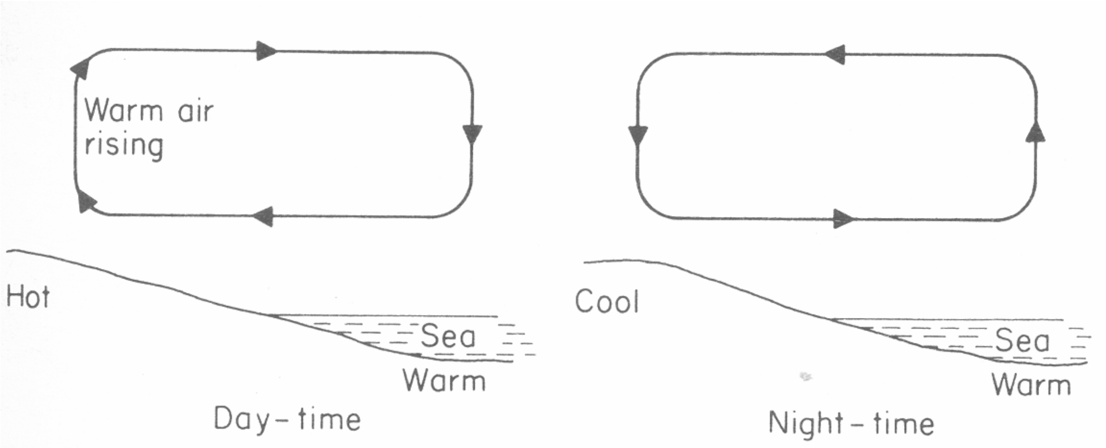


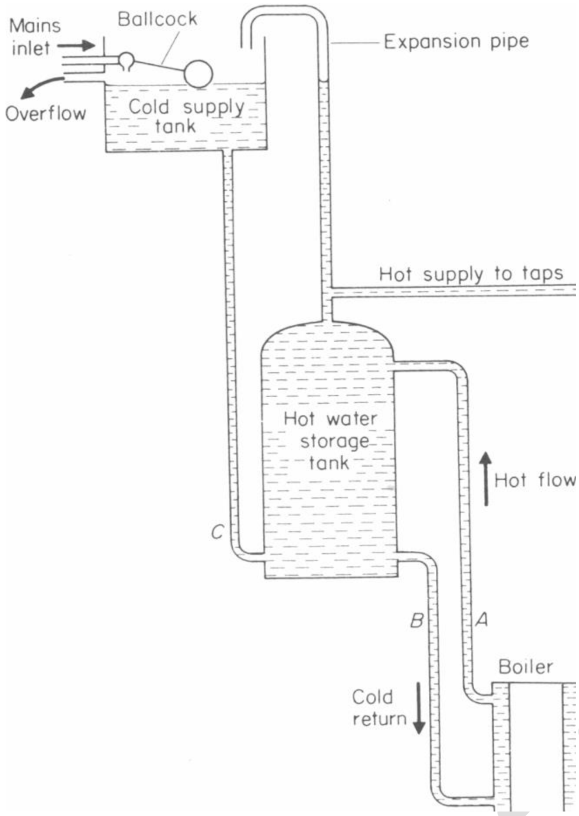
Fig. 17.15. Land and sea breezes

During the day the land is heated by the sun to a higher temperature than the sea. Air over the land is therefore heated expands and rises while cooler air blows in from the sea to take its place. The circulation is completed by the wind in the upper atmosphere blowing in the opposite direction.

At night the land is no longer heated by the sun and cools very rapidly. On the other hand the sea shows no change in temperature. The sea is warmer than the land so that air convection current is reversed.

Domestic hot water system

The domestic hot water supply system works on the principle of convection current of hot water rising through on pipe and cold water descending through another.



RADIATION

Radiation is the flow of heat from one place to another by means of electromagnetic waves.

Radiation is a form of heat transmission that does not require a material medium. Radiant energy consists of electromagnetic waves which pass through a vacuum. The waves are partly reflected and partly absorbed by objects on which they fall. The part which is absorbed becomes transferred into internal energy.

Absorption of radiation by a surface.

Absorbing powers of a dull black and polished surface can be compared using two sheets of tin plate one polished and the other painted black.

On the reverse side of each a cork is fixed by means of a little melted wax.

The plates are set up vertically with a Bunsen burner midway them. When the burner is lit both surfaces receive equal quantities of radiation. In a short time the wax on the dull black plate melts and the cork slides off.

The polished plate remains cool and the wax unmelted.

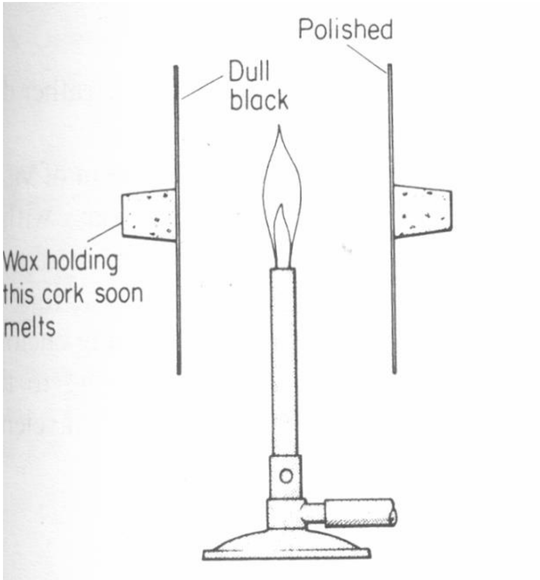
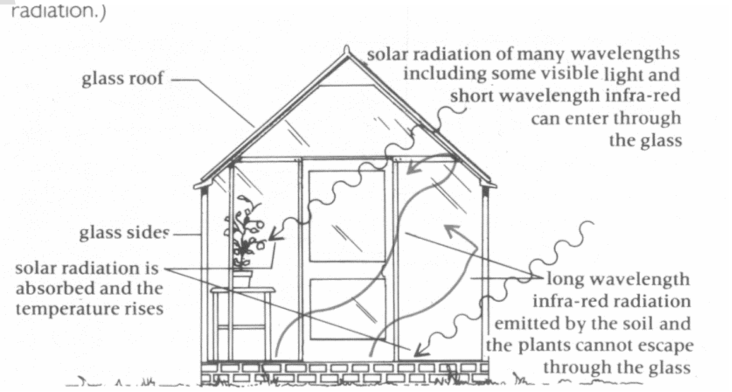


Fig. 17.19. Comparison of absorbing

The green house effect.
Greenhouses are used to help certain plants grow better by providing a warmer air temperature. In summer green houses do not need internal sources of heat because they are able to trap enough solar radiation to keep them very warm inside.
Sunshine contains radiation of many different kinds. Some of that radiation is the light which we can see ,but much of it is invisible infrared radiation .
The sun is very hot and sends this radiation in a form which can easily pass through the glass of a green house. This is short wavelength infrared radiation.

Once inside the green house this infrared radiation is absorbed by the plants and the soil making them warmer. The warm soil and the plants now also emit infrared radiation but since the soil is cool compared with the sun this radiation has a much longer wavelength and cannot pass through the green house glass.
In this way solar radiation becomes trapped inside the green house and causes its temperature to rise.



The vacuum flask.
To keep a drink or food hot inside a flask heat losses by all three processes must be reduced to a minimum.

Conduction is totally prevented through the sides of the flask by the vacuum between the double glass walls of the bottle.The cork or plastic stopper contains a lot of trapped air which is a bad conductor of heat.Convection is also totally prevented by the vacuum and can cause heat loss through the top of the flask only while the stopper is removed.
The radiation loss of heat is greatly reduced by the two silver coatings on the glass walls of the flask.

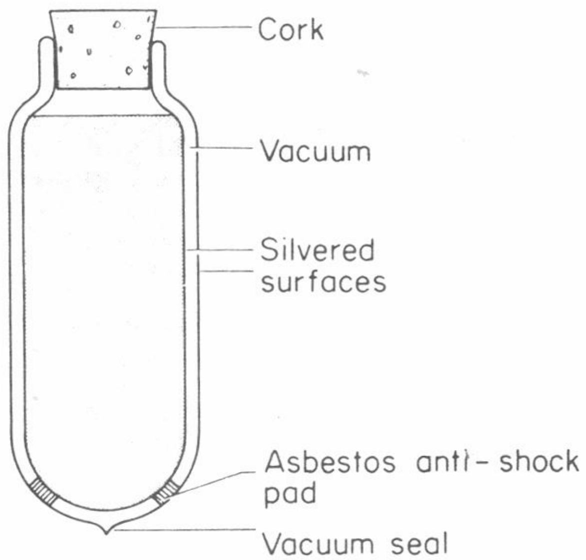


Fig. 17.20. Vacuum flask

CHAPTER 6: THE GAS LAWS

Boyle's Law
The volume of a fixed mass of gas is inversely proportional to the pressure provided the temperature remains constant.
Verification of boyle's law
The apparatus consists of a burette B connected by a length of rubber tubing to a glass reservoir containing mercury.
All water vapour which may be present with the air in the burrette should be removed.

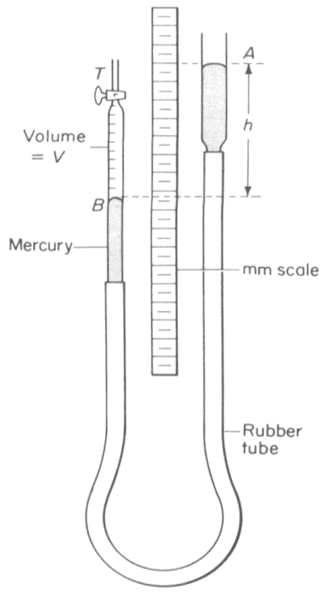


Fig. 16.3. Boyle's law apparatus

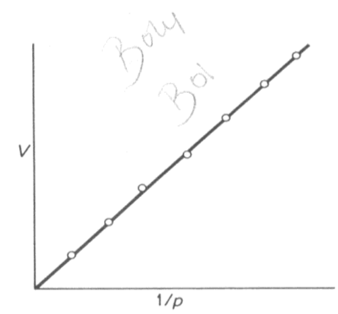
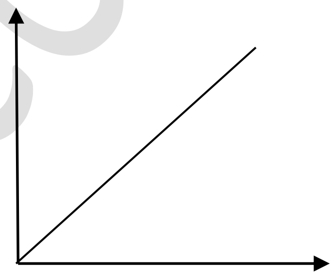


Fig. 16.4.

With the tap T closed the reservoir is adjusted and the mercury levels A and B in the open and closed limbs noted. The difference is calculated and recorded as h. The absolute pressure of the enclosed air is given by P=H+h where H is the atmospheric pressure read from a barometer.
The pressure P=H-h when A is below B the corresponding volume V of the trapped air is determined from V=AL where l is the length from T to B

With the tap T closed the reservoir is adjusted and the mercury levels A and B in the open and closed limbs noted. The difference is calculated and recorded as h. The absolute pressure of the enclosed air given by P=H+h where H is the atmospheric pressure read from a barometer.
The pressure P=H-h when A is below B .
The corresponding volume V of the trapped air is determined from $V = Al$ where l is the length from T to B.
We tabulate the results and plot a graph of P against $\frac{1}{V}$.
A straight line through the origin is obtained,indicating that P is proportional to $\frac{1}{V}$.



Charles' Law
The volume of a fixed mass of gas at constant pressure is directly proportional to its absolute temperature.
Verification of charles' law.
Arrange the apparatus as shown below.

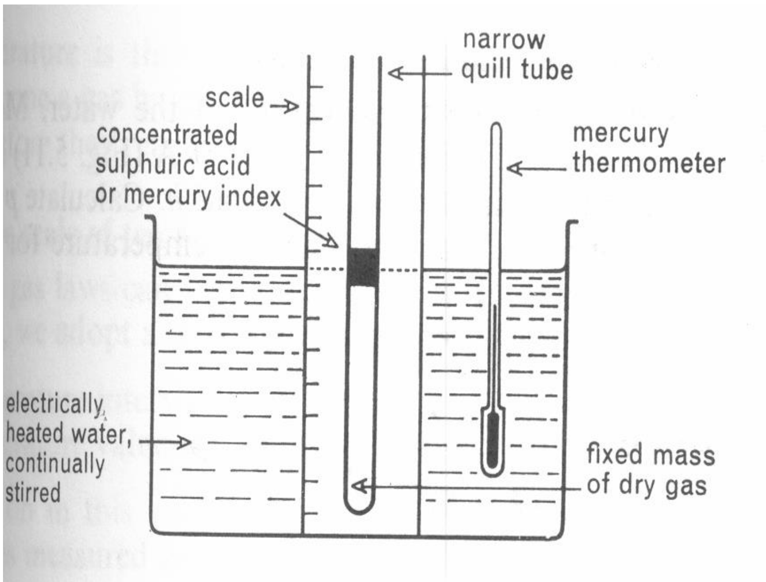
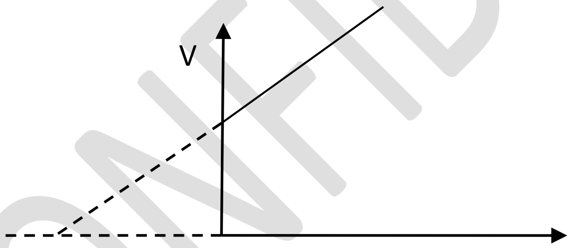


Fig. 5·9 Charles's Law

The index of concentrated sulphuric acid traps the air column to be investigated and also dries. Adjust the capillary tube so that the bottom of the air column is opposite the zero mark on the ruler.
Note the length of the air column at different temperatures but before taking the reading stop the heating and stir well to make sure that the air has reached the temperature of the water.
Plot a graph of volume against temperature in ^oC .
The pressure of the air column is constant.



Pressure Law
The pressure of a fixed mass of gas at constant volume is proportional to its absolute temperature.

$P \propto T$
$\frac{P}{T} = constant$
The three equations can be combined giving
$\frac{PV}{T} = Constant$
For cases where P,V and T all change from P_1, V_1 and T_1 to P_2, V_2 and T_2 then

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

Verification of the pressure law

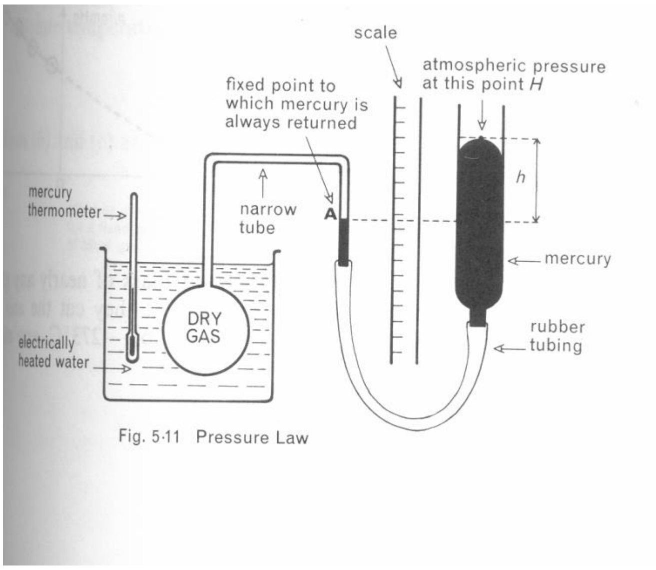
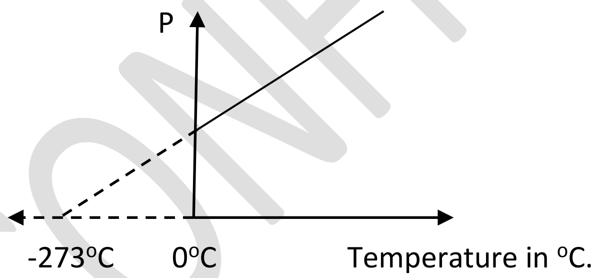


Fig. 5·11 Pressure Law

A glass bulb B joined to a capillary tube is connected to a mercury reservoir R by a length of rubber tubing. The bulb contains dry air.
Water in a large beaker is heated the heating is stopped and water stirred to obtain a steady temperature the open mercury tubing is adjusted so that the mercury in the closed limb is at the fixed mark M.
The difference in height h of mercury in the two limbs is determined. The experiment is repeated for different temperatures. The atmospheric pressure H is determined using a barometer.
The pressure at any temperature is given by P=H h. A graph of pressure against temperature is plotted. A straight line graph is obtained.



Absolute zero
The volume-temperature and pressure -Temperature graphs of a gas are straight lines. They show that gases expand uniformly with temperature as measured on a mercury thermometer. The graphs do not pass through the origin if the temperature is expressed in degrees Celsius. If they produced backwards they cut the temperature axis at about -273^{o}C .This temperature is called absolute zero because it is lowest temperature possible.
It is the zero of the absolute or Kelvin scale of temperature. Degrees on this scale are called kelvins and are denoted by K.

0^{o}C=273K

$\theta^o C = (273 + \theta)K$

Gas laws and the kinetic theory
A gas consists of a number of molecules moving randomly and colliding with each other and with the walls of the container in which the gas is enclosed.
A force is set up on the walls which is given by the rate of change of momentum as they bounce off.
The pressure of the gas is the value of this force per unit area. The absolute thermodynamic temperature of a perfect gas is proportional to the average kinetic energy of its molecules.

Boyle's law.
At constant temperature the average kinetic energy of the molecules is constant.If the volume of a fixed mass of gas is halved the number of molecules hitting the walls of gas is halved the number of molecules hitting the walls per second doubles hence the pressure doubles. Hence the pressure of a fixed mass of gas at constant temperature is inversely proportional to the volume.

Charle's law
If the pressure of a fixed mass of gas remains constant as the temperature is raised the rate of change of momentum of the molecules on impact with the walls remain constant.
The velocity of the molecules increases with temperature the change in momentum is greater. To keep the rate of change in momentum travel further between collisions with the walls.

Pressure Law
Raising the temperature of a fixed mass of gas at constant volume increases the average kinetic energy of the molecules so that they make more frequent impacts with walls at higher velocity. Thus the rate of change of momentum on impact is increased with consequent increase in pressure.

EXAMPLES

1. $125cm^3$ of gas collected at 15°C and 755mm of mercury pressure. Calculate the volume of the gas at s.t.p

$$\frac{PV}{T} = Constant$$

Initial values.
$P_1 = 755mmHg$
$V_1 = 125cm^3$
$T_1 = 288K$

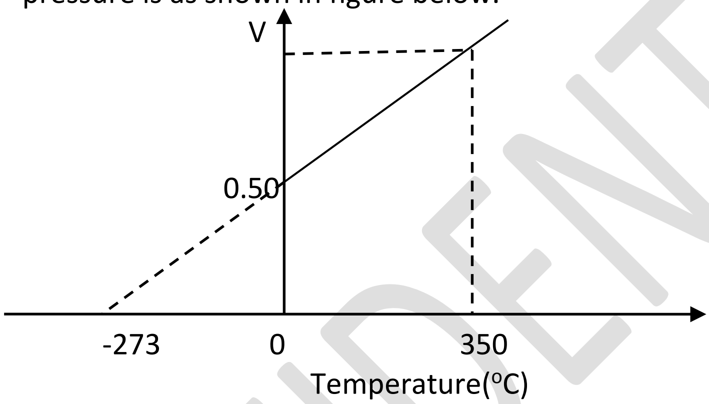
Current values
$P_2 = 760mmHg$
$V_2 = ?$
$T_2 = 273K$

$\frac{P_2V_2}{T_2} = \frac{P_1V_1}{T_1}$
$V_2 = 125x\frac{755}{760}x\frac{273}{288}$
$V_2 = 118cm^3$

Exercise

1. $1000 cm^3$ of air at 10°C is heated to 80°C.What will be the new volume if the pressure remains atmospheric?

2. To what temperature must 2litres of air at 17°C be heated at constant pressure in order to increase its volume to 3litres?
3. A volume of $50 cm^3$ of a gas is compressed at constant temperature until its pressure rises from 90cmHg to 150cmHg.Calculate the final volume of the gas.
4. A fixed amount of oxygen has a volume of $5 m^3$ at 27°C.Calculate the volume of oxygen at $77^o C$ when the pressure remains constant.
5. Explain using kinetic theory of gases why the temperature of the gas inside the bicycle pump increases when the pump is being used.
6. The graph of volume against temperature of a fixed mass of gas at constant pressure is as shown in figure below.



Calculate the value of V in the graph.

7. A fixed mass of gas is enclosed in a vessel. Explain in terms of molecular theory:

(i) how the pressure measured at the wall of the vessel is produced by the gas molecules.

(ii) how the pressure would be affected if the temperature increased, keeping the volume constant;

(iii) how the pressure would be affected if the volume of the vessel were reduced ,keeping the temperature constant.

CHAPTER 7: VAPOURS

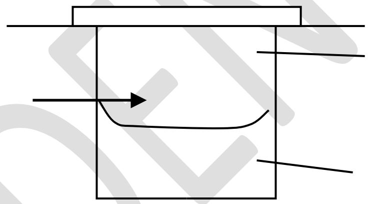
Liquids vary in the rate at which they evaporate at ordinary temperatures.
Methane and ether evaporate very rapidly and they are said to be volatile.
A vapour is the gaseous state of a liquid and it is produced when a liquid evaporates or boils.

VAPOUR PRESSURE

In a closed vessel containing a liquid and its vapour, the vapour molecules collide with the walls and rebound from it exerting a pressure on it called vapour pressure.

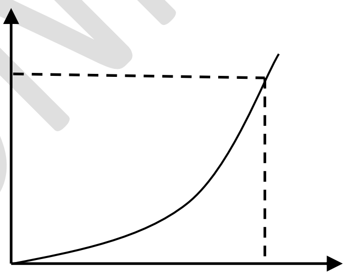
A state of dynamic equilibrium is when the rate at which molecules leave the surface of the liquid is equal to the rate at which they re-enter the liquid. The vapour is said to be saturated. The pressure of a vapour which is in dynamic equilibrium with its own liquid is called saturated vapour pressure.

A saturated vapour is one which is in a state of dynamic equilibrium with its own liquid. Before equilibrium has been reached the vapour is said to be unsaturated.



Variation of saturated vapour pressure with temperature .

The saturated vapour pressure increases with temperature. Below is a graph of s.v.p with temperature for water.



What happens when a liquid boils?

If a liquid is heated its temperature begins to rise and so its s.v.p will increase.
Ultimately the s.v.p becomes equal to the external atmospheric pressure.
The boiling point of a substance is defined as the temperature at which its saturated vapour pressure becomes equal to the external atmospheric pressure.

The Pressure cooker

If we raise the boiling point of water we can reduce the time taken to cook food. This is possible using a pressure cooker.

Pressure cookers are useful in places where atmospheric pressure is low like at the top of a mountain (high altitudes).

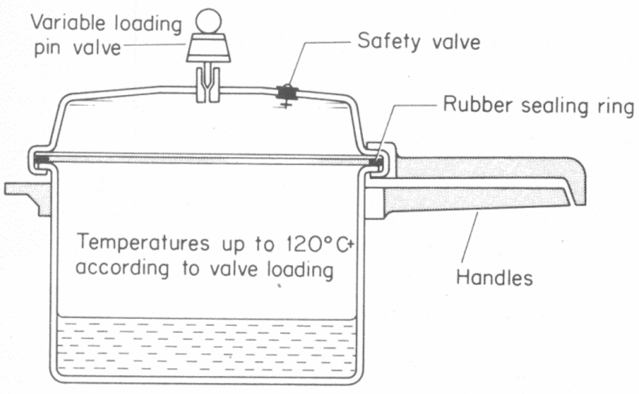


Fig. 20.5. Pressure cooker

CHAPTER 8: HEAT ENGINES

A heat engine is a machine which extracts mechanical energy (k.e) from a gas at a high temperature (obtained by burning a fuel) and then expels it at a lower temperature into the atmosphere.

PETROL ENGINES

The action of a 'four stroke' engine is shown below.

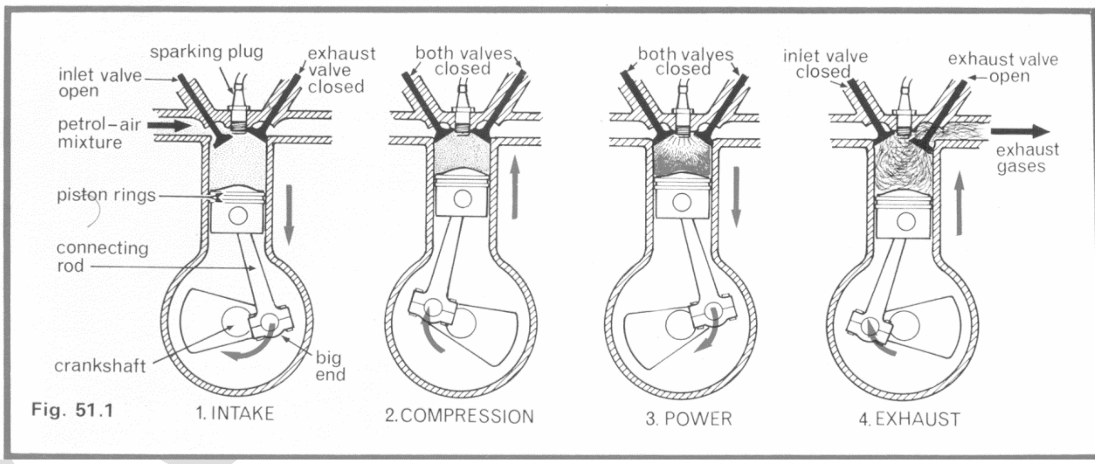


Fig. 51.1

1.On the **intake stroke**, the inlet valve opens and the piston moves down. Petrol and air are drawn into the cylinder.

2.On the **compression stroke** both valves are closed and the piston moves up compressing the mixture.

3.On the **power stroke** Both valves are still shut. As the piston reaches the top of the compression stroke the spark plug sparks and ignites the petrol-air mixture. The explosion produced forces the piston down.S

4.On the **exhaust stroke** the outlet valve opens and the piston rises pushing the exhaust gases out of the cylinder.