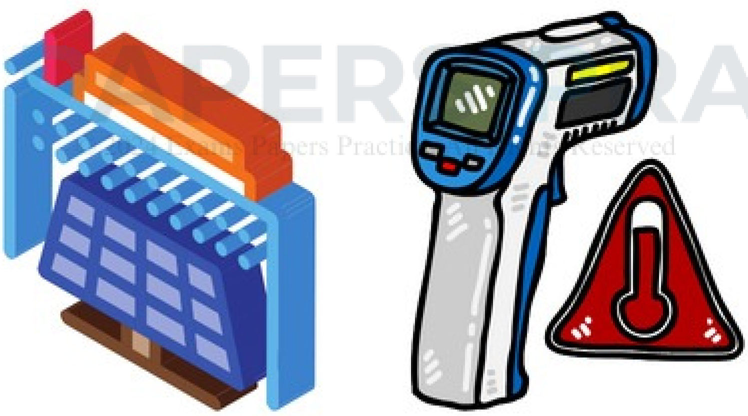
Chapter 11

Thermal energy transfers



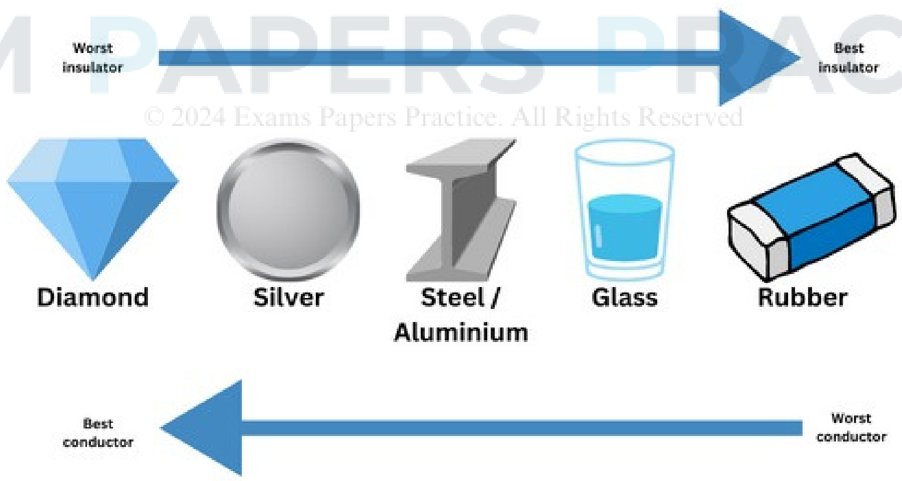
11.1 Conduction

Key terms:

Thermal conduction	Thermal conduction is the process where heat transfers through a material or between different materials that are in direct contact.
Thermal conductor	A thermal conductor is a material that allows heat to pass through it easily due to its high thermal conductivity.
Thermal insulator	A thermal insulator is a material that restricts the flow of heat, minimizing thermal conductivity and thus reducing heat transfer.

11.1.1 Explaining conduction in metals and non-metals

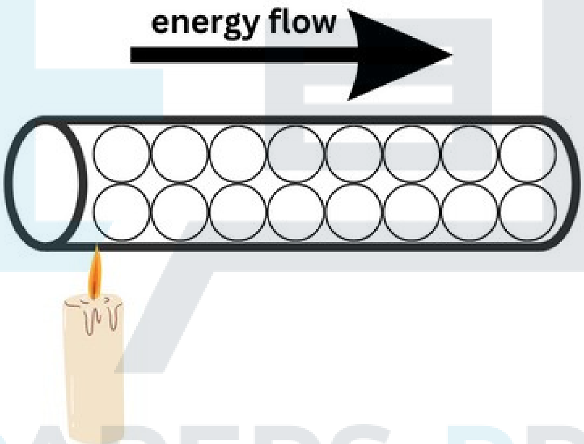
1. Typically, metals excel in transferring thermal energy, while nonmetals tend to be less effective in conducting heat.
2. Both air and water exhibit low efficiency in transferring thermal energy. The image below compares conductors and insulators:



3. We need different explanations of conduction for these two types of materials.

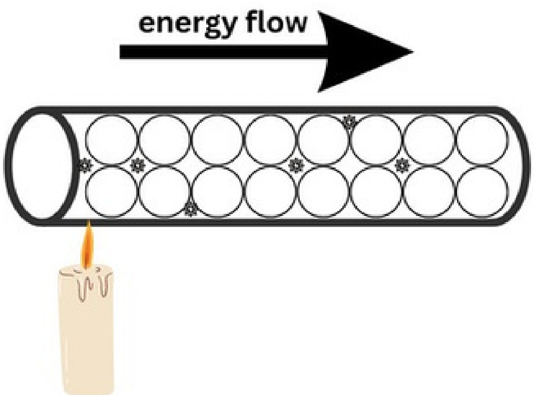
Conduction in non-metals

1. Heating one end of a glass rod causes increased vibration among its atoms at that end compared to the cooler end.
2. These vibrating atoms collide with adjacent atoms.
3. Consequently, each atom shares its energy with neighbouring atoms.
4. Over time, these collisions progressively transfer energy from the heated atoms to those at the cooler end.
5. This gradual process results in the steady transfer of energy along the rod, moving from the hot end to the cold end.



Conduction in metals

1. In metallic conductors, numerous electrons are unbound and capable of free movement.
2. These mobile electrons transport thermal energy as they become heated and traverse through the metal.



Conduction in liquid

1. In liquids, particles are closely packed together.
2. Because the particles can move freely, vibrations are not transmitted as effectively as in solids, resulting in liquids being weaker conductors compared to solids.

Conduction in gases

1. The particles in gases are very **spread out**, making gases very poor conductors of thermal energy.

11.2 Convection

1. Thermal energy in liquids and gases primarily transfers through a process called convection.

2. An example of convection is a hot air balloon:
    a. When air is heated, it expands, causing its density to decrease.
    b. The warm air becomes less dense than the surrounding cooler air, causing it to rise.
    c. To achieve flight, the balloon, basket, and passengers must collectively have a lower density than the cold surrounding air.

3. Hot air rises due to the fluid nature of air, and convection can be observed in any fluid, whether it's a liquid or a gas.

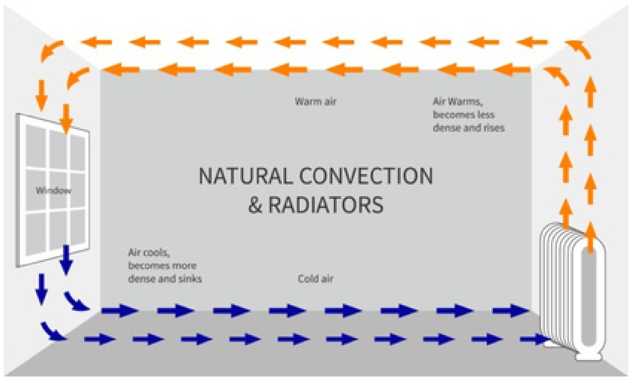
4. Difference between conduction and convection:

Convection	Conduction
Transfer of heat through the movement of fluid (liquid or gas)	Transfer of heat through direct contact between materials

11.2.1 Convection currents at work

Electric Heater

- Thermal energy will be moving around the room from the heater because of convection currents, which rise from the heater.



Refrigerator

- In a refrigerator, cold air sinks from the freezing compartment. If the freezer was at the bottom, cold air would remain there, and the food at the top would not be cold.

11.3 Radiation

1. Radiation is the sole method of thermal energy transfer that can propagate without requiring a medium.
2. It can propagate even through a vacuum.
3. In addition to visible light, the Earth receives various types of electromagnetic radiation from the Sun, such as infrared and ultraviolet radiation.

Infrared radiation

1. All objects emit infrared radiation.
2. The amount of infrared radiation emitted by an object increases with its temperature.
3. Characteristics of infrared radiation:
    a. Produced by warm or hot objects
    b. Form of electromagnetic radiation
    c. Propagates through empty space in wave form.
    d. Travels in straight lines
    e. Warms objects upon absorption
    f. Invisible to the naked eye
    g. Detectable by nerve cells in the skin

11.3.1 Good absorbers, good emitters

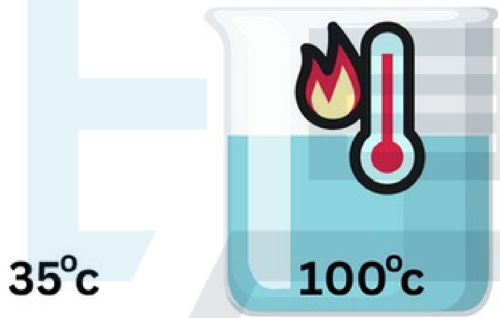
1. The surface characteristics of an object dictate whether it absorbs or reflects infrared radiation.
2. Surfaces that reflect well, such as shiny or white surfaces, tend to be poor absorbers of infrared radiation.
3. Surfaces that absorb well, like matte black surfaces, are typically good emitters of infrared radiation.

Sunshield

- Sunshield is usually shiny because it reflects light and infrared radiation from the Sun.

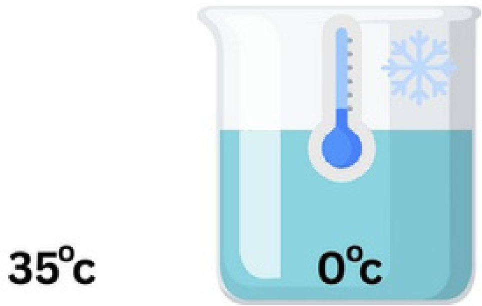
11.3.2 Factors affecting infrared radiation

1. All objects both emit radiation and absorb radiation from their environment.
2. The rate at which an object emits radiation increases with its temperature.
3. Scenario 1: An object that is hotter than its surroundings



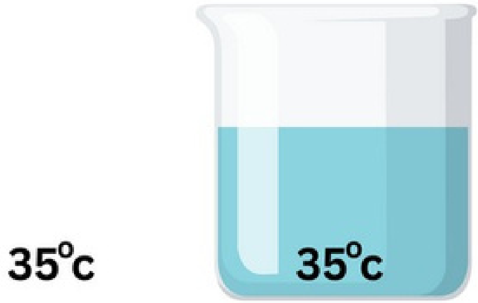
Radiate more energy per second than it absorbs and so will cool down.

4. Scenario 2: An object that is cooler than its surrounding.



Absorbs more energy per second than it radiates until it reaches the temperature of its surroundings.

5. Scenario 3: An object with a temperature similar to surrounding.



Absorbs thermal energy at the same rate as it emits thermal energy.

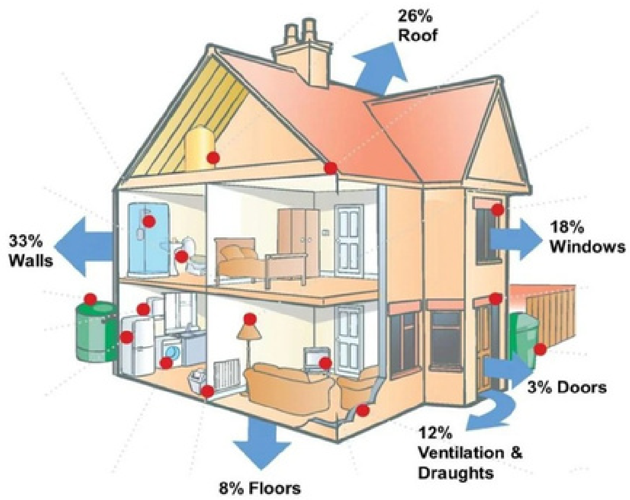
11.4 Consequences of thermal energy transfer

1. To retain thermal energy in an object hotter than its surroundings, insulation is necessary.
2. Understanding conduction, convection, and radiation enables the design of effective insulation methods.

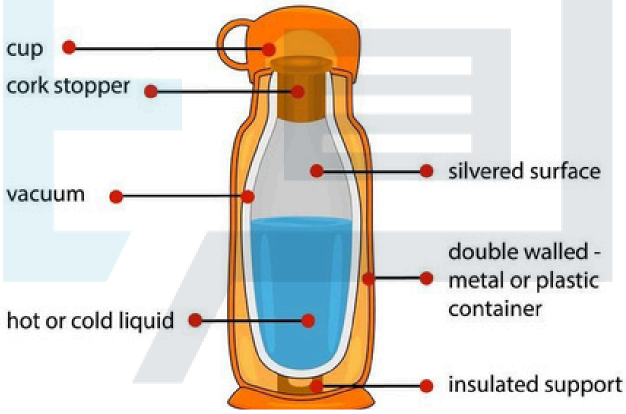
11.4.1 Home insulation

1. A well-insulated house can avoid a lot of energy wastage during cold weather.
2. Insulation can help the house from becoming uncomfortably hot during warm weather.
3. Some methods:

Method	Why does it work?
Draught Proofing	Sealing gaps around doors, windows, and floors reduces heat loss through convection by blocking air movement.
Loft Insulation	Installing insulating materials (e.g., fiberglass, cellulose) in the attic floor reduces heat loss by conduction and convection through the roof.
Double and triple glazing of windows	Using two panes of glass with a layer of insulating gas (e.g., argon) in between reduces heat loss through conduction and convection in windows.
Cavity walls	Injecting insulating material (e.g., foam, mineral wool) into the gap between outer and inner walls reduces heat loss through conduction.
Reflective Insulation	Installing reflective barriers (e.g., foil-backed insulation) reflects radiant heat, reducing heat transfer by radiation.



11.4.2 Keeping cool – vacuum flask

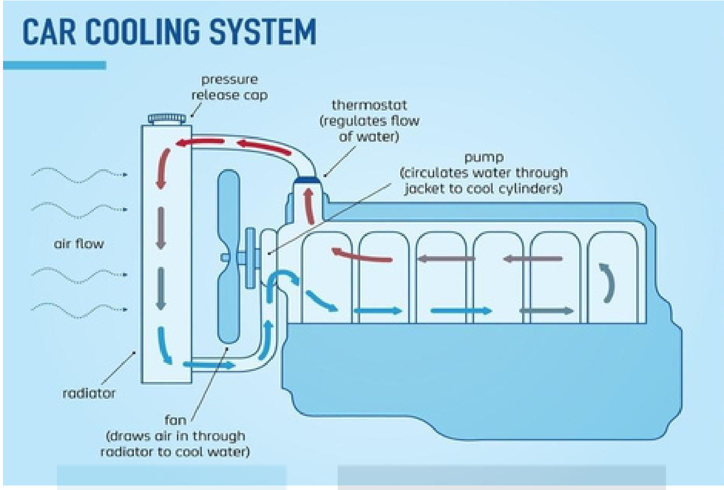


a. A vacuum flask is effective for maintaining the temperature of both hot and cold drinks.

b. Construction of a vacuum flask:

a. Glass is chosen for its excellent insulation properties.
b. Air is removed from between the double walls to create a vacuum, minimizing heat loss through conduction and convection, as both require a medium for heat transfer.
c. A silver coating on the glass reduces heat loss by reflecting infrared radiation.
d. The plastic stopper prevents heat loss through convection and reduces evaporation.

11.4.3 Keeping cool – car engine



1. A car engine generates intense heat through burning fuel, which must be managed by the cooling system to prevent overheating.

2. The system utilizes several principles:

   a. **Specific heat capacity**: Water circulates around the engine block to absorb thermal energy efficiently, chosen for its high specific heat capacity.

   b. **Convection**: Heated water creates a convection current, flowing as indicated by arrows, with a pump accelerating this circulation.

   c. **Conduction**: Metal fins on the radiator facilitate the conduction of thermal energy throughout the radiator.

   d. **Radiation**: Fins are designed with a large surface area and painted black to enhance the emission of thermal energy through radiation.

11.4.4 Thermal energy transfer, climate, and weather

Global Warming

1. Gases like carbon dioxide in the Earth's atmosphere absorb thermal energy, contributing to the warming of our atmosphere.
2. The concentration of greenhouse gases in the atmosphere is rising, leading to increased trapping of thermal energy.
3. Earth is now absorbing more infrared radiation than it emits, which is the primary cause of global warming.

Ocean current

1. Ocean currents facilitate the distribution of thermal energy from equatorial regions to cooler parts of the Earth's surface.
2. Surface warm water moves towards the poles, while in polar regions, colder water sinks and returns towards the Equator in a continuous circulation pattern.

Worked Example:

The coat below is designed for a cold climate.

Describe the features of the coat which prevent thermal energy loss by

a. Conduction

b. Convection

c. Radiation

The padded coat traps air, which acts as an effective insulator because the air cannot move, thereby preventing heat loss through convection. Additionally, the silver lining reflects heat radiation back towards the person's body.