

SLO 8: Thermal Physics

8.1 Kinetic Molecular Theory

8.1.1 State The Basic Assumptions Of The Kinetic Theory Of Matter

- Matter is composed of very small particles called molecules which are always in motion.
- Motion of particles may be vibrational, rotational or linear.
- There exists a mutual force of attraction between the molecules known as intermolecular force.
- This force depends upon the distance between the molecules. It decreases with increasing distance between them.
- The molecules possess kinetic energy due to motion and potential energy due to force of attraction.
- Temperature of the substance depends upon the average kinetic energy of its molecules.

8.1.2 Structure Of Solids, Liquids And Gas Based On The Kinetic Theory Of Matter

Solid:

- The molecules are closely packed together and occupy minimum space.
- The molecules usually arranged in a regular pattern called lattice.
- There is a large number of particles per unit volume. That is why solids have the highest densities.
- The forces of attraction between particles are very strong.
- The particles are not able to change positions.
- The particles vibrate about fixed positions thus are not entirely stationary. This explains why solids have fixed shapes and volumes.

Liquid:

- The molecules are slightly further apart compared to that of solids.
- The molecules occur in clusters.
- There is slightly lesser number of particles per unit volume compared to solids. This why liquids have relatively high densities.
- The forces of attraction between particles are strong.
- The particles are free to move about within the liquid.
- These features explain why liquids have fixed volumes, but take the shape of the container.

Gas:

- The molecules are very far apart.
- The molecules are arranged randomly and are free to move with very high speeds.
- There is small number of particles per unit volume.
- The forces of attraction between particles are negligible.
- The particles are able to move freely in random directions at very high speeds.
- The particles occupy any available space.

8.1.3 Describe Plasma As The Fourth State Of Matter

The plasma is a gas in which most of the atoms are ionized containing positive ions and electrons. They are freely moving in the volume of the gas. Due to presence of positive ions and free electrons, plasma is the conducting state of matter. It allows electric current to pass through it. Since the gas in plasma state has properties which are quite different from ordinary gas, therefore, plasma is known as fourth state of matter.

The Sun and the most of other stars are in plasma state. Plasma is also found in plasma TV and in gas discharge tubes when electric current passes through them. The plasma state also occurs during the early stages of lightning formation known as lightning streamers which are the conducting paths through the atmosphere due to ionized air molecules.

8.1.4 State The Relationship Between The Motion Of Particles And Temperature

Temperature is essentially a measure of the average kinetic energy of the particles (atoms or molecules) within a substance. Kinetic energy is the energy of motion. When the temperature of a substance increases, the particles move faster. They have more kinetic energy. Similarly, when the temperature decreases, the particles move slower, possessing less kinetic energy. Solids have low kinetic energy and are tightly packed, vibrating in fixed positions. Liquids have higher kinetic energy, allowing them to move around more freely. Gases have the highest kinetic energy, moving rapidly and randomly.

8.1.5 Increase In The Temperature Of An Object Increases Its Internal Energy

Matter is composed of molecules which are always in motion. The molecules possess kinetic energy on account of their motion. Potential energy is also associated with molecules because of their attractive forces.

The sum of kinetic and potential energies of the molecules of an object is called its internal energy.

$$\Delta U = K.E + P.E$$

$$\Delta U \propto T$$

When we heat a substance, its molecular motion becomes more vigorous which means an increase in its internal energy. As a result, temperature of the substance rises. The heat energy transferred to a body increases the internal energy of its molecules due to which its temperature rises.

8.2 Thermal Properties of Matter

8.2.1 Describe The Thermal Expansion Of Solids

When a solid is heated, its particles gain energy and vibrate more vigorously. This increased movement causes the particles to occupy more space, resulting in thermal expansion.

Linear Expansion

Linear expansion refers to the increase in the length of a solid when it is heated. Only one-dimension (length) increases. It is common in long objects like rods, rails, and beams.

$$\Delta L = L_0 \cdot \alpha \cdot \Delta T$$

ΔL = change in length

L_0 = original length

α = coefficient of linear expansion

ΔT = change in temperature

Volumetric Expansion

Volumetric expansion refers to the increase in the volume of a solid when it is heated. All three dimensions (length, width, and height) increase. It is important for solid objects that expand in all directions.

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

ΔV = volume change

V_0 = original volume

B = coefficient of volumetric expansion

ΔT = temperature change

8.2.2 Explain The Thermal Expansion Of Liquids

When a liquid is heated, its particles move faster and spread apart, causing the liquid to expand. The expansion of liquids is described in two ways:

1. **Real Expansion:** Real expansion is the actual increase in the volume of the liquid itself when it is heated, without considering the container. It represents the true expansion of the liquid. It is difficult to observe directly because the container also expands.
2. **Apparent Expansion:** Apparent expansion is the observed increase in the volume of a liquid when it is heated in a container. It is called "apparent" because the container also expands, so the rise in the liquid level is less than the real expansion. What we see in practical experiments is the apparent expansion.

8.2.3 Define The Terms ‘Heat Capacity’ And ‘Specific Heat Capacity’

Heat capacity is the amount of heat required to raise the temperature of a body by 1°C (or 1 K). It depends on the mass and material of the object. Larger objects usually have a greater heat capacity.

$$C = \frac{\Delta T}{Q}$$

- C = heat capacity ($\text{J}/^\circ\text{C}$ or J/K)
- Q = heat supplied (Joules)
- ΔT = change in temperature ($^\circ\text{C}$ or K)

Specific heat capacity is the amount of heat required to raise the temperature of 1 kg of a substance by 1°C (or 1 K). It is a property of the material, not of the object's size. Different substances have different specific heat capacities.

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

- c = specific heat capacity ($\text{J}/\text{kg}\cdot^\circ\text{C}$ or $\text{J}/\text{kg}\cdot\text{K}$)
- Q = heat supplied (Joules)
- m = mass of the substance (kg)
- ΔT = change in temperature ($^\circ\text{C}$ or K)

8.2.4 Describe Latent Heat Of Fusion And Latent Heat Of Vaporisation

Latent heat is the amount of heat energy required to change the state of a substance without changing its temperature. There are two main types:

Latent Heat of Fusion

The heat absorbed by a unit mass of a solid at its melting point in order to convert solid into liquid without change of temperature is called "heat of fusion". Example: melting ice into water at 0°C .

$$Q = m \cdot L_f$$

Q = heat energy (Joules)

m = mass (kg)

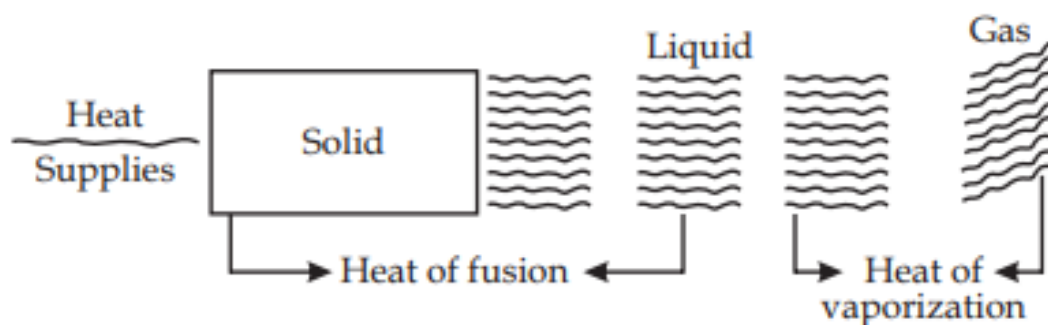
L_f = latent heat of fusion (J/kg)

Latent Heat of Vaporisation

The amount of heat energy required to change the state of a substance from liquid to vapor form, without changing its temperature is called “heat of vaporization”. Example: boiling water into steam at 100°C.

$$Q = m \cdot L_v$$

- Q = heat energy (Joules)
- m = mass (kg)
- L_v = latent heat of vaporisation (J/kg)



8.2.5 Describe Melting, Solidification, Boiling And Condensation In Terms Of Energy Transfer Without The Change In Temperature

When a substance changes its state (solid \rightleftharpoons liquid \rightleftharpoons gas), energy is transferred either to or from the substance. These processes occur at constant temperature because the energy is used to change the state, not to raise or lower the temperature.

Melting (Solid \rightarrow Liquid)

- Energy Transfer: Heat is absorbed by the solid.
- What Happens: Particles gain enough energy to overcome their fixed positions and move more freely.
- Temperature: Remains constant at the melting point.
- Example: Ice melting to water at 0°C.

Solidification / Freezing (Liquid \rightarrow Solid)

- Energy Transfer: Heat is released by the liquid to the surroundings.
- What Happens: Particles lose energy and become fixed in position, forming a solid.
- Temperature: Remains constant at the freezing point.
- Example: Water freezing to ice at 0°C.

Boiling (Liquid \rightarrow Gas)

- Energy Transfer: Heat is absorbed by the liquid.
- What Happens: Particles gain enough energy to completely overcome intermolecular forces and become gas.
- Temperature: Remains constant at the boiling point.
- Example: Water boiling to steam at 100°C.

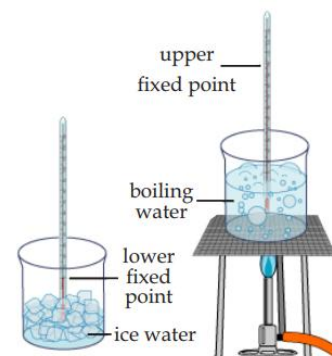
Condensation (Gas \rightarrow Liquid)

- Energy Transfer: Heat is released by the gas to the surroundings.
- What Happens: Particles lose energy and come closer together to form a liquid.
- Temperature: Remains constant at the condensation point (same as boiling point).
- Example: Steam condensing to water at 100°C.

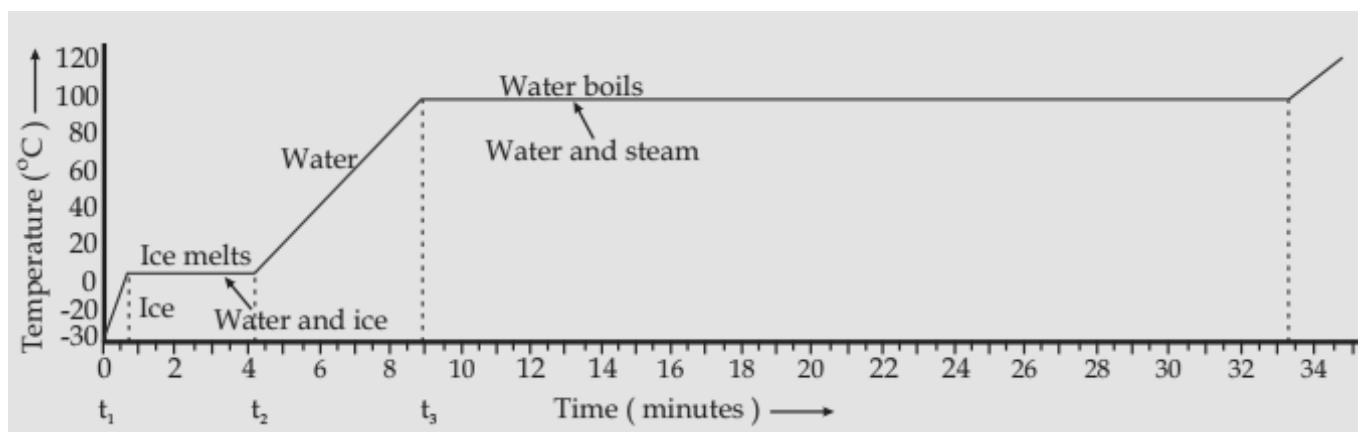
8.2.6 Determine The Heat Of Fusion Of Ice And Heat Of Vaporisation Of Water

Take a container and place it on a stand. Put small pieces of ice in the container. Suspend a thermometer in the container to measure the temperature. Take a stop watch to measure accurate time at different stages. Now place the container on the burner. The ice will start melting after absorbing heat. The temperature will remain same up to 0°C until all the ice melts. Note the time t_1 and t_2 , which the ice takes to melt completely into water at 0°C .

Supply heat continuously to water at 0°C , again note the time, its temperature will start to increase. Note the time, which water in container takes to reach its boiling point at 100°C from 0°C . Draw a temperature-time graph. Calculate the heat of fusion of ice from the data using the graph.



The container now contains boiling water we continue to supply heat to water, till all the water convert into steam. Note the time during which water in container completely changed into steam at its boiling point, using the temperature-time graph, calculate the heat of vaporization of water.



Heat of Fusion:

$$L_f = \frac{P \times \Delta t}{m}$$

By performing actual experiment, we will find the exact heat of fusion of ice. The standard value is

$$L_f = 3.34 \times 10^5 \frac{\text{J}}{\text{kg}}$$

Heat of Vaporisation:

$$L_v = \frac{P \times \Delta t}{m}$$

By performing actual experiment, we will find the exact heat of fusion of ice. The standard value is

$$L_f = 2.26 \times 10^6 \frac{\text{J}}{\text{kg}}$$

8.2.7 solve word problems involving the concept of specific heat capacity, latent heat of fusion and vaporisation

Practice questions provided on separate worksheet.

8.2.8 describe the process of evaporation and how it is different from Boiling

The process in which the water changes from liquid to gas or vapor form is known as “evaporation”. This happens more quickly if temperature is higher, air is dry and moving (windy), surface area is large.

Boiling is the process in which a liquid changes into gas throughout the entire liquid at a specific temperature called the boiling point. Heat is applied continuously. Bubbles form inside the liquid and rise to the surface. Temperature remains constant during boiling.

EVAPORATION	BOILING
It occurs at any temperature below boiling point	It occurs only at boiling temperature
It causes cooling	It does not cause cooling
It is relatively slow	It is relatively fast.
It takes place only at the liquid surface	It takes place throughout the liquid
No formation of bubbles	Bubbles are formed

8.2.9 explain that evaporation causes cooling

When evaporation occurs, the molecules of water with greater Kinetic energy escape from its surface. So, the molecules of water with lower Kinetic energy are left behind. This results in a decrease in the temperature of water. Hence, evaporation causes cooling.

Real-Life Examples:

1. Sweating in Humans: Sweat (water) evaporates from the skin. It takes away heat from the skin, making you feel cooler.
2. Water in Clay Pots: Water slowly seeps out and evaporates from the surface. The evaporation cools the water inside.
3. Alcohol on Skin: When alcohol is rubbed on the skin, it evaporates quickly. We feel a cooling sensation because it takes away heat from our skin.

8.2.10 describe factors that influence the rate of surface evaporation

1. Temperature: With the increase in temperature the rate of evaporation also increases.
2. Wind Speed: Rate of evaporation also increases with the increase in wind speed.
3. Surface area of liquid: Rate of evaporation increases with the increase in surface area of liquid.
4. Humidity: The rate of evaporation decreases with increase in humidity.
5. Nature of liquid: Nature of liquid also effect the rate of evaporation. Liquid with lower boiling point have grater vapor pressure and evaporate more rapidly.
6. Solute Concentration: Salty water evaporates more slowly than pure water.

8.3 Temperature Scale and Thermometer

8.3.1 describe the Celsius, Fahrenheit, and Kelvin temperature scales and their relationships using fixed reference points

For the measurement of temperature, a scale is to be constructed which requires two reference temperatures called two fixed points. One is the steam point slightly above the boiling of water at standard atmospheric

pressure. This corresponds to upper fixed point of the scale. The second fixed point is the melting point of pure ice or simply ice point. It is called the lower fixed point. Different scales of temperature have been constructed by assigning different numerical values to these fixed points.

Celsius or centigrade scale

In Celsius or centigrade scale, the numerical values assigned to lower and upper fixed points are 0 and 100. As the difference between these values is 100, so the space between these points is divided into 100 equal parts. Each part is known as 1°C

Fahrenheit scale

In Fahrenheit scale, the lower fixed point is labelled as 32 and upper as 212. As the difference between these two numbers is 180, so in this scale the space between these points is divided into 180 equal parts. Each part is known as 1°F

Kelvin scale

There is a third scale of temperature known as Kelvin scale or Absolute temperature. It is used in scientific measurements. In Kelvin scale, the lower and upper fixed points are labelled as 273 and 373. As the difference between these values is 100, so the width of 1 K is the same as that of 1°C . The zero point of this scale is the temperature at which the molecules of a substance cease to move. Their average kinetic energy becomes zero. This is known as absolute zero. Its value is -273.15°C . Absolute zero is the lowest possible temperature ever to be in the whole universe. The matter does not exist below absolute zero temperature.

8.3.2 Convert Temperature From One Scale To Another (Fahrenheit, Celsius, Kelvin)

Conversion of Celsius (centigrade) to Fahrenheit scale:

$$T_F = \frac{9}{5} \times T_C + 32$$

Conversion of Fahrenheit to Celsius scale:

$$T_C = \frac{5}{9} (T_F - 32)$$

Relationship between Kelvin and Celsius scales:

$$T_K = T_C + 273$$

8.3.3 Explain That A Physical Property That Varies With Temperature Can Be Used As A Criterion To Measure Temperature

The key principle behind measuring temperature is that “any physical property of a substance that changes consistently, reproducibly, and (ideally) in a predictable/nearly linear way with temperature can be used as a criterion (or basis) to measure temperature”. Such a property is called a thermometric property. A device that uses one of these properties to indicate temperature is a thermometer.

Temperature is not directly observable — we can't "see" or "touch" it in a fundamental way. Instead, we rely on indirect measurement: we observe how something else (a physical property) responds when its temperature changes, then calibrate that response against known temperature points (like boiling water to ice conversion) to create a scale. For this to be reliable, the property must satisfy these conditions:

1. It must change measurably and monotonically (always in the same direction — e.g., always increases or always decreases) with temperature.
2. The change should be reproducible (same change for the same temperature every time).

3. It should be sensitive enough to detect small temperature differences.

8.3.4 Illustrate The Sensitivity, Range And Linearity Of Thermometers

A thermometer is evaluated by its three key characteristics that are sensitivity, range and linearity. They help determine the suitability of the thermometer for specific use ensuring accurate and reliable measurement of temperature.

Sensitivity

Sensitivity of a thermometer refers to its ability to detect small changes in the temperature of an object. For example, the minimum division on the scale of a thermometer is 1°C . The accuracy of its temperature measurement will be 1°C . On another thermometer the marks are 0.1°C apart. Hence, its accuracy will be up to 0.1°C and said to be more sensitive. Its measurement will be more precise than the measurement by a thermometer with an accuracy of 1°C .

Range

This refers to the span of temperature, from low to high, over which the thermometer can measure accurately. For example, a clinical thermometer designed for human body temperature has a narrow or short range, say from 35°C to 45°C . A long-range thermometer is usually used for science experiments in the laboratory with markings from -10°C to 110°C . The choice of liquid for thermometers put a lower and upper limit for the range of a thermometer. For example, Mercury freezes at -39°C and boils at 357°C . Hence, we can construct mercury in glass thermometers within this range. The marking scale depends on desired range of measurement. For extremely low temperatures, alcohol is used. Alcohol has a much lower freezing point about -112°C which increases its lower limit for the range but it has lower upper limit as it boils at 78°C .

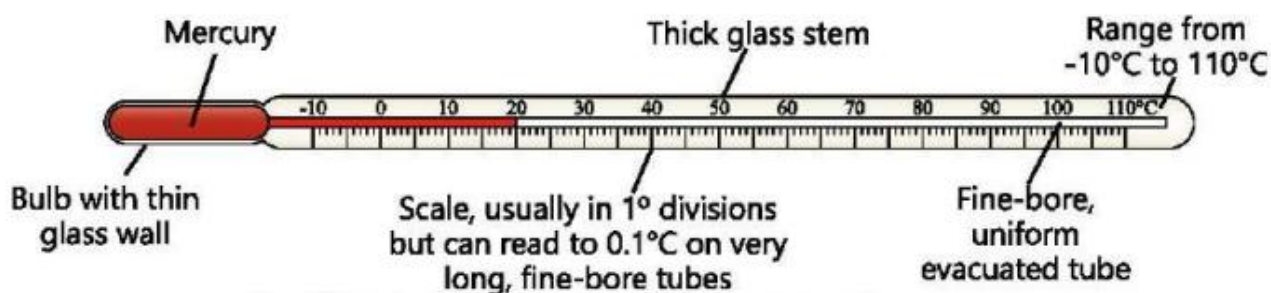
Linearity

This refers to a direct proportional relationship between the temperature and scale reading across entire range of measurement. A good linear thermometer should measure equal increments on the scale corresponding to equal change in the temperature. It means that marking on the scale should be evenly spaced over the whole range. High linearity means more consistent and proportional scale readings over the entire range to ensure accuracy of measurement.

8.3.5 Compare Liquid In Glass Thermometer And Thermo-Couple On The Bases Of Structure, Sensitivity, Range And Linearity

Liquid-in-glass Thermometer

A liquid-in-glass thermometer has a narrow and uniform capillary tube having a small bulb filled with mercury or alcohol at its lower end. The thin wall of the glass bulb allows quick conduction through glass to the liquid from a hot object whose temperature is to be measured. Mercury being metal is a good conductor and hence responds quickly to the change in temperature.

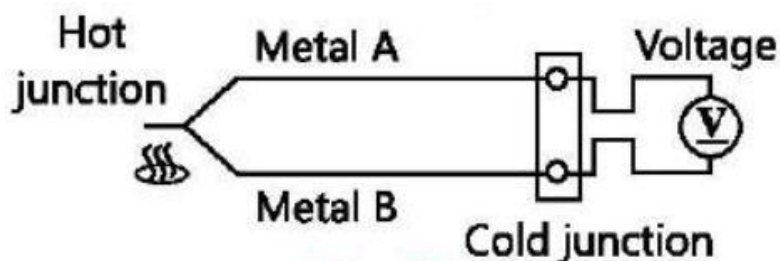


The small amount of liquid also responds more quickly to a change in temperature. The quick response makes the device sensitive. Use of mercury is quite sensitive for normal measurements. For greater accuracy, alcohol can be used as its expansivity is six times more than mercury but it has range limitation to higher temperature measurements due to its low boiling point (78°C).

The uniformity of the narrow tube or bore ensures even expansion of the liquid required to make the linear measuring scale. The choice of mercury allows to use it over a long-range temperature due to its low freezing point and high boiling point. It provides a fairly long range of measurement of temperature.

Thermocouple Thermometer

This type of thermometer consists of two wires of different materials such as copper and iron. Their ends are joined together to form two junctions. If the two junctions are at different temperatures, a small current flows across them. This current is due to the potential difference produced across the two junctions as the two wires have different resistance to the flow of current. The greater is the difference of temperatures, the greater is the potential difference or voltage produced across the junctions.



If one end of the junction is kept at a fixed lower temperature, say by placing it in an ice bath at 0°C for reference, the temperature of other junction at a higher temperature can be measured using a millivolt meter by a calibrated scale on it. This type of thermometer is particularly useful for very high temperatures and also rapidly changing temperature as there is only a small mass of metal (the junction) to heat up. Thermo-electric current is a thermometric property in a thermocouple.