212en14

14

THERMAL ENERGY

In previous lesson, we have studied that one of the most common forms of energy is thermal energy. It is the energy due to which we feel hot or cold. If the energy flows into our body we feel hot and if it flows out of our body we feel cold. To prevent heat from flowing out of our body we wear woolen clothes during winter.

Thermal energy is also called heat. We receive heat directly from the sun along with light. The heat from the sun dries our clothes, ripens our crops and evaporates water from water bodies to cause rain. We need heat to cook our food, to light the fire, to run a thermal power station. Generally, we produce heat for all such purposes by burning a fuel or by passing electric current through a conductor.

In antiquity, fire was produced by striking two stones together. We have now refined that method in the form of a match box. Heat is thus an important form of energy, connected intimately with our life and comfort.

In this lesson you will study about heat, its various effects and its role in our lives.

OBJECTIVES

After completing this lesson you will be able to:

- *distinguish between heat and temperature;*
- *describe experiments to show the expansion in solids, liquids, and gases;*
- *describe the construction and working of a laboratory thermometer and a clinical thermometer;*
- *state different scales of temperature, viz .fahrenheit, celsius and kelvin;*
- *relate readings on fahrenheit, celsius, and kelvin scales of temperature and solve numerical problems based on these relationships;*
- *give examples of latent heat and its applications in daily life and*
- *define specific heat and give its SI unit.*

14.1 HEAT AND TEMPERATURE

We know that thermal energy is provided to water in a kettle when it is placed on fire. If we touch water in the kettle before we start heating it and then after some time of heating we find that the water becomes warmer. This degree of hotness or coldness of a body due to which we call it warmer is called Temperature. Heat and temperature are intimately related. Normally, more the heat given to a body higher will become its temperature.

14.1.1 Heat

When water is boiled in a kettle the steam built up in the kettle raises its lid up and when the steam escapes out the lid falls down. Heat thus can do work, so, it is a form of energy. This property of steam was used to build **steam engines** – the devices which convert heat of steam into mechanical work.

You may ask, is the converse operation also possible? Can we convert mechanical work into heat? Why not? Why don't you recall that when you rub your hands together they become warm? In fact work done against friction is always converted into heat.

The equivalence of work and heat was noticed and experimentally established by J. P. Joule. While boring the barrel of a gun with a blunt borer Joule found that so huge amount of heat was produced in the process that even water in which the process of boring was being carried out started boiling.

Through further experiments he found that **one Calorie** (Unit of heat prevalent at that time) **of heat is equivalent to 4.2 Joule of work.**

14.1.2 Temperature

As discussed above temperature is a quantity which tells us how hot a body is? If a hot body is kept in contact with a colder body for some time, we will find that the hotter body does not remain that hot and the colder body becomes some what hotter. Thus heat is transferred from a hotter body (a body at higher temperature) to a Colder body (i.e. a body at lower temperature). Hence **temperature is the degree 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.

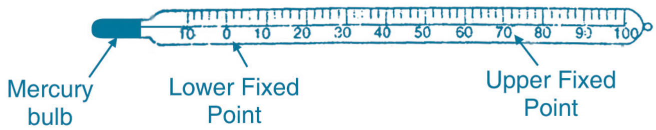
14.2 MEASUREMENT OF TEMPERATURE

You might have noticed that whenever a patient is brought to a doctor, the doctor normally measures his body temperature. Do you know the device the doctor uses to measure his body temperature? What do they call it? They call it **thermometer**.

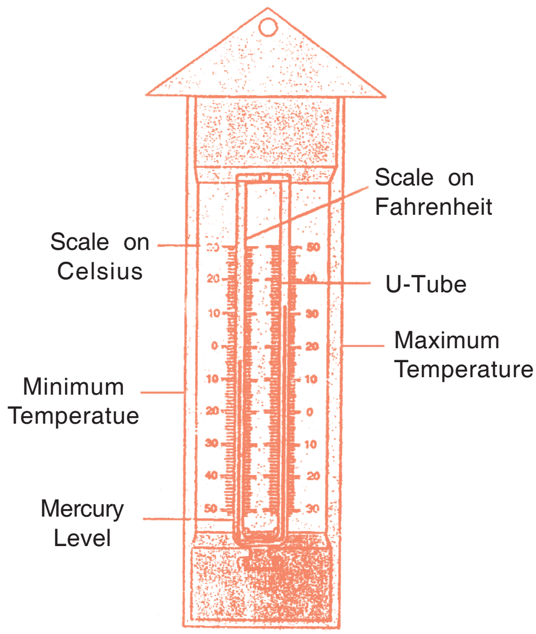
There are different types of thermometers that they use for different purposes. The thermometer that a doctor uses to measure the temperature of human body is called

Clinical thermometer Fig. 14.1(a). The thermometer that we use for measuring temperature in science experiments is called **laboratory thermometer** Fig. 14.1(b) and the thermometer that the **meteorologists** use for determining the maximum and minimum temperature during a day is called as **maximum – minimum thermometer** Fig. 14.1(c). These days they are using **digital thermometers** Fig. 14.1(d) for different purposes.

(a) Clinical thermometer



(b) Laboratory thermometer



(c) Maximum – minimum thermometer

(d) Digital thermometer

Fig 14.1 *Different types of Thermometers*

Notes

14.3. CONSTRUCTION OF A THERMOMETER

Normally mercury-in-glass thermometer is conveniently used in day to day applications. In this type of thermometer there is a thin walled bulb attached to a thick walled capillary. The bulb and to a certain height the capillary are filled with mercury by repeated heating and cooling. The capillary above mercury level is evacuated and its upper end is sealed. Then the thermometer is calibrated (marked) to measure temperature. For calibration lower and upper fixed points are marked respectively by burying the bulb first in melting ice and then in steam for sufficient time, so that mercury level in the stem remains fixed with time in each case (Fig.14.2).

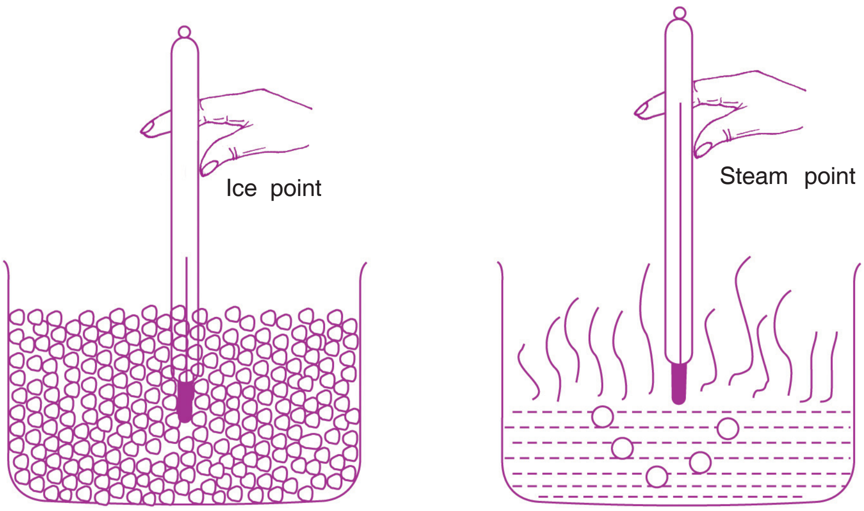


Fig. 14.2 *Calibration of a thermometer*

You may ask why use of mercury is preferred as thermometric liquid. The reasons are many. Mercury acquires the temperature of the body, it is kept in contact with very quickly; it absorbs very little heat from the body in contact and has large uniform expansion over a wide range. It is opaque and does not stick to the walls of the container. These properties make mercury the most appropriate liquid for accurate temperature measurements over a wide range.

Giving different values to the lower fixed point and upper fixed point and dividing the space between these two marks in equal number of divisions different scales are developed for measuring temperature. Three such scales are shown in Fig. 14.3. These are: celsius scale, fahrenheit scale and kelvin scale. In celsius scale the lower fixed point (ice point) is marked as 0, the upper fixed point(steam point) is marks as 100 and the intervening space is divided into 100 equal parts .In fahrenheit scale the lower fixed point is marked as 32, upper fixed point as 212 and the intervening space is divided into 180 equal pats. In case of a kelvin's scale the lower fixed point is marked as 273, steam point as 373 and the space between them is divided into 100 equal parts. SI Unit of temperature is kelvin (K).

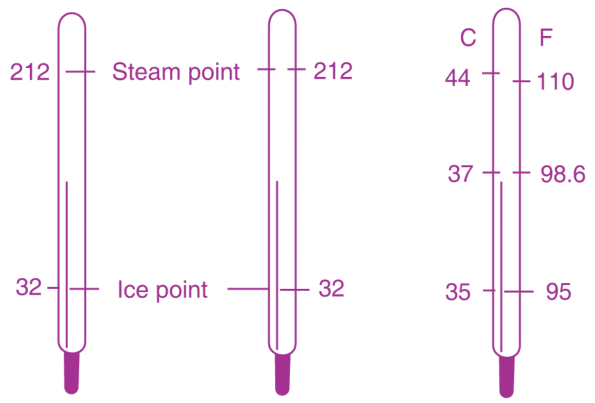


Fig. 14.3 *Different scales of temperature*

This is clear from Fig. 14.3 that the three scales are related by the formula

$$\frac{C}{100} = \frac{F-32}{180} = \frac{K-273}{100} \qquad (14.1)$$

INTEXT QUESTIONS 14.1

State whether the following statements are true or false:

(i) Heat can be measured in kelvin.

(ii) –30° F is a lower temperature than –30° C.

(iii) The numerical value of temperature of any hot body measured on kelvin's scale is always higher than the value on Fahrenheit scale.

(iv) Thermal energy can be measured either in calories or in joules.

(v) Pure alcohol can also be used as thermometric liquid.

(vi) A body is felt cold when heat flows from our body to that body.

14.4 EFFECTS OF HEAT

When a body is heated changes may occur in some of its properties .These changes are the effects of heat. Some of the effects of heat, as you might have observed are:

14.1 Rise in temperature

When a body is heated its temperature increases, that is why, it appears warmer when touched.

14.2 Change of state

When heat is supplied to a substance in solid state its temperature rises till at a particular temperature it may change into its liquid state without any further change in its temperature. This characteristic constant temperature at which a solid changes into its liquid state is called **melting point** of the solid. The melting point of a substance is a characteristic, constant value and different substances may have different values of melting points (Table 14.1).

Conversion of a solid into its liquid state at its melting point is called **change of state** from solid to liquid (fusion) and the heat that is transferred to the substance during melting is called **Latent Heat of Fusion**. Because, it does not becomes apparent in the form of rise in temperature. Latent heat of fusion of a solid substance is defined as the amount of heat (in joules) required to convert 1kg of the substance from solid to liquid state at its melting point (Table 14.1).

Similarly, when heat is supplied to a substance in liquid state its temperature rises but there is a possibility that it changes into its vapour state at a constant temperature. The heat supplied in this case is called **Latent Heat of Vaporization.** Latent heat of vaporization of a liquid is defined as the amount of heat (in joules) required to convert 1kg of the substance from its liquid to gaseous state at a constant temperature. Latent heats of vaporization of different substances are also different (Table 14.1).

It may be noted that vaporization may take place in two different ways: (i) Evaporation from the surface of a liquid at any temperature (ii) Boiling of the whole mass of the liquid at a constant temperature called boiling point of the liquid. Boiling points of different liquids may also be different (Table 14.1).

Table 14.1 Melting, boiling points, latent heat of fusion and latent heat of vaporization of some materials

S. No.	Name of Material	Melting Point (°C)	Latent heat of fusion ($\times 10^3$ J/kg)	Boiling Point (°C)	Latent heat of vaporization ($\times 10^3$ J/kg)
1.	Helium	–271	–	-268	25.1
2.	Hydrogen	–259	58.6	–252	452
3.	Air	–212	23.0	–191	213
4.	Mercury	–39	11.7	357	272
5.	Pure Water	0	335	100	2260
6.	Aluminum	658	322	1800	–
7.	Gold	1063	67	2500	–

This may again be noted that on cooling change of state may take place in reverse order. The chart given below illustrates the various events of change of state.

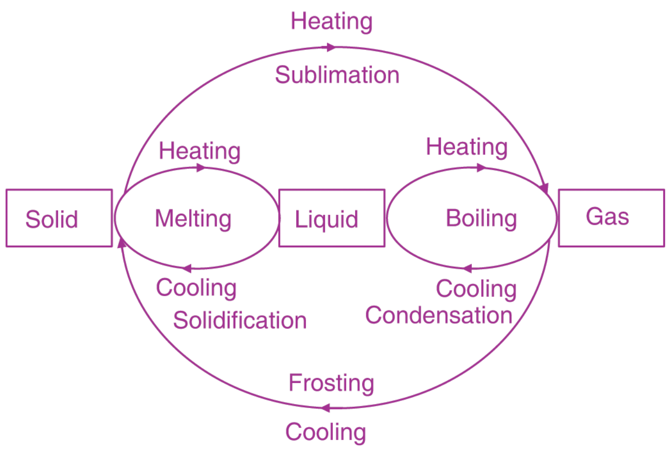


Fig. 14.4 *Change of state*

14.5 THERMAL EXPANSION

Take a metallic ring fitted with a handle and a sphere of the same metal fitted with a chain such that the sphere just passes through the ring (Fig. 14.5). Now heat the sphere in steam for some time and place it over the ring. Does it pass through the ring now? It doesn't. Obviously, the size of the sphere has increased on heating. In fact every material (except water which contracts on heating from 0°C to 4°C) expands on heating. The increase in the size of a body on heating is called **thermal expansion.**

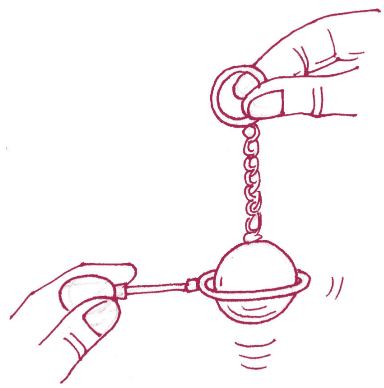


Fig. 14.5 *Ball and ring experiment to demonstrate thermal expansion*

The expansivity of different materials is normally different. The fact can be easily noticed with the help of a bimetallic strip. A bimetallic strip is a strip having two layers of two different metals one over the other. Consider the bimetallic strip made of steel and aluminium (Fig. 14.6). When we clamp one end of the strip and heat it uniformly with the help of a Bunsen burner, it bends with aluminium layer outward. This clearly shows that aluminium has increased in length more than steel and caused bending.

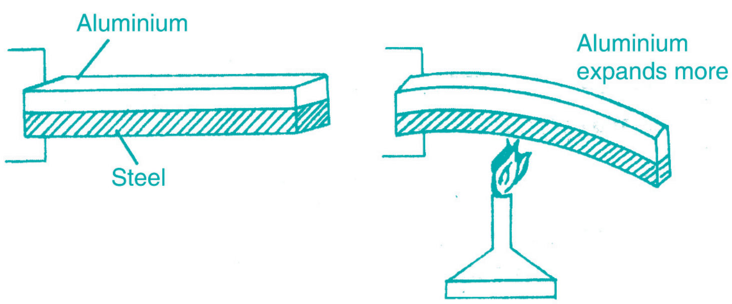


Fig. 14.6 *The bimetallic strip bends on heating*

It can be seen that increase in length of a metallic bar will be more for a longer bar and also for a greater rise in temperature of the same bar. Let us consider a metallic bar of length L_0 at temperature 0° C. Increase in its length ΔL at a temperature Δt is given by:

$$\Delta L \propto L_0 \Delta t$$

$$\Delta L = \alpha L_0 \Delta t$$

$$\alpha = \frac{\Delta L}{L_0 \Delta t}$$

Here α is a constant for the material of the bar and is called as the **Linear expansivity** of the bar.

The **Linear expansivity** (or **Coefficient of Linear expansion**) of a material is defined as the change in length per unit original length per degree celsius rise in temperature. The SI Unit of coefficient of expansion is per kelvin (which is same as per degree celsius in magnitude).

A piece of solid may expand along length, breadth and height simultaneously hence there will be an increase in its volume with temperature.

The **Volume expansivity** of a material may be defined as change in volume per unit original volume per degree celsius rise in temperature.

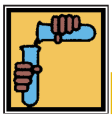
i. e. $$\gamma = \frac{\Delta V}{V \Delta t}$$

The value of coefficient linear expansion (α) and the coefficient of volume expansion (γ) of some materials are given in Table 14.2.

Table14.2 Values of Coefficient of Linear expansion and Coefficients of volume expansion of some common substances

S. No.	Name of Material	Coefficient of Linear Expansion (°C^{-1})	Coefficient of Volume Expansion (°C^{-1})
1	Quartz	0.4×10^{-6}	1.2×10^{-6}
2	Steel	8×10^{-6}	24×10^{-6}
3	Iron	11×10^{-6}	33×10^{-6}
4	Brass	18×10^{-6}	54×10^{-6}
5	Silver	18×10^{-6}	54×10^{-6}
6	Aluminium	25×10^{-6}	75×10^{-6}
7	Lead	2.9×10^{-6}	8.7×10^{-6}

The table clearly shows that expansivity of solids is very small therefore we cannot see and measure expansion of solids easily. But liquids expand much more than solids and gases many times more than liquids and so we can see expansion of liquids and gases easily. However, since liquids and gases do not have a definite shape, it will be volume expansivity only relevant for fluids.



ACTIVITY 14.1

Demonstration of expansion in liquids

Take a small transparent bottle (say an injection bottle) fill it with water up to the brim. Make a small hole in its cork and insert a thin transparent plastic pipe in it (say a used up empty ball-pan refill) so that the lower end of the pipe dips in water and water rises in the pipe up to a certain height. Mark the level of water in the pipe indicated as (A). Now heat the bottle. What do you find? Does the level of water in the pipe come down? Why so? Keep on heating the bottle. Does the level of water start increasing after reaching a certain minimum level (B)? Does it shoot off the initial position (A) and rises further up to the height (C)? Why so? Can you infer from this experiment that water expands more than glass for the same temperature rise?

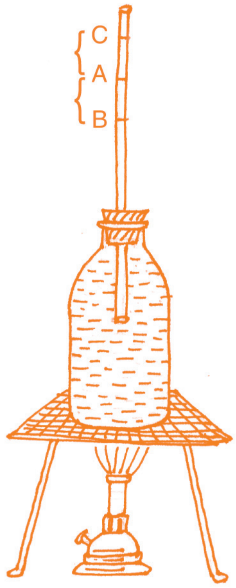
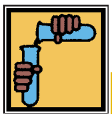


Fig. 14.7 *Expansion of Liquid*



ACTIVITY 14.2

Demonstration of expansion in gases

Take a thin walled narrow bored glass tube and entrap a drop of mercury in it. Then heat one end of the tube and pressing it on a hard surface seal this end. Let the tube cool to normal temperature. Hold the tube vertically and mark the position of mercury in the tube. This way we have entrapped a column of air between mercury drop and sealed end of the pipe. Now even if we warm the air column by holding it in our hand we can see the drop of mercury shifting its position. Does it move up or down? What do you conclude from this experiment? Does this show that gases have high expansion even for a small rise in temperature?

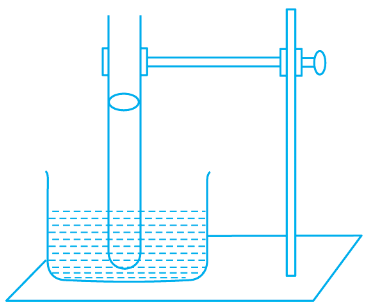


Fig. 14.8 *Expansion of gas*

14.5.1 Uses of thermal expansion in day to day life

1. The property of thermal expansion is used in the construction of thermometers.
2. A tightly closed metallic cap of a bottle may be opened by using thermal expansion. The cap on heating expands, becomes loose and may be opened easily.

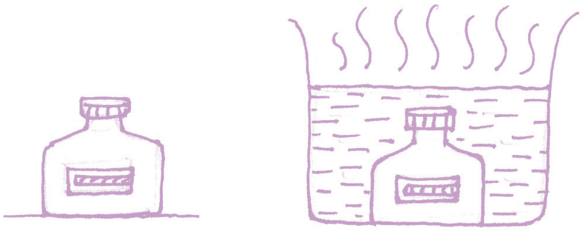


Fig. 14.9 *Loosening a metal cap by heating it*

3. Have you seen a horse-cart (Tanga)? It has wooden wheels on the rims of which iron rings are mounted. Do you know how the iron ring is mounted on a wooden wheel? The iron ring is, in fact, made of a radius slightly less than the radius of wheel. Then the ring is heated so that its radius becomes slightly more than the radius of the wheel. The ring is than slipped on the rim of the wheel while hot. Subsequently on cooling, it contracts and firmly holds the rim of the wheel.

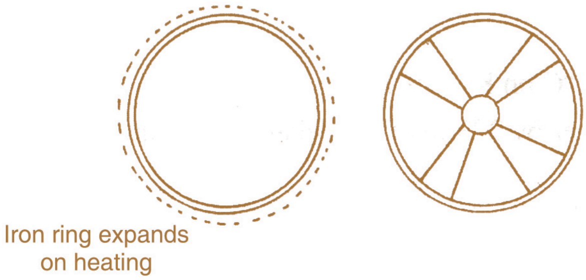


Fig. 14.10 *Fitting iron tyre on wooden wheel*

4. Thermostats used in heating/cooling devices make use of a bimetallic strip to automatically switch off the heating cooling circuit when the temperature rises/falls beyond a certain value. After some time when the temperature returns below/above a certain value the bimetallic strip resumes its original position and the circuit again becomes on. A simple bimetallic thermostat is shown in Fig. 14.11.

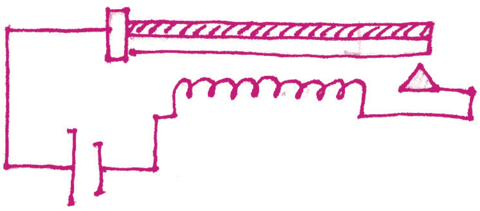
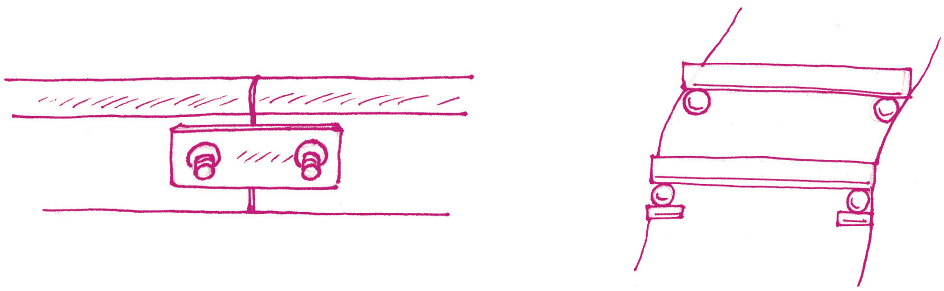


Fig. 14.11 *Principle of a thermostat*

5. We have to take care of thermal expansion while making big structures or otherwise these structures may collapse, for example:
   (a) Gaps are left at the joints of a railway tracks [Fig. 14.12(a)] or else during summer due to thermal expansion the rails will bend and derail the train.
   (b) The iron bridges are not made of continuous structures. At one end the girders are left open and placed over rollers [Fig. 14.12(b)].



(a) *(b)*

Fig. 14.12 *(a) Gap in railway tracks (b) Girders in iron bridges placed on rollers*

6. While pouring hot tea in a glass tumbler it is suggested that a metallic spoon be first placed in the tumbler and the tea be poured over it. In case the tea is directly poured in the tumbler it may get cracked due to uneven expansion of its different parts.

INTEXT QUESTIONS 14.2

Fill in the blanks with the correct choice

1. A bimetallic strip is used as a thermostat in the electrical device named …………….. (electric bulb, T.V., refrigerator).
2. Melting point of 1 kg wax will be …………….. the melting point of 2 kg wax (double, half, same as).
3. Latent heat of evaporation is measured in …………….. (J, J/K, J/kg).
4. 1 kg steam at 100 °C has 2260 J …………….. heat than water at 100 °C (more, less).
5. The cubical expansivity of a substance is …………….. its linear expansivity (equal to, two times, three times)
6. The expansivity of …………….. is maximum. (solids, liquids, gases).

14.6 SPECIFIC THERMAL CAPACITY OF A MATERIAL

When two bodies at different temperatures are kept in contact, heat is transferred from the hot body to the cold body till both of them acquire the same temperature. The two bodies then are called in **thermal equilibrium.** In acquiring thermal equilibrium the hot body loses heat and the cold body acquires an equal amount of heat, i.e., heat lost by hot body = heat gained by cold body, provided we assure that there is no loss of heat to the surrounding.

It can be seen that if the temperature of hot body is more, the rise in the temperature of cold body will also be more i.e. heat transferred from a hot body to a cold body is directly proportional to their temperature difference,

$$Q \propto \Delta\theta$$

Similarly it can be shown that if the mass of cold body is more it will absorb more heat from the cold body

i. e. $\qquad Q \propto m$

so, $\qquad Q \propto m\Delta\theta$

$$= ms\Delta\theta$$

Where s is a constant of proportionality which depends on the nature of the material of the body. This is also called as the specific heat capacity of the material.

The specific heat capacity of a material is defined as the amount of heat (in Joule) required to raise the temperature of 1kg mass of that material through 1 K.

The SI Unit of specific heat capacity (or simply specific heat) is J kg^{-1} K^{-1}

The specific heat capacities of different materials may have different values. Table 4.3.3 gives the specific heat of some materials.

Table 14.3 Specific heats of some materials at 20°C

S. No.	Substance	Specific Heat		Substance	Specific Heat	
		J kg^{-1} K^{-1}	Cal kg^{-1} K^{-1}		J kg^{-1} K^{-1} × 10^3	Cal kg^{-1} K^{-1}
1	Aluminium	875	0.29	Ethyl alcohol	2.436	0.58
2	Copper	380	0.091	Methyl alcohol	2.562	0.61
3	Caste Iron	500	0.119	Benzene	1.680	0.40
4	Wrought Iron	483	0.115	Ethene	2.352	0.56
5	Steel	470	0.112	Glycerin	2.478	0.59
6	Lead	130	0.031	Mercury	0.140	0.033
7	Brass	396	0.092	Turpentine	1.800	0.42
8	Ice	2100	0.502	Water	4.200	1.00

From the table it is clear that of all substances water has highest value of specific heat.

Higher the value of specific heat of a substance lower will be the rate at which it is heated or cooled as compared to the substance of lower specific heat under identical conditions.

INTEXT QUESTIONS 14.3

Choose the correct alternative

1. Two iron balls of radii r and $2r$ are heated to the same temperature. They are dropped in 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 than that in A.
   (d) in B will be four times than that in A.
2. An iron ball A of mass 2 kg at temerature 20°C is kept in contact with another iron ball B of mass 1.0 kg at 20°C. The heat energy will flow
   (a) from A to B only
   (b) from B to A only
   (c) in neither direction
   (d) Initially from A to B and then from B to A.
3. When solid ice at 0°C is heated, its temperature
   (a) rises (b) falls
   (c) does not change until whole of it melts.
   (d) first rises then falls back to 0°C.
4. When steam at 100°C is heated its temperature
   (a) does not change. (b) increases
   (c) decreases (c) none of these
5. Specific heat of aluminium is almost two times the specific heat of copper. Equal amount of heat is given to two pieces of equal masses of copper and iron respectively. Rise in temperature of
   (a) Copper will be equal to that of aluminium.
   (b) Copper will be twice the rise in temperature of aluminium.
   (c) Copper will be half the rise in temperature of aluminium.
   (d) Copper will be four times the rise in temperature of aluminium.

6. Equal heat is given to three pieces of copper A, B, and C having masses in the ratio 1:2:3. The rise in temperature will be in the order
   (a) $A > B > C$ (b) $B > C > A$
   (c) $C > B > A$ (d) $A > C > B$

WHAT YOU HAVE LEARNT

- Thermal energy is a form of energy and like any other form of energy can be used to do work. Therefore, the SI unit of thermal energy is also joule (J)
- Temperature is a measure of degree of hotness of a body and is measured in degree Fahrenheit (°F) or degree celsius (°C) or kelvin (K), with the help of a thermometer.
- The three scales of temperature are related as $\frac{C}{100} = \frac{F-32}{180} = \frac{K-273}{100}$
- When change of state does not take place on heating a body its temperature rises. The heat which does not become apparent in the form of rise in temperature during change of state is called latent heat.
- There are two types of latent heat (i) Latent heat of fusion of a solid. (ii) Latent heat of vaporization of a liquid
- The constant temperature at which a solid melts is called its melting point and the constant temperature at which a liquid boils is called its boiling point. Melting point and boiling point are characteristic properties of the substance.
- All substances expand on heating but different substances expand to different extents when heated for same rise in temperature.
- Expansivity of a substance is a constant. Expansivity of different substances are different.
- Liquids expand more than solids and gases expand very much more than liquids.
- Due to difference in expansivity of two metals a bimetallic strip bends on heating, This property of bimetallic strips is used in thermostats.
- Heat energy flows from a body at higher temperature to a body at lower temperature till both of them acquire a common final temperature.

TERMINAL EXERCISE

1. Distinguish clearly between heat and temperature.
2. During change of state: (i) Is there a rise in temperature of the material on heating it? and (ii)What happens to the heat we supply?

3. Name the factors on which the thermal expansion of a wire depends.
4. Give any two uses of a bimetallic strip.
5. If you have a uncalibrated mercury thermometer how will you calibrate it into a
   (a) celsius thermometer (b) fahrenheit thermometer.
6. Explain the following:
   (i) Why is mercury used as a thermometric liquid?
   (ii) Why does a bimetallic strip bend on heating?
   (iii) Why does steam at 100°C gives more severe burns than water at 100°C?
   (iv) Why do we use ice for cooling our drinks and not water at 0°C.?
7. Why is the heat given at the time of change of state called latent heat?
8. A certain amount of water is heated at a constant rate. The time to bring it to boiling is t_1 and the time required from beginning of boiling to boiling off the whole amount is t_2. Which is greater t_1 or t_2? Why?
9. At what temperature the numerical value of temperature on fahrenheit scale will be double the value on celsius scale.
10. A 50 cm silver bar shortens by 1.0 mm when cooled. How much was it cooled?
    (Given: Coefficient of linear expansion of silver = 18×10^{-6} per degree celsius)
11. How much heat energy is required to change 200 g of ice at –20°C to water at 70°C?
    (Given: Latent heat of fusion of ice = 335 kJ kg^{-1}, and specific heat of ice = 2100 J kg^{-1} $°C^{-1}$, specific heat of water = 4.2 kJ kg^{-1} $°C^{-1}$)

ANSWER TO INTEXT QUESTIONS

14.1

(i) False	(ii) False	(iii) True
(iv) True	(v) True	(vi) True

14. 2

1. refrigerator	2. same as	3. J/kg
4. more	5. three times	6. gases

4.3

1. (d)	2. (c)	3. (c)
4. (b)	5. (b)	6. (a)