Have you ever wondered why there are gaps in train tracks or why a cold bottle sweats? The answer lies in the relationship between temperature and matter. This chapter explores how heat affects particle movement, leading to phenomena like expansion, evaporation, and superconductivity.

We will begin with the kinetic theory of matter, examining how temperature influences particle motion and material properties. Then, we will look at thermal expansion, noting how solids and liquids expand with heat. Next, we will discuss state changes, including condensation, sublimation, and evaporation, along with latent heat. Finally, we will explore superconductivity, where certain materials lose no energy at very low temperatures. Let's explore these interesting thermal properties of matter!

11.1 KINETIC THEORY OF MATTER

In the previous class, we studied matter and its properties with help of kinetic molecular theory of matter. Let's revise some of their properties. Matter exists in three fundamental states: solid, liquid, and gas. Matter consists of particles (atoms and molecules). Gaps between these particles are the main reason that divides the matter into three states as shown in figure 11.1. Particles of matter apply attractive forces to each other. The difference in strength of this force is the reason for smaller or larger gaps between particles. The greater the strength of the attractive force between particles, the smaller the distance between them and vice versa.

Solids: In solids, particles are close to each other, and they have a high density. There is a strong, attractive force between particles, which keeps them closely packed. Particles in solids can only vibrate about their mean position. When a solid absorbs heat, the vibrational kinetic energy and amplitude of the vibration of its particles increase. These particles push each other away and increase the gap between them. This is how solids expand upon heating.

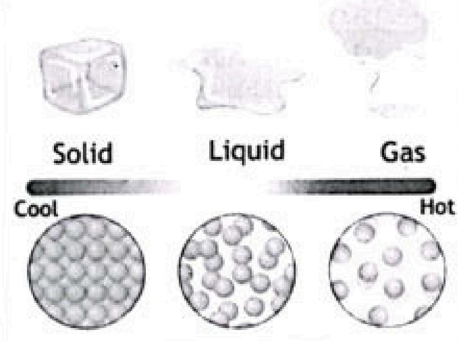


FIGURE 11.1
Effect of temperature on distance between particles of matter

Liquids: A liquid has intermediate density (smaller than a solid and higher than a gas). The attractive force between its particles is stronger than that of gases but weaker than that of solids. Due to it, the distance between particles in liquids is greater than that in solids. Liquid particles keep changing their position. Liquid particles flow. When a liquid is heated, attractive force between particles decreases and particles start moving.

Gases: In gases, there is negligibly weak attractive force between gas particles. Due to weak attractive force, distance between particles is larger as compared to the size of the particles. Particles are in constant random motion and they constantly colliding with each other and with the walls of the container. Due to collisions of gas particles with container, they exert pressure. Gases are less dense than liquids and gases. When gases are heated, kinetic energy of gas molecules increases. They move faster and expand quicky. Figure 11.1 shows the change in distances between the particles of different states of matter due to change in their temperature.

11.1.1 CHANGING STATES OF MATTER

Figures 11.2 shows the change in state of ice (solid) into water (liquid) and then into water vapours (gas) with increase in its temperature. Attractive forces among particles of matter usually decrease with increase in temperature.

As we now know that temperature of matter effects the attractive forces between its particles. Pressure on matter also effects the phase changes of matter. Particles of liquids and gases come close to each other on increasing the pressure on them and vice versa.

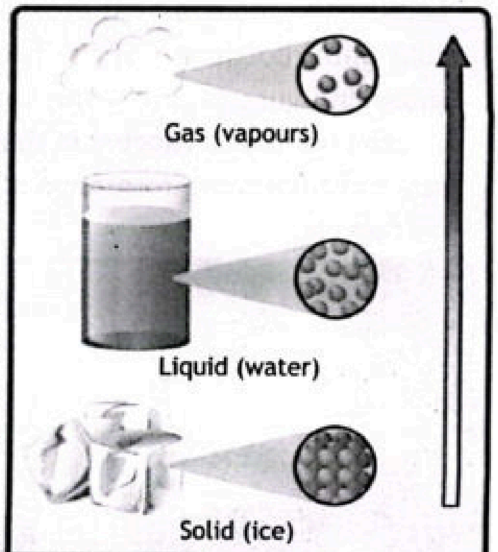


FIGURE 11.2 Phases of matter

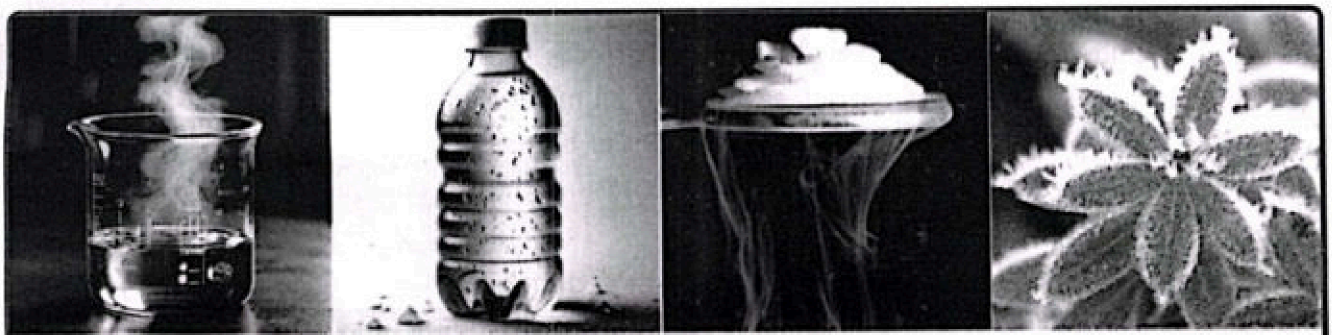
A. Changes Between Liquids and Solids: Let's discuss various phenomena involved in phase changes of matter.

- **Freezing:** It is the phenomenon in which any liquid changes into solid. When a liquid is placed at a place where its surroundings have low temperature then it loses heat to its surroundings. Its particles come close to each other and become solid at temperature called freezing point. For example, water changes into ice at 0 °C (freezing point of water).
- **Melting:** It is the phenomenon in which solid changes into liquid. When a solid is placed at a place where temperature of its surroundings is high then it absorbs heat from its surroundings. When its temperature reaches melting point, its particles overcome their bonding attractive forces and start flowing. For example, ice placed in warm surroundings melts at 0 °C. Freezing point and melting points are same.

B. Changes Between Liquids and Gases:

- **Vaporisation:** It is the phenomenon in which a liquid is converted into gas (vapours) upon boiling. When a liquid is heated, its particles gain kinetic energy. On continuous heating, their kinetic energy becomes sufficiently high that they overcome the attractive forces between them and escape from the liquid. Vaporisation is shown in figure 11.3 (a) this happens at a certain temperature of the liquid called its boiling point.

- **Evaporation:** It is phenomenon of conversion liquid into vapours at any temperature. We will discuss it in detail later in the chapter.
- **Condensation:** It is a phenomenon in which gases (vapours) change into liquids. Condensation happens in vapours where the temperature and pressure are low. Warm air can hold more moisture than cool air. When the warm, moist air cools down, the water vapours condense because the cooler air has a lower capacity to hold water vapour. For example, when you take a cold water bottle out of the fridge, you often see water droplets forming on the outside as shown in figure 11.3 (b). This happens because the cold-water bottle cools the air around it, causing the water vapours in the air to condense into liquid water on the bottles surface. Its other examples are formation of dew drops on grass, Foggy car wind screen, foggy bathroom mirrors etc.



(a) Boiling water changing into vapours (b) Condensation of water vapours on cold bottle (c) Sublimation of dry ice (d) Deposition of frost on leaves

FIGURE 11.3 Changing states of matter

C. Changes Between Solid and Gases:

- **Sublimation:** It is a phenomenon in which solids change directly into gases. Its most common example is converting dry ice (solid carbon dioxide) into smoke (carbon dioxide gas) as shown in figure 11.3 (c). Dry ice is solid at extremely low temperature (-78.5 °C). When it is exposed to room temperature and pressure, its molecules overcome all the attractive forces and convert directly into gas without going into the liquid phase.

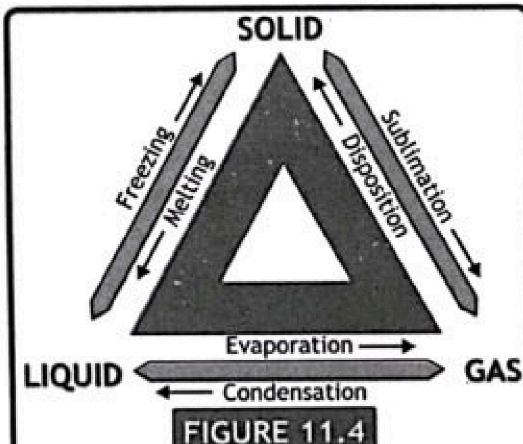
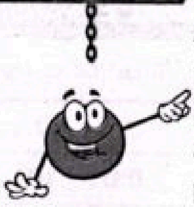


FIGURE 11.4
Change of states of matter with relating processes

- **Deposition:** It is a phenomenon in which gas changes directly to solid. Gas does not go into liquid phase during this phenomenon. It is reverse process of sublimation. Formation of frost is example of deposition. On a cold night, water vapour in the air comes in contact with surfaces like leaves or windowpanes that are much cooler than the surrounding air. The water vapor loses heat to

POINT TO PONDER



How food is preserved using deposition and sublimation?

A food preservation technique relies on deposition and sublimation to remove moisture from food or other materials. The product is frozen or frosted using deposition an then it is and placed in a vacuum chamber with very low pressure. The water in the frozen or frosted material sublimates directly into the vacuum, leaving the dehydrated product behind.

these cold surfaces, condenses directly into ice crystals forming the frost as shown in figure 11.3.

11.2 THERMAL EXPANSION

Thermal expansion means "increase in size of matter on heating". On heating, particles of matter gain energy and they start to vibrate or move around fast. They hit each other and increase the gap between them. Thus, matter expands on heating. Thermal expansion of matter depends upon nature of its material, increase in temperature and its original size (original amount of matter in it before heating). For the same increase in temperature, solid expands the least and gases expands the most.

Table 11.1: DIFFERENCE IN RELATIVE EXPANSION FOR SOLID LIQUID AND GAS

State	Expansion
Solids	Expand slightly because the low energy molecules cannot over intermolecular forces of attraction holding them together.
Liquids	Expands more than solids because the molecules have enough energy to partially overcome the intermolecular forces of attraction holding them together.
Gases	Expands significantly because the molecules have enough energy to completely overcome the intermolecular forces of attraction holding them together.

11.2.1 THERMAL EXPANSION IN SOLIDS

There are three types of thermal expansions in solids, linear thermal expansion (one dimensional thermal expansion), surface area thermal expansion (two dimensional thermal expansion) and volumetric thermal expansion (three dimensional thermal expansion). Here we will discuss linear and volumetric thermal expansions.

A. Linear Thermal Expansion of Solids: It is change in length of a solid on heating. Change in one dimension of a solid object on heating is called linear thermal expansion in solids.

Linear thermal expansion of solids depends upon three factors:

I. Increase in temperature of the rod: When a solid rod is heated, its atoms gain kinetic energy and vibrate with greater amplitude about their mean position. This increased vibrations causes the atoms to move slightly further apart resulting in an increase in the length of the rod. If we continue to increase the temperature, their kinetic energy and amplitude of vibration will further increase. This will further increase the length of the rod. Therefore, thermal expansion in length of the rod is directly proportional to the increase in temperature of the rod.

ii. Original length of the rod: On heating the rod the increase in length of the rod is directly proportional to the original length of the rod. This is because longer rod has more atoms, each atom contribute to overall thermal expansion. So, a longer rod will expand more than a shorter rod when heated to the same temperature.

iii. Nature of material of the rod: Different materials expand differently on heating. Thermal expansion depends on the atomic structure an the strength of attractive force between its atoms. For example, aluminum rod expands more than steel rod of same length for same rise in temperature.

Table 11.2 COEFFICIENTS OF LINEAR THERMAL EXPANSION

Material	Value of α (K^{-1})
Steel	1.2×10^{-5}
Quartz	0.04×10^{-5}
Invar	0.09×10^{-5}
Glass	0.4×10^{-5}
Copper	1.7×10^{-5}
Brass	2×10^{-5}
Aluminum	2.4×10^{-5}

Consider a metal rod of original length 'L_o' at initial temperature 'T_o' as shown in figure 11.5. This rod is heated to final temperature 'T' and its final length becomes 'L'. Increase in length of the rod is 'ΔL' ($\Delta L = L - L_o$) for increase in temperature 'ΔT' ($\Delta T = T - T_o$).

From our previous discussion, we know that change in length is directly proportional to original length 'L_o' and change in temperature 'ΔT'. Mathematically

$$\Delta L \propto L_o \Delta T$$

$$\Rightarrow \Delta L = \alpha L_o \Delta T \quad \text{--- } \boxed{11.1}$$

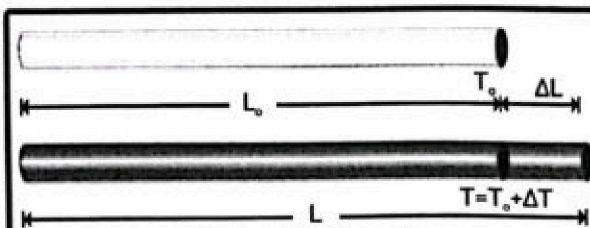


FIGURE 11.5

Linear thermal expansion of the rod

Where 'α' is the constant of proportionality and it is called coefficient of linear thermal expansion. From equation 11.1, we have

$$\alpha = \frac{\Delta L}{L_o \Delta T} \quad \text{--- } \boxed{11.2}$$

$$\text{or} \quad \alpha = \frac{\Delta L / L_o}{\Delta T} = \frac{\textit{Change in length} / \textit{Original length}}{\textit{Change in temperature}} \quad \Rightarrow \quad \alpha = \frac{\textit{Fractional change in length}}{\textit{Change in temperature}}$$

The coefficient of linear expansion is defined as the fractional change in length per kelvin change in temperature. It tells how much length of the rod will change with respect to its original length when its temperature rises by 1 kelvin.

The linear expansion coefficient is an intrinsic property of every material. Hence it varies from one material to another. SI unit of coefficient of linear thermal expansion is K^{-1}.

B. Volumetric Thermal Expansion of Solids: It is change in volume of a solid on heating. Change in three dimensions of a solid object on heating is called volumetric thermal expansion in solids. Volumetric thermal expansion of solids also depends upon three factors:

i. Increase in temperature of the object: When a three-dimensional object (like a cube shaped object) is heated, kinetic energy of its particles increases, their vibrations become more vigorous and they spread out further apart. As a result, particles of the object occupy more volume. its atoms push each other and increase the volume of the object. Therefore, thermal expansion in volume of is directly proportional to the increase in its temperature.

ii. Original volume of the object: For the similar reason that we discussed in the case of linear thermal expansion, increase in volume of the solid object is directly proportional to its original volume.

iii. Nature of material of the object: Different materials expand differently on heating. Therefore, increase in volume of an object will be different for different materials on heating.Let original volume of solid cube is 'V_o' at temperature 'T_o' as shown in figure 11.6. It final volume becomes 'V' when its final temperature becomes 'T' ($T = T_o + \Delta T$). Let increase in its volume is 'ΔV' ($\Delta V = V - V_o$) for increase in temperature ΔT ($\Delta T = T - T_o$).

Table 11.3: COEFFICIENTS OF VOLUMETRIC THERMAL EXPANSION

Material	Value of β (K^{-1})
Methanol	113×10^{-5}
Glycerin	49×10^{-5}
Mercury	18×10^{-5}
Turpentine	90×10^{-5}
Acetone	132×10^{-5}

From our discussion, we can write increase in volume of the object as:

$$\Delta V = \beta V_0 \Delta T \quad \boxed{11.3}$$

Where 'β' is the constant of proportionality and it is called coefficient of volume expansion. From equation 11.3, we have:

$$\beta = \frac{\Delta V}{V_0 \Delta T} \quad \boxed{11.4}$$

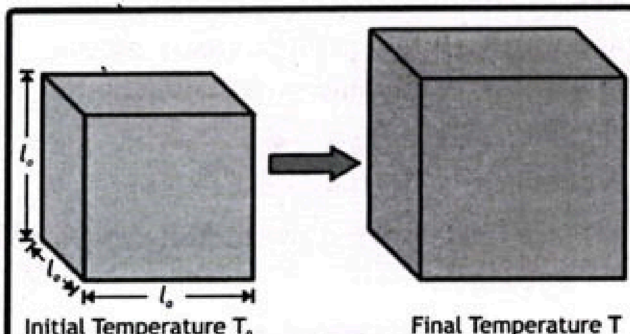


FIGURE 11.6
Volumetric thermal expansion of the solid cube

$$\text{or} \quad \beta = \frac{\Delta V / V_0}{\Delta T} = \frac{\textit{Change in volume} / \textit{Original volume}}{\textit{Change in temperature}} \Rightarrow \beta = \frac{\textit{Fractional change in volume}}{\textit{Change in temperature}}$$

The coefficient of volumetric thermal expansion of solids is defined as the fractional change in volume per kelvin change in temperature. It tells how much volume of the solid object will change with respect to its original volume when its temperature rises by 1 kelvin. Its value is different for different materials. SI unit of β is K^{-1}. As we know that solid expands on heating and contract on cooling. We can use the same relations for contraction of solids on cooling.

Example 11.1

An old steel bridge has original length of 1.5 km (1500 meters). The average daily temperature change in the region is 15 °C (from mid night to noon). Steel has a coefficient of linear expansion of $12 \times 10^{-6}\ K^{-1}$. How much will the bridge length change due to this daily temperature swing?

GIVEN:

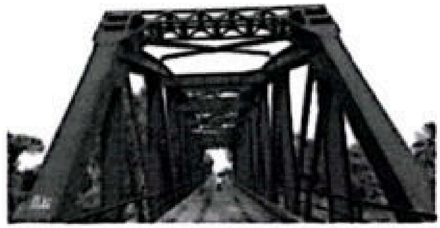
Original length 'L_o' = 1.5 km = 1500 m

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

Change in temperature 'ΔT' = 15 °C = 15 K

REQUIRED:

Change in length 'ΔL' = ?



Old steel bridge at Jhang

SOLUTION:

Increase in length of the bridge is calculated by the formula: $\Delta L = \alpha L_o \Delta T$

putting values $\Delta L = (12 \times 10^{-6} K^{-1})(1500\,m)(15\,K)$

Therefore $\boxed{\Delta L = 0.27\,m}$ **ANSWER**

So, Increase in the length of the bridge is 0.27 m.

C. Experimental demonstration of thermal expansion of solids: A metal bolt snap bounded by a heated metal rod as shown in figure 11.7.

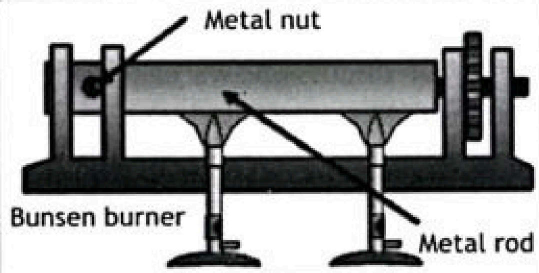


FIGURE 11.7

Experimental demonstration of thermal expansion in solids

Apparatus: Metal rod (e.g., steel), metal bolt and nut (e.g., brass or aluminum), a Bunsen burner, stand and clamps

Procedure:

1. Place the metal rod horizontally with a bolt tightly fastened to it.
2. Gradually heat the rod using a heat source.
3. As the rod heats up, it will expand due to thermal expansion.
4. The expansion will cause the rod to exert pressure on the bolt.
5. If the expansion is significant enough, the bolt will eventually snap.

Conclusion: Different metals expand at different rates when heated. The rod expands and exerts pressure on the bolt. If this pressure exceeds the bolt's strength, it snaps. This experiment shows that we should consider thermal expansion in engineering applications to prevent damage in structures.

D. Relation between coefficients of linear and volume expansions: The coefficient of linear expansion and volume expansion are related by:

$$\beta = 3\alpha \quad \text{— } \boxed{11.5}$$

Example 11.2

You are designing a hot air balloon. The balloon's fabric has a volume of 500 cubic meters at room temperature of 20 °C. You need to know how much the volume will increase when hot air of 80 °C fills the balloon. The fabric material has a coefficient of volumetric expansion of $3.5 \times 10^{-5} K^{-1}$. Calculate the volume increase of the balloon fabric when filled with hot air.

GIVEN:

Original volume 'V_o' = 500 m^3

Coefficient of volume thermal expansion 'β'= $3.5 \times 10^{-5} K^{-1}$

Change in temperature 'ΔT' = 80 °C - 20 °C = 60 °C = 60 K

REQUIRED:

Change in volume 'ΔV' = ?

Hot Air Balloon

SOLUTION:

Increase in volume of the balloon is calculated by the formula:

$$\Delta V = \beta V_0 \Delta T$$

putting values $\Delta V = (3.5 \times 10^{-5} K^{-1})(500\, m^3)(60\, K)$

Therefore $\boxed{\Delta V = 1.05 m^3}$ — **ANSWER**

After raising temperature by filling air at 80 °C, the increase in volume of the hot air balloon is 1.05 m^3.

11.2.2 THERMAL EXPANSION IN LIQUIDS

We have discussed earlier that liquids expand on heating. Liquids have intermediate attractive forces between its particles (molecules) and their particles can move relatively free as compared to solid particles. When we heat the liquid, kinetic energy of the particles increases, they push each other and increase their occupied space. This is the reason behind liquid expansion on heating. The thermal expansion in liquids is greater than solids due to the weak attractive forces between their particles.

To study the increase in volume of the liquid, we have to heat it in a container because it cannot be heated directly for this purpose. Therefore, we consider change in volume of the liquid and change in volume of the container as well during heating. There are two types of thermal volume expansion for liquid.

i. Real volume expansion   ii. Apparent volume expansion

A. Real Volume Expansion: When heat is applied directly to a liquid, causing it to expand, the increase in its volume is called real volume expansion.

Generally, this expansion is similar to volume thermal expansion of solids. We can use the same formula for coefficient of real volume expansion of liquids 'γ_r' as we do for solids. It is defined as **'fractional increase in real volume of the liquid for 1 kelvin rise in temperature'.**

$$\gamma_r = \beta = \frac{\Delta V}{V_0 \Delta T} \quad \boxed{11.6}$$

B. Apparent Volume Expansion: When we heat the liquid in a container then increase in its volume from its initial to final position is called apparent expansion of the liquid. We can also define it as: **The expansion of liquid apparently observed without considering the expansion of the container or vessel is called the apparent expansion of the liquid.** The coefficient of apparent expansion of liquid 'γ_a' defined as **'fractional increase in apparent volume of the liquid for 1 kelvin rise in temperature'.**

$$\gamma_a = \frac{\Delta V_{apparent}}{V_0 \Delta T} \quad \boxed{11.7}$$

Its SI unit is also per kelvin (or K^{-1}).

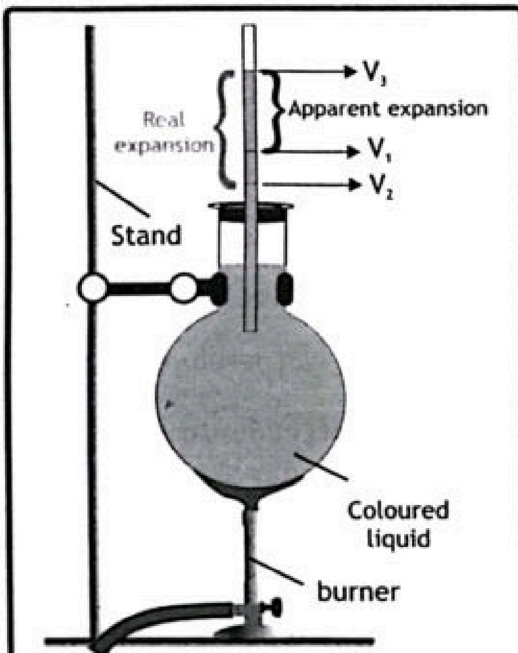


FIGURE 11.8

Real and apparent expansion of liquids

Experiment: Take a coloured liquid in a neck glass flask as shown in figure 11.8. Note initial level of liquid before heating it as 'V_1'. Now start heating the flask form its bottom. The liquid level first falls to 'V_2' and then rises to 'V_3'. Why does this happen?

The heat first reaches the glass flask which expands first and its volume increases. As a result, liquid volume falls in the flask to level 'V_2'. After this, heat conducts to the liquid and the liquid begins to rise above 'V_2' on getting hot. At certain temperature it reaches at level 'V_3'. The increase in volume of liquid from 'V_1' to 'V_3' is called the apparent expansion in the volume of the liquid. But actually heat is transferred to liquid when it is at level 'V_2'. Therefore, rise in the level of liquid from 'V_2' to 'V_3' is called real expansion of liquid.

Actual expansion of the liquid is greater than its apparent expansion. While, fall level of liquid from 'V_1' to 'V_2' represents expansion in glass flask. Hence,

Real expansion of the liquid = Apparent expansion of the liquid + Expansion of the flask

or $$V_2V_3 = V_1V_3 + V_1V_2 \quad \boxed{11.8}$$

The Coefficient of real rate of volume expansion (γ_r) is always greater than the apparent rate of volume expansion (γ_a) by an amount equal to the rate of volume expansion of the container (γ_g).

Thus:

$$\gamma_r = \gamma_a + \gamma_g \quad \boxed{11.9}$$

It should be noted that different liquids have different coefficients of volume expansion.

SCIENCE TIDBITS

All liquids expand on heating and contract on cooling except water. When water cools down from 4°C to 0°C, it actually expands. This strange property is called the anomalous expansion of water. When water freezes at 0°C, the hydrogen bonds become more stable and cause the water molecules to arrange themselves into a crystalline lattice structure. This structure casuses the expansion of water upon freezing. At 4°C water has highest density. It's why ice (0°C) floats in liquid water, a property crucial for life in aquatic ecosystems. As water in lakes and rivers freezes, the ice floats on top, insulating the lower water layers and preventing them from freezing completely. This allows life to survive harsh winters.

Example 11.3

A laboratory flask is filled with 250 ml of glycerine at a temperature of 20 °C. Calculate the volume of glycerine at 70 °C. The coefficient of volumetric thermal expansion for glycerine is $500 \times 10^{-6}\,K^{-1}$.

GIVEN:

Original volume 'V_o' = 250 ml = $250 \times 10^{-6}\,m^3$

Coefficient of real expansion 'γ_r' = $500 \times 10^{-6}\,K^{-1}$

Change in temperature 'ΔT' = 70 °C - 20 °C = 50 °C = 50 K

REQUIRED:

Change in volume 'ΔV' = ?

SOLUTION:

Increase in in volume of the glycerine is calculated by the formula: $\Delta V = \gamma_r V_0 \Delta T$

putting values $\Delta V = (500 \times 10^{-6} K^{-1})(250 \times 10^{-6} m^3)(50\,K)$

Therefore $\boxed{\Delta V = 6.25 \times 10^{-6} m^3 = 6.25\,ml}$ ANSWER

Increase in the volume of glycerine is 6.25 ml when its temperature rises by 50 °C.

11.2.3 APPLICATIONS AND CONSEQUENCES OF THERMAL EXPANSION IN REAL LIFE

There are many applications of thermal expansions in our daily life. Let's discuss some of these applications.

A. Thermometers (Mercury and Alcohol Thermometers): Expansion of liquids (mercury or alcohol) is used to measure temperature in mercury and alcohol thermometers. As the temperature increases, the liquid expands and rises in the calibrated capillary tube. From which we read temperature.

B. Bimetallic Strips (Thermostats and switches): A bimetal strip consists of two thin strips of different metals such as brass and iron joined together as shown in figure 11.9. On heating the strip, one metal strip expands more than the other metal strip. This unequal expansion causes bending of the strip. Bimetal strips are used as switches and thermostats. For example in an electric iron, a bimetal thermostat switch controls the temperature of the heating coil.

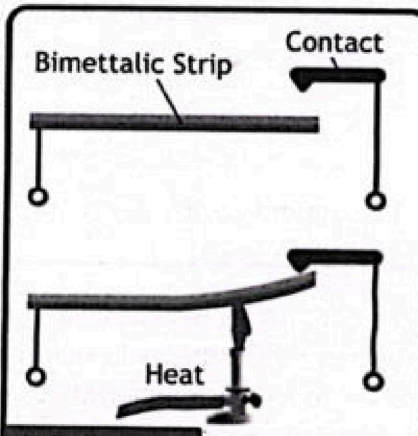


FIGURE 11.9 Bimetallic strips

C. Expansion Joints: The purpose of expansion joints is to accommodate the expansion and contraction of materials resulting from changes in temperature. This prevents structural damage in bridges, railways, pipelines, and buildings.

D. Opening Cap of A Bottle: To open the cap of a bottle that is tight enough, immerse it in hot water for a minute or so. Metal cap expands and becomes loose. It would now be easy to turn it to open.

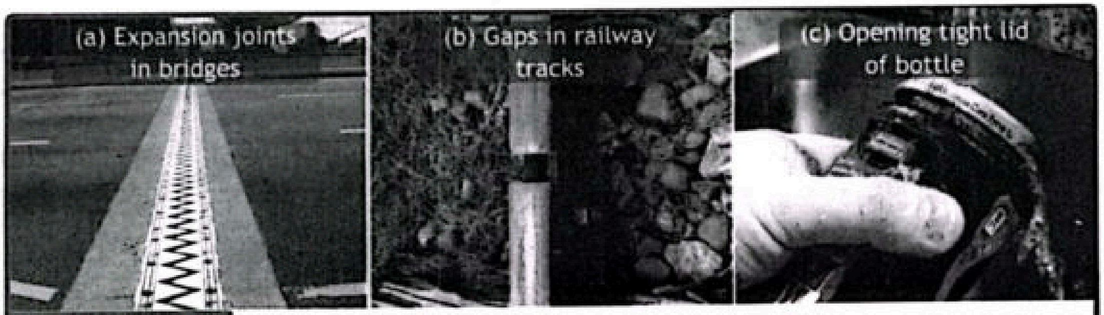


FIGURE 11.10 Expansion Joints

E. Power Lines: Overhead transmission lines are also given a certain amount of sag so that they can contract in winter without snapping (figure 11.11).

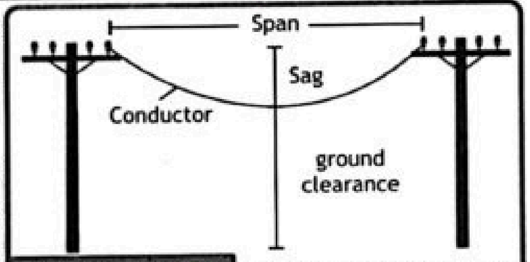


FIGURE 11.11 Sagging in power lines

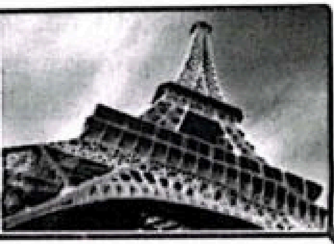
F. Designing Instruments and Machinery: Different materials expand differently. Understanding thermal expansion is crucial for designing reliable and safe infrastructure, instruments, and machinery.

G. Consequences of thermal Expansions: If we ignore thermal expansion during construction, designing machines and instruments etc., we will face different problems. Some of them are:

- Temperature changes can cause materials like concrete and asphalt to expand and contract. Without proper joints or gaps, this can lead to cracks and structural damage.
- Overheated power lines might sag excessively, causing short circuits or power outages.
- In hot weather, railway tracks can expand and buckle if there are no expansion gaps.
- Pipes carrying fluids can burst if the liquid inside expands due to heating and there's no room for expansion, causing leaks and significant damage.
- Instruments with parts that expand when heated may give wrong readings if they are not

DO YOU KNOW?

The Eiffel Tower is made up of iron. It can grow up to 6 inches (15 cm) taller in summer due to thermal expansion. As iron heats up, it expands, causing the tower to increase in height. Engineers account for such thermal expansion this in their designs to ensure structural strength and safety.



properly calibrated.

- Metals get weaker when they expand and contact many times, which can damage items like airplanes, machines and buildings.

11.3 EVAPORATION

Have you ever thought how wet clothing dry on a clothesline or why puddles disappear on a hot summer day? This happens by a process known as evaporation. Evaporation is the process by which liquid changes into vapours (gas) at any temperature. This occurs at the surface of the liquid.

11.3.1 CAUSE OF EVAPORATION

In a liquid, Molecules in a liquid have different kinetic energies due to collision with each other and with walls of container. High energy molecules moving near the surface of the liquid escape from the surface in the form of vapours as shown in figure 11.12. This is how evaporation takes place.

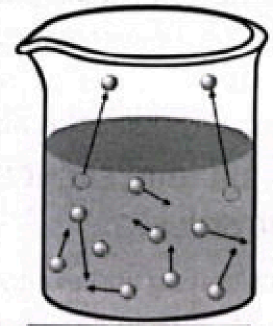


FIGURE 11.12
Molecules escaping from the surface of liquid in evaporation

11.3.2 EVAPORATION CAUSES COOLING

During evaporation, fast moving molecules escape from the surface of the liquid. Molecules that have lower kinetic energies are left behind. This lowers the average kinetic energy of the liquid molecules and, hence, the temperature of the liquid.

The temperature of a substance relates to the average kinetic energy of its molecules. A decrease in temperature causes a cooling sensation. For example when we sweat the evaporation of moisture from the skin cools the body. Similarly, when a liquid evaporates from the surface of a solid, it lowers its temperature. This principle is used in refrigerators and air conditioning systems.

11.3.3 FACTORS AFFECTING RATE OF EVAPORATION

The rate of evaporation indicates how quickly molecules at the surface of a liquid escape and become a gas. Higher rate of evaporation means the liquid will evaporate faster. Rate of evaporation depends upon different factors, such as:

A. Temperature: Rate of evaporation is directly proportional to temperature. Higher temperature of the liquid increases kinetic energy of its molecules and increase the rate of evaporation. Water in sunshine (high temperature area) evaporates faster than water in shade (low temperature area).

B. Surface Area: A larger surface area allows more molecules to escape, speeding up evaporation. Larger is the surface area of a liquid, greater number of molecules has the chance to escape from its surface. It is why wet clothes are stretched out to dry quickly.

C. Humidity: Dry air is less humid air (It has low value of moisture in it). It has ability to store more moisture. Therefore, lower humidity levels increase the rate of evaporation as dry air can allow more water vapours to be absorbed. You now understand that room air coolers function most efficiently in the dry air months of June and less efficiently in the humid months of August.

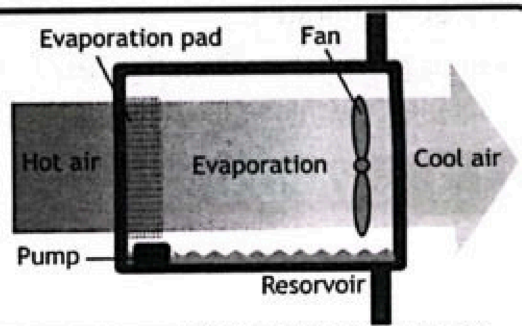


FIGURE 11.13 Schematic diagram of room air cooler

D. Wind Speed: Increased wind speed blows away the moist air near the surface, which speeds up the rate of evaporation. It is why wet clothes dry quickly in windy day than on a calm day.

CAN YOU TELL?

Why wet clothes dry up more quickly in summer than in winter?

11.3.4 DIFFERENCE BETWEEN EVAPORATION AND BOILING

Both boiling and evaporation represent the change of liquid into vapours. But there are some differences in both processes, as shown in table 11.4.

Table 11.4: DIFFERENCE BETWEEN EVAPORATION AND BOILING

Properties	Evaporation	Boiling
Occurs	at the surface of liquid	Throughout the liquid
Temperature	at any temperature	only at boiling point of liquid
Energy Source	Uses surrounding energy	uses continuous external heat source
Rate/speed	Generally slower and depends on many factors	Fast process (after reaching boiling point)
Process Completion Time	It takes longer to be completed	It is quick process than evaporation
Effect of pressure	Less effected by external pressure	Highly effected by external pressure
Formation of Bubble	No bubble formation	Bubbles are formed throughout the liquid and rise from the surface
Dependence on surface area	Depends on surface area	Does not depend on surface area
Effect on temperature of surrounding	Causes cooling in surrounding	Increases temperature of surrounding

11.3.5 APPLICATIONS OF EVAPORATION

A: Refrigeration using evaporation (without CFCs): Cooling is produced in the fridge/refrigerators by evaporation of refrigerant (a liquefied gas), which absorbs heat and creates a cooling effect.

Freons, or chlorofluorocarbons (CFCs), were the type of refrigerant gas used in fridge. However, since it was found that CFCs are depleting the ozone in the upper atmosphere which increases the amount of UV rays from the sun. All living things are harmed by ultraviolet radiation. Therefore, CFCs use has been prohibited. CFCs are replaced by the environment friendly substances like water, ammonia and hydrocarbons (propane, butane) etc.

DO YOU KNOW?

The density and viscosity of a liquid determine how quickly it evaporates. Liquids that are less viscous and dense, such as those found in perfume bottles, evaporate more quickly.

The refrigerator contains a coil (called evaporation coil) filled with refrigerant at low pressure. When the warm air inside the fridge comes into contact with the evaporator coil, the refrigerant absorbs heat and changes from liquid to gas, which cools the inside of the fridge. This gas is then compressed, releasing heat outside, and is condensed back into a liquid by the condenser. This cycle continues to maintain a cool temperature inside the fridge.

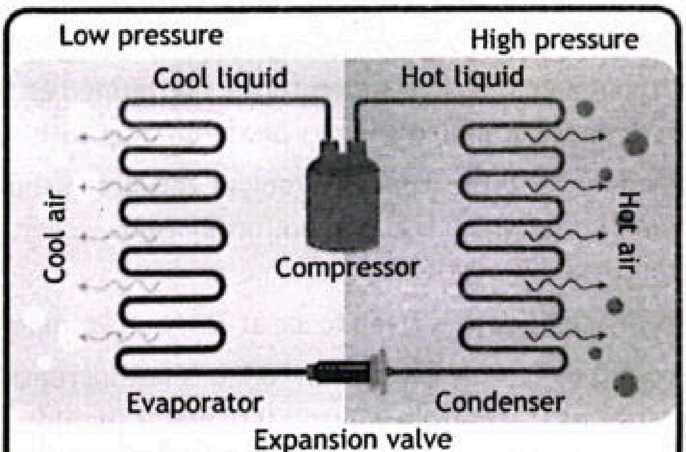


FIGURE 11.14 Refrigeration cycle

B. Food preservation: Many food items are preserved by removing the water content through evaporation. This concentrates the flavours and prevents spoilage. Examples include dried fruits, jerky (dried meat), as shown in figure 11.5 (a).

C. Production of salt: Sea water is stored in large pools. As the water evaporates, the salt is left behind as shown in figure 11.5 (b).

D. Air conditioning: Air conditioners use evaporation to cool air. They work by passing warm air over a coil that is filled with a cool liquid. As the liquid evaporates, it takes heat from the air, cooling it down.

(a) Fruits dried using evaporation

(b) Sea salt obtained from evaporation of sea water

FIGURE 11.15

Uses of evaporation

E. Fever control: When someone has a high fever, they apply a wet cloth to their forehead. The reason behind this is that heat from the head is removed when the water evaporates. As a result, the patient's brain temperature stays within acceptable bounds and no brain injury occurs.

11.4 LATENT HEAT

Consider you are boiling a pot of water. The temperature of the water increases gradually as you turn up the heat. But then, something interesting happens. The water reaches 100°C. Even when you apply more heat, the temperature does not change! Where is all that energy going?

The answer lies in a concept called latent heat. It is the hidden heat absorbed or released by a substance during a phase change (like melting, freezing (solidification), boiling or condensation) without a change in temperature. It is defined as **'It is the amount of heat energy absorbed or lost by a substance during its phase change without change in its temperature'.**

To understand this concept, look at this graph shown in figure 11.16 between temperature and heat energy which is added uniformly to the ice at -20 °C to 110 °C (after its boiling points). This graph has five portions.

From A to B: Heat is given to ice at -20 °C. Its temperature rises and but it is still ice at 0 °C.

From B to C: Now heat given to ice is not increasing its temperature. This heat is being used to change its states from ice (solid) to water (liquid) at its melting point 0 °C. This amount of heat is called latent heat of fusion (L_f). This process continues till all the ice is converted into water.

From C to D: In this portion, added heat again increases the temperature of the water uniformly till it reaches its boiling point.

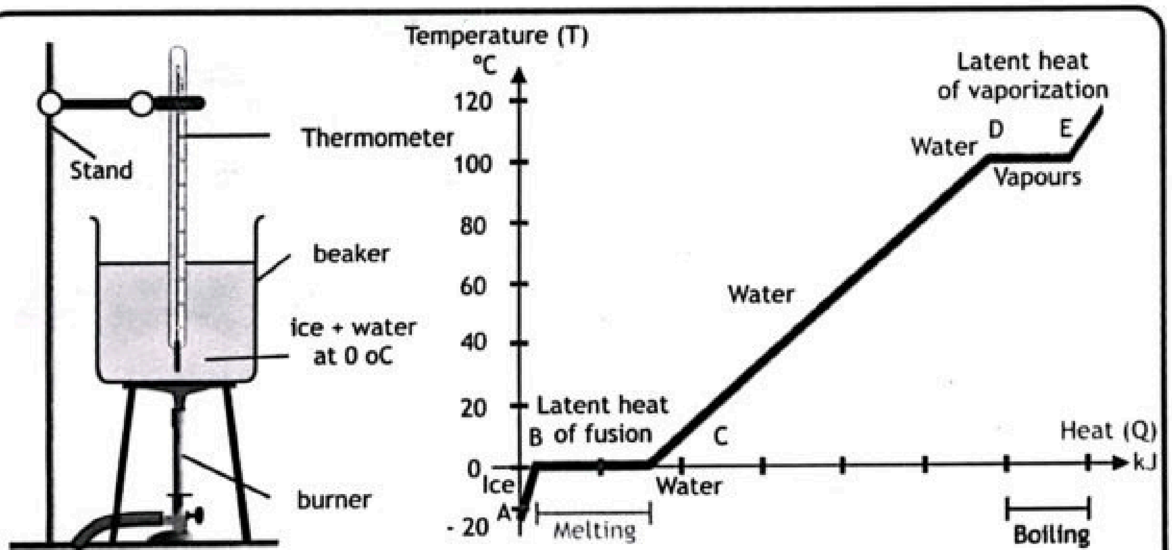


FIGURE 11.16 Phase change of ice to vapours

From D to E: In this portion, added heat again is not used to increase the temperature of water. It is used to change the state of water (liquid) into vapours (gas) at its boiling point 100 °C. Heat added at this stage to water is called latent heat of vaporization (L_v).

From E to F: After complete change of water into vapours at its melting point, added heat increases the temperature of the vapours (steam).

Temperature of a substance is related with the average kinetic energy of the particles. Therefore, whenever added heat increases the average kinetic energy of particles of the substance, it will increase the temperature of the substance. But when added heat is used to change the state of substance, it does not change its temperature. Here, heat is used to weaken the attractive forces between its particles, instead of increasing their average kinetic energy. This happens at meting point and boiling point of the substance.

During melting, the amount of heat is absorbed by the substance to change its state from solid to liquid at its melting point without the change in its temperature. Similarly, the same amount of heat is released by the same substance at its freezing point during solidification (from liquid to solid). The same happens for boiling of a liquid and its condensation from vapour to solids at boiling point. Heat energy absorbed during boiling is equal to heat energy released during condensation. In all these processes, heat absorbed or released by the substance is used to accommodate the attractive forces between its particles.

11.4.1 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 without change in its temperature is called its latent heat of fusion. During freezing, liquids release same amount of heat to change state to solids.

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:

$$\Delta Q = mL_f \quad \text{—} \boxed{11.10}$$

Where 'L_f' is the specific latent heat of fusion of substance. It is defined as: 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) without any change in temperature is called its specific latent heat of fusion (L_f) of the solid.

$$L_f = \frac{\Delta Q}{m} \quad \text{—} \boxed{11.11}$$

The SI 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. Latent heat of fusion of ice is 3.33×10^5 J kg^{-1}.

Table 11.5: LATENT HEATS OF FUSION AND VAPORISATION OF SELECTED MATERIALS

Material	Melting Point (°C)	Latent Heat of fusion (J/kg)	Boiling Point (°C)	Latent Heat of Vaporisation (J/kg)
Helium	- 269.65	5.23×10^3	- 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

11.4.2 LATENT HEAT OF VAPORISATION

The amount of heat energy required to convert a given mass of a substance from the liquid state to the gaseous state without any change in its temperature is called its latent heat of vaporization. During condensation same amount of heat is released by the gases to change its state to liquids. 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:

$$\Delta Q = mL_v \quad \boxed{11.12}$$

Where 'L_v' is the latent heat of vaporization of substance. It is defined as: 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.

$$L_v = \frac{\Delta Q}{m} \quad \boxed{11.13}$$

The SI unit of specific latent heat of vaporisation is joule per kilogram (Jkg^{-1}). Different substances have different specific latent heat of vaporisation. Latent heat of vaporisation of water is $2.26 \times 10^6\ Jkg^{-1}$.

11.4.3 EXPERIMENT TO FIND LATENT HEAT OF FUSION OF ICE

1. Place a beaker over a stand as shown in figure 11.17.
2. Add small pieces of ice to the beaker.

3. To find out the ice's temperature, hang a thermometer inside the beaker.

4. Set a burner below the beaker.

5. Start calculating the time by stopwatch.

6. The ice will begin to melt.

7. Now, it will have mixture of ice and water but its temperature will not rise above 0°C until all the ice melts.

8. Note the time which the ice takes to melt completely into water at 0°C.

9. When all the ice converts to water, its temperature will begin to rise. Continue heating the water at 0°C in the beaker. Its temperature will begin to increase.

10. Note the time which the water in the beaker takes to reach its boiling point at 100 °C from 0 °C.

11. Darw a temperature-time graph such as shown in figure 11.18.

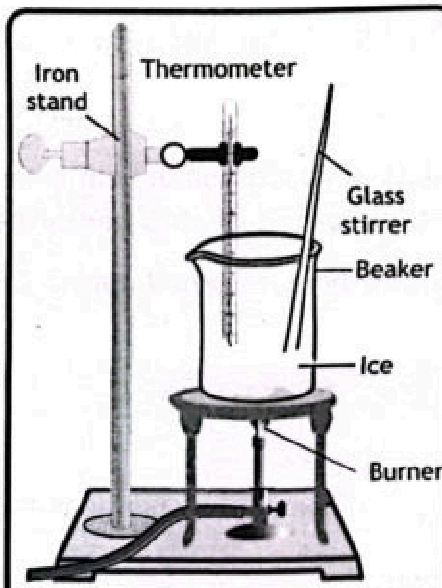


FIGURE 11.17

Experimental arrangement to find latent heat fusion of ice

Let's do some calculations to find the latent heat of fusion of ice from the graph data as follows:

Let, mass of ice = m

Finding the time from the graph:

I. Time taken by ice to melt completely at 0 °C (time for fusion) = $t_f = t_2 - t_1$ = 3.7 minutes

ii. Time taken by water for its temperature rise from 0 °C to 100 °C = $t_R = t_3 - t_2$ = 4.6 minutes

Specific heat of water = c = 4200 J kg^{-1} K^{-1}

Increase in the temperature of water from 0 °C to 100 °C = ΔT = 100 °C = 100 K.

Heat required by water to raise its temperature from 0 °C to 100 °C is given by:

$$\Delta Q = mc\Delta T$$

putting values $\Delta Q = m(4{,}200\,J\,kg^{-1}\,K^{-1})(100\,K)$

$$\Delta Q = m(4.2\times10^5\,J\,kg^{-1})$$

This is the heat absorbed by water to raise its temperature from 0 °C to 100 °C. This heat is absorbed by the water in time t_R (4.6 minutes). Heat is absorbed at uniform rate. So, Rate of absorption of

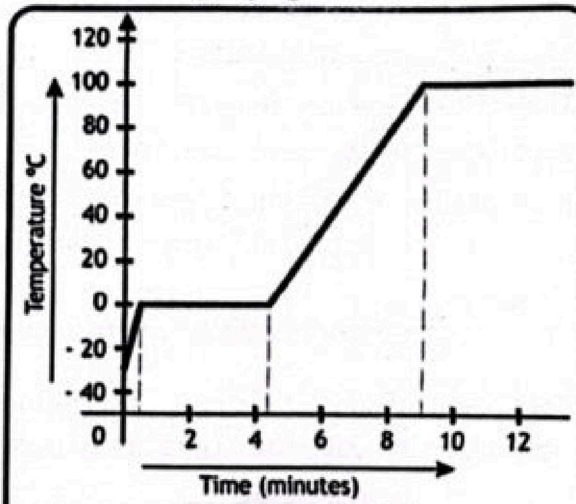


FIGURE 11.18

Temperature time graph for ice and water heat (heat absorbed by the water in unit time) is given by:

$$Rate\ of\ absorption\ of\ heat = \frac{\Delta Q}{t_R}$$

Rate of absorption of heat is same during fusion process time 't_f' and raising temperature time 't_R'. Hence, Heat absorbed by the water in time 't_F' during fusion process is:

$$Total\ heat\ absorbed\ during\ fusion\ of\ ice = Rate\ of\ absorption\ of\ heat \times Total\ time\ of\ fusion$$

$$\Delta Q_F = \frac{\Delta Q}{t_R} \times t_F = \Delta Q \times \frac{t_F}{t_R} \quad \boxed{1}$$

as: $$\Delta Q_F = m \times L_f \quad \boxed{2}$$

Comparing equations 1 and 2: $$m \times L_f = \Delta Q \times \frac{t_F}{t_R}$$

Putting values in above equation and simplifying it: $$m \times L_f = m \times (4.2 \times 10^5\ J\,kg^{-1}) \times \frac{3.7\,min}{4.6\,min}$$

Therefore, $$L_f = 3.9 \times 10^5\ J\,kg^{-1}$$

The latent heat of fusion of ice found by the above experiment is $3.37 \times 10^5\ J\,kg^{-1}$ while its actual value is $3.36 \times 10^5\ J\,kg^{-1}$.

11.4.4 EXPERIMENT TO FIND LATENT HEAT OF VAPORISATION OF WATER

To find latent heat of vaporisation of water, we keep on heating beaker contains boiling water as shown in figure 11.18. Continue heating water till all the water changes into steam. Note the time taken by water to change completely into steam at its boiling point 100 °C. Extend the temperature-time graph such as shown in figure 11.19. Let's calculate the latent heat of fusion of ice from the data as follows:

Time taken by water at 100 °C to change it into steam (time of vaporization) $= t_v = t_4 - t_3 = 24.4$ min.

In experiment to find latent heat of fusion L_f, we have calculated the rate of absorption of heat by water.

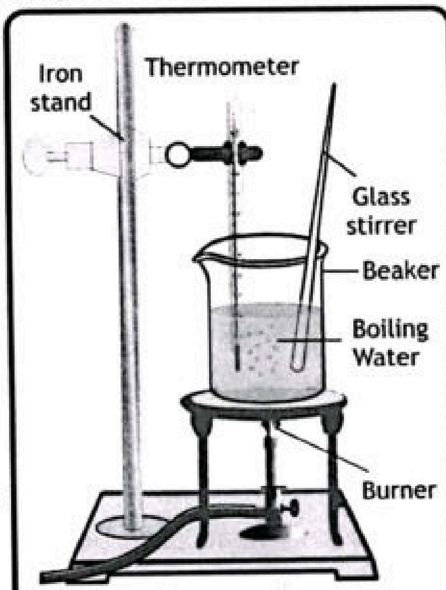


FIGURE 11.19

Experimental arrangement to find latent heat vaporization of water

$$Rate\ of\ absorption\ of\ heat\ by\ water = \frac{\Delta Q}{t_R}$$

Total heat absorbed during vaporization of water = Rate of absorption of heat × total time of vaporization:

$$\Delta Q_v = \frac{\Delta Q}{t_R} \times t_v = \Delta Q \times \frac{t_v}{t_R} \quad \boxed{1}$$

as: $$\Delta Q_v = m \times L_v \quad \boxed{2}$$

Comparing equations 1 and 2: $m \times L_v = \Delta Q \times \frac{t_v}{t_R}$

Putting values in above equation and simplifying it:

$$m \times L_v = m \times (4.2 \times 10^5\ J\,kg^{-1}) \times \frac{24.4\,\text{min}}{4.6\,\text{min}}$$

$$\text{Therefore,}\quad L_v = 2.23 \times 10^6\ J\,kg^{-1}$$

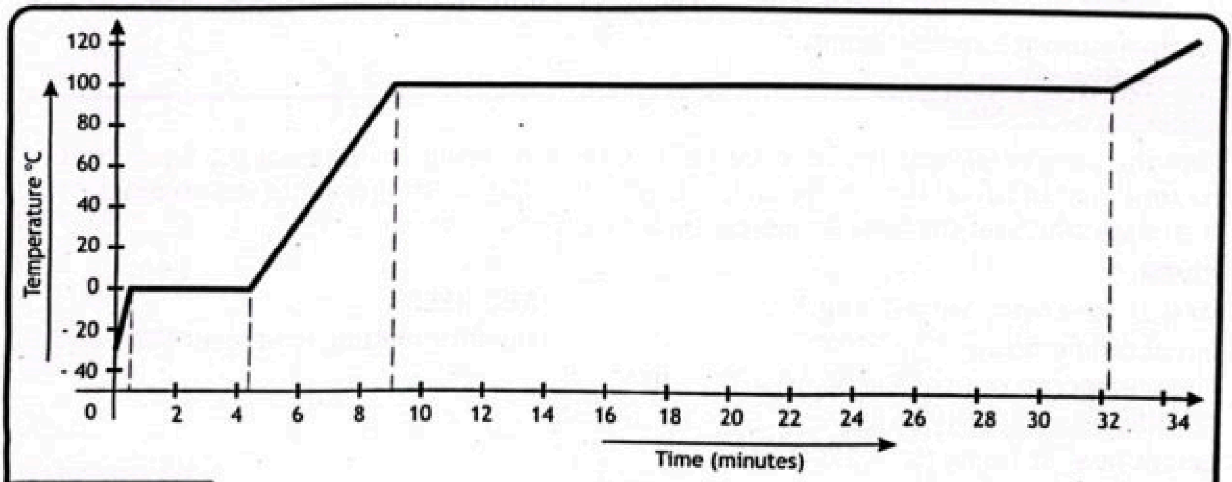


FIGURE 11.20 Temperature Vs Time graph for water

The latent heat of vaporization of water found by the above experiment is $2.23 \times 10^6\ J\,kg^{-1}$ while its actual value is $2.26 \times 10^6\ J\,kg^{-1}$.

From these two experiments we outline the following general procedural steps for calculating latent heat of fusion and vaporisation.

1. Take the solid at its melting point in a beaker and heat it at uniform rate.
2. Note the following time taken by the substance.
   a. Time in which it completely melts without any change in its temperature at melting point (fusion process)
   b. Time in which its temperature rises from melting point to boiling point
   c. Time in which it changes its state from liquid to gas without change in its temperature at its boiling point (boiling process)
3. Calculate the heat absorbed by the substance during the time its temperature rises from melting point to boiling point.
4. Calculate the rate of absorption of heat by dividing above calculated heat in point 3 by the time in which its temperature rises.

$$\text{Rate of absorption of heat} = \frac{\Delta Q}{t_R}$$

5. **Latent heat of fusion:** To calculate late of fusion of substance, multiply this rate of absorption of heat with time in which it completely melts without any change in its temperature at melting point

6. **Latent heat of vaporisation:** To calculate late of vaporisation of substance, multiply this rate of absorption of heat with time in which it changes its state from liquid to gas without change in its temperature at its boiling point.

Example 11.4

Find the amount of heat required for melting the ice-cream having mass 0.5 kg at 20 °C? (Latent heat of fusion for ice-cream L_f = 3.347 ×10^5 J/kg, melting point of ice-cream is - 10 °C and specific heat capacity for ice-cream is c = 2.1 × 10^3 J/kg °C).

GIVEN:

Mass of ice-cream 'm' = 0.5 kg
Initial temperature 'T_o' = 20 °C
Final temperature (melting point) = T = - 10 °C
Specific heat capacity of ice 'c' = 2.1 × 10^3 J/kg °C
Latent heat of fusion 'L_f' = 3.347 ×10^5 J/kg

REQUIRED:

Heat for melting ice-cream 'ΔQ' = ?

SOLUTION:

Change in temperature is given by: ΔT = T - T_0 = - 10 °C - (- 20 °C) = 10 °C

First, we will provide heat to increase the temperature of the ice-cream from 20 °C to - 10 °C (melting point).

$\Delta Q_1 = mc\Delta T$ putting values $\Delta Q_1 = (2.1 \times 10^3 J\,kg^{-1 0}C^{-1})\,(0.5\,kg)(10\,^0C)$

Hence, $\Delta Q_1 = 1.05 \times 10^4 J$

Now we will find heat required for melting ice-cream at its melting point is: $\Delta Q_2 = mL_f$

putting values $\Delta Q_2 = (0.5\,kg)(3.347 \times 10^5 J\,kg^{-1}) = 16.735 \times 10^4\ J$

Total heat required will be: $\Delta Q = \Delta Q_1 + \Delta Q_2$

putting values $\Delta Q = 1.05 \times 10^4 J\,kg^{-1} + 16.735 \times 10^4 J\,kg^{-1}$

Therefore, $\Delta Q = \boxed{17.785 \times 10^4 J\,kg^{-1} = 177.85\,kJ}$ **ANSWER**

So, a total of 177.85 kJ of heat will be required to melt an ice-cream of 0.5 kg at - 20 °C.

11.5 PRESSURE EXERTED BY GAS PARTICLES

The molecules of a gas are in a state of continuous random motion in a container. They collide with one another and also with the walls of the container, as shown in figure 11.21. Pressure is the measure of force exerted by the gas particles on unit area of the walls of the container perpendicularly.

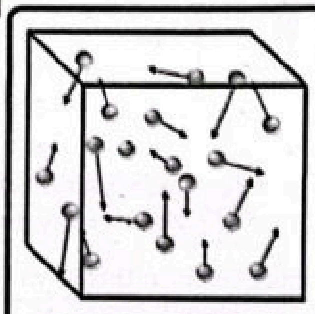


FIGURE 11.21
Random motion gas particles in a container

$$\text{Pressure} = \frac{\text{Force exerted by particle due to collision}}{\text{Area of the walls of container}} \quad \text{or} \quad P = \frac{F}{A}$$

Pressure of a gas in a container change with change in temperature, volume and amount of substance (number of particles).

A. Effect of temperature: If the temperature of the gas increases, the particles move faster. Faster particles collide with the walls with greater force and more frequently. This increases the pressure of the gas in the container. Pressure of the gas will decrease if its temperature decreases. So, the pressure of a gas inside a container is directly proportional to its temperature provided the volume remains constant.

B. Effect of volume: Pressure of a gas is inversely proportional to its volume if its temperature is kept constant (Boyle's law). If the volume of the container is reduced while keeping the number of particles constant, particles have less space to move around. This increases the number of collisions of its particles with the walls, which results in increase in pressure. Conversely, If the volume is increased, particles have more space and collide with the walls less frequently, which decreases the pressure as shown in figure 11.22.

C. Effect of amount of gas (number of particles): By increasing the number of particles of the gas in a fixed volume increases the number of collisions of gas molecules with the walls of the container and hence, it increases the pressure of the gas in the container. By decreasing the number of particles of the gas in the container, its pressure will decrease as shown in figure 11.22.

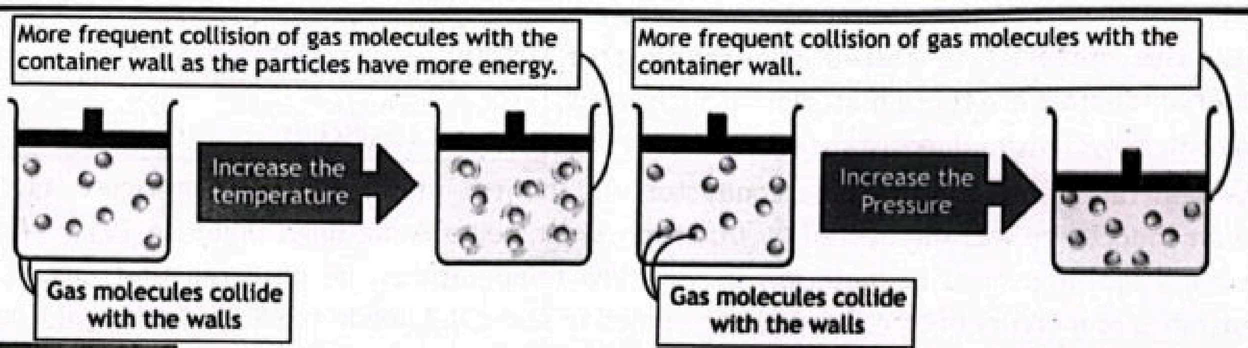
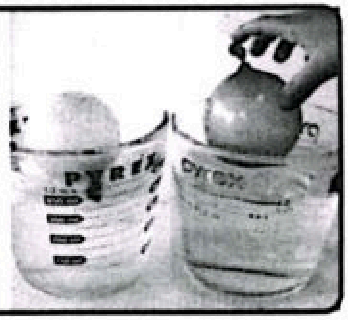


FIGURE 11.22 Effect of temperature and volume on pressure of gas

MINI LAB

Consider an inflated balloon filled with gas. When heated, the gas particles inside the balloon move faster and hit the balloon's inner walls more forcefully. This causes the balloon to expand. If you cool the balloon in air or in cold water, the particles move slow down, hit the walls less forcefully, and the balloon may shrink.



Note: Perform this in your home under the supervision of your parents.

11.6 SUPERCONDUCTIVITY

When we connect a wire or a device like bulb with the cell, current flows through it. Current flow means free electrons in the wire move through gaps between the atoms of the conductor. But they collide with the atoms of the conductor. This cause a hindrance to their flow which is called resistance of the conductor and if we relate it with the material then it is called specific resistance or resistivity of the material of the conductor. Atoms of the conductor are in vibrational motion. With decrease in temperature, their amplitude of vibration decreases. This increases the size of the gap between the atoms. Due to which collisions of flowing electrons with the atoms of the conductor decrease and hence, resistivity of the material also decreases.

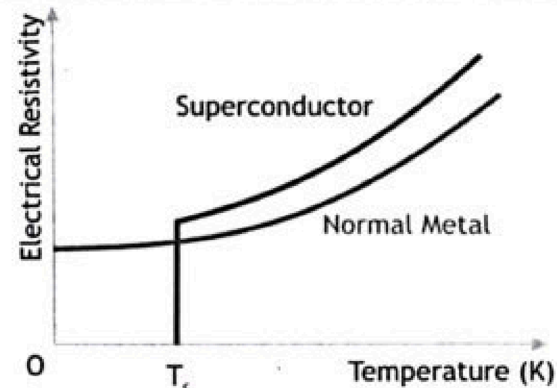


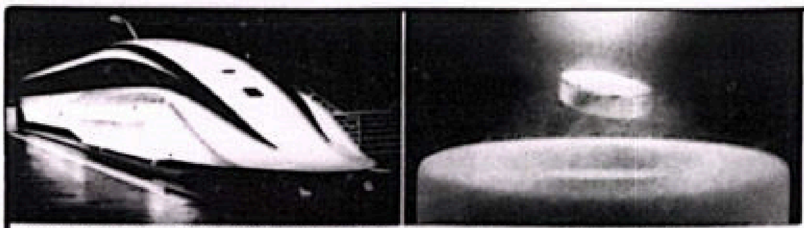
FIGURE 11.23 Superconductors

If we keep on decreasing the temperature then at a certain temperature (critical temperature) comes when resistivity of the material becomes zero and then the material is called superconductor. **Superconductors are those material through which current flows without resistance.**

Table 11.6 CRITICAL TEMPERATURES OF SOME SUBSTANCES

Substance	Critical temperature
Mercury (Sb)	4.2 K
Aluminum (Al)	1.18 K
Tin (Sn)	3.72 K
Lead (Pb)	7.2 K
Yttrium Barium Copper Oxide (YBCO)	92 K
Bismuth Strontium Calcium Copper Oxide (BSCCO)	108 K

The general graph relating superconductor and normal metal is shown in figure 11.23. Superconductivity was discovered by Dutch physicist Heike Kamerlingh Onnes in 1911. While studying the properties of materials at very low temperatures, he observed that electrical resistance of mercury becomes zero when cooled to about 4.2 Kelvin (-268.95°C). He got Nobel Prize in Physics in 1913.



(a) Magnetic levitation (Maglev) trains

(b) Magnetic levitation by superconductors

FIGURE 11.24 Applications of superconductors

DO YOU KNOW?

Critical Temperature: The temperature at which and below which the resistance and resistivity of substance become zero is called the critical temperature or superconducting transition temperature.

Superconductors are used in powerful electromagnets, particle accelerators, magnetic levitation (Maglev) trains as shown in figure 11.24 (a), small but powerful electric motors, fast computer chips, and potentially more efficient power transmission lines. Researchers continue to explore ways to achieve superconductivity at higher temperatures, which would make it more practical for everyday use.

SUMMARY

- **Freezing** is the phenomenon in which liquid changes into solid.
- **Melting** is the phenomenon in which solid changes into liquid.
- **Vaporization** is the phenomenon in which a liquid is converted into gas (vapours) upon boiling.
- **Evaporation** is phenomenon of conversion liquid into vapours at any temperature.
- **Condensation** is a phenomenon in which gases (vapours) change into liquids.
- **Sublimation** is a phenomenon in which solids change directly into gases.
- **Deposition** is a phenomenon in which gas changes directly to solid.
- **Thermal expansion** means "increase in size of matter on heating".
- **Linear thermal expansion** of solids is increase in length of substance on heating.
- **Volume thermal expansion** of solids is increase in volume of substance on heating.
- **Coefficient of linear thermal expansion** is the fractional change in length per kelvin change in temperature.
- **Coefficient of volume thermal expansion** is the fractional change in volume per kelvin change in temperature.
- **Real volume expansion** is thermal expansion in volume of liquid when it is heated directly.
- **Apparent volume expansion** is thermal expansion of volume of liquid in a container without considering the expansion of its container.

- **Bimetallic Strips** consists of two thin strips of different metals joined together which bend on heating.
- **Humidity** is content of water in air.
- **Refrigerant** is a material used to produce cooling in refrigerator that absorb an releases heat by cycling between liquid and gaseous state.
- **Latent Heat** is the amount of heat energy absorbed or lost by a substance during its phase change without change in its temperature.
- **Latent Heat of Fusion** is the amount of heat energy required to convert a given mass of a substance from the solid state to the liquid state without change in its temperature is called its latent heat of fusion.
- **Latent Heat of Vaporization** is the amount of heat energy required to convert a given mass of a substance from the liquid state to the gaseous state without any change in its temperature is called its latent heat of vaporization.
- **Pressure** is Force on unit area on an object perpendicularly.
- **Pressure of Gas** is the measure of force exerted by the gas particles on unit area of the walls of the container perpendicularly.
- **Superconductor** are those material through which current flows without resistance.
- **Critical temperature** is the temperature at which and below which the resistance and resistivity of substance become zero is called the critical temperature.

EXERCISE

MULTIPLE CHOICE QUESTIONS

QI. Choose the best possible option in the following questions.

1. During a hot summer day, a metal bridge might expands slightly. This expansion is caused by
   A. the bridge rusting and weakening.
   B. the metal atoms in the bridge vibrating more intensely.
   C. the weight of cars driving over the bridge.
   D. a decrease in the air pressure around the bridge.

2. Fog forms on a cold window pane in the morning. Which change of state is occurring?
   A. Melting B. Boiling C. Condensation D. Deposition
3. Which process involves the change of state from a gas to a solid without passing through the liquid phase?
   A. Deposition B. Melting C. Freezing D. Sublimation
4. Boiling point of water is:
   A. 212 °C B. 212 °F C. 100 K D. 373 °C
5. $J\,kg^{-1}K^{-1}$ is the unit of:
   A. specific Heat Capacity B. heat Capacity
   C. latent Heat of Fusion D. heat Energy
6. Evaporation takes place from
   A. surface B. bottom C. center D. any location
7. Relation between linear and volume expansion of solids is
   A. $\beta = \alpha/3$ B. $\beta = 1.5\alpha$ C. $\alpha = \beta/3$ D. $\alpha = 3\beta$
8. Heat added to a substance, at its melting pointing, is used to:
   A. increase K.E. of particle.
   B. decrease K.E. of particles
   C. increase the attraction between particles
   D. decrease the attraction between particles
9. 336 J/g is latent heat of fusion of a material. How much heat is required to melt 10 g of material at its melting point?
   A. 336 J B. 3360 J C. 33600 J D. 3.36×10^5 J
10. Which of the following factors increases the rate of evaporation?
    A. Decrease in temperature B. Increase in humidity
    C. Increase in wind speed D. Decrease in surface area
11. What is value of α for a solid if its β is $9 \times 10^{-7}\,K^{-1}$?
    A. $3 \times 10^{-7}\,K^{-1}$ B. $4.5 \times 10^{-7}\,K^{-1}$ C. $9 \times 10^{-7}\,K^{-1}$ D. $27 \times 10^{-7}\,K^{-1}$
12. The process that involves the latent heat of vaporization is
    A. Melting of ice B. Freezing of water C. Eveporation D. Condensation of steam
13. The sum and difference of the coefficient of real and apparent expansion of a liquid are in the ratio 2:1. The ratio of the coefficient of real expansion and apparent expansion must be
    A. 1:1 B. 2:1 C. 2:3 D. 3:1

14. Latent heat refers to the energy absorbed or released by a substance during a change of state, but with no change in temperature. What does "latent" mean in this context?

A. Constant B. Visible C. Hidden D. Transparent

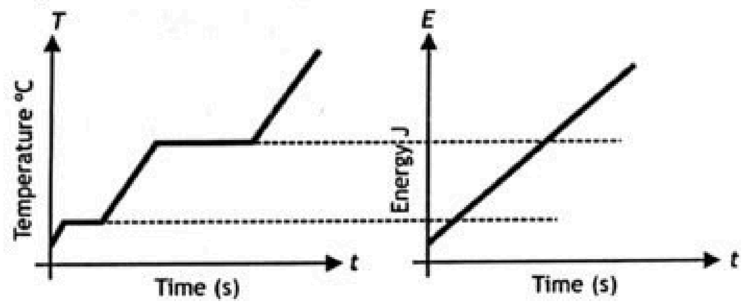
CONSTRUCTED RESPONSE QUESTIONS

QII. Follow the directions to respond to the following questions.

1. Look at these graphs for heating the ice, Energy (E)-time (t) graph shows that energy is being supplied to ice at constant rate to change it into liquid and finally into steam. While the temperature (T)-time (t) graph shows that change of temperature of ice and water during different stages.

a. There are two horizontal parts of this graph, where temperature is not changing but energy is being supplied to substance at constant rate. Explain why does temperature not change at these two stages?

b. Explain why the temperature and energy trends are not same for the same time intervals.



2. A heater supplies energy at a constant rate to a 100g of a substance. The variation with time of the temperature of the substance is shown in the figure. The substance is perfectly insulated from its surroundings. The power of the heater is 250 W.

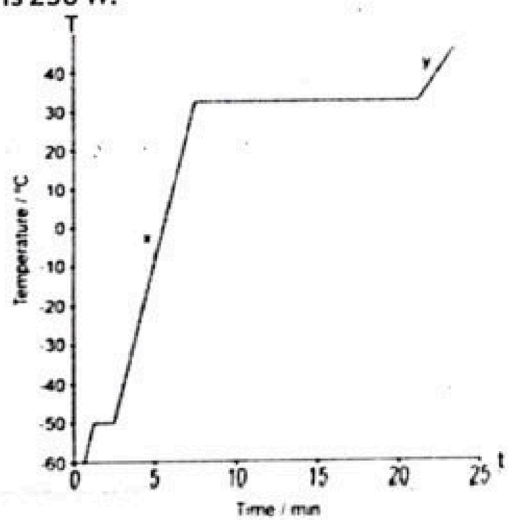
From the figure, answer the following questions:

a. What is melting and boiling point of the substance?

b. How long does it take to melt completely and how long does it take to vaporise from liquid state?

c. How much temperature increases in its liquid phase (x part of the graph)?

d. Calculate latent heat of vaporization of the substance?



SHORT RESPONSE QUESTIONS

QIII. Give a short response to the following questions.

1. Why do dew-drops form on leaves and grass in a spring morning?
2. What is the effect of pressure and temperature variation on sublimation and deposition?
3. Why do vapors form on the handle and cylinder of a fire extinguisher when it is discharged?
4. How does sweating helps to cool our body down during exercise?
5. Consider a piece of metal X initially at a temperature of 100 °C. It is placed on a heater (which is providing heat at constant rate) until it reaches a final temperature of 400 °C. The metal has a melting point of 250 °C.

   (i) Draw a temperature-time graph illustrating the changes in temperature of metal X as it is heated.

   (ii) Now, examine a different metal, Y, which has a higher latent heat of fusion compared to metal X. Both metals have identical melting points and heat capacities. The heating procedure for metal Y is conducted under the same energy supply rate as metal X. Describe how the temperature-time graph for metal Y will differ from that of metal X, considering the implications of its greater latent heat of fusion.
6. How does the pressure in a car tyre change during a long drive on a hot day?
7. How does understanding thermal expansion help prevent cracks in sidewalks during hot weather?
8. Imagine you are stuck in the snow with your car. Which would be more effective for melting the snow trapped underneath, a pot of hot water or a high-powered heat lamp?
9. How does the evaporation of water from a plant's leaves help to transport water and nutrients throughout the plant?
10. Why does adding ice to a drink cool it down more effectively than adding cold water?
11. What are the challenges associated with maintaining the extremely low temperatures required for superconductivity to occur?

LONG RESPONSE QUESTIONS

QIV. Give a detailed response to the following questions.

1. Define latent heat. Differentiate between latent heat and specific latent heat of fusion. Write their formulae.
2. Differentiate between latent heat of vaporisation and specific latent heat of vaporisation. Give their formulae and units.
3. What is evaporation? Differentiate between boiling and evaporation. On what factors evaporation depends?

4. What are linear and volume thermal expansion of solids? Discuss qualitatively the factors upon which these thermal expansions depend.
5. What are uses of thermal expansion in our daily life? Give examples
6. Explain thermal expansion of liquids in detail.
7. Discuss the application of bimetallic strips in temperature control devices like thermostats. Explain the principle of thermal expansion that allows the bimetallic strip to function, and illustrate how the differing expansion rates of the two metals are utilized in practical.
8. What is superconductivity? Explain the phenomenon in detail. What is their scope in future world?

NUMERICAL RESPONSE QUESTIONS

QV. Solve the questions given below.

1. Consider a steel bar of length 1.5m at 10 °C. It is heated to raise its temperature to 100 °C. Calculate (a) Increase in length (b) Final length at 100 °C. (Coefficient of linear thermal expansion of steel is $1.2 \times 10^{-5}\ K^{-1}$) **(Ans. 1.62 mm, 1.5 m)**
2. A solid cube of side length 10 cm at 25 °C is heated. What will be increase in its volume at 125 °C if its coefficient of linear thermal expansion is $9 \times 10^{-6}\ K^{-1}$. **(Ans. 2.7 cm^3)**
3. A steel railroad track segment is 10 meters long at a cool morning temperature of 15 °C. The coefficient of linear expansion for steel is 1.2×10^{-5} per °C. Later in the day, the temperature rises to 30 °C. How much will the steel track segment expand in length? **(Ans. 1.8 mm)**
4. A 2-liter (2000 cm^3) glass bottle is filled completely with orange juice at a room temperature of 20 °C. The coefficient of volumetric expansion for orange juice is 5×10^{-5} per °C. If the bottle is left in a hot car where the temperature reaches 40 °C, what volume of orange juice will overflow? Expansion of glass bottle is negligible. **(Ans. 2 cm^3)**
5. How much heat is required to change 15 kg of ice into water at its melting point? **(Ans. 4.95×10^6 J)**
6. How much heat is required to change 7 kg of water into steam at its boiling point? **(Ans. 1.58×10^7 J)**
7. 4 kg of ice has temperature of -20 °C. It is heated to convert into steam. Its final temperature is 120 °C. Calculate the total amount of heat energy involve for this conversion of ice into steam. (Specific heat of ice = 2100 J $kg^{-1}\ K^{-1}$, Specific heat of water = 4200 J J $kg^{-1}\ K^{-1}$, Specific heat of steam = 2000 J J $kg^{-1}\ K^{-1}$, Latent heat of fusion of ice = 3.3×10^5 J kg^{-1} and Latent heat of vaporization of water = 2.26×10^6 J kg^{-1}). **(Ans. 1.236×10^7 J)**