CHAPTER TEN

MEASUREMENT OF HEAT

Heat: This is the type of energy which flows from a region of a higher temperature to that of a lower temperature.

Temperature: This is a number which tells us how hot or cold a body is.

Distinction between heat and temperature:

(1) Temperature is a fundamental quantity, where as heat is a derived quantity.
(2) Temperature is a measure of the heat level, where as heat is a measure of the total internal energy of the body.
(3) Temperature is measured in Kelvin (K) where as heat is measured in joule, J.

Factors which determines the quantity of a heat possessed by a body:

These factors are:

(1) The mass of the body.
(2) The nature of the body.
(3)The body`s excess temperature over its` surrounding.

The effects of the addition of heat on substances:

- These effects are:
  (1) The expansion of the substances may occur.
  (2) It can cause an increase in the temperature of the substances, except when the substance is undergoing a change of state.
  (3) If the substance is an electrical conductor, then its electrical resistance can increase.
  (4) It can cause a substance to undergo a change of state.
  (5) It increases the rate of evaporation of a liquid, or the rate of sublimation of a solid.

Sources of heat:

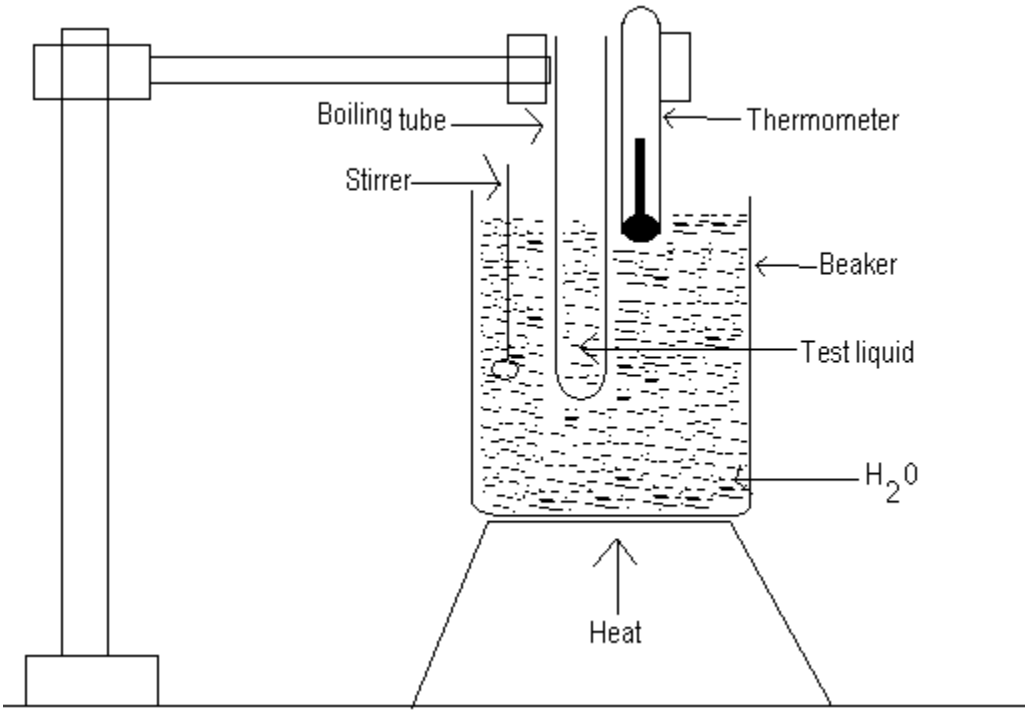
The main sources of heat include some natural and certain artificial sources. These include:

(a) Solar energy
(b) Fossil fuel (petroleum).
(c)Nuclear energy.
(d) Hydroelectric power.
(e) Geothermal energy.
(f) Friction.

Boiling and the boiling point:

- When a liquid is heated in a container, its temperature increases.
- As the temperature increases, the saturated vapour pressure of the liquid which forms on its upper surface also increases, and bubbles are formed throughout the liquid.
- At a particular point, the vapour pressure of the liquid becomes equal to the atmospheric pressure, and when this occurs, the bubbles will start to escape into the atmosphere.
- The liquid is then said to be boiling.- The boiling point of a liquid is therefore defined as the temperature, at which its vapour pressure becomes equal to the atmospheric pressure.

The determination of the boiling point of a liquid, whose boiling point is less than 100^{0c} , [when a few drops are available]:



Procedure:

- In this experiment, a few drops of the liquid are placed in a boiling tube, and a thermometer is attached to it using a rubber band, so that the bulb of the thermometer is in line with the liquid in the boiling tube.
- The assembly is suspended by means of a clamp and a stand in a water bath.
- The water in the bath is continuously stirred as the water is slowly heated.
- The temperature at which the liquid begins to bubble is noted and this is taken as the boiling point of the liquid.

Precautions to be taken:

(1) The water is continuously stirred in order to obtain a uniform temperature within the water bath.
(2) The heating must be done slowly in order to obtain a thermal equilibrium between the boiling tube and the water.

(3) It must also be ensured that the thermometer is in line with the liquid in the boiling tube, so as to record the true temperature of the boiling liquid.

The assumptions of the Kinetic Theory:

These assumptions are:
(i) Gases are made up of small solid particles which are in constant random motion.
(ii) The particles move in straight lines and their motion is only affected by their collisions with other particles, or with the walls of the vessel in which they are contained.
(iii) All the collisions are perfectly elastic i.e. there is no loss of kinetic energy when two particles collide or a particle strikes the walls of a container.
(iv) The time for which the particles are actually in contact with each other, is very small and they may be neglected.
(v) The actual volume of the molecules is very small, compared with the volume of the container in which they are found.

Explanation of evaporation using the kinetic theory:

- As a result of the random collisions in a liquid, a molecule may acquire enough kinetic energy to break away from the attraction of their neighbours.
- They may also acquire a velocity which is greater than the average velocity of the liquid molecules, even though the temperature at that instant is well below the boiling point of the liquid.
-A molecule at the surface can leave the liquid, giving rise to the evaporation of the liquid.

Cooling by evaporation: According to the kinetic theory of matter, the temperature of a liquid is directly proportional to the average kinetic energy of its molecules. During evaporation, the more energetic molecules escape from the liquid surface, leaving behind the less energetic molecules. The average kinetic energy of the molecules remaining in the liquid falls, and as such the temperature of the liquid falls. This phenomenon is referred to as cooling by evaporation.

Comparing and contrasting boiling and evaporation:

(a) The differences between boiling and evaporation:

(1) Boiling takes place at a fixed temperature referred to as the boiling point, but evaporation takes place at any temperature.
(2) Boiling occurs throughout the whole body of the liquid (i.e. both surface and inside), but evaporation only occurs at the surface.
(3) During boiling, the temperature remains constant but during evaporation, the temperature may change.

(b) Similarities between boiling and evaporation:

(1) Both lead to the reduction in the volume or mass of the liquid.
(2) Changes in temperature and pressure affect them.
(3) In both, molecules are released from the liquid.
(4) Both occur at the surface of the liquid.

Factors affecting evaporation:

(1) Temperature:

- The rate of evaporation increases with temperature.
- In short, as the temperature increases, the rate at which a liquid evaporates also increases.

(2) Air current:

- The stronger the air current, the greater becomes the rate of evaporation.

(3) The suface area of the liquid:

- As the surface area of the liquid increases, the rate of evaporation also increases.

(4) Humidity:

- The lower the humidity, the greater the rate of the evaporation.

N/B: Pressure also affects the rate of evaporation.

The boiling point elevation:

- This is the increase in the boiling point of a liquid, due to the presence of dissolved particles within it.
- For example, the boiling point of water is 100^{0c}, but by dissolving sugar or salt in the water, the boiling will be greater than 100^{0c}.

- This is due to the fact that salt and sugar molecules have greater masses than water molecules (i.e. they are more massive than water molecules), and as a result, the attractive forces are increased when they are added.
- For this reason, more energy in the form of heat will be required to overcome them, causing a rise in the boiling point.
- The boiling point of sea water which is around $104^{0c}$is higher than that of water, since it contains dissolved salt particles, and the increase in the temperature, (i.e. the 4^{0c}) is what is referred to as the boiling point elevation.

Freezing (melting) point depression:

- This is the decrease in the freeing or the melting point of a substance, due to the presence of dissolved particles within it.
- For example, the melting point of ice is 0^{0c}, but the addition of salt to the ice depresses the melting point well below 0^{0c}.

The attainment of the saturated vapour pressure of a liquid:

- Evaporation causes the surface above the liquid to become occupied by vapour molecules.
- These molecules move randomly and on hitting the walls of the container, they bounce off and this exerts vapour pressure on the wall.
- They can also strike the surface of the liquid and re – enter it.
- After some time, the rate at which the molecules leave the liquid becomes equal to the rate at which they enter.
- This attainment of dynamic equilibrium gives the maximum vapour pressure that can be exerted by molecules from the liquid, and it`s known as the saturated vapour pressure.

The reduction in boiling point at higher elevation:

- The atmospheric pressure decreases as we move higher.
- For this reason, the atmospheric pressure at the top of a mountain will be lower than that at the bottom of the same mountain.
- The boiling point of a liquid will be lower on the top of a mountain than that at its bottom.
- This due to the fact that the pressure at the top of the mountain is lower than that at the bottom.
- Consequently, the temperature at which the saturated vapour pressure of the liquid becomes equal to the surrounding atmospheric pressure which is referred to as the boiling point, will be lower on top of the mountain that that at its bottom.

- In short, the boiling point of a liquid decreases with height.

Cooling produced by evaporation:

- Some liquids have low boiling points and as such, they change easily from the liquid into the vapour state at ordinary temperature.
- Such liquids are called volatile liquids and examples are methylated spirit and ether.
- If a little methylated spirit or any volatile liquid is split or placed on the hand, it evaporates quickly and the hand feels very cold.
- In order to change from the liquid into the vapour state, heat is needed by the methylated spirit.
- This heat needed is taken from the hand, causing it to become cold or cool.
- In a similar manner, water will also cause a similar effect but this is less noticeable since water is less volatile.
- Therefore since methylated spirit has a lower boiling point, it evaporates more quickly from the hand than the water.
- It is also a well known fact that milk can be kept cool more efficiently by wrapping its container (i.e. the bottle or the mill can) in wet cloth, rather than allowing it to stand in cold water.
- In this case, as the water evaporates from the wet cloth, it removes heat from the milk causing it to be cold.
- If the rate of evaporation can be increased by placing the milk wrapped in the wet cloth in a draught or moving air, so much the better.
- Sweating or perspiration by the body is a means of loosing the excess heat found in a body, so as to maintain a constant temperature (i.e. keep the temperature of the body constant).
- Sweat is produced when the body becomes hot and as it evaporates, heat is taken from the body causing it to cool.
- Lastly dogs which do not perspire from the skin hang out their tongues during hot weather in order to achieve a cooling effect.

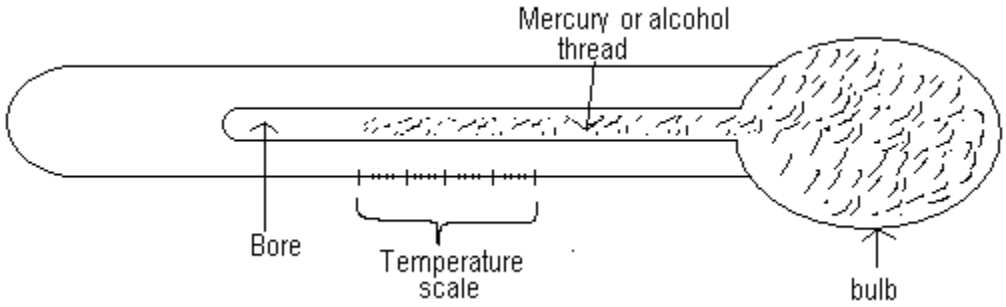
Thermometers: These are devices which are used to measure temperature.

Types of thermometers:

- There are different types and some well known types are:
  (1) Liquid in glass thermometer.
  (2) Thermoelectric thermometer.

(3) Platinum resistance thermometer.
(4) The gas thermometer.
(5) The pyrometer.
(6) Digital thermometer.

Liquid in glass thermometers:



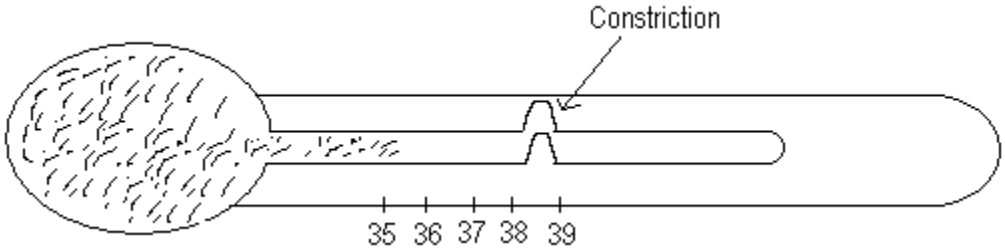
- This type of thermometer contains a liquid and there are two types which are:
  (a) The mercury thermometer.
  (b) The alcohol thermometer.
- The liquid in glass thermometer consists of a glass bulb, which contains a liquid which is either alcohol or mercury.
- This liquid is capable of rising or falling within the bore, as a result of its expansion or contraction.
- It also has a temperature scale.

The principle of operation of the liquid in glass thermometer:

- It works on the principle that matter expands when heated and contracts when it cools.
- If the thermometer is brought into contact with a hot body, or brought into a hotter environment, heat moves from the hot body or the hotter surrounding into the liquid within the thermometer.
- This causes the liquid to expand and rise within the bore, to indicate a high temperature.
- If the thermometer is now brought into contact with a cold body or into a cold environment, heat will now move from the liquid within the bulb into the cold body or the cold surrounding.

- The liquid therefore becomes cool and contracts causing the level of mercury or alcohol (i.e. the mercury or alcohol thread) to fall, indicating a low temperature.

The clinical thermometer:



- This is a special type of liquid in glass thermometer, which is designed to measure the temperature of a human being.
- It therefore has a few range of degrees below and above the normal temperature of a normal human being.
- It is normally placed beneath the patient`s tongue or ampit, and left there for a few minutes.
- When it is removed from the mouth or the ampit, the sudden contraction of the mercury or alcohol in the bulb causes the thread to break at the constriction.
- This causes the mercury or the alcohol to remain in the stem, and the temperature can be read at will or leisure.
- Before it is used again, the mercury or the alcohol in the stem or bore must be returned to the bulb by shaking.
- The average body`s temperature of a healthy person is about $37^{0c.}$

Sterilization of clinical thermometers:

- Sterilization is the process of destroying the germs found on an object.
- Since a clinical thermometer is used on several patients, there is the need to subject it to sterilization after each use, so as to stop the passage of disease causing germs from one person unto the other.
- Clinical thermometers are usually sterilized in alcohol rather than in boiling water
.- This is mainly due to the fact that alcohol especially those rated 70% and above, are known to be capable of killing almost all micro-organisms or germs.
- Clinical thermometers are not sterilized in boiling water for two main reasons.

- The first reason is that, there are several micro-organisms referred to as hemophilic organisms which are able to survive at the temperature of boiling water.
- For this reason, sterilization of clinical thermometer in boiling water will not lead to the destruction of these germs.
- Secondly, since the temperature range on a clinical thermometer lies between 35^0C and 43^0C, inserting it in boil water at 100^0C for sterilization, will lead to the excessive expansion of the alcohol or the mercury within the thermometer, leading to the possible destruction of the glass used in making the thermometer.

Thermometric liquids:

- These are liquids which are used within thermometers.
- For a liquid to be a good thermometric liquid, it must possess the following features:

(1) It must have a wide temperature range within which it boils and freezes.
(2) It must have a regular volume of expansivity.
(3) It must not wet glass.
(4) It must be a good conductor of heat.
(5) It must be coloured and opaque.

Reasons why water is not used as a thermometric liquid:

- Water is considered unsuitable for measuring temperature due to the following reasons:

(1) It has an irregular expansion between 0^{0C} and 4^{0c}, in which it contracts when it is warmed.
(2) It wets glass.
(3) It is colourless and cannot easily be seen in the glass used in making the thermometer.
(4) It is a bad conductor of heat.

Precautions to be taken when using a liquid in glass thermometer to measure the temperature if a liquid:

(1) The liquid must be stirred, to ensure an even distribution of heat in the entire liquid.
(2) The bulb of the thermometer must be fully immersed into the liquid.

(3) The bulb must not touch the bottom or the side of the container, since these areas may be at higher temperature than the liquid itself.

The choice of liquid for thermometers: This choice depends on certain factors, since each liquid has its own advantages as well as disadvantages.

Reasons why mercury is preferred to alcohol i.e. the advantages of mercury over alcohol: Mercury may be preferred to alcohol since it has these advantages:

(1) Unlike alcohol, it does not wet glass.
(2) It does not like alcohol vapourize to occupy the upper part of the bore.
(3) Since it is coloured and opaque, mercury thermometers are easier to read than the alcohol thermometers, since alcohol is colourless.
(4) Since mercury is a better conductor of heat than alcohol, mercury thermometers respond more rapidly to temperature changes than alcohol thermometers.

The disadvantages of mercury thermometers (or the use of mercury as a thermometric liquid):

The disadvantages of mercury thermometer are:

(1) They cannot be used in extremely cold area, since the liquid mercury will freeze.
(2) The mercury within the thermometer has a low coefficient of expansion.

The advantages of alcohol thermometer over mercury thermometer:

(1) It can be used in extremely cold areas, where mercury thermometers will not function or work.
(2) Alcohol also possesses a coefficient of expansion which is about six times that of mercury.

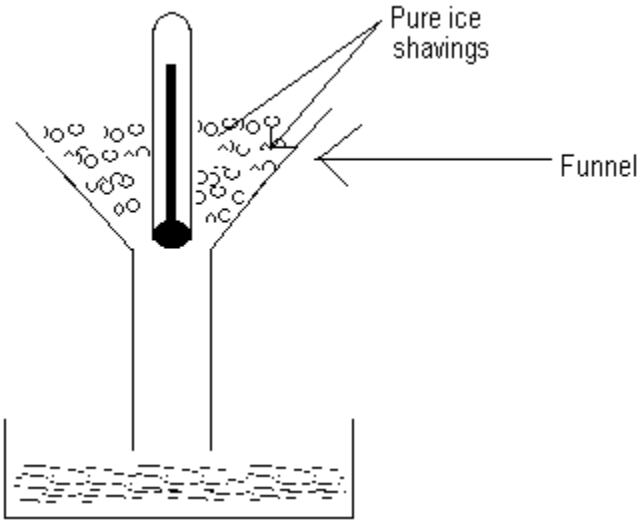
The disadvantages of alcohol thermometers:

(1) Because alcohol is colourless, alcohol thermometers are difficult to read.
(2) The alcohol it contains also wets glass; which can lead to inaccurate readings.
(3) The alcohol can also vapourize to occupy the upper part of the bore, which can also lead to inaccurate readings.
(4) Because alcohol is not a good conductor of heat, alcohol thermometers respond slowly to temperature changes.

The calibration or graduation of a liquid in glass thermometer:

- After the construction of a new thermometer, we have to calibrate or graduate it.
- To graduate or calibrate a thermometer, we must choose two fixed points, and these are the upper and the lower fixed points.
- The upper fixed point is the temperature of steam from boiling water, when the atmospheric pressure is 760 mmHg.
- The lower fixed point is the temperature of pure melting ice.
- After the detection and the marking of the locations of these two fixed points, the distance between then called the fundamental interval is divided into a number of equal parts or degrees.

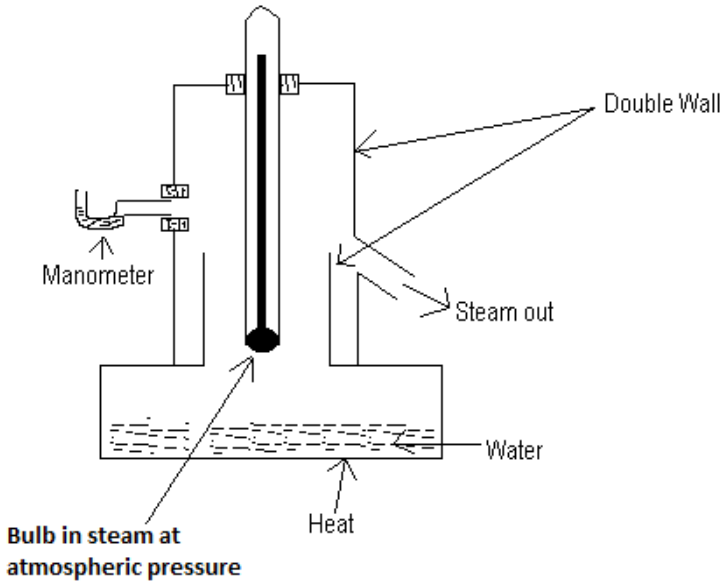
Determination of the lower fixed point (ice point):



- To determine the lower fixed point of an ungraduated thermometer, the thermometer is pushed into pure ice shavings.
- The alcohol or the mercury thread in the bore or the stem, then starts to fall.
- At a particular point, the thread stops falling and remains steady.
- This point is marked as the lower fixed point.

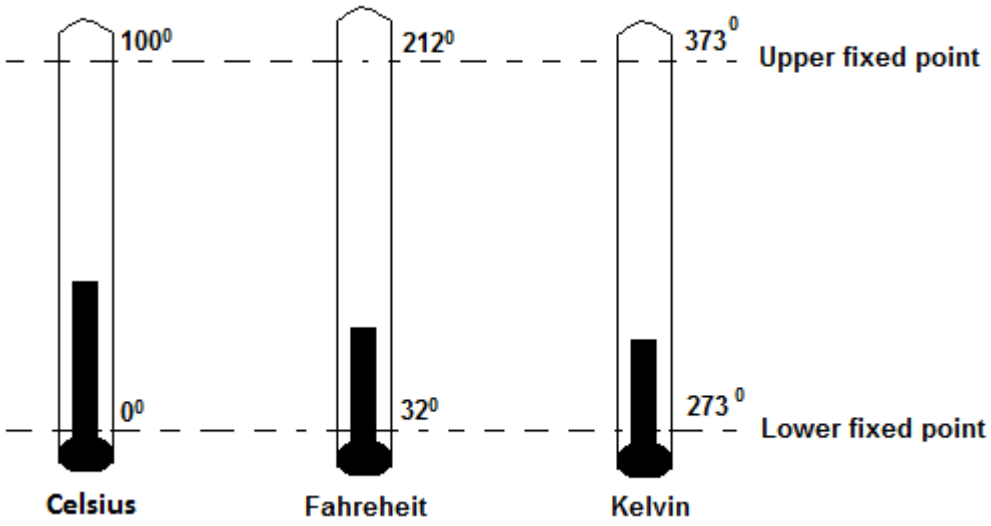
Determination of the upper fixed point:

The hypsometer:



- The thermometer is pushed through a hole in a cork and placed inside the hypsometer.
- Water is boiled at the lower part of the hypsometer, and the steam produced is made to surround the bulb.
- The mercury or alcohol thread begins to rise and stops rising at a particular point.
- This point is marked as the upper fixed point.
- The double wall reduces the loss of heat, and the consequent cooling of the vapour surrounding the bulb.
- The manometer gives a warning if the pressure inside the hypsometer, becomes different from that of the atmosphere.

Temperature Scales:



- There are three types of temperature scale in use, and these are:
  (1) The Celsius scale.
  (2) The Fahrenheit scale.
  (3) The Kelvin scale.

The Celsius Scale:

- A thermometer using the Celsius scale has a lower fixed point of 0^{0C} and an upper fixed point of 100^{0C}.
- The fundamental interval is 100^{0c}.

The Fahrenheit Scale:

- A thermometer using the Fahrenheit scale has a lower fixed point of 32^{0C} and an upper fixed point of 212^{0C}.
- It also has a fundamental interval of 180^{0}.

The Kelvin scale:

- A thermometer using the Kelvin scale has a lower fixed point of 273^{0} and an upper fixed point of 373^{0}.
- Its fundamental interval is 100^{0c}.

(Q1) The distance between the upper fixed point and the lower fixed point of a thermometer is 25cm. Determine the temperature when the mercury thread is 10cm above the ice point mark or the fixed point.

Soln:

25cm = 100^0

=>10cm = $\frac{10}{25} \times 100 = 40^{0c}$.

(Q2) Convert 16^{0c} into Kelvin

Soln:

16^{0c} = 16 + 273 = 289K.

i.e. To convert from degrees Celsius into degree Kelvin, just add 273^0.

(Q3) Convert 450^0k into Celsius.

Soln:

450k = 450 – 273 = 177^{0c}.

i.e. To convert from Kelvins into Celsius, we subtract 273^0.

(Q4) The lower and the upper fixed points are marked 80^0 and 120^0 respectively on a certain thermometer.

(I) Determine the temperature in degrees Celsius when the reading on this thermometer is 90^0.
(II) What is the thermometer`s reading when the temperature is 10^{0c}.

Soln:

For the unknown thermometer:

Upper fixed point = 120^0.

Lower fixed point = 80^0.

Fundamental interval = 120 – 80 = 40^0.

For the Celsius thermometer:

upper fixed point = 100^0

Lower fixed point = 0^0

Fundamental interval = 100 – 0 = 100^0

Let x = the temperature on the Celsius scale which corresponds to 90^0 on the unknown scale, then $\frac{\text{x – lower fixed point of the celcius thermometer}}{fundamental\ interval\ of\ the\ celcius\ thermometer}$

= $\frac{90-lower\ fixed\ point\ of\ unknown\ thermometer}{fundamental\ interval\ of\ unknown\ thermometer}$

=> $\frac{x-0}{100} = \frac{90-80}{40}$

=> 4x – 0 = 100 => 4x = 100 => x = $\frac{100}{4}$

=> x = 25^0c.

(I)Let N = the temperature on the unknown thermometer which corresponds to 10^{0c}.

Then $\frac{x-0}{100} = \frac{N-80}{40}$

=> $\frac{10-0}{100} = \frac{N-80}{40}$ => 0.1 = $\frac{N-80}{40}$

=> $0.1 \times 40 = N - 80 \times => 4 = N - 80$

=> 4 + 80 = N => N = 84^0.

(Q5) Explain why when a poor quality thermometer with thick glass bulb is placed in hot water, the liquid level may be seen to first fall slightly and then rise rapidly.

Soln:

(1) The liquid level of the thermometer first falls, because the expansion of the glass takes place first before that of the mercury.
(2) When heat later enters the mercury, it rises rapidly since it cubic expansivity is greater than that of the glass material used to make the thermometer.

(Q6) State three physical properties of substances which may be used to measure temperature

Soln:

(I) The length or the volume as in the mercury thermometer.
(II) The resistance as in the case of the platinum resistance thermometer.
(III) The pressure.

(Q7) Name one device in the clinical thermometer, which makes it suitable for measuring the body`s temperature.

Soln:

- The constriction or kink causes a break in the mercury thread, when the thermometer is removed from the patient`s ampit or mouth.
- One part of the thread remains in the upper part of the thermometer and as such, the reading can be taken at will or leisure.

(Q8) Explain why a glass stopper stuck in the neck of a bottle, can be made to become loose by vigorously pulling to and fro a strip of cloth, wrapped round the neck of the bottle.

Soln:

- The glass stopper originally stuck in the neck of the bottle becomes loose, since the heat generated by the continuous rubbing causes the neck to expand.

(Q9) As a corked empty bottle is slowly heated, the cork is blown out. Explain.

Soln:

- The heated air expands and acquires a pressure which is greater than that of the surrounding atmosphere.
- It is this greater air pressure within the bottle which blew out the cork.

(Q10) An aluminum wash is heated. State whether the following decreases, increases or remains the same.

(I) Volume.
(II) Mass.
(III) The diameter of a hole.
(IV) The density.

Soln:

(I) Since matter expands when heated, the volume increases.

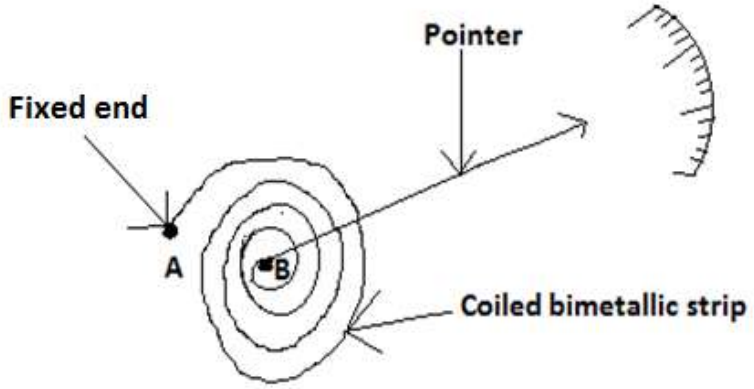
(II) The mass remains the same.

(III) Since expansion takes place, the diameter of the hole will expand and as such, increase.

(IV) Density = $\frac{mass}{volume}$

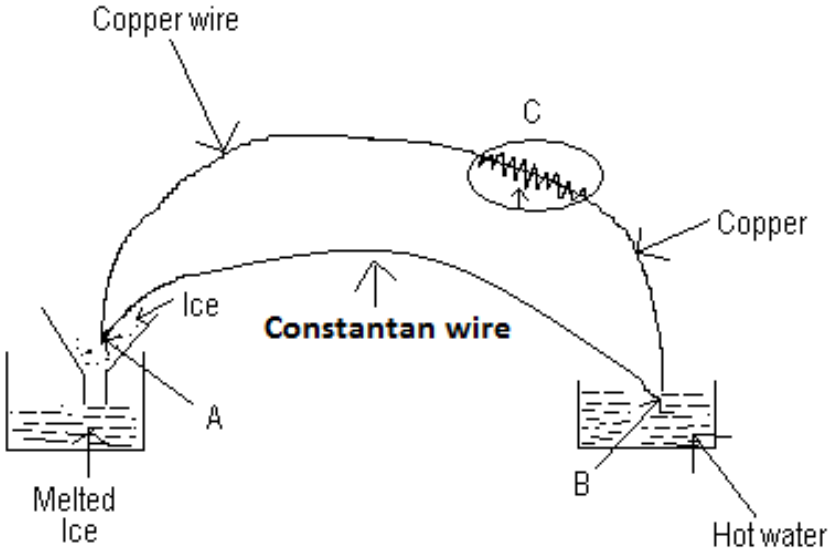
- Since the mass remains the same and the volume increases, then the density will decreases.

The Bimetallic Thermometer:



- This type of thermometer can be made using a bimetallic strip.
- It consists of a coiled bimetallic strip, which is wound in the form of a spiral spring.
- One end of the spiral spring which is indicated as B in the diagram, is attached to the spindle of a pointer, while the other end which is indicated as A is fixed.
- The bimetallic strip used in this case is formed by riveting invar and brass together.
- An increase in temperature causes a greater expansion in the brass than the invar.
- This difference in expansion causes the pointer to slide over a calibrated dial or scale, in a clockwise direction to indicate the exact temperature.

The thermocouple:



- The thermocouple or the thermoelectric thermometer takes the form of two copper wires and a constantan wire, welded together at points B and A and connected to a galvanometer C, which has been calibrated to read the temperature of the body.
- The joint B is immersed in a hot substance and the joint A is kept in melting ice.
- This causes the generation of an electromotive force (e.m.f) between the junction B and A, causing an electric current to flow through the meter C or the galvanometer.
- Since the strength of this current depends on the temperature, then the higher the temperature, the greater will be the current which flows through C and vice versa.
- In short, the current generated within the thermocouple determines or is used to determine the temperature.
- Industries such as aluminum works and steel works, use thermocouple constructed from metals of very high melting points, to measure the temperature of molten aluminum or steel.

Advantages of thermocouple:

(1) It can be used to measure the temperature of small bodies.
(2) It has a wide range of temperature i.e. $200^{0c} – 1500^{0c}$.
(3) It is sensitive.
(4) It is portable and durable.
(5) It responds quickly to temperature changes.

Disadvantages of the thermocouple:

(1) It is not accurate.
(2) It is difficult to read.

N/B: On the Celsius scale, the temperature is calculated on the thermocouple thermometer using the expression

$$\theta = \frac{E_\theta - E_0}{E_{100} - E_0} \times 1000$$

Where E_θ = the e.m.f at the temperature of the body.

E_0 = the e.m.f at ice point.

E_{100} = e.m.f at steam point.

(Q1) The e.m.f of a thermocouple is 50v at 0^{0c}, 300v at 100^{0c} and 200v at the temperature of a heated body. Calculate the temperature of the body.

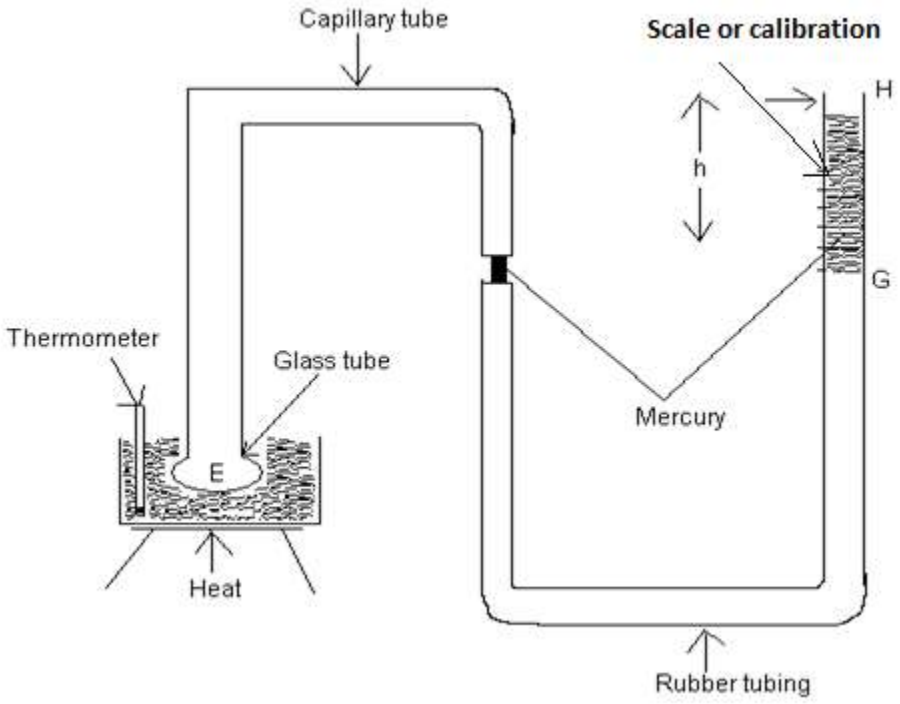
Soln:

E_0 = 50v, E_{100} = 300v, E_θ = 200v. From $\theta = \frac{E_\theta - E_0}{E_{100} - E_0} \times 1000$

$$\Rightarrow \theta = \frac{200-50}{300-50} \times 100$$

$\Rightarrow \theta = 60^{0c}$.

The gas thermometer:



- The gas thermometer consists of a glass bulb, labeled E which contains air.
- This bulb is connected to a mercury manometer by means of a capillary tube.
- When the bulb is heated, the air it contains expands forcing the mercury within the manometer to rise within the limb GH, which has been calibrated.
- The air is then returned to its original volume by lowering or raising the opening tube.
- The difference in height between the two mercury levels, is then measured to provide a pressure reading for the gas, by using the expression p = egh
  where P = the pressure of the gas, e = density of mercury, h = the difference between the mercury levels and g = acceleration due to gravity.

Advantages of the gas thermometer:

(1) It is very accurate.
(2) It is very sensitive to temperature changes.
(3) It has a wide temperature range i.e. 272^{0c} – 1300^{0c}.

Disadvantages of the gas thermometer:

(1) It is bulky.
(2) It has a long response time.

N/B:

- On the Celsius scale, temperature is calculated on the gas thermometer using the expression:
  $\theta = \frac{P_\theta - P_0}{P_{100} - P_0} \times 100^{0C}$, where P_θ = the pressure of the gas at the temperature of the substance, P_0 = the pressure of the gas at ice point, P_{100} = the pressure of the gas at steam point.

(Q1) The pressure of a gas thermometer was 800mmHg at ice point, 1200 mmHg at steam point and 1000 mmHg at the temperature of the liquid. Determine the temperature of the liquid.

Soln:

P_0 = 800mmHg, P_{100} = 1200mmHg, P_θ = 1000 mmHg.

Since $\theta = \frac{P_\theta - P_0}{P_{100} - P_0} \times 100^{0C}$

=> $\theta = \frac{1000-800}{1200-800} \times 100^{0C}$

=> $\theta = 50^{0C}$.

N/B:

- On the Kelvin scale, temperature is calculated on the gas thermometer using the expression:
  $T = \frac{P_T - P_0}{P_{tr} - P_0}$, where P_{tr}= the pressure at the triple point, P_T = pressure at a Kelvin temperature, P_0 = pressure at absolute zero.

(Q2) The pressure recorded by a constant volume gas thermometer at a Kelvin temperature T is $4.80 \times 10^4 Nm^{-2}$. Calculate T if the pressure at the triple point 273.16k is $4.20 \times 10^4 NM^2$.

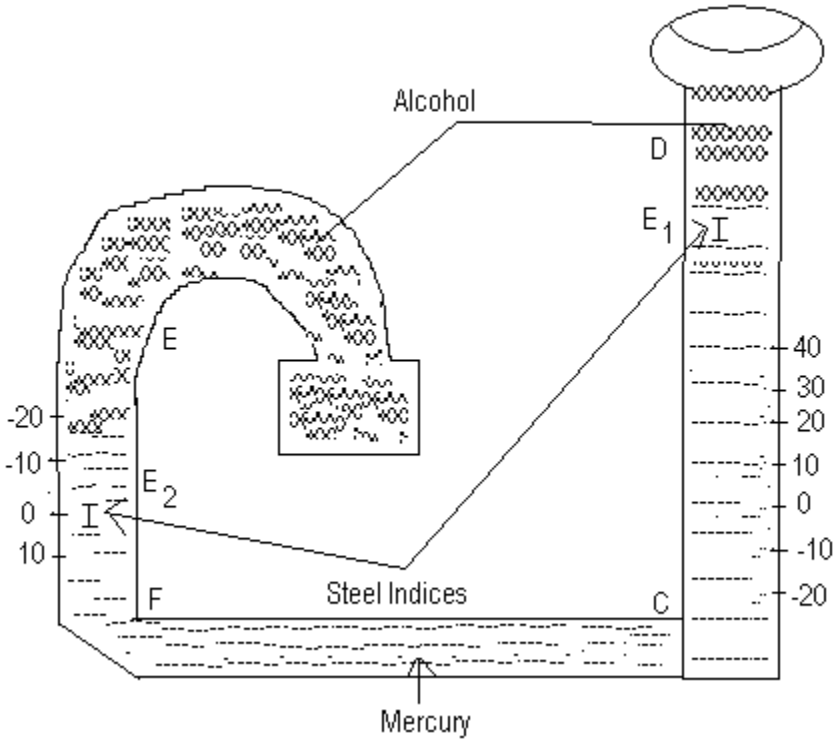
Soln:

$T = \frac{P_T - P_0}{P_{tr} - P_0} \times 273.16$

Also since P_0, the pressure at absolute zero is not given, then the equation given boils down to $T = \frac{P_T}{P_{tr}} \times 273.16$

$\Rightarrow T = \frac{4.80 \times 10^4}{4.20 \times 10^4} \times 273.16 \Rightarrow T = 312k.$

The minimum and the maximum thermometer (the six`s thermometer):



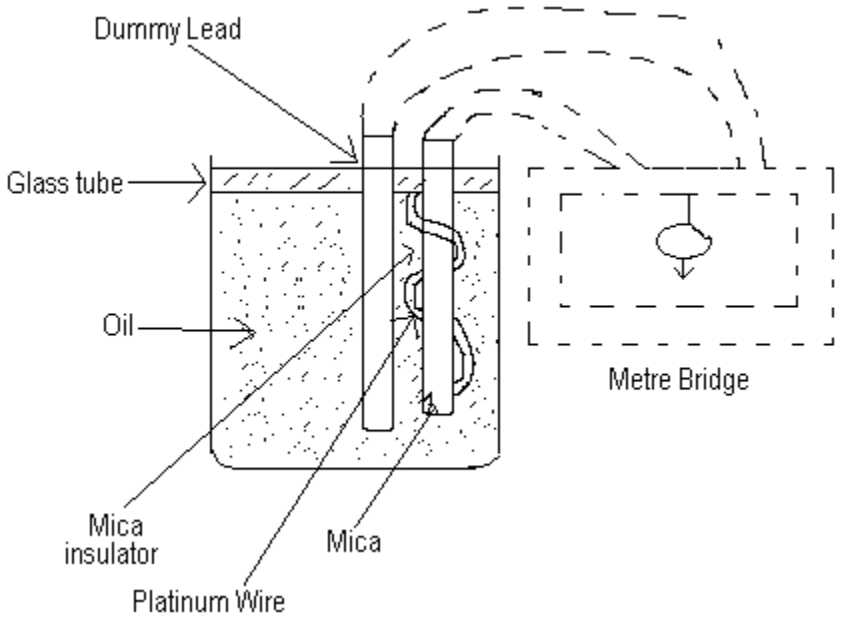
- This type of thermometer is used to measure the maximum, as well as the minimum temperature experienced during the day.
- It consists of a U – shaped tubing which contains mercury.
- Connected to each end of the U tube are bulbs which contain either creosol or alcohol.
- Scales are marked on both arms of the U – tube, so that the temperature can be read from either end at any time.
- At the top of the mercury in each tube is a steal index, which is pushed up by the mercury as the temperature rises or falls.

- Each index is held in place by a small steel spring, which prevents it from moving away from the highest temperature recorded, if the temperature drops in the day.
- An increase in temperature during the day causes an expansion of the alcohol in the arm EF.
- This pushes the mercury round the U – tube, causing the index E_1 to move upwards until the lower end of this steel index records the highest temperature.
- When the temperature falls, the alcohol in the arm EF contracts and move in the upward direction.
- The mercury follows it leaving the index E_1 in place in the limb CD, to indicate the highest temperature.
- The steel index E_2 is then pushed upward in the limb EF, to record the lowest temperature.
- After the readings are made, the indices are brought back into contact with the mercury in each limb on daily basis, using a magnet i.e to reset.

Resistance Thermometer:

- The electrical resistance of a material is greatly affected by changes in temperature.
- For example, with reference to metals, the electrical resistance increases with temperature or when temperature increases.
- But for semi – conductors, an increase in temperature rather causes a decrease in electrical resistance.
- A thermometer whose operation is based on the fact that, temperature changes affect the electrical resistance is known as a Resistance Thermometer.
- There are two types and these are:
  (I) Platinum resistance thermometer.
  (II) Thermistor thermometer.

Platinum resistance thermometer:



- The platinum resistance thermometer uses platinum wire as its thermometric substances, and the thermometric property is the electrical resistance of the platinum wire.
- The electrical resistance of the platinum wire increases with its temperature.
- Platinum is chosen because it is readily available in the purest state, and also has a high melting point.
- The platinum resistance thermometer consists of a platinum wire wound inductively on mica, and placed in a glass tube containing oil.
- There is also another wire of a different metal inside the glass tube, which serves as dummy leads (auxiliary wire).
- The glass tube is sealed at the mouth so that it is made draught proof, and such a thermometer has no scale on it.
- In order to measure the temperature of a body, the whole thermometer is immersed into the body up to the neck.
- The thermometer gets heated and the heat is conducted to the platinum wire through the oil, which is only providing thermal contact for the platinum wire.
- The temperature of the platinum wire changes and this affects its electrical resistance.
- The new electrical resistance of the platinum is measured by connecting both the platinum wire and the dummy lead to a meter bridge or a Wheatstone bridge.

- The higher the resistance value, the higher the temperature and vice versa.

Advantages:

- It is small and portable.
- It is accurate.
- It is sensitive.
- It has a wide range of temperature.

Disadvantages:

- It is fragile.
- It is difficult to read.
- It has a high heat capacity.

N/B:

(1) On the Celsius scale, the temperature is calculated on the resistance thermometer using the expression:
$\theta = \frac{R_\theta - R_0}{R_{100} - R_0} \times 100^{0C}$, where R_θ = the electrical resistance at the temperature of the body.
R_0 = the electrical resistance at the ice point.
R_{100} = the electrical resistance at stream point.

(2) On the Kelvin scale, temperature is calculated on the resistance thermometer using the expression:
T = $\frac{R_T - R_0}{R_{tr} - R_0} \times 273.16K$, where R_T = resistance at the temperature of the metal.$R_0 = the\ resistance\ at\ absolute\ zero$.
Rtr = resistance at triple point.

(Q1) Calculate the temperature of a body, if its resistances at $0^{0c}$is 0.5Ω, at 100^{0C} is 5.5Ω and the electrical resistance of the body is 10Ω.

Soln:

R_0 = 0.5Ω, R_{100} = 5.5Ω and R_θ = 10.0Ω.

$\theta = \frac{R_\theta - R_0}{R_{100} - R_0} \times 100^{0C}$

$\theta = \frac{10-0.5}{5.5-0.5} \times 100^{0C}$

θ =190^{0C}.

(Q2) The resistance of a certain metal measured at the triple point and absolute zero of temperature are 3.018Ω and 2.003Ω respectively. Calculate the resistance of the metal at 50^{0c}.

Soln:

T = $\frac{R_T - R_0}{R_{tr} - R_0} \times 273.16k$.

θ = 50^{0c} => T = 50 + 273 = 323k.

R_0 = 2.003Ω, $R_{tr} = 3.018\Omega$,

R_T =?

=> 323 = $\frac{R_T - 2.003}{3.018 - 2.003} \times 273.16k$.

=> 323 = $\frac{R_T - 2.003}{1.015} \times 273.16k$

=> R_T – 2.003 = $\frac{323 - 1.015}{273.16}$

=> R_T = 1.200 + 2.003

=> R_T = 3.203Ω.

The thermistor thermometer:

This type of thermometer uses a semiconductor as its thermometric substance.
The thermometric property is the electrical resistance of the semiconductor, which decreases as the temperature increases.

Advantages:

- It is portable.
- It is cheap to manufacture.
- It has a short response time.
- It is very sensitive.

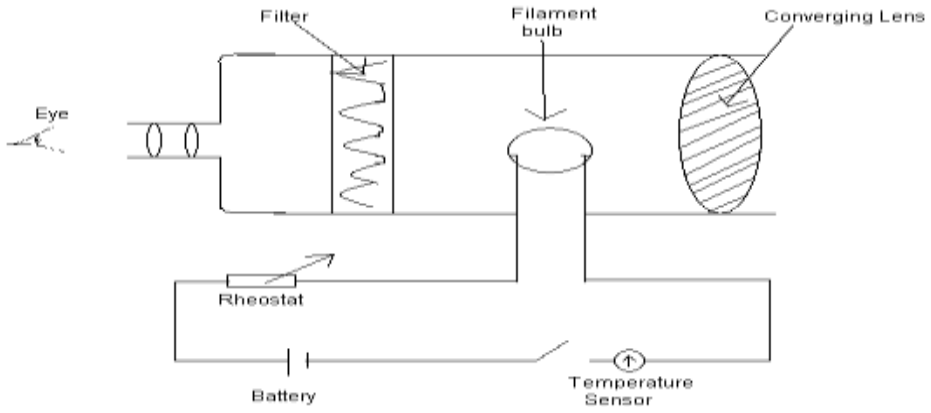
- It has a small heat capacity.

Pyrometers:

- These are thermometers which are used to measure very high temperatures, such as the temperature of an oven furnace or the sun.
- Bodies with very high temperatures are extremely hot, and such bodies give off heat radiations which come out as colours.
- The spectrum of white light has seven colours, which are represented by the term ROYGBV.
- The hottest radiation has violent colour, and the least hot radiation has a red colour.
- A radiation whose colour is blue, is stronger than one with a red colour.
- For this reason when a gas stove is lighted and a red flame comes out, one can easily tell the flame is not strong.
- If the flame has a blue colour, then you can have the hope that the flame is very strong and as such can cook very well.
- The thermometric substance is the heat from the body, and the colour of the radiation is the thermometric property.

– There are two types and these are:

(1) The optical pyrometer.
(2) The total radiation pyrometer.



- The pyrometer consists of a converging lens, filament bulb and a filter, all arranged at one end of a tube.
- On the other end of the tube is a telescope.
- The bulb is connected to a circuit of a rheostat key, a temperature sensor and a battery as shown in the diagram.

Mode of operation:

- The pyrometer is arranged to face the hot body, and heat radiation from the hot body is focused into the thermometer by the converging lens.
- The colour of the radiation is viewed through the telescope and the background.
- The key is then closed and the bulb lights up.-The rheostat is then adjusted until the colour of the bulb matches with the colour of the radiation.
- At this point, the colour of the radiation and the filament bulb disappears from the background.
- The temperature of the filament bulb is the same as the temperature of the hot body. - The sensor records the temperature of the filament bulb, and this is the same as the temperature of the hot body.

Advantages:

- It can measure very high temperatures i.e. up to 3000^{0c}.
- It measures the temperatures of hot bodies without getting near it.

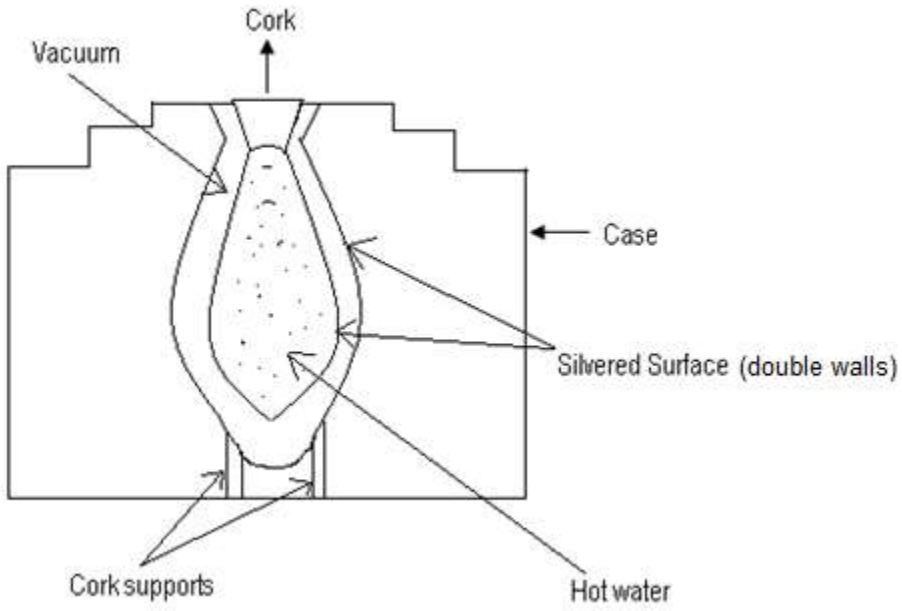
Disadvantages:

(1) it is bulky and cumbersome.
(2) It is not a direct reading instrument.

The thermometric substances and the properties of some thermometers:

Type of thermometer	Thermometric substance	Thermometric property
Mercury thermometer	Mercury	Change in volume or the length of a column of mercury with temperature.
Alcohol thermometer	Alcohol	Change in volume or the length of a column of alcohol with temperature.
Resistance thermometer	Pure metal	Change in the electric resistance of a pure metal with temperature.
Constant volume gas thermometer	Gas	Change in the pressure of a gas at constant volume with temperature.

The vacuum flask:



- The vacuum flask is used to keep hot liquids stay hot.
- In order to be able to do this, heat losses by all the three processes of transfer must be reduced to a minimum.
- This is done by these means:

(1) By conduction:

- The presence of the double walls, between which is found a vacuum, the cork support and the cork lid, all prevent the loss of heat by conduction.
- Cork is a poor conductor of heat, and a vacuum is a non conductor of heat.

(2) By convection:

- The presence of the vacuum makes the loss of heat by convection impossible, since there is no material medium to carry the heat along.

(3) By radiation:

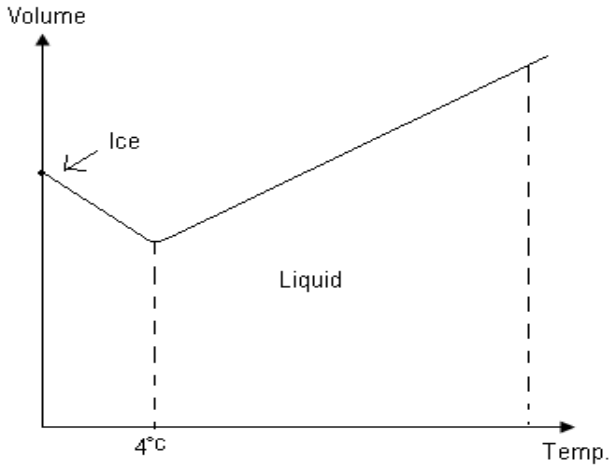
- Even though a certain amount of heat is lost by the flask through radiation, this is reduced to a minimum owing to the silvering.

The anomalous expansion of water:

- When ice is heated from a temperature of about $-4^{)}$ to 0^{0c}, the ice expands slightly and melts to form water.
- When this melted ice (liquid) is warmed from 0^{0c} to 4^{0c}, it contracts.
- When it is further warmed, it expands as the temperature increases, until it reaches a temperature of 100^{0c}.
- This behavior of water is said to be irregular or anomalous.

Biological importance of the anomalous expansion of water:

- It has an important bearing on the preservation of aquatic life, during vey cold weather.
- As the temperature of the lake or pond falls, the water contracts, becomes denser and sinks to a lower level.
- This is due to the fact that matter contracts when cooled.
- A circulation is therefore set up until all the water reaches its maximum density at 4^{0c}. -
- If there is any further cooling, any water which will be cooled below 4^{0c}, will have a lower density and as such will be positioned on top of the pond or the lake.
- If further cooling takes place, the water at the top part of the pond or lake will be converted into ice in due course.
- The layers of water below this ice, whose temperature will be at 4^{0c}, will continuously be losing heat to the ice in due course.
- This prevents these layers from also being converted into ice, since their temperature cannot get to the freezing point of ice.
- This preserves aquatic life, since the conversion of these layers also into ice will see an end to the aquatic life (i.e. the dead of the living creatures it contain).

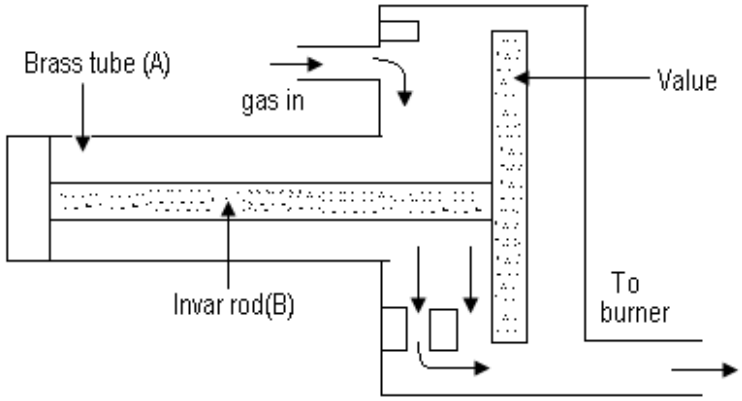


Dew: This is formed when the water vapour within the atmosphere becomes cooled and saturated, causing part of it to form water on the surface of items. Dew forms faster on metal parts than on rubber parts, because the heat given out when dew forms is quickly conducted away in metals than in rubber. The dew point is defined as the temperature, at which the water vapour present within the air is just enough to saturate it.

Differences between mist and cloud:

(1) Mist is formed very close to the ground, as against cloud which is generally formed in the sky.
(2) Mist is formed when water vapour in the air close to the ground, gets cooled during the night, resulting in the dew point being reached.
- But in cloud formation, rising air mass gets cooled at cooler atmospheric skies, thus forming a large group of condensed water droplets which forms the cloud.
(3) Mist is dissipated during the day when the temperature is high, and reconverted into vapour, while cloud is not changed into vapour but comes down as rain.

The gas cooker thermostat:



- This type of thermostat is used to control the temperature of a gas cooker.
- It consists of a brass tube A projecting into the oven, whose temperature is to be regulated.
- This brass tube encloses an invar rod B.
- At the end of the invar rod is attached a valve, which controls the flow of gas from the gas cylinder into the burner or burners.

- When the temperature decreases, the brass contracts, causing the value to move forward.
- This movement opens the entrance and increases the flow of gad to the burner.
-The temperature is adjusted by the temperature control knob, which controls the opening of the value.

Electrical power associated with the study of heat:

- Electrical appliances can convert electrical energy, and power (P) is the amount of electrical energy converted on one second.
- Power is measured in joules per second or watts (W), and a power of one watt means that 1 joule of energy is changed every second.
- Power can also be measured in kilowatts (kw) and 1kw = 1000W.
- If a kettle converts 2400J of electrical energy into heat every second, then it has a power of 2400W or 2.4kw, ,and the electrical rating of such a kettle is 2.4kw.
- Electrical power can be calculated using the equation Power = Voltage x Current, where power is in watts, voltage in volts and current in amperes.

(Q1) A 240V television takes a current of 0.5A. Calculate the power.

Soln

V = 240V, I = 0.5A

Since P = V x I => P = 240 x 0.5

= 120W.

(Q2) A 240V kettle has a power rating of 2000W. Calculate the current it takes.

Soln:

V = 240V, P = 2000W, I = ?

Since P = V x I => 2000 = 240 x I,

=>240I = 2000 => I = $\frac{2000}{240}$ = 8.3A

(Q3) A water heater is rated 1000W, 240V. Calculate the maximum current that the heater can take.

Soln:

Power rating = P = 1000W.

V = 240V and I = ?

From P = VI

=> 1000 = 240I => I = $\frac{1000}{240}$ = 4.2A.

(Q4)Determine the current which can be taken by an electric iron, whose power rating is given as 3kW, 230V.

Soln:

P = 3kW = 3 x 1000 = 3000W,

V = 230 and I = ?

From P = IV => 3000 = 230I,

=> I = $\frac{3000}{230}$ = 13A.

N/B:

Electical power is the same as power.

Heat supplied by an electrical device = I x V x t,

Where I = current in amperes.

V = the voltage in volts.

t = time in seconds.

(Q5)An electric heater draws a current of 10A, and operates from a 240V source. Calculate (i) the power generated (ii) the heat supplied.

Soln:

(i) the electrical power generated = IV = 10 x 240 = 2400W.

(ii) I = 10A, V = 240V and t = 5minutes = 5 x 60 = 300 seconds.

Heat supplied = IVt = 10 x 240 x 300 = 720,000J

= $\frac{720000}{1000} = 720kJ.$

(Q6) A 250V kettle is rated at 4kW. Determine

(a) the current it takes.

(b) the quantity of current which passes through it, if it is used for2 seconds.

Soln:

(a) P = 4kW = 4 x 1000 = 4000W.

V = 250V and I = ?

From P = VI => 4000 = 250I,

=> I = $\frac{4000}{250} = 16A.$

(b)The quantity of current which passes through it or used = It, where I is in amperes and t is in seconds . Since I = 16A and t = 2 seconds, then the quantity of current of electricity which passes throuh it = It = 16 x 2 = 32A.

(Q7) A water heater is rated 2000W, 250. Determine

(a) the current it takes.

(b) the quantity of current used, if it is used for 3minutes.

Soln:

(a) P = 2000W, V = 250V and I = ?

From P = VI => 2000 = 250I,

=> I = $\frac{200}{250} = 8A$.

(b) t = 3minutes = 3 x 60 = 180 seconds.

The quantity of electricity used = It = 8 x 180 = 1440A.

N/B: - To convert hours into seconds, we multiply by 3600.

(Q8) A heating device was used to provide heat for another device for 2hours. If it`s rating is 0.004kw, 20V, determine

(a) the current it takes.

(b) the quantity of electricity used.

Soln:

(a) P = 0.004KW = 0.004 x 1000 = 4W, V= 20V and I = ?

From P = VI => 4 = 20I,

=> I = $\frac{4}{20} = 0.2A$.

(b) I = 0.2A and t = 2hrs = 2 x 3600 = 7200seconds.

The quantity of current used = It = 0.2 x 7200 = 1440A.

N/B: The power in watts or the power rating can be calculated using any of the following formulae.

(i) $P = I^2R$ (ii) $P = VI$ (iii) $P = \frac{V^2}{R}$ where P is the power in watts, V = the voltage in volts and R = the resistance in ohms.

(Q1) A 5A current is passed through an element whose resistance is 10Ω. Calculate the power in watts or the power rating of the element in watts.

Soln:

A = 5A and R = 10Ω.

From $P = I^2R$ => $P = 5^2 \times 10$

= 25 X 10 = 250W.

(Q2) Determine the current which must be passed through an element of resistance 20Ω, so as generate a power of 320W.

Soln:

P = 320W, R = 20Ω and I = ?

From $P = I^2R$ => $320 = 20J^2$

=> $I^2 = \frac{320}{20} => I^2 = 16$, => $I = \sqrt{16} = 4A$.

(Q3) A current of 5A and whose voltage is 20V is passed through a device. Determine the power developed.

Soln:

From P = VI => P = 20 x 5 = 100A.

(Q4)A 5A current passed through an electrical device led to the production of a 40W power. What was the voltage?

Soln:

I = 5A, P = 40W and V = ?

From P = VI => 40 = 5V, => $V = \frac{40}{5} = 8V$.

(Q5) A lamp is rated 12V, 24W. How many joules of energy does it consume?

N/B:

First determine the current and the power used in one hour in watts.

Also, 1 watt = 3600J.

Soln:

P = 24W, V = 12V and I = ?

From P = VI => 24 = 12I,

=> I = $\frac{24}{12}$ = 2A.

Power in watts used in one hour by the lamp = VI

= 12 x 2 = 24W.

But since 1 watt = 3600J, then 24watts = $\frac{24}{1}\ x\ 3600$ = 8640J.

Energy consumed in one hour in joules = 8640J.

(Q6)A current whose voltage is 20V, passes through an electrical devise whose resistance is 40Ω. Calculate the power.

Soln:

V = 20V, R = 40Ω and P = ?

From P = $\frac{V^2}{R}$ => P = $\frac{20^2}{40}$ = $\frac{400}{40}$

= 10W.

(Q7)An electric kettle is rated 2KW, 240V. Calculate the resistance of the element when it is in use.

Soln

P = 2kw = 2000W and V = 240V.

From P = $\frac{V^2}{R}$ => 2000 = $\frac{240^2}{R}$

=> 2000R = 576000,

=> R = $\frac{57600}{2000} = 28.8.\Omega.$

(Q8)An electrical kettle operates on a voltage of 220V and its power rating is 4000W.

Determine

(i) the resistance of the kettle.

(ii) the current which flows through the kettle.

Soln:

V = 220V and P = 4000W.

From P = $\frac{V^2}{R}$ => R = $\frac{V^2}{P} = \frac{220^2}{4000}$

$= \frac{48400}{4000} = 12 => R = 12\Omega.$

(ii) From I = $\frac{V}{R}$ => I = $\frac{220}{12} = 18A.$

(Q9) An electrical equipment which has a power rating of 2KW, operates on a voltage of 240V. Calculate

(a) its resistance.

(b) the current which flows through the equipment.

Soln:

(a) P = 2KW = 2 (1000) = 2000W and V = 240V.

From P = $\frac{V^2}{R}$ => R = $\frac{V^2}{P}$ = 240(240)/2000 = 29 Ω.

(b) . From I = $\frac{V}{R}$ => I = 240/29 = 8.3A

(Q10) A current of 5A whose voltage is 20V, is passed through a piece of wire for 10seconds. Find the work done by the current in joules.

Soln

V = 20V, I = 5A and t = 10sec.

Work done in joules = VIt

= 20 x 5 x 10 = 100J.

(Q11) A current of 2A and of voltage 50V was passed through a heating device for 3 minutes. Find the work done.

Soln:

I = 2A, V = 50V and t = 3 minutes

= 3 x 60 = 180 seconds.

Work done = VIt = 50 x 20 x 180

= 18000J = 18kJ.

(Q12) A current of 4A is passed through an element whose resistance is 40Ω for 2 seconds. Find the work done by this current in joules.

Soln:

I = 4A, R = 40Ω and t = 2sec.

Work done in joules = I^2Rt

= 4^2 x 40 x 2 = 1280J.

Q13) A 3A current was passed through a piece of metal of resistace 5Ω for 6 minutes. Find the work done.

Soln:

I = 3A, R = 5Ω and t = 6 minutes = 6 x 60 = 360sec.

Work done = $I^2Rt = 3^2$ x 5 x 360

= 9 x 5 x 360 =16200J = 16.2kJ.

(Q14) A current of voltage 30V, was passed through a wire of resistance 4Ω for 2 seconds. Find the work done in joules.

Soln:

V = 30V, R = 4Ω and t = 2 sec.

Work done = $\frac{V^2 t}{R} = \frac{30^2 \ x \ 2}{4}$

= $\frac{900 \ x \ 2}{4} = 450J.$

(Q15) A 240V current was passed through a heating element for 2 minutes. If the element has a resistance of 30Ω, determine the work done by the current in joules.

Soln:

V = 240V, R = 30Ω and t = 2 minutes = 2 x 60 = 120sec.

Work done in joules = $\frac{V^2 t}{R}$

= $\frac{240^2 \ x \ 120}{30}$ = 230.4kJ.

(Q16) An appliance rated 750W was used for one hour. Find the energy used.

N/B: Power = $\frac{Energy}{time \ (in \ seconds)}$

Soln:

P = 750W and t = 1 x 3600

= 3600 seconds.

From power = $\frac{Energy}{time}$

=> Energy = time x power

=> Energy = 3600 x 750 = 2700000 = 2700kJ.

Questions:

(1) (a) Differentiate between heat and temperature.
(b) List three factors which determine the amount of heat possessed by a body.
(c) List four sources of heat.

(2) Explain what is meant by the boiling point of a liquid.

Ans: It is the temperature at which its vapour pressure becomes equal to the atmospheric pressure, and the bubbles formed within the liquid start escaping into the atmosphere.

(3) With the aid of a labeled diagram, briefly explain how you will determine the boiling point of a liquid.

(4) Water placed on a boy`s hand, causes its cooling. Why is this so?
Ans: Liquids need heat in order to evaporate. As the water evaporate from the hand, this needed heat is taken from the hand leading to its cooling

(5) List four factors which determine the rate of evaporation of a liquid.

(6) A student dissolved sugar within a liquid. Explain the effect this will have on its boiling point as well as its freezing point.
Ans: As a result of boiling elevation, its boiling point will increase.

- Also, as a result of freezing point depression, its freezing point decreases.

(7) Make a labeled diagram of a liquid in glass thermometer, and explain its principle of operation.

(8) (a) Differentiate between the lower and the upper fixed points of a thermometer.

(b) With the aid of diagrams, explain how you will determine the lower and the upper fixed points of a thermometer.

(9) With the aid of a diagram, briefly describe and explain the mode of operation of the following: (a) The thermocouple. (b) The bimetallic thermometer.

(c) The resistance thermometer.

(10) (a) What do you understand by the anomalous expansion of water.

(b) Explain its importance with reference to the preservation of aquatic life.

CHAPTER ELEVEN