10

Thermal Energy

You are aware that energy is required for all types of activities. In the previous lesson you have learnt about mechanical form of energy. Heat is also a form of energy, called thermal energy. Fire has heat in it . When fuels like coal, petrol, wood, kerosene-oil are burnt, heat is produced. You would have noticed that in winter season, when it is cold, generally people rub their palms to warm up. Here, doing mechanical work against friction produces heat. You must have learnt that in ancient times man used to produce fire by rubbing two pieces of stone together. Even now a days we produce fire by the same method when we rub the tip of a matchstick on the special surface of the matchbox.

Why do we need heat? We require heat to cook, to iron clothes, to have hot water for bathing in winter season, to melt solids, to vaporize the liquids, etc. Why do the wet clothes get dried when hanged in sunlight? Have you seen an iron smith heating an iron rod red hot and then beating it to give the required shape of a knife or a scissor? You must have got a chance to see a gold smith working with flames of a lamp in designing an ornament. What is the use of flame? In thermal power plants coal is burnt to generate electricity. In steel industry and glass industry, iron and glass are melted to give them definite shapes. Steam engine can pull a train due to the power of steam. In all these activities heat is used. Let us learn all about heat and its effects in this lesson.

OBJECTIVES

After completing this lesson, you will be able to

- differentiate between heat and temperature;
- explain that heat is transferred from one body to another when there is a temperature difference between the two bodies;
- describe construction, calibration and use of thermometers;
- explain the effect of heat on matter resulting in thermal expansion of solids, liquids and gases;
- explain the constancy of temperature of a substance during change of phase even though heated continuously;
- state the factors upon which the total transferable heat of a body depends;
- calculate heat flow from a hotter body to a colder body in contact;
- predict the variation in melting point and boiling point of materials due to the presence of impurities and with variation in pressure;
- explain why the food gets cooked easily and quickly in a pressure cooker.

10.1 WHAT IS HEAT?

Heat is a form of energy. We call it **thermal energy**. It is measured in **joule**. Sunrays have heat in them. This heat is called radiant heat. It travels with the speed of light i.e. 3×10^{8} m s^{-1}.

10.1.1 How is heat produced?

Rub your palms together. What happens? They become warmer, indicating generation of heat. Here friction is generating heat. When you burn coal, wood or kerosene oil, fire is produced. Fire has heat energy in it. Here, the chemical energy gets converted into heat by the process of burning.

Fig. 10.1 Rubbing the palms together makes them warmer

Fig. 10.2 Fire has heat energy

10.1.2 Heat is energy of molecular motion

Every material is made up of molecules, which are in a state of continuous random motion. This is due to the heat in them. When we heat up this material, this molecular motion increases. This suggests that heat is kinetic energy of molecular motion.

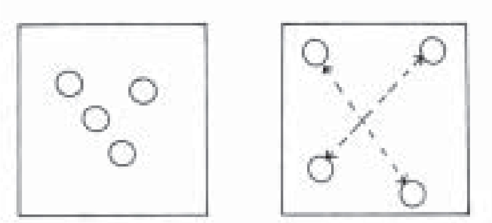


Fig. 10.3 Molecular motion increases with absorption of heat

Kinetic energy of a body in motion can be utilized in doing work against frictional forces. This results in the heating up of the body. It is due to transfer of kinetic energy from the moving body to the molecules. Let us perform an activity to demonstrate conversion of mechanical energy into heat energy.

ACTIVITY 10.1

Aim: Demonstration of conversion of mechanical energy into heat

What to do?

i) Keep bicycle on its stand and rotate the paddle with hand so that the rear wheel rotates very fast.

ii) With the help of a pad of cloth on your finger tip, touch the rim of the wheel to stop the wheel.

Fig. 10.4 Conversion of mechanical energy into heat energy

What do you observe?

At the finger tip you feel that cloth has become hot.

What do you conclude?

The kinetic energy of motion of the wheel has been transferred to the cloth due to friction and it appears in the form of heat.

10.1.3 Heat can lead to work

You might have seen water boiling in a kettle. Due to steam formed in the kettle, its lid moves up and down. This shows that heat can do work.

You must have seen a steam engine pulling a long array of coaches. Thus, heat can be utilized to do work. Thus, we can conclude that **heat is a form of energy since it can do work**. Also, heat and work are inter convertible.

The device that converts thermal energy into mechanical work is called **heat engine**.

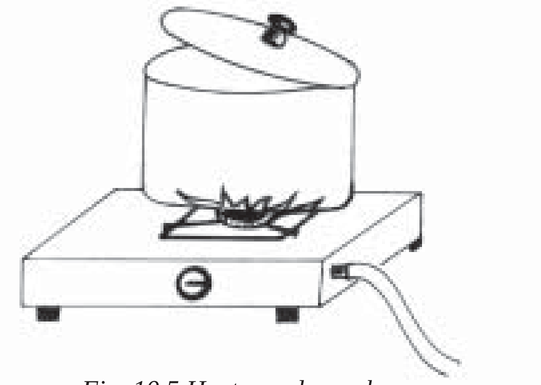


Fig. 10.5 Heat can do work

10.1.4 Temperature and need for its measurement

How will you measure the hotness of a given body? You may suggest that this can be done simply by touching the body. It means feeling of hotness by our hand can be used to estimate how hot a body is. But sometimes it may be difficult (if the body is very hot and may cause burns) and sometimes the conclusion may be confusing. Can you have a wrong sensation of hotness by touch?

ACTIVITY 10.2

Aim: Our sense of touch may be misleading

What to do?

i) Take three bowls A, B and C. Fill ice cold water in bowl A, ordinary tap water in bowl B and hot water in bowl C (Fig. 10.6).

ii) Now dip your left hand in bowl C containing hot water and right hand in bowl A containing ice cold water and let them remain there for two minutes.

iii) Now take your hands out of both bowls and put both of them in bowl B containing tap water.

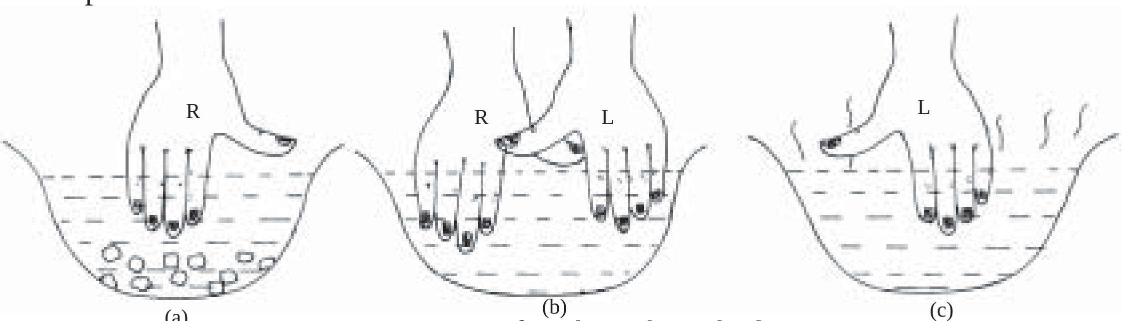


Fig. 10.6 Sense of touch may be misleading

What do you feel?

You will be surprised to note that your left hand will give you the sensation that this water is cold, while the right hand will give you the sensation that it is warm.

Thus, confusing sensations can be felt by skin. The difficulty in using the sensation as a measure of hotness arises because of the fact that the terms hot and cold are relative terms and cannot be used in the absolute measurement of hotness.

Therefore, there is a need of some standard for the measurement of the hotness of a body.

The degree of hotness of a body is called its ***temperature****.* It is measured by devices called ***thermometer***. It is represented as a number on a ***thermometric scale***.

10.1.5 Difference between heat and temperature

Heat is energy in transit, which is transferred from one body to another due to temperature difference between them. *While heat is a form of energy, the temperature is the degree of hotness of a body*. Heat is measured in Joule while the temperature is measured in degree **Fahrenheit (^{o}F), degree Celsius (^{o}C)** or **Kelvin (K)**.

10.1.6 Various types of scales for measurement of temperature

The thermometers in common use have two different types of scales of measurements namely Fahrenheit and Celsius scales of temperature. For scientific work, Kelvin scale of temperature is more often used. However, the construction and working of these thermometers is same.

It is obvious that a hotter body would show higher temperature and a colder body a lower temperature on the same scale. The thermometers cannot have confusing or wrong sensations.

10.1.7 Construction and use of a thermometer

Mercury thermometers are the most common thermometers in use. Mercury is filled in a thin walled glass bulb joined at the end of a capillary tube by the process of repeated heating and cooling. The mercury is seen in the form of a thin dark thread in the capillary. The space above the mercury level in capillary is evacuated. The other end is now sealed. Mercury has the property of uniform thermal expansion over a wide range of temperatures. This means, the length of the mercury thread in the thermometer increases by same amount for each degree rise in its temperature. The tip of the mercury thread can be easily seen in the transparent glass tube as shown in Fig 10.7.

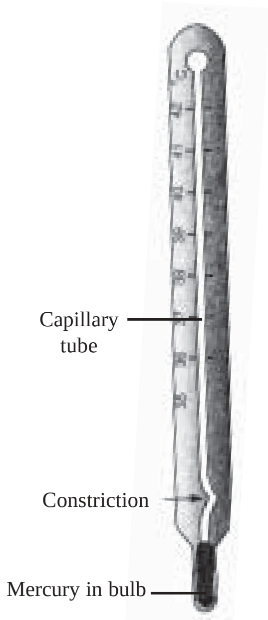


Fig. 10.7 Mercury thermometer

Calibration of mercury thermometer

To calibrate a scale on a thermometer, two fixed points are marked, the lower fixed point or ice point and upper fixed point or steam point.

To mark the **ice point**, the bulb of thermometer is placed in a vessel containing mixture of water and crushed ice. When the level of the mercury becomes stable, a mark is put at the position of the tip of mercury thread in the glass tube. This is called ice-point. Next, the same bulb is placed in steam just above boiling water in a vessel. The position of the tip of mercury thread changes due to thermal expansion of mercury in the bulb. A mark is again made on the glass tube at this new position of the tip of the mercury thread. This is called **steam point**.

Now to mark a Celsius scale on this thermometer, zero is written at the ice point mark and 100 is written at the steam point mark. The length between these two marks is then divided into 100 equal parts. This now becomes a **Celsius thermometer**.

To mark a Fahrenheit scale, 32 is written on the ice-point mark and 212 is written on the steam point mark. The length between these two marks is then divided into 180 equal parts. This now becomes a **Fahrenheit thermometer**.

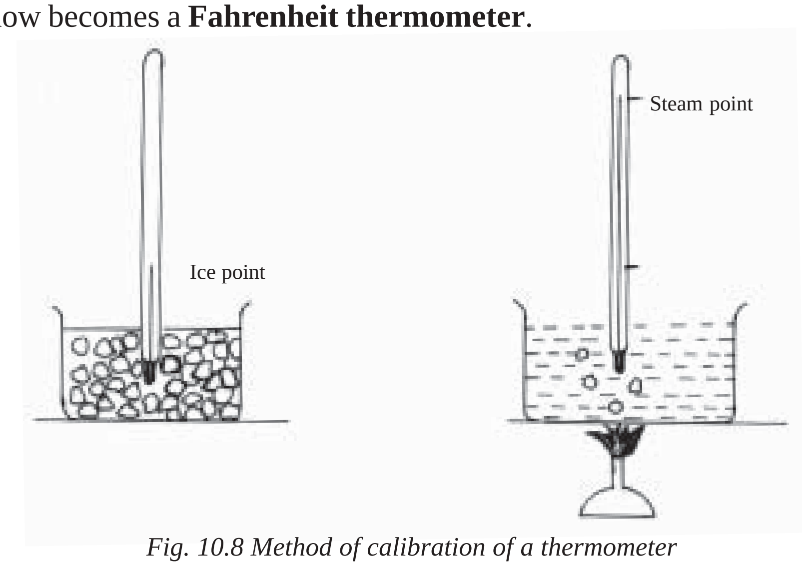


Fig. 10.8 Method of calibration of a thermometer

In a clinical thermometer, the marks are shown only in the range 95 ^{0}F to 110 ^{0}F. [These are the two limits of human body temperature beyond which human beings cannot survive].

Kelvin scale can be marked on a Celsius scale by writing 273 at ice point and 373 at steam point. Thus, each mark is calibrated with a value higher by 273 than on Celsius scale. The Kelvin scale begins with the lowest possible temperature as its zero, which is –273.15 ^{0}C. This temperature is also called **absolute zero**.

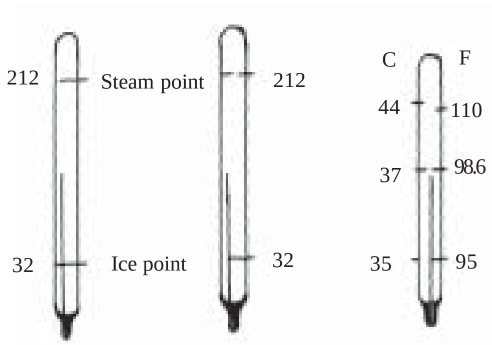


Fig. 10.9 Calibration of thermometers in different scales

To measure the temperature of a hot body, the bulb of the thermometer, is put in contact with that body. Mercury in the bulls expands, resulting in the increase of the length of the mercury thread in the glass capillary. The position of the tip of the mercury thread on the scale (calibrated on the capillary) is read. This gives the value of temperature. When you measure temperature of a cooler body, mercury contracts, length of mercury thread decreases and it gives the value of temperature. As mercury does not stick to glass, the receding tip of mercury thread does not leave any mercury in empty part of capillary, which could cause error in the reading.

ACTIVITY 10.3

Aim: To measure the temperature of a patient

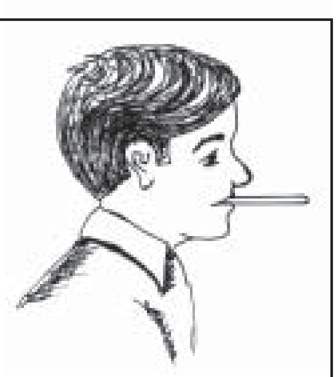


Fig. 10.10 To measure the temperature of a pateint

What to do?

i) Take a clinical thermometer (also called Doctor's thermometer) (Fig. 10.7).

ii) Wash the thermometer in running cold water under a tap, rinse carefully and give a few jerks to bring tip of the mercury thread below 95 ^{0}F.

iii) Now put the bulb end of the thermometer in the mouth under the tongue of the patient for about 2 minutes.

iv) Now take it out gently and read it. This gives the body temperature of the patient.

v) Is it more than 98.6 ^{0}F? If yes! The patient has fever. It may be somewhere in between 97 ^{0}F and 98.6 ^{0}F, if the patient does not have fever.

vi) Wash it again in running tap water; hold it from the other end and give it 3-4 jerks so that the thermometer reading reduces to 95 ^{0}F.

vii) Now put the bulb of the thermometer under the armpit of the patient inside the shirt and keep it slightly pressed. Hold it for about 2 minutes.

viii) Take it out gently and note the thermometer reading.

ix) Is it about 1.0 ^{0}F lower than before?

What do you conclude?

The mouth temperature called the body temperature is about 1^0 higher than armpit temperature.

To know the body temperature of an infant who cannot keep the bulb of the thermometer in his mouth, the temperature of the armpit is measured and then 1^0 is added to this reading to find the body temperature and decide if he has fever.

10.1.9 Relation between Fahrenheit and Celsius scales of temperature

Let us solve the following examples:

Example 10.1: A thermometer reads the temperature of some hot liquid as 100 ^{0}F. What would be the reading of the Celsius thermometer used to measure this temperature?

Solution : You have known that Fahrenheit scale starts from 32 ^{0}F instead of 0 ^{0}C. Both of these are the ice points. Also steam points on these scales are marked as 212 ^{0}F and 100 ^{0}C, respectively.

Thus, 180 divisions of F scale are equivalent to 100 divisions of C scale.

Hence, 1 division of F scale = 100/180 divisions of C scale

Now if F is the reading on the F scale, then

Number of divisions above ice point are = F – 32

Therefore, value of (F – 32) divisions of F scale = (100/180) x (F – 32) divisions of C scale i.e. reading of Celsius thermometer will be = (100/180) (F – 32) = C

or $$\frac{F-32}{180}=\frac{C}{100}$$

$$\frac{F-32}{9}=\frac{C}{5}$$

This becomes the required formula to convert any reading of F scale to C scale or vice versa.

In the present case F = 100

$$C=\frac{5}{9}(100-32)=\frac{340}{9}=37.78 \text{ degree Celsius}$$

$$\approx \ 37.8\ ^0C$$

Example 10.2: Which temperature has same numerical value on Fahrenheit scale and Celcius scale of temperature ?

Solution: Here, we are given F = C

Therefore, in the conversion formula $\frac{F-32}{9}=\frac{C}{5}$,

put F = C, we get

$$\frac{C-32}{9}=\frac{C}{5}$$

$$5C - 160 = 9C \quad \rightarrow \quad C = -40^0$$

Thus –40 ^{0}C = –40 ^{0}F

Example 10.3: What would be the value of 80 ^{0}C on Kelvin scale?

Solution: Since Kelvin scale readings are higher by 273 than on Celsius scale, the value on Kelvin scale is 80+273 = 353 K

Kelvin scale is used in system international (SI) to report the temperature. However, in laboratory we use only Celsius scale for measuring temperature.

On Kelvin scale, the temperature is mentioned in Kelvin only and not degree Kelvin.

CHECK YOUR PROGRESS 10.1

State whether the following statements are True or False.

1. Heat can be measured in Kelvin. (T/F)
2. –30 ^{0}F is a lower temperature than – 30 ^{0}C. (T/F)
3. The numerical value of temperature of any hot body measured on Kelvin scale is always higher than measured on Fahrenheit Scale. (T/F)
4. Thermal energy can be measured either in calories or Joules. (T/F)

5. Pure alcohol can also be used as thermometric liquid. (T/F)
6. When we touch a cold body, heat flows from our hand to the cold body. (T/F)

10.2 EFFECTS OF HEAT

When objects are heated, they may show a change in their shape, size, colour or sometimes in their state. However, the magnitude of change depends upon the quantity of heat absorbed by the object.

10.2.1 Solids expand on heating

Have you ever faced a problem of opening the jammed metallic cap of an inkpot? Sometimes, it is too much tightly closed. Place the inkpot in a wide vessel containing hot water for few minutes. Now take it out and try to open the cap. It opens easily. Why? Metallic cap undergoes thermal expansion in its size (more than the mouth of inkpot which is made of glass) due to absorption of heat from the hot water and therefore, gets loosened.

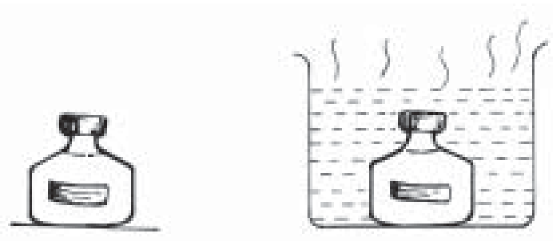
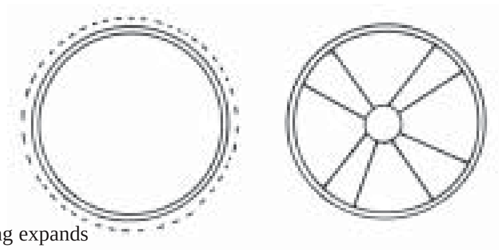


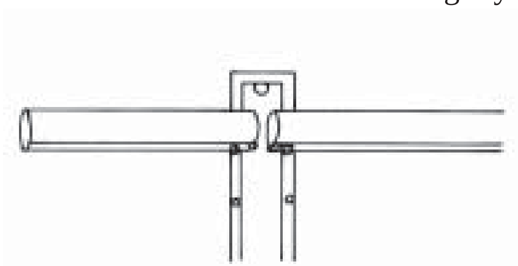
Fig. 10.11 Method to open tightly closed metallic cap of an inkpot

The phenomenon of expansion of solids is used for various purposes.

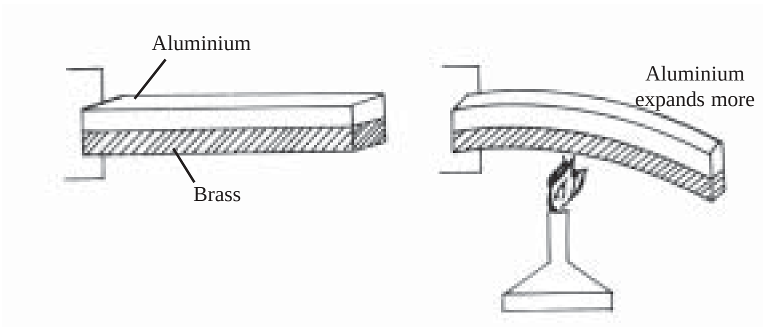
(i) Fitting of tyres on wheels: Do you know, how is the iron ring mounted on the wooden wheel of a horse-cart? The radius of the iron ring is slightly less than that of the wooden wheel. It, therefore, cannot be easily slipped on to the rim of wooden wheel. The iron ring is, therefore, first heated to a higher temperature so that it expands in size and the hot ring is then easily slipped over to the rim of the wooden wheel. Cold water is now poured on the iron ring so that it contracts in size and holds the wooden wheel tightly (Fig. 10.12a)



(a) Fitting of tyres on wheels



(b) Gaps in railway tracks at joints



(c) Thermostat in electrical appliance

Fig. 10.12 Some applications of thermal expansion

(ii) Gaps in the railway track at joints: You must have noticed gaps at the joints in a railways track. Why is it left like that? If this gap is not left then during summer the iron rail will expand due to hot weather and will get bent at the joints (Fig. 10.12b).

(iii) Thermostat in electrical appliances: Thermostat is a temperature control device. It is a bi-metallic strip made up of two different metals having different expansivity. As the temperature rises, due to unequal thermal expansion, the strip bends. Due to this the contact breaks and the circuits gets disconnected. Similarly, it can be used to make contact as temperature rises and thus, to switch on a circuit, as in case of a fire-alarm (Fig. 10.12c). Thus, bimetallic strip is a technical application of differential expansion of metals.

10.2.2 How to measure the expansivity of the material of a body?

All substances do not expand by the same amount when heated through the same difference of temperature. Also it is seen that the same substance expands by a different amount when heated to a different temperature. It is found that larger the rise in temperature, larger is the expansion. It is understood that the ratio of change in length (ΔL) to the original length (L) is directly proportional to the rise in temperature (Δt) of solid bodies ; i.e.

$$\frac{\Delta L}{L} \propto \Delta t$$

or

$$\frac{\Delta L}{L} = \alpha \Delta t$$

α is a constant and depends on the nature of the material of the body. It is called **linear coefficient of thermal expansion** of the material. It is measured in per degree celsius**.** It is defined as fractional increase in length for each degree rise in temperature.

Example 10.4: The length of a steel rod at room temperature of 25 ^{0}C is 20.00 cm. What would be its length when its temperature is raised to 325 ^{0}C? [Given linear coefficient of thermal expansion of steel as 0.000012 $^{0}C^{-1}$].

Solution : Since ,

$$\frac{\Delta L}{L} = \alpha \Delta t \qquad \text{and } t = 300\ ^\circ C$$

or

$$\Delta L = L\, \alpha\, t = 200 \text{ x } 0.000012 \text{ x } 300 = 0.072 \text{ cm}$$

Therefore, the increased length will be 20.00 + 0.072 = 20.07 cm.

Please note that the result is rounded off to 2nd decimal place because 20.00 cm, the term with smallest decimal place in addition has 2 decimal places.

ACTIVITY 10.4

Aim: To study the expansion of water

What to do?

i) Take a small glass bottle (say a used medicine/ injection bottle). Fill it with water up to the rim.

ii) Take the thin plastic tube of a used, empty ball-pen refill. Warm it, bend it and pass through a cork into the mouth of the bottle.

iii) Now heat the bottle gradually. Do you find droplets of water coming out of the bent tube?

What do you conclude?

Liquids expand on heating

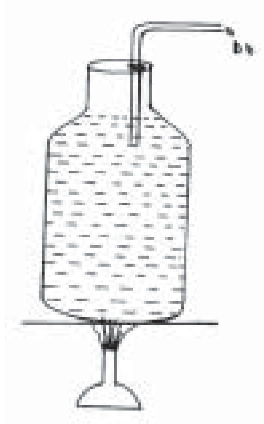


Fig. 10.13 Expansion of liquids

Mercury is a liquid. The property of thermal expansion of mercury has been used in the construction of a thermometer. Different liquids expand by different extent for the same rise in temperature.

Gases also expand on heating. It is important to know that unlike solids and liquids all gases expend by same amount for the same rise in temperature. Thus heating causes expansion of solids, liquids and gases. However, in case of liquids and gases we measure their volume expansivity. It is found that fractional increase in volume of liquids or gases is directly proportional to rise in their temperatures, i.e.

$$\frac{\Delta V}{V} \propto t$$

or

$$\frac{\Delta V}{V} = \gamma t$$

Where, γ is a constant called volume coefficient of thermal expansion, which is different for different liquids. It is defined as the fractional increase in volume for each degree rise in its temperature. It is also measured in per degree Celsius. For gases this constant has the unique value 1/273 per Kelvin.

It is interesting to note that unlike other liquids, water expands when it freezes into ice. Also when water is heated from 0 ^{0}C to 4 ^{0}C, its volume decreases. But further heating beyond 4 ^{0}C results in volume expansion.

You must have noticed that if water bottles or cold drink bottles are left in the freezer of a refrigerator for some days, they crack. Similarly, there is bursting of water pipes under extreme cold conditions at hill stations. This is due to the fact that water expands on freezing into ice. Table 10.1 shows the values of linear and volume coefficients of thermal expansion of some materials. It is seen that volume coefficient of thermal expansion is equal to three times the linear coefficient of thermal expansion.

Table 10.1: Coefficients of linear expansion and volume expansion for some substances

Material	Coefficient of linear expansion ($^oC^{-1}$)	Coefficient of volume expansion ($^oC^{-1}$)
Quartz	0.4×10^{-6}	1.2×10^{-6}
Steel	8×10^{-6}	24×10^{-6}
Iron	11×10^{-6}	33×10^{-6}
Silver	18×10^{-6}	54×10^{-6}
Brass	18×10^{-6}	54×10^{-6}
Aluminium	25×10^{-6}	75×10^{-6}
Lead	2.9×10^{-6}	8.7×10^{-6}

10.2.3 Heating causes change of state of matter

When a solid material is heated, its temperature rises. When the temperature reaches a certain value, the solid starts melting. The temperature remains constant till whole of the solid material gets melted. This temperature is called the **melting point** (M.P.) of the material. It is a characteristic temperature for the material. It does not depend upon the shape or size of the solid. Different materials have different melting points.

ACTIVITY 10.5

Aim: Determination of melting point of ice

What to do?

i) Take some crushed ice in a cooking utensil. Place a thermometer in it and note down its temperature (it should be 0 ^{0}C) (Fig. 10.14).

ii) Now heat it on a gas stove slowly. Do you see conversion of ice into water? Keep an eye on the level of mercury thread of the thermometer. Does it change?

iii) Keep on heating till whole of the ice gets melted. What is the temperature? Is it constant at 0 ^{0}C. Heat further. Do you find that the temperature of water is now increasing?

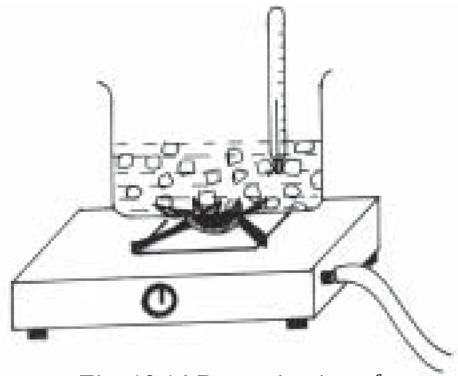


Fig. 10.14 Determination of melting point of ice

What do you conclude?

You will find that the ice melts at 0 ^{0}C and the temperature of ice-water mixture remains constant at 0 ^{0}C till whole of ice gets melted.

Repeat this activity for other solids to find their melting points. You can perform a similar activity with boiling water to find its boiling point. You have to take care that thermometer measures the temperature of steam a little above water surface. If it dips in boiling water the water must be quite pure.

Whenever there is a change of state between solid and liquid or liquid and gaseous states, the temperature does not change even though the heat is either continuously absorbed (as in the process of melting or boiling) or continuously given out (as in the process of freezing and liquefaction) by the material under observation.

Table 10.2: Melting points and boiling points of some materials

Material	Melting point (^oC)	Latent heat of fusion (kj/kg)	Boiling point (^oC)	Latent heat of evaporation (kJ/kg)
Helium	-271	-	-268	25.1
Hydrogen	-259	58.6	-252	452
Air	-212	23.0	-191	213
Mercury	-39	11.7	357	272
Pure water	0	335	100	2260
Aluminium	658	322	1800	–
Gold	1063	67	2500	–

10.2.4 Effects of impurities on melting point and boiling point

Pure substances have definite melting points and boiling points characteristics of the material. But on addition of impurities their values change. Let us study this with the help of some activities.

ACTIVITY 10.6

Aim: To find out effect of impurities on melting point of ice

What to do?

i) Take two containers A and B. In container A, put some pure water and crushed pure ice. In container B, ice is mixed with about $1/3^{rd}$ its weight of powdered salt. Observe that in B some ice melts and a saturated solution of salt is formed.

ii) Measure the temperature of liquid in both the containers. Obviously, temperature of ice in any container is same as that of its liquid. In which container is temperature lower?

iii) The temperature is lower in B.

What do you conclude?

Presence of impurities lowers the freezing point/melting point.

Activity 10.7

Aim: To find out effect of impurities on boiling point of water

What to do?

i) In the above activity 10.6, heat both the containers until the water starts boiling.
ii) Note the boiling point of water in the both containers, keeping the bulbs of the two thermometers inside the levels of respective boiling liquids.

What do you observe?

The boiling point of salted water is higher than that of pure water.

What do you conclude?

Presence of impurities increases the boiling point.

10.2.5 Effect of pressure on melting point and boiling point

The melting and boiling points of a material also change with the change in atmospheric pressure. Let us study the effect of pressure on melting point and boiling point with the help of some activities.

ACTIVITY 10.8

Aim: To study the effect of pressure on the melting point of a substance

What to do?

i) Take an ice block, a wooden block and a wire.
ii) Press the wire to first cut the ice block and then the wooden block. You cannot cut a wooden block by pressing a wire on it though wood is softer. Why does the wire pass through the ice block easily?

What do you conclude?

The pressure applied through the wire melts the ice in immediate vicinity allowing the wire to pass through it. Thus, the melting point of ice is lowered with increase in pressure.

It should be noted that in case of all solids other than ice, the volume of liquid obtained on melting is generally larger than solid volume. Water is an exceptional case. In such solids, which increase in volume on melting, the melting point increases with increase of pressure.

All liquids expand on evaporation. Hence, increase in pressure will obstruct the change of phase on boiling. This results in an increase in the boiling point of liquids with increase in pressure.

10.2.6 Cooking is easier in pressure cooker

In a pressure cooker, (which is air tight from all sides), when water together with vegetables is heated, its temperature rises. Initially, when valve of the cooker is open, water boils to form steam at 100^0 C. This steam so formed occupies larger volume than what it had in liquid state. Now the valve is closed. The steam, having no exit to come out, exerts pressure on the surface of water in the cooker, which stops boiling. More heat is now supplied. This increases the temperature of water without allowing the remaining water to boil any more. Thus, inside a pressure cooker, there is steam and water at higher temperature and at high pressure. The higher temperature and pressure quickly softens the vegetable and causes the quicker cooking of food.

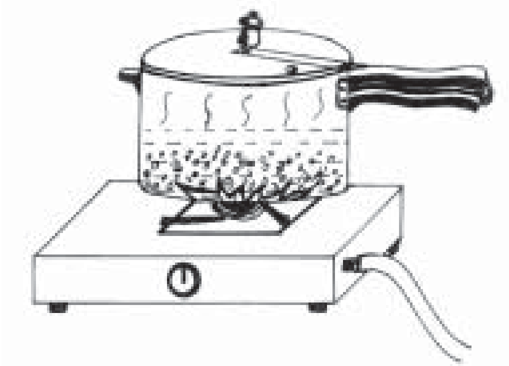


Fig. 10.15 Cooking is easier in a pressure cooker

There is always a certain weight put on the nozzle of the lid of the pressure cooker. If the force due to the pressure of the steam exceeds this weight, the weight gets lifted and some of the steam leaks out and reduces pressure. Do you now understand why it is called pressure cooker?

The importance of pressure cooker for persons living at hill stations is very great. The atmospheric pressure in hilly areas is lower due to the high altitude, and thus, water starts boiling at a lower temperature. In such a situation if the ordinary utensil is used for cooking food (especially food like rice and pulses), it will take a long time, resulting in wastage of precious fuel.

10.2.7 Latent heat

We have already discussed in the previous parts of this section that the temperature does not change during the change state even though heat is continuously supplied to the material. What happens to this heat supplied? It is used up wholly in changing the state of the substance. Therefore, it does not appear in the form of rise in temperature of the body. This is, therefore called latent heat (or hidden heat). Its value is constant and is different for different materials.

Latent heat of a material is defined as the amount of heat required to completely change the state of unit mass of that substance either from solid to liquid or liquid to gaseous state. It is generally denoted by capital letter L and is measured in Joules per kilogram (J/kg). When material changes from solid to liquid, it is called as **latent heat of fusion** and when the state changes from liquid to vapours it is **latent heat of evaporation**.

Do you understand why does water filled in a clay pitcher become cold even when placed inside a room? In this case, water drops leaking through the fine pores of clay pitcher absorb heat for evaporation from the water inside. Therefore, the inside water gets cooled.

Example 10.5: How much thermal energy is required for complete melting of 10 kg of ice at 0 ^{0}C to form water at 0 ^{0}C?

Solution: Thermal energy for melting *m* kg ice at its melting point

= *m* L

= 10 x 335 kJ

= 3350 kJ

Heat required for a mass *m* kg of a substance for change in state at its melting point or boiling point is = *m*L joule.

10.2.8 Sublimation

Some solid substances when heated directly change to gaseous state without becoming liquid. This process is called sublimation.

ACTIVITY 10.9

Aim: To study the sublimation of camphor

What to do?

Take some camphor tablets in a spoon and heat the spoon slowly over a gas stove.

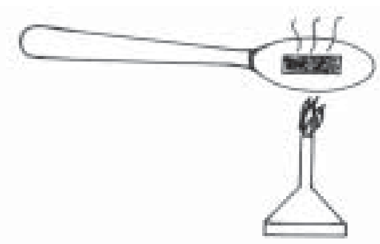


Fig. 10.16 Camphor sublimates on heating

What to observe?

Do you see fumes coming out and camphor gradually vanishing without melting?

What do you conclude?

This shows that camphor sublimates on heating.

Naphthalene balls (used for preserving woolen clothes) and iodine are also sublime substances.

CHECK YOUR PROGRESS 10.2

Fill in the blanks with the correct choice.

1. A bimetallic strip is used as a thermostat in the electrical device named ____________ (geyser, camera, T.V.)
2. If the mass of a substance is doubled, its melting point will ______________ (be lowered, be raised, remains same)
3. When solid ice is heated, the volume of the water formed on melting is __________ the initial volume of the solid ice. (more than, less than, same as)
4. Latent heat of evaporation is measured in ________________ (J, J/k, J/kg)
5. The water containing little salt dissolved in it boils at a temperature ________ 100 ^{0}C. (higher than, lower than, equal to)

10.3 THERMAL EQUILIBRIUM

When two bodies at different temperatures are brought in contact heat energy will always flow from the body at higher temperature to the body at lower temperature, till both the bodies acquire the same temperature. The two bodies are then said to be in thermal equilibrium.

ACTIVITY 10.10

Aim: To study the state of thermal equilibrium

What to do?

i) Take a steel tumbler. Fill it $2/3^{rd}$ with tap water. Put a thermometer in it and measure its temperature.

ii) Now take a large heavy metallic spoon which can be inserted in the tumbler. Heat it on a flame and put it in the tumbler and keep an eye on the temperature scale of the thermometer.

What do you observe?

Does the temperature of the water rise? Does the temperature stops rising after some time? Touch the spoon with the thermometer bulb and note the temperature of the spoon. Is the temperature of spoon same as that of water?

What do you conclude?

The heat energy keeps on flowing from the hot body to the cold body till both acquire same temperature. This is called state of **thermal equilibrium**.

10.3.1 Can we measure the amount of heat transferred?

Heat gets transferred from a hotter body to a cooler body in contact. The larger the quantity of heat transferred, larger would be the rise in the temperature of the colder body before a state of thermal equilibrium is achieved.

Therefore, the heat energy transferred is proportional to the rise in temperature of the cold body. Similarly, heat energy lost by the hot body is proportional to the fall in temperature of the hot body.

ACTIVITY 10.11

Aim: To study the factors on which the heat transferred from a hot body to a cold body depends

What to do?

i) Take two identical vessels A and B and put equal amount of tap water in both of them.

ii) Now take another larger vessel C containing some water and heat it on a gas stove till it boils. Note its temperature.

iii) Now pour a small quantity of water from vessel C into vessel A and larger quantity of water into vessel B. Note the new temperatures of water in vessels A and B.

What do you observe?

The temperature of water in vessel B is more than that of water in vessel A.

What do you conclude?

The vessel B, in which larger quality of boiled water was added, has been given larger quantity of heat. Thus, the quantity of heat transferred not only depends on the temperature of the hot body but also depends upon its mass.

The quantity of heat (H) transferred from a hot body is proportional to (i) mass (m) and also to (ii) fall in temperature (t).

$$H \propto m \times t$$

or $$H = s \times m \times t$$

Where, s is a constant of proportionality and is called specific heat of the material of the body. It is a characteristic constant of the material of the body and does not depend upon the shape or size or mass of the body. Since s = H/m x t, specific heat of a material can be defined as the amount of heat required to raise the temperature of unit mass of that substance through unit degree. In S.I., it is measured in J/kg ^{0}C or Jkg^{-1} ^{0}C $^{-1}$.

Using the concept of conservation of energy

Heat given by hot body = Heat received by colder body

Example 10.6: How much thermal energy is required to raise the temperature of 10 kg of water form 25 ^{0}C to 100 ^{o}C? [Given specific heat of water s = 4200 J kg^{-1} C^{-1}].

Solution: Heat required = m x s x t

= 10 x 4200 x (100 –25) J

= 315 0 kJ

Example 10.7: A hot iron ball of mass 1.0kg and specific heat 3000 J kg^{-1} ^{0}C^{-1} at temperature 60 ^{0}C is placed in water of mass 3.0kg at a temperature 25 ^{0}C. Calculate the final temperature when thermal equilibrium is achieved. Neglect the heat sharing by the vessel containing water.

Solution: Let the final temperature of the mixture be θ ^{0}C

Then, heat given by the iron ball = ms t = 1 x 3000 (60- θ)J

Heat taken by water = 3 x 4200 (θ – 25) J

Since heat given = heat taken

$$1 \times 3000 \times (60 - \theta) = 3 \times 4200 (\theta - 25)$$

or $$180000 - 3000\,\theta = 12600\,\theta - 315000$$

or $$15600\,\theta = 495000$$

This gives θ = 31.7 ^{0}C

CHECK YOUR PROGRESS 10.3

Which of the following is the correct alternative?

1. Two iron balls of radii r and 2r are heated to same temperature. They are dropped into two different ice boxes, A and B, respectively. The mass of ice melted
   (a) will be same in the two boxes
   (b) in A will be twice than in B
   (c) in B will be twice that melted in A
   (d) in B will be 8 times that melted in A

2. An iron ball A of mass 2 kg at temperature 20 ^{0}C is kept in contact with another iron ball B of mass 1.0 kg at 20 ^{0}C. The heat energy will
   (a) flow from A to B only
   (b) flow from B to A only
   (c) not flow form A to B or B to A
   (d) flow from B to A as well as A to B

3. When solid ice at 0 ^{0}C is heated, its temperature
   (a) rises immediately.
   (b) falls
   (c) does not change until whole of it melts
   (d) first rises then falls back to 0^{o}C

4. Which of the following bodies when gently dropped in a vessel containing water at 20^{0}C will cause highest rise in the temperature of water?
   a) An iron ball of mass 1.0 kg at temperature 50 ^{0}C.
   b) A brass ball of mass 2.0 kg at temperature 40 ^{0}C with specific heat half that of iron.
   c) A block of ice of mass 0.1 kg at temp –10 ^{0}C.

5. When steam at 100 ^{0}C is heated its temperature
   a) does not change
   b) increases
   c) decreases

LET US REVISE

- Heat is a form of energy while the temperature is the degree of hotness of the body.
- Heat energy is measured in joule while the temperature is measured either in degree Fahrenheit (^{0}F) or degree Celsius (^{0}C) or in Kelvin (K).
- Mercury is used as a thermometric substance, because it is opaque and does not stick to the walls of the glass capillary. Also it has uniform coefficient of thermal expansion over a wide range of temperature.
- A Fahrenheit scale of temperature is related to Celsius scale of temperature by the relation $\frac{F-32}{9}=\frac{C}{5}$
- The Kelvin scale is related to Celsius scale by the relation K = 273 + °C
- All substances expand on heating i.e. a rise in temperature.
- Linear coefficient of thermal expansion of a solid material is defined as the increase in length per unit length per degree Celsius rise in temperature. It is measured in $^0C^{-1}$.
- Volume coefficient of thermal expansion of a solid material or a liquid or gaseous material is defined as the change in volume per unit volume per unit rise in temperature. It is also measured in $^0C^{-1}$.
- Volume coefficient of thermal expansion of a solid material is equal to three times its linear coefficient of thermal expansion.
- Different substances expand to different extents when heated for same rise in temperature.
- Bi-metallic strip is a technical application of differential expansion of solid metals. It can be used as an on/off switch in electrical circuits in response to a rise in temperature.
- Melting point and boiling point of a material are characteristic temperatures for that material. They do not depend upon their shape or size.
- Melting point of a substance decreases while its boiling point increases with mixing of impurities.

- Melting point and boiling point change with rise in pressure. The solids (like ice) which contract in volume on melting show a fall in their melting point with rise in pressure. The boiling point of all liquids increases with rise in pressure.
- The temperature of substances remains constant when heat energy is supplied at their Melting point and boiling point. This is used in changing their phases and is called latent heat. It is measured in joule per kg.
- Heat always flows from a body at higher temperature to another body in contact at lower temperature. It keeps on flowing till both the bodies acquire a common final temperature and a state of thermal equilibrium is achieved.
- Heat transferred is equal to mass $\times$ specific heat $\times$ change in temperature.
- In all heat transfer cases; heat given by hot body is equal to heat taken by cold body.

TERMINAL EXERCISES

Descriptive type questions.

1. What is the difference between the temperature of a hot body and its thermal energy?
2. What happens to the temperature of a body when it changes its state from liquid to solid?
3. On what factors does the thermal expansion in a wire depend?
4. What is the difference in the units of specific heat and latent heat of substances.
5. Name any two uses of a bimetallic strip.
6. If you have a mercury thermometer without any calibration, how will you make a (i) Celsius scale (ii) Fahrenheit scale for it?
7. Why is the mercury used as a thermometric substance?
8. Why does a bimetallic strip bend on heating?
9. Heats of fusion and vaporization of substances are often referred to as latent heats. Why?
10. When some water in a tea kettle is heated on a gas stove, it always takes a much lesser time for the water to start boiling than for all the water to vaporize? Why is it so?
11. Why is the steam-burn far more serious than the one obtained from a spilling hot water.
12. A solid substance expands on melting. What will happen to its freezing point when the pressure is reduced, just like at a hill station?
13. At what temperature the numerical value of Fahrenheit scale will be just double of that on Celsius scale? (Ans. 160 ^{0}C or 320 ^{0}F)
14. A 50 cm silver bar becomes shorter by 1.0 mm when it is cooled. How much was it cooled. Given coefficient of linear expansion for silver = 18 x 10^{-6} C $^{-1}$.
15. The iron rim of a wagon wheel has an internal diameter of 1.000 m when the temperature is 150 ^{0}C. What would be its diameter when it cools off to 25 ^{0}C? (Coefficient of linear expansion for iron = 12 x 10^{-6} ^{0}C $^{-1}$)
16. How much heat energy is required to change 200 g of ice at –20 ^{0}C to water at 70 ^{0}C? [Given latent heat of fusion of ice = 335 kJ/kg and specific heat of ice = 2100 j/kg ^{0}C]

17. A 2.0 kg block of iron at 100 ^{0}C is dropped into a 0.75 kg of water contained in a 0.325 kg copper Calorimeter. If the initial temperature of water and Calorimeter was 12 ^{0}C, what will be the final temperature.
    Given specific heat of iron = 105 cal kg $^{-1}$ °C^{-1}; specific heat of water = 1000 cal kg^{-1}^{0}C^{-1}; specific heat of copper = 93 cal kg^{-1}^{0}C^{-1} (use 1.0 cal = 4.25J)
18. A heavy box of mass 200 kg is pulled along the floor for 15 m. If the coefficient of sliding friction is 0.4, how much heat energy is developed?
19. A 50 g bullet of lead at 27 ^{0}C fired form a rifle moves with a velocity of 200 m s^{-1}. What temperature would it attain when it stops after the impact? [Given specific heat of lead = 130 J/kg ^{0}C]. Assume that entire heat generated by impact goes to the bullet and not to target.

ANSWERS TO CHECK YOUR PROGRESS

10.1

1. F 2. T 3. F 4. T 5. F 6. T

10.2

1. hot water geyser 2. remains same 3. less than

10.3

1. (d) 2. (c) 3. (c) 4. (a) 5. (b)

GLOSSARY

Heat: A form of energy which gives us sensation of warmth.

Latent heat of fusion of a solid: The amount of heat required (in joules) to convert 1 kg mass of the solid into its corresponding liquid state at its melting point.

Latent heat of vaporization of a liquid: The amount of heat required to convert 1 kg of the liquid into its corresponding gaseous state at a constant temperature.

Principle of Calorimetry: In case no heat is lost to the surroundings and no change of state is taking place, the heat lost by hot body is equal to the heat gained by the cold body, when these are brought into contact.

Specific heat of a substance: Defined as the amount of heat required (in joule) to raise the temperature of 1 kg of a substance by 1 ^{0}C (or 1 K).

Sublimation: The process in which a solid changes into its gaseous state directly without passing through liquid state.

Temperature: A numerical measure of hotness of a body which determines the direction of flow of heat. Heat always flows from a body at higher temperature to a body at lower temperature.

Thermal equilibrium: Implies that the two bodies are at the same temperature and hence no net heat transfer is taking place between them.

Thermal expansion: Implies the increase in the size of an object on heating.**Principle of Calorimetry:** In case no heat is lost to the surroundings and no change of state is taking place, the heat lost by hot body is equal to the heat gained by the cold body, when these are brought into contact.

Thermometer: A device used for measuring temperature.

Thermostat: A temperature control device usually made of a bimetallic strip.