

- 7 State and explain Archimedes principle.
- 8 What is elasticity? Explain.
- 9 State and explain Hooke's law.
- 10 Define and explain, Stress, Strain and Young's modulus

NUMERICAL QUESTIONS

- 1 A rectangular glass block of dimensions 30 cm by 5 cm by 10 cm weighs 37.5 N. Calculate the least and the greatest pressure it can exert when resting on a horizontal table?
- 2 What is the height of a water barometer at atmospheric pressure?
- 3 The small piston of a hydraulic lift has an area of 0.20 m^2 . A car weighing $1.20 \times 10^4 \text{ N}$ sits on a rack mounted on the large piston. The large piston has an area of 0.90 m^2 . How large a force must be applied to the small piston to support the car?
- 4 The deepest point in the ocean is 11 km below sea level, deeper than Mt. Everest is tall. What is the pressure in atmospheres at this depth?
- 5 A block is fully immersed in water. Before the immersion the block weighed 30 N and while immersed, its apparent weight was found to be 25 N. Calculate (a) the upthrust on the block (b) the weight of the water displaced, (c) the volume of water displaced, (d) the volume of the block, and (e) the density of the block.
- 6 When a weight of 30 N is hung from a wire of original length 2.0 m, its new length becomes 2.20 m. Calculate the force constant for the wire, if the elastic limit is not exceeded?
- 7 An 80-cm-long, 1.0-mm-diameter steel guitar string must be tightened to a tension of 2000 N by turning the tuning screws. By how much is the string stretched?

WEB LINK

<http://www.strangematterexhibit.com/whatis.html>

NOT FOR SALE

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Unit

8

THERMAL PROPERTIES OF MATTER

High temperature and heat are evident in this fire-breathing performance. The performer sprays the fuel (highly purified lamp oil is a preferred choice) in order to create a fine mist, which facilitates the combustion. A good technique is essential to keep the flame far enough away from the face to minimize the risk of injury.

CHECK LIST

After studying this unit you should be able to:

- ✓ define temperature (as quantity which determine the direction of flow of thermal energy).
- ✓ define heat (as the energy transferred resulting from the temperature difference between two objects).
- ✓ list basic thermometric properties for a material to construct a thermometer.
- ✓ convert the temperature from one scale to another (Fahrenheit, Celsius and Kelvin scales).
- ✓ describe rise in temperature of a body in term of an increase in its internal energy.
- ✓ define the terms heat capacity and specific heat capacity.
- ✓ describe heat of fusion and heat of vaporization (as energy transfer without a change of temperature or change of state).
- ✓ describe experiments to determine heat of fusion and heat of vaporization of ice and water respectively by sketching temperature-time graph on heating ice.
- ✓ explain the process of evaporation and the difference between boiling and evaporation.
- ✓ explain that evaporation causes cooling.
- ✓ list the factors which influence surface evaporation.
- ✓ describe qualitatively the thermal expansion of solids (linear and volumetric expansion).
- ✓ explain the thermal expansion of liquids (real and apparent expansion).
- ✓ solve numerical problems based on the mathematical relations learnt in this unit.

NOT FOR SALE

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The study of heat transformations into other forms of energy, called thermodynamics, began with the eighteenth-century engineers who built the first steam engines. These steam engines were used to power trains, factories, and water pumps for coal mines, and thus they contributed greatly to the Industrial Revolution. Although the study of thermodynamics began in the eighteenth century, it was not until around 1900 that the concepts of thermodynamics were linked to the motions of atoms and molecules in solids, liquids, and gases.

Today, the concepts of thermodynamics are widely used in various applications that involve heat and temperature. Engineers use the laws of thermodynamics to continually develop higher performance refrigerators, automobile engines, aircraft engines, and numerous other machines.

8.1 TEMPERATURE

Temperature is a concept we all understand from experience. Even as small children we learn to perceive hotness and coldness of objects. We hear weather forecasters tell us that the temperature will be 32°C today. We hear doctors tell us that our body temperature is 98.6°F . We know from General Science for class 8, chapter 9: SOURCES AND EFFECTS OF HEAT ENERGY, that temperature is defined as 'the measure of the degree of hotness or coldness of a body with respect to some standard'.

Temperature is measured in $^{\circ}\text{C}$, $^{\circ}\text{F}$, and K. Here we would extend our understanding of temperature on the basis of kinetic molecular description. According to this theory atoms and molecules are in continuous random motion. According to this theory, the temperature can also be defined as: 'The average kinetic energy of molecules of a body'.

INFORMATION



Death Valley, California: The hottest place on Earth, in summer temperature reach to 56°C .



The Antarctic: During the continuous darkness of mid-winter, the temperature here can be as low as -87°C .

Internal Energy and Temperature:

Internal energy is the sum of the kinetic and potential energies associated with the motion of the atoms of the substance. For example, in a gas made up of

single atoms (monoatomic gas), such as helium, the atoms move around, randomly colliding with each other and the walls of the container. So each atom has some translational kinetic energy. However, if the gas is made up of molecules with two or more atoms, the molecules can also stretch, contract and spin, so these molecules also have other types of kinetic energy called vibrational and rotational kinetic energy.

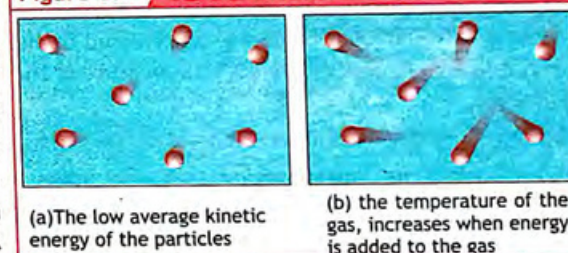
Like a gas, molecules in a liquid are free to move, but within the confines of the surface of the liquid. There is some attraction between molecules, which means there is some energy stored as molecules approach each other.

In a solid, atoms jiggle rather than move around. They have kinetic energy, but they also have a lot of potential energy stored in the strong attractive force that holds the atoms together.

Temperature is a measure of the average kinetic energy of particles. The other contributions to the internal energy do not affect the temperature. The kinetic energy may be in the form of translational, vibrational and rotational kinetic energy. As atoms or molecules of the material are in constant motion, at high temperatures the kinetic energy of molecules is more and at lower temperatures it is less.

As atoms or molecules of the material are in constant motion, at high temperatures the kinetic energy of molecules increases. The monoatomic gas is shown in the figure 8.1 which only have translational kinetic energy, at high temperature the increase in translational kinetic energy is observed.

Figure 8.1 TEMPERATURE



(a) The low average kinetic energy of the particles

(b) the temperature of the gas, increases when energy is added to the gas

8.2 HEAT

Take some water in a kettle and place it on a flame. The water gradually becomes warmer and eventually starts boiling. How does it happen? In fact, the temperature of the flame is much higher than that of the kettle and the water. Something must have transferred from the hot flame to the cold water. In general temperature of any object can be raised (heated) by placing it in thermal contact with another hotter object.

For example, Water in a kettle can be heated by placing it on flame. The earth is heated by the hot sun as thermal contact.

It is evident from these examples that in the process of raising the temperature of a body something must have flown from the hotter body to the colder body. This something which flows from the hotter body to the colder body till the temperatures of the two bodies become equal is called heat. Thus we can define heat as,

Heat is thermal energy transferred from a hotter body to a colder body. When two objects with different temperatures are placed in thermal contact, the temperature of the warmer object decreases while the temperature of the cooler object increases. With time they reach a common equilibrium temperature (thermal equilibrium) somewhere in between their initial temperatures. During this process, we say that energy is transferred from the warmer object to the cooler one.

The relationship of heat to thermal energy is analogous to the relationship of work to mechanical energy we studied in Chapter 6. The symbol Q is used to represent the amount of energy transferred by heat between a system and its environment. As heat (like work) is a measure of the transfer of energy, its SI unit is joule J.

Distinguishing Temperature, Heat, and Internal Energy:

Using the kinetic theory, we can make a clear distinction between temperature, heat, and internal energy. Temperature (in kelvins) is a measure of the average kinetic energy of individual molecules. Internal energy refers to the total energy of all the molecules within the object. Thus two equal-mass hot ingots of iron may have the same temperature, but two of them have twice as much internal energy as one does. Heat, finally, refers to a transfer of energy from one object to another because of a difference in temperature.

8.3 MEASUREMENT OF TEMPERATURE

Temperature could be measured in a simple way by using our hand to sense the hotness or coldness of an object. However, the range of temperatures that our hand can bear is very small, and our hand is not precise enough to measure temperature correctly.

Temperature measurement in today's industrial environment encompasses a wide variety of needs and applications. To meet this wide array of needs

Figure 8.2 HEAT



inventors has developed a large number of sensors and devices to handle this demand. The branch of physics which deals with the measurements of temperature is called **thermometry**. For scientific work, we need some reliable device or instrument to measure temperature accurately. Such an instrument is called **thermometer**.

ACTIVITY TEMPERATURE SENSE CAN BE DECEPTIVE

Try an experiment at home, fill one container with water that is hot (but not too hot to touch); fill a second container with lukewarm water; and fill a third container with cold water. Put one hand in the hot water and one in the cold water for about 10 to 20 s. Then plunge both hands into the container of lukewarm water. Although both hands are now immersed in water that is at a single temperature, the hand that had been in the hot water feels cool while the hand that had been in the cold water feels warm. This demonstration shows that we cannot trust our subjective senses to measure temperature.



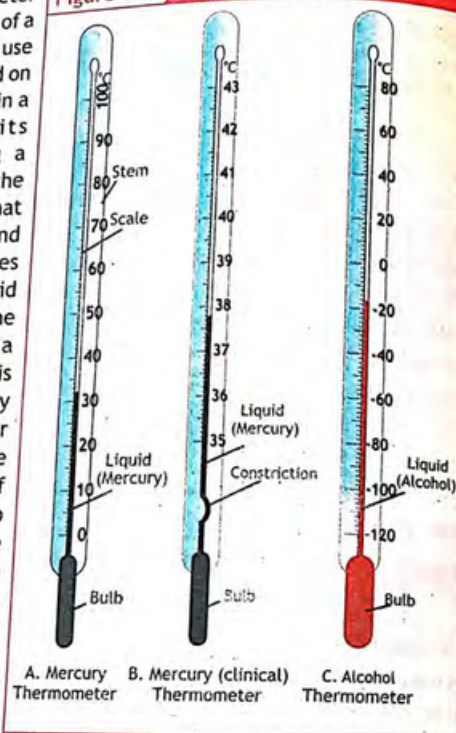
8.3.1 THERMOMETRIC PROPERTY

In order to construct a thermometer, we make use of a certain physical property of matter that increases or decreases uniformly with rise and fall in temperature. This particular property of a substance that increases and decreases uniformly with temperature and can be used for the measurement of temperature is called **thermometric property**. Some examples of thermometric properties include the volume of a liquid, length of a solid, gas pressure, electrical resistance and electromotive force.

The commonly used thermometric property is the **thermal expansion of materials**. This property make use of the fact that matter (solid, liquid or gas) expands on heating and contracts on cooling. Thus the degree of expansion or contraction of matter can be calibrated on suitable scale to record temperature. The most common of these devices is the liquid in glass thermometer.



Figure 8.3 THERMOMETERS



The Liquid in Glass thermometer utilizes the variation in volume of a liquid in temperature. They use the fact that most fluids expand on heating. The fluid is contained in a sealed glass bulb, and its expansion is measured using a scale etched in the stem of the thermometer. If we consider that the thermometer does not expand then as physical property it utilizes the variation of length of liquid with temperature. In this type the liquid in a glass bulb expands up a capillary tube when the bulb is heated. The liquid must be easily seen and must expand (or contract) rapidly and by a large amount over a wide range of temperature. It must not stick to the inside of the tube or the reading will be too high when the temperature is falling. Liquids commonly used include Mercury and Alcohol. Different Thermometers are shown in the figure 8.3.

8.3.2 TEMPERATURE SCALES

The scale which is made for the measurement of temperature is called temperature scale or thermometric scale. The scale comprises of two reference points, called fixed points. These points are given arbitrarily assigned numerical values. They must be reproducible. The interval between these points is divided arbitrarily into equal divisions.

There are three scales of temperature which are commonly used.

A. Centigrade or Celsius scale:

This scale was introduced by a Swedish astronomer Anders

INFORMATION

Centigrade scale and Fahrenheit scale are the modified form of kelvin scale. Centigrade scale is used in laboratory for scientific purposes and fahrenheit scale is used for clinical purposes to measure the temperature of patient.

Celsius. In this scale of temperature, the ice point marked as 0°C and the steam fixed point is marked as 100°C at standard pressure. The interval between these two fixed points is divided into 100 equal parts (divisions). Each division on the scale is called one degree centigrade or Celsius and denoted by $^{\circ}\text{C}$.

B. Fahrenheit Scale:

This scale was introduced by German physicist Daniel Gabriel Fahrenheit. In this scale of temperature, the ice point marked as 32°F and the steam point is marked as 212°F . The interval between these points is divided into 180 equal parts. Each part on the scale called one degree Fahrenheit and is denoted by $^{\circ}\text{F}$.

C. Kelvin or Absolute Scale:

This scale was devised by William Thomson, (Lord Kelvin). He named this scale as absolute scale. In this scale of temperature, the ice points is marked as 273 K and the boiling point of water marked as 373 K. Thus the interval between them is divided into 100 equal parts. Each part on the scale is called one Kelvin and denoted by K.

The lowest temperature at which the molecular movements of matter ceases is called Kelvin Zero or absolute zero. Its magnitude on the Celsius scale is -273°C . Kelvin scale is adopted in the international system (SI) of units.

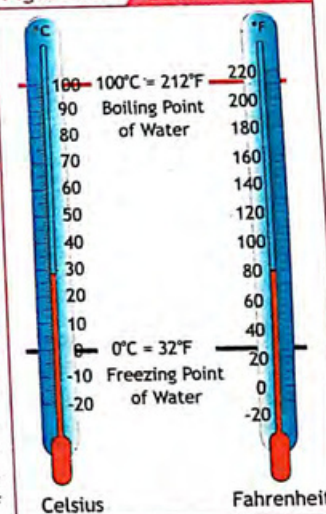
8.3.3 RELATIONSHIP BETWEEN DIFFERENT SCALES of Temperature

A temperature measured on one scale, sometimes, needs conversion to another scale. Let $^{\circ}\text{C}$, $^{\circ}\text{F}$ and K, as measured on the three scales, denote the same temperature. The length of the mercury column in the capillary of the thermometer is of fixed value. Degrees of temperature are measured from the ice - point which are respectively 0°C , 32°F and 273 K. A general relation for the conversion of temperature from one scale to the other is

$$\frac{\text{Temperature on one scale} - \text{ice point}}{\text{number of divisions between fixed points}} = \frac{\text{Temperature on other scale} - \text{ice point}}{\text{number of divisions between fixed points}}$$

$$\text{or } \frac{T_{\text{Scale 1}} - T_{\text{ice}}}{N} = \frac{T_{\text{Scale 2}} - T_{\text{ice}}}{N} \quad \text{8.1}$$

Figure 8.4 COMPARISON



A. Conversion Between centigrade and Fahrenheit scale

Using the general relation we have

$$\frac{T_{°C} - 0}{100} = \frac{T_{°F} - 32}{180}$$

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

$$\text{or } T_{°C} = 100 \times \left[\frac{T_{°F} - 32}{180} \right]$$

$$\text{or } T_{°C} = \frac{100}{180} (T_{°F} - 32)$$

$$\text{therefore } T_{°C} = \frac{5}{9} \times (T_{°F} - 32) \quad \text{8.2}$$

$$\text{or } T_{°F} = \frac{9}{5} T_{°C} + 32 \quad \text{8.3}$$



Conversion Between Centigrade and Kelvin scale

Using the general relation we have

$$\frac{T_{°C} - 0}{100} = \frac{T_K - 273}{100}$$

$$\text{therefore } T_{°C} = T_K - 273 \quad \text{8.4}$$

$$\text{or } T_K = T_{°C} + 273 \quad \text{8.5}$$

? CAN YOU TELL?
How would we convert °F into K?

Example 8.1 HUMAN BODY TEMPERATURE

The temperature of a normal human body is 37°C. Find this temperature on the Fahrenheit and Kelvin Scale.

SOLUTION

GIVEN:

Celsius Temperature $T_{°C} = 37^{\circ}\text{C}$ To convert °C into °F, we use $T_{°F} = \frac{9}{5} T_{°C} + 32$

$$T_{°F} = \frac{9}{5} \times 37^{\circ}\text{C} + 32^{\circ}\text{C}$$

$$\text{or } T_{°F} = 66.6^{\circ}\text{C} + 32^{\circ}\text{C}$$

$$\text{therefore } T_{°F} = 98.6^{\circ}\text{C}$$

REQUIRED:

Fahrenheit Temperature $T_{°F} = ?$ Kelvin Temperature $T_K = ?$ thus $37^{\circ}\text{C} = 98.6^{\circ}\text{F}$ To convert °C into K, we use $T_K = T_{°C} + 273$ putting values $T_K = 37^{\circ}\text{C} + 273^{\circ}\text{C}$ therefore $T_K = 310^{\circ}\text{C}$ thus $37^{\circ}\text{C} = 310\text{ K}$ — Answer

Assignment 8.1 KELVIN SCALE

Temperature of an object is 250 K. Find its temperature in centigrade.

8.4 THERMAL EXPANSION

Thermal expansion means "increase in size of a substance on heating". Most substances expand when heated and contract when cooled. However, the amount of expansion or contraction varies, depending on the material, the change in temperature and the original size of the substance. Thermal expansion is different for different states e.g. solid, liquid or gas of the same substance. It is experienced that gases expand more than liquids and liquids expand more than solids.

8.4.1 THERMAL EXPANSION OF SOLIDS

A solid substance can undergo three types of expansion : expansion in length (linear thermal expansion), expansion in area (superficial thermal expansion) and expansion in volume (volume or cubical thermal expansion). As the temperature of a solid is raised, the molecules vibrate through larger distance. The increase in amplitude of vibration of molecules causes an increase in the average distance between them. Hence Solids expand on heating. Conversely solids contract as the temperature is lowered.

A. Linear Thermal Expansion of solids:

The increase in length of a substance due to rise in temperature is called linear thermal expansion.

Consider a metal rod having an original length ' l_0 ', at temperature ' T_0 '. After heating metal rod to temperature ' T ', the rod expand to its new length ' l_T ' as shown in the figure 8.5. This means for the change in temperature ΔT (where $\Delta T = T - T_0$), there is corresponding change in length Δl (where $\Delta l = l_T - l_0$). Experiments indicate that the change in length Δl of almost all solids is, to a good approximation, directly proportional to the change in temperature ΔT as long as is not too large. This means by changing temperature the length also change, more the change in temperature more is the change in length and vice versa.

$$\Delta l \propto \Delta T \quad \text{1}$$

The change in length Δl is also proportional to the original length l_0 of the object. That is, for the same temperature increase, a 4-m-long iron rod will increase in length twice as much as a 2-m-long iron rod. We can write this proportionality as an equation:

$$\Delta l \propto l_0 \quad \text{--- 8.5}$$

combining equation 1 and equation 2 we get

$$\Delta l \propto l_0 \Delta T$$

changing proportionality into equality

$$\Delta l = \alpha l_0 \Delta T \quad \text{--- 8.6}$$

where 'α' the proportionality constant, is called the coefficient of linear thermal expansion for the particular material and has units of °C⁻¹ and in SI as K⁻¹.

since $\Delta l = l_t - l_0$, we can write the above equation as

$$l_t - l_0 = \alpha l_0 \Delta T$$

taking l_0 common

$$l_t = l_0 + \alpha l_0 \Delta T$$

$$\text{therefore } l_t = l_0(1 + \alpha \Delta T) \quad \text{--- 8.7}$$

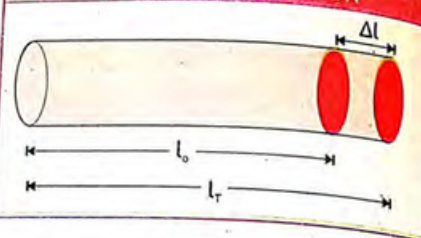
If the temperature change $\Delta T = T - T_0$ is negative, then $\Delta l = l_t - l_0$ is also negative; the length shortens as the temperature decreases.

From equation 8.6, we can define coefficient of linear thermal expansion α of a substance as the increase in length per unit length of the solid per kelvin 'K' rise in temperature.

$$\alpha = \frac{\Delta l}{l_0 \Delta T} \quad \text{--- 8.8}$$

In simple words, α is numerically the increase in 1 m long wire for 1 degree rise of temperature. The value of α depends upon the nature of material, the values of coefficients of linear thermal expansion (α) for different materials are given in the table 8.2.

Figure 8.5 LINEAR EXPANSION



Example 8.2 BRIDGE ENGINEERING

The steel ($\alpha = 12 \times 10^{-6} \text{ K}^{-1}$) bed of a suspension bridge is 200 m long at 20°C. If the extremes of temperature to which it might be exposed are -5°C to 50°C how much will it contract and expand?

GIVEN:

Original length $l_0 = 200 \text{ m}$

Coefficient of linear thermal expansion $\alpha = 12 \times 10^{-6} \text{ K}^{-1}$

Reference Temperature $T_0 = 20^\circ \text{C}$

Temperature $T_1 = -5^\circ \text{C}$

Temperature $T_2 = 50^\circ \text{C}$

REQUIRED:

(a) Change in length $\Delta l_1 = ?$

(b) Change in length $\Delta l_2 = ?$

SOLUTION

(a) When temperature decreases to -5°C the change in temperature $\Delta T_1 = T_1 - T_0 = -5^\circ \text{C} - 20^\circ \text{C} = -25^\circ \text{C}$, since the change in temperature is same in Celsius ($^\circ \text{C}$) and Kelvin scale (K). Therefore $-25^\circ \text{C} = -25 \text{ K}$. The linear thermal expansion is given by

$$\Delta l_1 = \alpha l_0 \Delta T_1$$

$$\text{putting values } \Delta l_1 = 12 \times 10^{-6} \text{ K}^{-1} \times 200 \text{ m} \times (-25 \text{ K})$$

$$\text{or } \Delta l_1 = -6 \times 10^{-2} \text{ m}$$

$$\text{therefore } \Delta l_1 = -6 \text{ cm} \quad \text{--- Answer}$$

(b) When temperature increases to 50°C change in temperature $\Delta T_2 = T_2 - T_0 = 50^\circ \text{C} - 20^\circ \text{C} = 30^\circ \text{C}$, since the change in temperature is same in Celsius ($^\circ \text{C}$) and Kelvin scale (K). Therefore $30^\circ \text{C} = 30 \text{ K}$. The linear thermal expansion is given by

$$\Delta l_2 = \alpha l_0 \Delta T_2$$

$$\text{putting values } \Delta l_2 = 12 \times 10^{-6} \text{ K}^{-1} \times 200 \text{ m} \times 30 \text{ K}$$

$$\Delta l_2 = 7.2 \times 10^{-2} \text{ m}$$

$$\text{therefore } \Delta l_2 = 7.2 \text{ cm} \quad \text{--- Answer}$$

The total range the expansion joints must accommodate is $7.2 \text{ cm} + 6 \text{ cm} = 13.2 \text{ cm}$

Assignment 8.2 COEFFICIENT OF LINEAR THERMAL EXPANSION

The length of a bar of certain metal is 60 cm. When the bar is heated from 8°C to 100°C , its length becomes 60.127 cm. Calculate the coefficient of linear thermal expansion of the metal.

B. Volume (cubical) thermal expansion of solids

The increase in volume of a substance due to rise in temperature is called volume thermal expansion.

Consider a metal block having an original volume ' V_0 ' at temperature ' T_0 '. After heating metal block to temperature ' T ', the block expand to its new volume ' V_T ' as shown in the figure 8.6. This means for the change in temperature ΔT (where $\Delta T = T - T_0$) there is corresponding change in volume ΔV (where $\Delta V = V_T - V_0$).

The increase in volume of a metal block, on heating, is directly proportional to original volume of the metal block and rise in temperature. Mathematically,

$$\Delta V \propto \Delta T \quad \text{and} \quad \Delta V \propto V_0$$

combining these proportionalities, we get

$$\Delta V \propto V_0 \Delta T$$

changing proportionality into equality

$$\Delta V = \gamma V_0 \Delta T \quad \text{--- 8.9}$$

where ' γ ' the proportionality constant, is called the coefficient of volume thermal expansion for the particular material and has units of $^{\circ}\text{C}^{-1}$ and in SI as K^{-1} .

since $\Delta V = V_T - V_0$ we can write the above equation as

$$V_T - V_0 = \gamma V_0 \Delta T$$

taking V_0 common $V_T = V_0 + \gamma V_0 \Delta T$

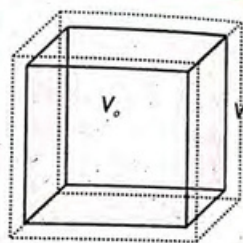
$$\text{therefore } V_T = V_0(1 + \gamma \Delta T) \quad \text{--- 8.10}$$

From equation 8.9, we can define coefficient of volume thermal expansion (γ) of a substance as the change in volume per unit volume per kelvin change in temperature.

$$\gamma = \frac{\Delta V}{V_0 \Delta T} \quad \text{--- 8.11}$$

This is a general rule for solids that they expand to the same extent in all three directions. It can be proved that the coefficient of volume thermal expansion of solids γ is about three times

Figure 8.6



Volume thermal expansion for cubical object

RECALL

General Science for class 8, chapter 9: SOURCES AND EFFECTS OF HEAT ENERGY, Thermal expansion of solids, liquids and gases. We also learned important applications of thermal expansion, we used bimetallic strip for fire alarms and automatized switching of electric iron. Also the effects of thermal expansion in daily life were discussed.

the coefficient of linear thermal expansion α of solids

$$\gamma = 3\alpha \quad \text{--- 8.12}$$

The values of coefficients of volume thermal expansion γ for different substances are given in the table 8.2, which is approximately three times the coefficient of linear thermal expansion α .

TABLE 8.2: THERMAL EXPANSION COEFFICIENTS AT 20°C

Material	Coefficient of linear expansion α ($^{\circ}\text{C}^{-1}$ or K^{-1})	Coefficient of volume expansion γ ($^{\circ}\text{C}^{-1}$ or K^{-1})
Solids		
Aluminum	25×10^{-6}	75×10^{-6}
Brass	19×10^{-6}	57×10^{-6}
Copper	17×10^{-6}	51×10^{-6}
Iron or Steel	12×10^{-6}	35×10^{-6}
Lead	29×10^{-6}	87×10^{-6}
Concrete, Brick	12×10^{-6}	36×10^{-6}
Fluids		
Ethyl alcohol	-	1100×10^{-6}
Petrol	-	950×10^{-6}
Mercury	-	180×10^{-6}
Water	-	210×10^{-6}
Air and most other gases at atmospheric pressure	-	3400×10^{-6}

To see how this relationship comes about, suppose that the solid has the shape of a cube of side L . The increment in the length of each side is ΔL , and treating this as a small (infinitesimal) quantity, the increment in the volume ΔV is

$$\Delta V = \Delta(L)^3 = 3L^2 \Delta L$$

$$\text{or } \Delta V = 3L^2 \times \alpha L \Delta T$$

$$\text{or } \Delta V = 3\alpha L^3 \Delta T$$

$$\text{therefore } \Delta V = 3\alpha V \Delta T$$

Comparing this result for ΔV with Equation 8.9, we see that $\gamma = 3\alpha$.

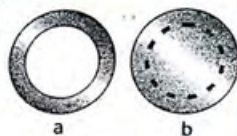
TID-BIT

DO HOLES EXPAND OR CONTRACT?

If you heat a thin, circular ring in the oven, does the ring's hole get larger or smaller?

If you guessed that the metal expands into the hole, making the hole smaller, it is not so. Imagine the ring is solid, like a coin.

Draw a circle on it with a pen as shown. When the metal expands, the material inside the circle will expand along with the rest of the metal; so the dashed circle expands. Cutting the metal where the circle is shows that the hole in Figure a increases in diameter.



INFORMATION



Place a dented Ping-Pong ball in boiling water, and you'll remove the dent. Why?

Example 8.3 GLASS LASER EXPANSION

The active element of a certain laser is made of a glass rod 30.0 cm long and having volume $5.30 \times 10^{-5} \text{ m}^3$. Assume the average coefficient of linear expansion of the glass is equal to $9.00 \times 10^{-6} \text{ K}^{-1}$. If the temperature of the rod increases by 65.0°C , what is the increase in (a) its length and (b) its volume?

GIVEN:

Original length $l_0 = 30 \text{ cm} = 0.3 \text{ m}$

Original Volume $V_0 = 5.30 \times 10^{-5} \text{ m}^3$

Coefficient of linear thermal expansion

$\alpha = 9 \times 10^{-6} \text{ K}^{-1}$

change in temperature $\Delta T = 65.0^\circ\text{C} = 65 \text{ K}$

REQUIRED:

(a) Change in length $\Delta l = ?$

(b) Change in Volume $\Delta V = ?$

(a) The linear thermal expansion is given by $\Delta l = \alpha l_0 \Delta T$

putting values $\Delta l = 9.00 \times 10^{-6} \text{ K}^{-1} \times 0.300 \text{ m} \times 65 \text{ K}$

therefore $\Delta l = 1.76 \times 10^{-4} \text{ m}$ — Answer

(b) The Volume thermal expansion is given by $\Delta V = \gamma V_0 \Delta T$

Since $\gamma = 3\alpha$, therefore $\Delta V = 3\alpha V_0 \Delta T$

putting values $\Delta V = 3 \times 9.00 \times 10^{-6} \text{ K}^{-1} \times 5.30 \times 10^{-5} \text{ m}^3 \times 65 \text{ K}$

therefore $\Delta V = 93.0 \times 10^{-9} \text{ m}^3$ — Answer

Assignment 8.3 CHANGE IN VOLUME OF LEAD

A 200 cm^3 piece of lead ($\gamma = 87 \times 10^{-6} \text{ K}^{-1}$) is at 10°C . If it is heated to a temperature of 40°C , find the change in volume of the lead.

8.4.2 THERMAL EXPANSION OF LIQUIDS

Like solids, liquids also expand on heating and contract on cooling. A liquid has no definite length and surface area; therefore, we cannot consider the linear expansion or superficial expansion of a liquid.

But liquids always take up the shape of the containing vessels. Therefore in case of liquids we are concerned only with volume changes when they are heated. The increase in the volume of a liquid due to the thermal effect of heating is called thermal expansion of liquids. Since heat affects both the liquid and the container the real expansion of a liquid cannot be detected directly. In case of liquids, we have two kinds of thermal expansion: the apparent expansion and the real expansion.

A. Real expansion of liquid:

A real increase in the volume of a liquid, that takes place due to increase of temperature is called real expansion V_R of liquid. This expansion is independent of the expansion of the container.

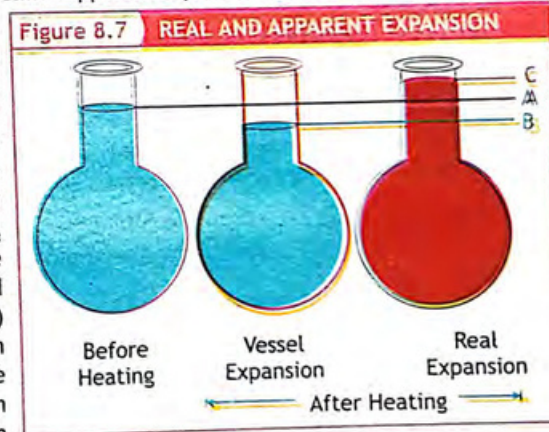
B. Apparent expansion of liquid:

An apparent increase in the volume of a liquid, that takes place due to increase of temperature is called apparent expansion V_A of liquid.

When a liquid is taken in a container and heated, both the liquid and the container expand at same time. The difference of these expansions are called apparent expansion. If V_R is the expansion in the volume of the liquid (called real expansion) and V_C is the expansion in the volume of the container on heating then the apparent expansion V_A is given by as;

$$V_A = V_R - V_C \quad \text{--- 8.13}$$

Let a vessel has water up to level A. If heat is applied, the vessel will first expand which will produce an illusion that the water has fallen. This is due to the



expansion of the vessel and is given by the measurement of the difference of the two levels i.e. AB.

If heating is further done, heat energy will start reaching the liquid. The liquid will then start expanding rapidly, according to its nature, exceeding its previous level, to reach up to level C. So the measurement of BC gives the true (real) expansion of the liquid only.

An observer present at the start and at the end will see the whole episode as just the expansion of the liquid from A to C. So AC measures the apparent expansion of the body. Mathematically,

$$BC = AC + AB$$

Or, Real Expansion of liquid = Apparent Expansion of liquid + Vessel Expansion

Since there are two different types of expansion of liquids, their coefficients of expansion should also be defined differently.

C. **Coefficient of Real Expansion ' γ_R ' :**

It is defined as the real increase on volume of liquid per unit original volume per unit degree rise in temperature. It is defined as:

$$\gamma_R = \frac{\text{real increase in volume}}{\text{original volume} \times \text{rise in temperature}} \quad \text{8.14}$$

Its unit is per degree rise in temperature i.e. $^{\circ}\text{C}^{-1}$ or K^{-1} .

D. **Coefficient of Apparent Expansion ' γ_A ' :**

It is defined as the apparent increase in volume of liquid per unit original volume per unit degree rise in temperature.

$$\gamma_A = \frac{\text{apparent increase in volume}}{\text{original volume} \times \text{rise in temperature}} \quad \text{8.15}$$

Its unit is per degree rise in temperature i.e. $^{\circ}\text{C}^{-1}$ or K^{-1} .

E. **Anomalous Expansion of Water:**

Liquids expand on heating except water between 0°C and 4°C . Water is unusual in its expansion characteristics. When water at 0°C is heated, its volume decreases upto 4°C and from 4°C its volume increases with the increase of



temperature. This peculiar behaviour of water is called anomalous expansion of water. Due to the formation of more number of hydrogen bonds, water has anomalous expansion.

As the temperature increases from 0°C to 4°C , the density increases and as the temperature further increases the density decreases. Hence water has maximum density at 4°C . This is why ice floats on water, we can see this when we put ice cubes in water to cool it or icebergs floating in ocean.

Example 8.4 LOST DIESEL

An oil trucker loaded 37,000 L of diesel fuel with $\gamma = 9.5 \times 10^{-4} \text{ K}^{-1}$ at Jackobabad, where on hot day the temperature is 50°C . This oil is transported to Kalam where on cold day the temperature is 0°C . What is the change in volume of diesel? How many liters did he deliver?

SOLUTION

GIVEN:

Original volume $V_o = 37000 \text{ L}$

Coefficient of volume thermal expansion

$$\gamma = 9.5 \times 10^{-4} \text{ K}^{-1}$$

$$\text{Change in Temperature } \Delta T = 0^{\circ}\text{C} - 50^{\circ}\text{C} = -50^{\circ}\text{C} = -50 \text{ K}$$

REQUIRED:

(a) Change in volume $\Delta V = ?$

(b) Volume Delivered $V_D = ?$

(a) The volume of the diesel fuel depends directly on the temperature. Thus, because the temperature decreased, the volume of the fuel also decrease.

The volume thermal expansion is given by

$$\Delta V = \gamma V_o \Delta T$$

$$\text{putting values } \Delta V = 9.5 \times 10^{-4} \text{ K}^{-1} \times 37000 \text{ L} \times -50 \text{ K}$$

$$\text{therefore } \Delta V = -1757.5 \text{ L} = -1760 \text{ L} \quad \text{Answer}$$

(b) A decrease in 1760 liters is observed and the amount delivered was

$$V_D = V_o + \Delta V = 37000 \text{ L} - 1760 \text{ L}$$

$$\text{therefore } V_D = 35240 \text{ L} \quad \text{Answer}$$



Assignment 8.4 CHANGE IN VOLUME OF PATROL

If patrol at 0°C occupies 250 Liters. What is its volume at 50°C ? For patrol take $\gamma = 9.6 \times 10^{-4} \text{ K}^{-1}$.

8.4.3 APPLICATIONS AND CONSEQUENCES OF THERMAL EXPANSION

Thermal expansion is used in our daily life. In thermometers, already we have seen the use of thermal expansion to measure temperature.

A. Railway lines:

When railway tracks are laid the engineers leave a small gap between two rails as shown in figure A. If two railway tracks are laid together without any gap between them they will push against each other when they expand with the rise of temperature. This may cause them to bend as shown in figure B or tracks may also break free from one another. Such a situation will result in the derailment of the trains causing major accidents and loss of lives.

So, the railway engineers always leave a small gap between two rails to compensate for the expansion of the rails during the hot summer and contraction during cold winter.

B. Opening a tight jar lid:

When the lid of a glass jar is too tight to open, holding the lid under hot water for a short time will often make it easier to open. The top expands before the heat reaches the bottle. But even if not, metals generally expand more than glass for the same temperature change (α is greater)

C. Transmission Lines:

Transmission lines in the summer sag more as compared to winter.

D. Shrink-fitting' of axles into gear wheels:

The axles have been shrunk by cooling in liquid nitrogen at -196°C until the gear wheels can be slipped on to them. On regaining normal temperature the axles expand to give a very tight fit.



E. Expand fitting' iron ring to a cart wheel:

An iron ring can be tightly fixed into the wooden wheel of a Tonga. At room temperature, the diameter of the iron ring is slightly less than the diameter of the wooden wheel. The ring expands on heating and can be placed around the wooden wheel. When the ring comes to room temperature, it contracts and produces a tight fit.



F. Expansion Joints:

Most large bridges include expansion joints, which look rather like two metal combs facing one another, their teeth interlocking. When heat causes the bridge to expand during the sunlight hours of a hot day, the two sides of the expansion joint move toward one another; then, as the bridge cools down after dark, they begin gradually to retract. Thus the bridge has a built-in safety zone; otherwise, it would have no room for expansion or contraction in response to temperature changes.



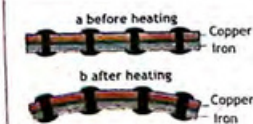
G. Bimetallic Strip:

A bimetallic strip is used to convert a temperature change into mechanical displacement. The strip consists of two strips of different metals which expand at different rates as they are heated. When their temperature increases, the unequal amounts of expansion causes the bimetallic strip to bend as shown in Figure.

For example if equal lengths of two different metals, such as copper and iron, are riveted together so that they cannot move separately, they form a bimetallic strip. When heated, copper expands more than iron and to allow this the strip bends with copper on the outside. If they had expanded equally, the strip would have stayed straight. Bimetallic strips have many uses, like fire alarm and thermostat.



When the thin bimetal strip is heated, it bends because of unequal expansion of the two metals. Here brass expands more than steel when heated, making the strip bend toward the steel side.



8.5 HEAT CAPACITY AND SPECIFIC HEAT CAPACITY

When a substance absorbs heat its temperature rises. Conversely, when a substance loses heat, its temperature decreases. Experiments show that the thermal response of different materials to heat absorption is different. For example water requires a lot of heat to change its temperature while silver requires less heat to change its temperature. A massive body requires more heat energy to raise its temperature to a certain value than a lighter body of the same material.

8.5.1 HEAT CAPACITY (THERMAL CAPACITY)

The quantity of heat required to raise the temperature of a substance of mass (m) by 1°C or 1 K is called the heat capacity (c_m) of that substance.

If ΔQ is the change in heat and ΔT is the change in temperature, then

$$c_m = \frac{\Delta Q}{\Delta T} \quad \text{--- 8.16}$$

The value of ' c_m ' depends upon

1. The nature of the material of the substance.
2. The mass of the material of the substance.
3. The rise in temperature.

In the Standard International System the unit of heat capacity is joule per Kelvin which is expressed as J K^{-1} .

8.5.2 SPECIFIC HEAT CAPACITY (SPECIFIC HEAT)

If we take equal amounts of different substances for example copper, iron and water. Heat them for a given interval of time under the same flame so that they all absorb the same amount of heat energy from the heat source. At the end of the interval, the rise in temperature is not the same for all. It is maximum for copper, minimum for water and intermediate for iron. This shows that copper is heated quickly where as water very slowly. This means that if they are all heated so as to have the same rise in temperature, copper will need least amount of heat and the water will need the greatest amount for this purpose.

The quantity of heat required to raise the temperature of unit mass (1.0 kg) of the substance by 1°C or 1 K is called specific heat capacity of that substance. Mathematically

$$c = \frac{c_m}{m}$$

$$c = \frac{\Delta Q}{m \Delta T} \quad \text{--- 8.17}$$

putting value of c_m from equation

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The S.I. unit of specific heat capacity or specific heat is joule per kilogram per Kelvin which is expressed as $\text{J kg}^{-1} \text{K}^{-1}$.

Different substances have different specific heat. The quantity of heat needed also depends on the nature of the material; raising the temperature of 1 kg of water by 1 K (1°C) requires 4190 J of heat, but only 910 J is needed to raise the temperature of 1 kg of aluminum by 1 K (1°C). The specific heat of water at 15°C is $4190\text{ J kg}^{-1} \text{K}^{-1}$. No other substance has a high specific heat capacity and it has natural benefits in sustaining life on the planet earth.

8.5.3 IMPORTANCE OF THE HIGH SPECIFIC HEAT CAPACITY OF WATER

The specific heat capacity of water is equal to $4190\text{ J kg}^{-1} \text{K}^{-1}$. It has some important implications.

A. Moderate climate of sea shore:

The specific heat of sand is about $800\text{ J kg}^{-1} \text{K}^{-1}$ about. A certain mass of water needs five times more heat than the same mass of soil for its temperature to rise by 1°C or 1 K . Hence, the land gets heated much more easily than water. Also, it cools down much easily. Hence, a large difference in temperature is formed that gives rise to land breeze and sea breeze. It keeps the climate of the coastal areas moderate. Monsoon in Pakistan is also due to the difference in temperature between the land and the surrounding sea.

B. As a coolant:

Water is used as an effective coolant. By allowing water to flow in radiator pipes of the vehicles, heat energy from such parts is removed. Thus, water extracts much heat without much rise in temperature.

TABLE 8.3: SPECIFIC HEATS OF VARIOUS SUBSTANCES

Materials	Specific heat $\text{J kg}^{-1} \text{K}^{-1}$
Aluminum	910
Copper	387
Glass	840
Gold	129
Iron/ steel	452
Lead	128
Silver	230
Wood	1700
Ethanol	2450
Glycerin	2410
Mercury	139
Water	4190
Air	721
Carbon dioxide	638
Oxygen	651
Steam (100°C)	1520

INFORMATION

These two blocks of metal (aluminum on the left and lead on the right) have equal volumes. In addition, they were heated to equal temperatures before being placed on the block of paraffin wax. Notice, however, that the aluminum melted more wax—and hence gave off more heat—even though the lead block is about 4 times heavier than the aluminum block. The reason is that lead has a very small specific heat; in fact, lead's specific heat is about 7 times smaller than the specific heat of aluminum. As a result, even this relatively large mass of lead melts considerably less wax per degree of temperature change than the lightweight aluminum.



Example 8.5 AMOUNT OF HEAT TO RAISE THE TEMPERATURE OF WATER

How much heat is required to increase the temperature of 0.5 kg of water (with specific heat capacity of $4190 \text{ J kg}^{-1} \text{ K}^{-1}$) from 10°C to 65°C ?

SOLUTION

GIVEN:

Mass of water $m = 0.5 \text{ kg}$ Initial temperature $T_i = 10^\circ\text{C}$ Final temperature $T_f = 65^\circ\text{C}$ Rise in temperature $\Delta T = T_f - T_i = 65^\circ\text{C} - 10^\circ\text{C} = 55^\circ\text{C} = 55 \text{ K}$ Specific heat of water $c = 4190 \text{ J kg}^{-1} \text{ K}^{-1}$

The specific heat capacity is given by

$$c = \frac{\Delta Q}{m \Delta T}$$

$$\text{or } \Delta Q = cm \Delta T$$

$$\text{putting values } \Delta Q = 4190 \text{ J kg}^{-1} \text{ K}^{-1} \times 0.5 \text{ kg} \times 50 \text{ K}$$

$$\text{therefore } \Delta Q = 104750 \text{ J} \quad \text{— Answer}$$

REQUIRED:

Heat required, $\Delta Q = ?$

Assignment 8.5 SPECIFIC HEAT OF SILVER

If 117.60 J of heat is required to raise the temperature of 10 g of silver through 50°C . Calculate the specific heat of silver.

LAB WORK

To find specific heat by method of mixture using Polystyrene cups (used as containers of negligible heat capacity).

8.6 LATENT HEAT AND PHASE CHANGE

A substance usually undergoes a change in temperature with transfer of energy (heat). In some cases, however, the transfer of energy doesn't result in a change in temperature. This can occur when the physical characteristics of the substance change from one form to another, commonly referred to as a phase change. Some common phase changes are solid to liquid (melting), liquid to gas (boiling), liquid to solid (freezing) and gas to liquid (condensation).

Energy used to cause a phase change does not cause a temperature change. When ice melts at 0°C it becomes water at 0°C ; when water boils at 100°C , it becomes steam at 100°C . The same is true in reverse: When water at 0°C freezes it becomes ice at 0°C ; when steam at 100°C condenses it becomes water at 100°C .

The heat required to change the physical state of a substance (solid into a liquid or vapour, or a liquid into a vapour) but does not change its temperature is called latent heat of that substance.

8.6.1 LATENT HEAT OF FUSION

The amount of heat energy required to convert a given mass of a substance from the solid state to the liquid state (melt) with out any rise in temperature is called its latent heat of fusion. Liquids release the same amount of heat when they solidify (freeze).

Specific latent heat of fusion:

The amount of heat energy required to convert unit mass (one kilogram) of the solid at its melting point to liquid, (or liquid into solid) with out any change in temperature is called its specific latent heat of fusion of the solid. If ' ΔQ ' is the amount of heat energy needed to melt mass ' m ' of a solid to liquid (or freeze liquid to solid), then mathematically

$$\Delta Q = mL_f \quad \text{— 8.18}$$

Where L_f is the latent heat of fusion of substance and is given as

$$L_f = \frac{\Delta Q}{m} \quad \text{— 8.19}$$

The S.I. unit of specific latent heat of fusion is joule per kilogram which is expressed as J kg^{-1} . Different substances have different specific latent heat of fusion.

TID-BIT

As a thermometer comes into thermal equilibrium with an object, the object's temperature changes slightly. In most cases the object is so massive compared with the thermometer that the object's temperature change is insignificant.

8.6.2 LATENT HEAT OF VAPORIZATION

The amount of heat energy required to convert a given mass of a substance from the liquid state to the gaseous state (boil) without any rise in temperature is called its latent heat of vaporization. Gases release the same amount of heat when they liquify (condense).

Specific latent heat of vaporization:

The amount of heat energy required to convert unit mass (one kilogram) of the liquid at its melting point to gas, (or gas into liquid) without any change in temperature is called its specific latent heat of vaporization of the solid. If ' ΔQ ' is the amount of heat energy needed to vaporize mass ' m ' of a liquid to gas (or condense gas to liquid), then mathematically

$$\Delta Q = mL_v \quad \text{8.20}$$

Where L_v is the latent heat of vaporization, such that

$$L_v = \frac{\Delta Q}{m} \quad \text{8.21}$$

The S.I. unit of specific latent heat of vaporization is joule per kilogram which is expressed as J kg^{-1} . Different substances have different specific latent heat of vaporization.

8.6.3 EXPERIMENT FOR ICE - WATER PHASE CHANGE AND TEMPERATURE-TIME GRAPH ON HEATING ICE

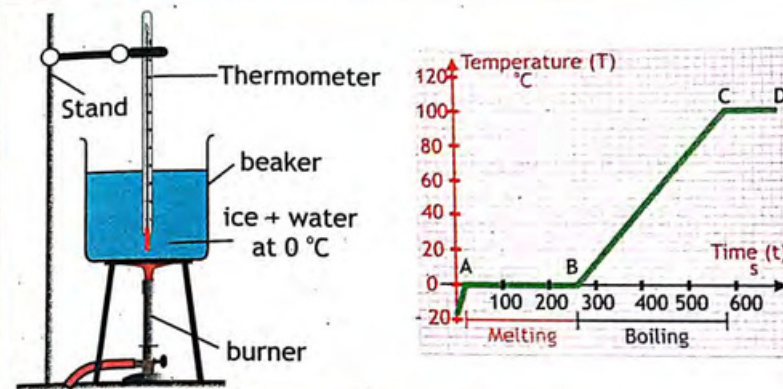
Take a beaker and place it over a stand. Put small pieces of ice in the beaker and suspend a thermometer in the beaker to measure the temperature. Place a burner under the beaker. The ice will start melting. The temperature of the mixture containing ice and water will not increase above 0°C until all the ice melts. Note the time which the ice takes to melt completely into water at 0°C . Continue heating the water at 0°C in the beaker. Its temperature will start to increase. Note the time which the water in the beaker takes to reach its boiling point at 100°C .

Draw a temperature-time graph such as shown in figure. From the graph we can see that at curve 'AB', even we were providing heat to the ice water mixture but the temperature remained constant at 0°C . At point B, all the ice has melted to form water.

LAB WORK

- To draw graph between temperature and time when ice is converted into water and then to steam by slow heating.
- To measure specific heat of fusion of ice.

Figure 8.8 ICE WATER PHASE CHANGE

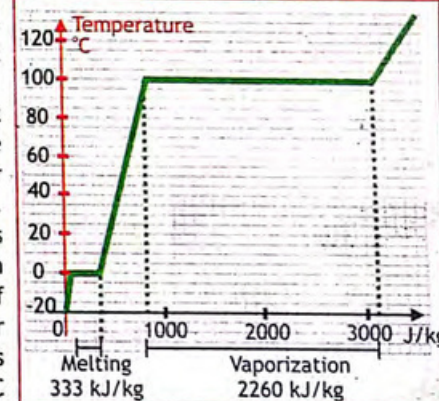


Now, on heating beyond point 'B', the temperature of water started rising as shown by the slope line 'BC' in the graph. Since the heat absorbed during the change of state of a substance does not raise its temperature, it is called latent

heat or hidden heat. The graph also shows when water is boiling and changing into steam, the temperature remains constant at 100°C though heat is being given continuously to water. This heat which is going into water but not increasing its temperature is the energy required to convert the water from the liquid state to the vapor state. Since this heat does not show its presence by producing a rise in temperature, it is called latent heat of vaporization of water. Let us look, for example, that how much energy is needed to melt a kilogram of ice at 0°C to produce a kilogram of water at 0°C .

Using the equation for a change in temperature and the value for water from Table 8.4, we find that $Q = mL_v = (1.0 \text{ kg})(334 \text{ kJ/kg}) = 333 \text{ kJ}$ is the energy to melt a kilogram of ice. This is a lot of energy as it represents the same amount of energy needed to raise the temperature of 1 kg of liquid water from 0°C to 79.8°C . Even

Figure 8.9 PHASE CHANGE



more energy is required to vaporize water; it would take 2260 kJ to change 1 kg of liquid water at the normal boiling point (100°C at atmospheric pressure) to steam (water vapor). This example shows that the energy for a phase change is enormous compared to energy associated with temperature changes without a phase change.

The latent heat of fusion for a given substance is different from the latent heat of vaporization for that substance. Representative values for melting point, latent heat of fusion, boiling point, and latent heat of vaporization are listed in Table 8.4.

TABLE 8.4: LATENT HEATS OF FUSION AND VAPORIZATION

Material	Melting Point (°C)	Latent Heat of fusion (J/kg)	Boiling Point (°C)	Latent Heat of Vaporization (J/kg)
Helium	-269.65	5.23×10^2	-269	2.09×10^4
Oxygen	-218.79	1.38×10^4	-183	2.13×10^5
Water	0	3.33×10^5	100	2.26×10^6
Mercury	-39	1.13×10^4	357	2.93×10^5
Sulphur	119	3.81×10^4	445	3.26×10^5
Lead	327	2.45×10^4	1750	8.70×10^5
Aluminum	660	3.97×10^5	2450	1.14×10^7
Copper	1083	1.34×10^5	1187	5.06×10^6
Silver	961	8.82×10^4	2193	2.33×10^6
Gold	1063	6.44×10^4	2660	1.58×10^6

INFORMATION



The element gallium has a heat of fusion of only 80 kJ/kg¹ and a melting of 30 °C hence it melts ever when placed on palm.

POINT TO PONDER

Why is a scald from steam often more serious than one from boiling water?

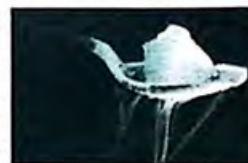
Steam at 100 °C contains more thermal energy than water. The difference is due to the latent heat of vaporization, which for water is quite high. As the steam touches the skin and condenses, a large amount of energy is released, causing more severe burns.



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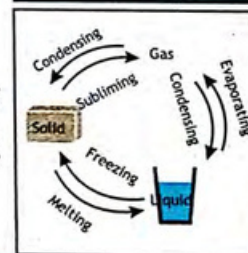
It is also possible for a substance to change directly from a solid to a gas. This process is called sublimation. For example, sublimation occurs when dry ice, which is solid (frozen) carbon dioxide, changes directly to gaseous carbon dioxide without passing through the liquid state.



When a comet approaches the Sun, some of its frozen carbon dioxide sublimates, helping to produce the comet's visible tail.



The conversion between three different states of matter (solid, liquid and gas) freezing, melting, evaporating, condensing and subliming are shown in the figure.



Example 8.6 MELTING ICE

Find the amount of heat for melting the ice having mass 1.3 kg at -10 °C? (Latent heat of fusion for ice $L_f = 3.3 \times 10^5$ J/kg and specific heat for ice $c = 2.2 \times 10^3$ J/kgK)

GIVEN:

Mass of ice $m = 1.3$ kg

Initial temperature $T_o = -10$ °C

Final temperature $T = 0$ °C

Temperature change $\Delta T = T - T_o = 0$ °C - (-10 °C) = 10 °C = 10 K

Specific heat for ice $c = 2.2 \times 10^3$ J/kgK

Latent heat of fusion for ice $L_f = 3.3 \times 10^5$ J/kg

REQUIRED:

Heat required $\Delta Q = ?$

We first we will provide heat to increase the temperature of the ice from -10 °C to 0 °C (melting point).

$$\Delta Q_1 = cm\Delta T$$

putting values $\Delta Q_1 = 2200 \text{ J kg}^{-1} \text{ K}^{-1} \times 1.3 \text{ kg} \times 10 \text{ K}$

therefore $\Delta Q_1 = 2.86 \times 10^4 \text{ J}$

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Now we will find heat required for melting ice at 0°C , such that

$$\Delta Q_2 = mL_f$$

putting values $\Delta Q_2 = 1.3\text{ kg} \times 3.3 \times 10^5 \text{ J/kg}$

therefore $\Delta Q_2 = 4.29 \times 10^5 \text{ J}$

Total heat required for the whole process

$$\Delta Q = \Delta Q_1 + \Delta Q_2$$

putting values $\Delta Q = 2.86 \times 10^4 \text{ J} + 4.29 \times 10^5 \text{ J}$

or $\Delta Q = 4.58 \times 10^5 \text{ J}$ — **Answer**

Assignment 8.6 EVAPORATING WATER

Find the amount of heat for evaporating 2.8 kg of water at 45°C ? (Latent heat of vaporization for water $L_v = 2.3 \times 10^6 \text{ J/kg}$ and specific heat of water $c = 4190 \text{ J/kgK}$).

8.7 EVAPORATION OF LIQUIDS

We observed that water and other liquids start to boil if they are heated to their boiling temperatures. The liquid starts to transform into vapours but the change of liquids into vapours goes on even when the temperature is below the boiling point. For example, A spread wet cloth on being exposed to the air becomes dry in a short time due to evaporation of water. Water left in an open dish also disappears due to evaporation.

We know that the molecules of a liquid move with wide range of instantaneous velocities and they have different kinetic energies ranging from minimum to a very high value. Some of the molecules, having sufficient kinetic energy to overcome the forces of attraction, leave the surface of the liquid and escape out in the form of vapour. We call this escaping of the high energy molecules as evaporation.

The process by which a liquid slowly changes into its vapours at any temperature (below its boiling point) without the aid of any external source of heat is called evaporation of liquids. Experiments have shown that evaporation of liquids depends on the following factors.

A. Nature of liquid:

Liquid with low boiling points evaporates more rapidly than those with higher boiling points. For example the rate of evaporation of alcohol is higher than that of water.



B. Temperature of liquid:

Due to higher temperature, molecules of liquid at the surface will have more kinetic energy and chances of escaping will increase and evaporation will be fast. This can be seen while ironing clothes. Under a hot iron wet clothes dry out quickly as the water evaporates quickly.



C. Temperature of surrounding:

The higher the temperature of the surrounding, the higher is the rate of evaporation. It is for this reason that wet clothes dry rapidly in summer than in winter.



D. Presence of water vapour in Air:

The more the amount of water vapour present in air, the less is the rate of evaporation. It is for this reason that wet clothes dry slowly in rainy season as a lot of water vapour are present in the air.



E. Area of the exposed surface of the liquid:

Increased surface area gives the molecules a greater chance of escaping. Wet roads dry out quickly because the rain water is spread over a large area.

F. Movement of Air:

The more rapid the flow of air, the higher is the rate of evaporation. It is for this reason that wet clothes dry more rapid on a windy day compared on a calm day.

G. Dryness of Air:

Drier the air, the more rapid is the evaporation. Presence of water vapour reduces the rate of evaporation. Desert room coolers are more effective in cooling by evaporation in the dry month of June than it is in the humid month of August.



H. Air pressure on the surface of the liquid:

The lower the pressure on the surface of the liquid, higher is the rate of evaporation.

8.7.1 EVAPORATION CAUSES COOLING

When a liquid evaporates, its molecules convert from the liquid phase to the vapor phase and escape from the surface. The process that drives it is latent heat. In order for the molecule to leave the liquid surface and escape as a vapor, it must take heat energy with it. Since the molecule is taking heat with it as it's leaving, this has a cooling effect on the surface left behind. For example, spirit spilled on your palm quickly evaporates. As a result, your palm feels cold. Water evaporates much slower than ether and spirit. Evaporation of water also produces cooling. You can feel the chilling effect of the evaporation of water if you sit under a fan and wearing wet clothes. Perspiration in a human body helps to cool the body and to maintain a stable body temperature.

The kinetic theory explains the cooling caused by evaporation. During evaporation, more energetic molecules escape from the liquid surface. Molecules that remain in the liquid have lower kinetic energy. A liquid with molecules of less kinetic energy has a lower temperature. Thus evaporation produces cooling.

8.7.2 EVAPORATION VS BOILING

Vaporization (or vapourisation) of an element or compound is a phase transition from the liquid phase to vapour. There are two types of vaporization: evaporation and boiling.

Evaporation is a phase change from the liquid phase to vapour that occurs at temperatures below the boiling temperature at a given pressure. Evaporation usually occurs on the surface. Boiling is a phase transition from the liquid phase to gas phase that occurs at or above the boiling temperature. Boiling, as opposed to evaporation, occurs below the surface.

Applications of Cooling by Evaporation:

A. Cooling by Fans:

We use fans in the hot season because the moving air increases the rate of evaporation or perspiration from our bodies. Hence we get a cooling sensation. As discussed earlier, perspiration helps in cooling the body and regulating its temperature.

B. Fever Control:

Wet towel is applied on the forehead of a person running high fever. It is because, as the water evaporates, it takes heat from the head. Thus the temperature of the head remains within the safe limits and the patient does not suffer any brain damage.

C. Refrigerator:

The Working principle of refrigerator is evaporation and compression.

There are six parts of a refrigerator.

1. Heat exchanging pipes:

These coils are present on the inside and the outside of the fridge, they carry the refrigerant from one part of the fridge to another.

2. Refrigerant:

This is the substance which evaporates in the fridge causing freezing temperatures.

3. Expansion Valve:

The expansion valve which is made up of a thin copper coil reduces the pressure on the liquid refrigerant.

4. Compressor:

A compressor is a metal object which compresses the refrigerant thus raising the pressure and in turn the temperature of the gas.

5. Condenser:

A condenser, condenses, that is, it converts the refrigerant into liquid form, reducing its temperature.

6. Evaporator:

A evaporator absorbs the heat in the refrigerator with assistance of the evaporating liquid refrigerant.

Working:

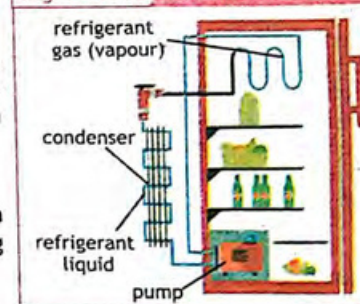
Refrigerator has a pipe that is partly inside a refrigerator and partly outside it, and sealed so it is a continuous loop. The pipe is filled with a refrigerant. Inside the refrigerator, we make the pipe gradually get wider, so the refrigerant expands and cool as it flowed through it. Outside the refrigerator, we have a pump (compressor) to compress the gas and release its heat. As the gas flow round and round the loop, expanding when it is inside the refrigerator and compressing when it is outside, it constantly pick up heat from the inside and carry it to the outside.

Refrigerant and Environmental Concern:

The cooling effect in many refrigerators is produced by the evaporation of a volatile liquid (refrigerant) called Freon a chlorofluorocarbon (CFC) chemical.

An increasingly important environmental concern is the disposal of old refrigerators because of the chlorofluorocarbon (CFC) chemical as coolant has a

Figure 8.10 REFRIGERATOR



property of damaging the ozone layer. Modern refrigerators usually use a refrigerant called hydrofluorocarbon (HFC), which was supposed to have zero potential to deplete the ozone layer. However in 1974 researchers predicted that emissions of HFCs could damage Earth's atmosphere by the catalytic destruction of ozone in the stratosphere. The hypothesis has been proven in 1985 by measurements which have shown the destruction of the ozone layer over Antarctica. Scientists are now looking to develop new refrigerant that is natural and have low global warming potential (GWP) and zero Ozone Depletion Potential (ODP).

KEY POINTS

Thermometry: The branch of physics which deals with the measurements of temperature is called thermometry.

Temperature: The measure of degree of hotness or coldness of a body is called temperature.

Thermometer: The device which is used to measure temperature is called thermometer.

Heat: The form of energy which is transferred from one body to another body due to the difference in temperature is called heat.

Thermal expansion: The expansion of substances on heating is called thermal expansion.

Specific Heat: The amount of heat required to raise the temperature of a unit mass of a substance by 1°C or 1 K is called the specific heat of that substance.

Change of state of matter: Change of solid to liquid or liquid to gas and vice versa without any change in temperature is called change of state of matter or change of phase.

Fusion or melting: The process in which a solid change into liquid state with out rise of temperature by the absorption of heat energy is called fusion or melting.

Latent heat of fusion of ice: The amount of heat energy required to melt one kilogram (1 kg) of a ice at its melting point 0°C with out any rise in temperature is called its latent heat of fusion of ice.

Boiling or vaporization: The process in which a liquid change into gaseous state with out rise of temperature by the absorption of heat energy is called boiling or vaporization.

Latent heat of water: The amount of heat energy required to vaporize one kilogram (1 kg) of a water at its boiling point 100°C with out any rise in temperature is called its latent heat of water.

Evaporation: The process by which a liquid slowly changes into its vapours below its boiling point is called evaporation.

PROJECTS

GROUP - A

REFRIGERANT: Talk to someone who works on air conditioners or refrigerators to find out what fluids are used in these systems. What properties should refrigerant fluids have? Research the use of freon and freon substitutes. Why is using freon forbidden by international treaty? What fluids are now used in refrigerators and car air conditioners? For what temperature ranges are these fluids appropriate? What are the advantages and disadvantages of each fluid? Summarize your research in the form of a presentation or report.

GROUP - B

TEMPERATURE MEASUREMENT: Research how scientists measure the temperature of the following: the sun, a flame, a volcano, outer space, liquid hydrogen, mice, and insects. Using what you learn, prepare a chart or other presentation on the tools used to measure temperature and the limitations on their ranges. Prepare the presentation to share it with your class fellows.

GROUP - C

BIMETALLIC STRIP: What is a bimetallic strip? How it is used in thermostat? Explain the use of bimetallic strip in different equipment. Prepare a chart to be displayed in classroom.

GROUP - D

HISTORY PRESENTATION: Discuss with elder people that until refrigerators, air conditioners or even fans and electricity was limited what methods people used to cool themselves and water for their use. How they stored fruits and vegetables. Prepare a presentation for the class discussion.

GROUP - E

WRITING FOR SCHOOL MAGAZINE ON LARGE VALUES OF WATER: Water has an unusually large specific heat and large heats of fusion and vaporization. Our weather and ecosystems depend upon water in all three states. How would our world be different if water's thermodynamic properties were like other materials, such as methanol? Write an essay to be published in school magazine.

EXERCISE

Choose the best possible answer:

- MULTIPLE CHOICE QUESTIONS**
- The S.I. unit of heat is
A. J B. kg C. K^1 D. K
 - The S.I. unit of temperature is
A. $^{\circ}C$ B. $^{\circ}F$ C. J D. K
 - The Fahrenheit and Celsius scale reading of temperature coincide at
A. 0° B. -460° C. -273° D. -40°
 - 310 K in centigrade scale is
A. $37^{\circ}C$ B. $310^{\circ}C$ C. $63^{\circ}C$ D. $273^{\circ}C$
 - When water at $0^{\circ}C$ is heated, it contracts till temperature reaches
A. $1^{\circ}C$ B. $4^{\circ}C$ C. $100^{\circ}C$ D. 100 K
 - The S.I. unit of specific heat is
A. JK^{-1} B. $JK^{-1}kg^{-1}$ C. Jkg^{-1} D. $JKkg$
 - The relation between coefficient of linear and volume expansion is;
A. $\alpha = 3\gamma$ B. $\gamma = 3\alpha$ C. $\gamma = \alpha/2$ D. $\gamma = 6\alpha$
 - The S.I. unit of Latent heat is
A. JK^{-1} B. Jkg^{-1} C. $JKkg^{-1}$ D. $JKkg$
 - How much heat is required to melt of 1 kg of Zinc at its boiling temperature $240^{\circ}C$ with latent heat of $113 \times 10^3 Jkg^{-1}$
A. $113 \times 10^3 J$ B. $1.13 \times 10^3 J$ C. $2.4 \times 10^3 J$ D. $2.71 \times 10^3 J$
 - The amount of heat required to raise the temperature of 1 kg of water by 1 K is
A. 1 J B. 400 J C. 310 J D. 4190 J

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CONCEPTUAL QUESTIONS

Give a brief response to the following questions.

- Ordinary electric fan increases the kinetic energy of the air molecules caused by the fan blades pushing them means the air temperature increases slightly rather than cool the air? why use it?
- Why are small gaps left behind the girders mounted in walls?
- Why you should not put a closed glass jar into a campfire. What could happen if you tossed an empty glass jar, with the lid on tight, into a fire?
- Explain why it is advisable to add water to an overheated automobile engine only slowly, and only with the engine running.
- Explain why burns caused by steam at $100^{\circ}C$ on the skin are often more severe than burns caused by water at $100^{\circ}C$.
- Explain why cities like Karachi situated by the ocean tend to have less extreme temperatures than inland cities at the same latitude.
- An iron rim which is fixed around a wooden wheel is heated before its fixture. Explain why?
- Why is ice at $0^{\circ}C$ a better coolant of soft drinks than water at $0^{\circ}C$?
- Why we feel cool after perspiration?

COMPREHENSIVE QUESTIONS

Give an extended response to the following questions.

- Explain the terms internal energy and temperature. Use kinetic theory to distinguish between heat internal energy and temperature.
- How do we measure temperature? Explain liquid in glass thermometer.
- What are various temperature scales. Derive mathematical expressions to convert between various scales of temperature.
- What is meant by linear thermal expansion and volume thermal expansion of solids?
- What is thermal expansion of liquids? Why we have real and apparent thermal expansion in liquids. Illustrate with the help an experiment.
- Define heat capacity and specific heat capacity of a substance. Explain the importance of high specific heat capacity of water.

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