Chapter Name: Heat and Thermometry

Concept of Heat

Heat is a form of energy that flows from one body to another due to a difference in temperature.

When two objects at different temperatures come in contact, heat always flows from the hotter object to the colder one, until both reach the same temperature — known as thermal equilibrium.

Heat is actually the total kinetic energy of all the particles in a substance. The faster the particles move, the more heat energy they possess.

Characteristics of Heat:

- Heat is a form of energy.
- It flows from a region of higher temperature to a region of lower temperature.
- It depends on the mass, temperature, and specific heat of a substance.
- It can change the temperature, physical state, or size of a body.
- Heat can be transferred by conduction, convection, or radiation.

Units of Heat:

- SI Unit: Joule (J)
- Other Unit: Calorie (Cal)
- 1 Calorie=4.18 Joules

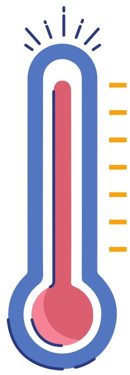
Example: When you heat a metal rod, energy in the form of heat flows through the rod, increasing the motion of its atoms.

Concept of Temperature

Temperature is the measure of the degree of hotness or coldness of a body. It indicates how hot or cold an object is, but not how much heat it contains. It is a measure of the average kinetic energy of the molecules of a substance.

Even though a large bucket of warm water has more heat than a cup of boiling water, both may have the same temperature. Thus, temperature and heat are related but not the same.

Units of Temperature:



Celsius (°C)

- Freezing point of water = 0°C
- Boiling point of water = 100°C

Fahrenheit (°F)

- Freezing point = 32°F
- Boiling point = 212°F

Kelvin (K)

- Absolute zero = 0 K = -273°C
- Boiling point of water = 373 K

Conversion Formulas:

$$K = {}^\circ C + 273$$

$${}^\circ F = \frac{9}{5}({}^\circ C) + 32$$

$${}^\circ C = \frac{5}{9}({}^\circ F - 32)$$

Measurement of Heat

Heat absorbed or released by a substance can be measured using the following formula:

$$Q = m \times c \times \Delta T$$

Where,

- Q = Heat gained or lost (in Joules)
- m = Mass of the body (in kg)
- c = Specific heat capacity (J/kg·K)
- ΔT = Change in temperature (T_2 - T_1)

Example:

How much heat is required to raise the temperature of 2 kg of water from 20°C to 60°C?

Answer:

$$Q = m \times c \times \Delta T = 2 \times 4200 \times (60 - 20) = 336,000\,J$$

So, **336 kJ** of heat is required.

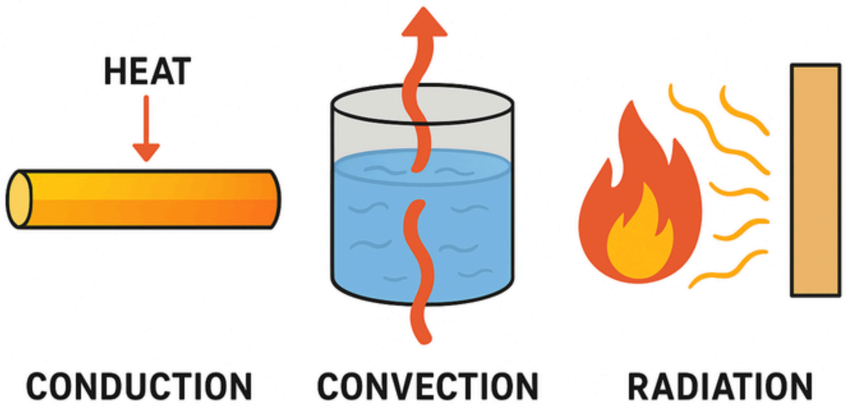
Measurement of Temperature

Temperature is measured using thermometers, which work on the principle of thermal expansion of substances.

Types of Thermometers:

- **Mercury Thermometer:** Used in laboratories for measuring temperature of substances.
- **Clinical Thermometer:** Used to measure human body temperature (35°C to 42°C).
- **Thermocouple Thermometer:** Used for measuring very high temperatures in industries.
- **Resistance Thermometer:** Works on change in electrical resistance with temperature.

Mode of Heat Transfer



Heat energy can be transferred from one body to another by **3 main processes**:

Conduction

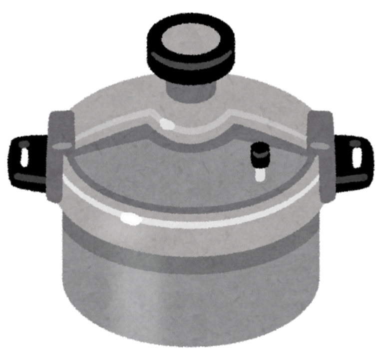
Conduction is the process of heat transfer from one molecule to another without actual movement of particles.
It mainly occurs in solids, especially metals.

Explanation

When one end of a metal rod is heated, its atoms gain energy and start vibrating faster. These vibrations are passed on to neighboring atoms, and heat energy moves from the hot end to the cold end.

Example

- A metal spoon becomes hot when kept in a hot cup of tea.
- Cooking utensils are made of metal because they are good conductors.



Good Conductors: Copper, Aluminum, Silver.

Bad Conductors (Insulators): Wood, Glass, Plastic, Rubber.

Mathematical Expression:

$$Q = \frac{KA(T_1 - T_2)t}{L}$$

Where;

- Q = Heat conducted (J)
- K = Coefficient of thermal conductivity (W/m·K)
- A = Area of cross-section (m^2)
- (T1-T2) = Temperature difference (K)
- t = Time (s)
- L = Length of the rod (m)

Convection

Convection is the process of heat transfer in liquids and gases due to the actual movement of particles from one place to another.

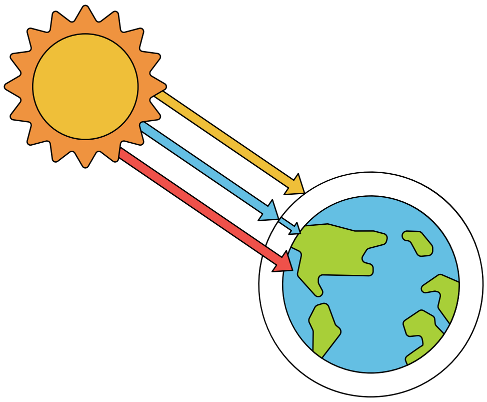
Explanation

When water is heated from below, the water at the bottom becomes hot, expands, and becomes lighter. It rises, while the colder, heavier water moves down to take its place. This continuous movement forms a convection current that transfers heat.

Example

- Heating water in a pan.
- Sea breeze and land breeze (caused by convection in air).
- Chimneys in kitchens or factories help remove hot air by convection.

Radiation



Radiation is the process of heat transfer in the form of electromagnetic waves (infrared rays), without any medium. It can occur through vacuum, unlike conduction or convection.

Explanation

When you stand near a fire, you feel warm even though the air between you and the fire is not very hot. The heat reaches you through radiation.

Example

- Heat from the Sun reaches the Earth by radiation.
- Heat felt from a bulb or heater.
- A black surface absorbs more radiant heat than a white surface.

Important Properties:

- No medium is required for radiation.
- Black and dull surfaces are good absorbers and emitters of heat.
- Polished and shiny surfaces are poor absorbers but good reflectors.

Difference Between Conduction, Convection, and Radiation

Point of Difference	Conduction	Convection	Radiation
Definition	Transfer of heat from one particle to another without actual movement of particles.	Transfer of heat by actual movement of fluid (liquid or gas) molecules.	Transfer of heat in the form of electromagnetic waves without any medium.

Medium Required	Requires a material medium, mainly solids.	Requires a medium — liquids or gases.	Does not require any medium (can occur through vacuum).
Nature of Process	Heat transfer occurs molecule to molecule.	Heat transfer occurs by mass movement of particles.	Heat transfer occurs by radiation waves (infrared).
Movement of Particles	No actual movement of particles.	Particles move from one place to another.	No movement of particles needed.
Speed of Heat Transfer	Comparatively slow.	Faster than conduction.	Fastest mode of heat transfer.
Direction of Heat Transfer	Along the length of the material only.	Vertically or in circular currents.	In straight lines (rays).
Examples	A metal spoon becomes hot when placed in hot tea.	Boiling of water, sea and land breeze.	Heat from the Sun, warmth near a fire.
Occurs In	Solids.	Liquids and gases.	Solids, liquids, gases, and even vacuum.
Dependence on Medium	Depends strongly on nature of medium.	Depends on movement and density of medium.	Independent of medium.
Practical Use	Cooking utensils made of metals.	Water heaters, air conditioners.	Solar panels, radiant heaters.

Coefficient of Thermal Conductivity

The coefficient of thermal conductivity (K) of a material is defined as the quantity of heat that passes per second through 1 m² of a material, of thickness 1 m, when there is a temperature difference of 1 K between its faces.

$$K = \frac{QL}{A(T_1 - T_2)t}$$

Where;

- Q = Quantity of heat conducted (J)
- L = Thickness or length of conductor (m)
- A = Cross-sectional area (m²)
- (T1-T2) = Temperature difference (K)
- t = Time (s)

SI Unit:

Watt per meter per Kelvin (W/m·K)

Interpretation:

- A higher K value means the material is a better conductor.
- Metals have high thermal conductivity, while non-metals have low conductivity.

Example:

A copper rod 0.5 m long and 1 cm² in area conducts 100 J of heat in 10 seconds when the temperature difference between its ends is 20°C. **Find K**.

Answer:

$$K = \frac{QL}{A(T_1 - T_2)t}$$

$$K = \frac{100 \times 0.5}{(1 \times 10^{-4}) \times 20 \times 10} = 25\, W/m\cdot K$$

Difference Between Heat and Temperature

Heat	Temperature
It is a form of energy.	It is the measure of degree of hotness or coldness.
Depends on mass and nature of substance.	Does not depend on mass.
SI unit is Joule (J).	SI unit is Kelvin (K).
It is total kinetic energy of molecules.	It is average kinetic energy of molecules.

Applications of Heat Transfer

Conduction:

- Cooking utensils and iron rods use conduction to transfer heat efficiently.

Convection:

- Room heaters warm up air through convection currents.
- Sea and land breezes occur due to convection in air.

Radiation:

- Solar cookers and solar heaters work on radiation.
- Black objects absorb more radiant heat.

Concept of Expansion

When a body is heated, its temperature increases, and the molecules move more vigorously. As a result, the body expands. This phenomenon is known as thermal expansion.

Similarly, when a body is cooled, it contracts.

Expansion of Solids

- When solids are heated, they expand in three possible ways depending on the dimensions considered:
- **Linear Expansion (1D)** — Expansion in one direction (length).
- **Superficial or Areal Expansion (2D)** — Expansion in two directions (area).
- **Cubical or Volumetric Expansion (3D)** — Expansion in all three directions (volume).

Linear Expansion

When the temperature of a solid increases, its length increases. If L1 is the original length and L2 is the new length at temperature rise ΔT, then

$$\text{Increase in length, } \Delta L = L_2 - L_1 = \alpha L_1 \Delta T$$

Where:

- α = **Coefficient of Linear Expansion**
- ΔT = Rise in temperature

$$\boxed{\alpha = \frac{\Delta L}{L_1 \Delta T}}$$

Unit of α: per °C ($°C^{-1}$)

Superficial Expansion

When a solid expands in area,

$$\Delta A = \beta A_1 \Delta T$$

Where:

- β = **Coefficient of Superficial Expansion**
- A1 = Original area
- ΔA = Increase in area

$$\boxed{\beta = \frac{\Delta A}{A_1 \Delta T}}$$

Unit of β: per °C ($°C^{-1}$)

Cubical Expansion

For expansion in volume,

$$\Delta V = \gamma V_1 \Delta T$$

Where:

- γ = **Coefficient of Cubical Expansion**
- V1 = Original volume
- ΔV = Increase in Volume

$$\boxed{\gamma = \frac{\Delta V}{V_1 \Delta T}}$$

Unit of γ: per °C (°C^{-1})

<u>Relation Among α, β, and γ:</u>

$$\boxed{\beta = 2\alpha \quad \text{and} \quad \gamma = 3\alpha}$$

Expansion of Liquids

Liquids also expand on heating, but their expansion is measured through the vessel that contains them.

There are three types:

- **Apparent Expansion:** The observed increase in the volume of liquid when heated in a container.
- **Real Expansion:** The actual increase in volume of the liquid when the expansion of the container is also considered.

Relation:

$$\text{Real Expansion} = \text{Apparent Expansion} + \text{Expansion of Container}$$

Expansion of Gases

Gases expand much more than solids and liquids when heated. At constant pressure and temperature conditions, gases obey:

A. Charles's Law:

- Volume of a gas ∝ Temperature (at constant pressure).

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

B. Gay-Lussac's Law:

- Pressure of a gas ∝ Temperature (at constant volume).

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Specific Heats of a Gas

The amount of heat required to raise the temperature of 1 mole of gas by 1ºC (or 1 K) is called specific heat.

(a) Specific Heat at Constant Pressure (Cp):

Heat required to raise the temperature of a gas when pressure is constant.

(b) Specific Heat at Constant Volume (Cv):

Heat required to raise the temperature of a gas when volume is constant.

Relation Between Cp and Cv:

For an ideal gas:

$$\boxed{Cp - Cv = R}$$

Where R = Universal Gas Constant

and

$$\boxed{\frac{Cp}{Cv} = \gamma} \quad \text{(Ratio of specific heats)}$$