9. Transfer of Thermal Energy

9.1 Conduction

9.1.1 Explain Thermal Conduction In Solids

Definition:
Thermal conduction is the transfer of thermal (heat) energy through a material without any bulk movement of the material itself.

How it happens:
It occurs from regions of higher temperature to regions of lower temperature. In solids, conduction is the main way heat transfers.

- Heat causes atoms/molecules to vibrate more vigorously.
- These vibrations pass from one particle to neighbouring particles through collisions or bonds.
- In metals, free electrons carry most of the heat energy quickly.
- In non-metals (insulators), heat transfer relies mainly on slower vibrations of atoms in the lattice.

Example:
If we heat one end of a metal rod, the other end eventually gets hot because heat flows through the solid.

9.1.2 Define The Term 'Thermal Conductivity'

Thermal conductivity (symbol: k or λ) is a measure of how easily a material allows heat to pass through it by conduction. It is defined as *the rate of heat transfer per unit area through a material per unit temperature gradient* (temperature difference per unit length). Its unit is watts per meter per kelvin ($W\ m^{-1}\ K^{-1}$ or W/m·K)

9.1.3 Describe Factors Affecting Transfer Of Heat Through Solid Conductors

Fourier's law of heat conduction explains the rate of heat transfer:

$$\frac{Q}{t} = k\,\frac{A\,\Delta\theta}{L}$$

1. Thermal conductivity (k) of the material — higher k → faster heat transfer (most important factor).
2. Cross-sectional area (A) — larger area → more heat can flow (directly proportional).
3. Temperature difference (Δθ) — greater difference → faster heat transfer (directly proportional).
4. Length / thickness (L) — longer / thicker material → slower heat transfer (inversely proportional).

9.1.4 Solve Word Problem Related To Thermal Conductivity Of Solid Conductors

Questions available on worksheet.

9.1.5 Describe Good And Bad Conductors Of Heat With Examples

Good conductors (high thermal conductivity, k > ~10–50 W/m·K):
Allow heat to pass through quickly. For example, Silver (best, ~429), Copper (~400), Aluminium (~237), Iron/Steel (~50), Brass (~100–120), Graphite (carbon allotrope, ~100–200 in some forms).

Bad conductors / insulators (low k, usually < 1 W/m·K):
Resist heat flow; heat transfers very slowly. For example, Wood (~0.1–0.2), Plastic / rubber (~0.1–0.5), Glass (~0.8–1.0), Air (still air ~0.025 — excellent insulator), Cork, Styrofoam, wool, fiberglass, cotton (~0.03–0.05)

9.1.6 List The Uses Of Good And Bad Conductors

Uses of good conductors (metals):

1. Cooking utensils (pots, pans, spoons) — quickly transfer heat from stove to food.
2. Heat exchangers (car radiators, air conditioners, boilers) — fast heat transfer.
3. Soldering irons — copper tip conducts heat to melt solder quickly.
4. Engine blocks and heat sink in electronics — remove heat efficiently.
5. Wires in heating elements (e.g., nichrome has moderate k but high resistance).

Uses of bad conductors (insulators):

1. Handles of kettles/pans/saucepans (wood, plastic, rubber) — prevent burns.
2. Thermal insulation in homes (fiberglass, foam, wool) — reduce heat loss in winter / gain in summer.
3. Thermos flasks / vacuum flasks — silvered surfaces + vacuum + cork stopper minimize conduction.
4. Clothing in cold weather (wool, cotton, fur) — trap air (poor conductor) to keep body warm.
5. Ovens / refrigerators — insulating materials keep heat in/out.

9.2 Convection

9.2.1 Explain Convection In Liquids And Gases In Terms Of Density Changes With Reference To The Following Real-Life Examples:

Convection is the transfer of thermal (heat) energy in fluids (liquids and gases) by the bulk movement of the fluid itself. It occurs because heating causes expansion. The heated fluid becomes less dense and rises (buoyancy force pushes it up). Cooler, denser fluid from above sinks to take its place. This creates a convection current (circulating loop of rising hot fluid and sinking cold fluid). Convection cannot occur in solids (particles are fixed and cannot move freely to carry heat). This process continues as long as there is a temperature difference. Eventually, the fluid mixes and reaches a uniform temperature.

Gliders

Gliders have no engine and rely on upward convection currents called thermals to stay aloft and gain altitude. On a sunny day, the ground (especially dark surfaces like fields or roads) absorbs heat from the sun and becomes hotter than the surrounding air. This heats the air above it. Air expands, becomes less dense, and rises as a column or bubble of warm air (thermal). Glider pilots circle within these rising thermals to gain height (often thousands of meters) without using power. They then glide to the next thermal, allowing long-distance flights (hundreds of km) using only natural convection currents.

Flying Of Birds

Many large birds (e.g., eagles, vultures, hawks, storks, albatrosses) use thermal soaring to fly long distances with minimal effort. Birds detect rising thermals (columns of warm, rising air formed over heated land). They circle inside the thermal to gain altitude effortlessly. Once high enough, they glide forward to the next thermal, repeating the process. This allows birds to migrate thousands of km, search for food, or migrate without tiring.

Land Breezes And Sea Breezes

These are daily wind patterns near coasts caused by convection due to different heating rates of land and water. During the day, the sun heats the land more quickly than the sea. Air over land heats up, expands, becomes less dense, and rises. Cooler, denser air over the sea flows inland (from high pressure to low pressure) to replace the rising air; this onshore wind is the sea breeze. At night, land cools faster than the sea. Air over land cools, contracts, becomes denser, and sinks. Warmer, less dense air over the sea rises slightly; cooler land air flows out to sea; offshore wind is the land breeze.

9.2.3 Describe That Convection Currents In Seawater Facilitate The Distribution Of Heat, Nutrients, And Oxygen In Supporting Marine Ecosystems

Large-scale convection currents in the oceans are part of the thermohaline circulation (driven by temperature (thermos) and salinity (haline)). These affect water density. Cold, salty water is denser and sinks (mainly in polar regions like the North Atlantic and Antarctic). Warm, less salty water rises or flows at the surface. This creates a slow, deep global circulation. Surface currents carry warm water poleward; deep currents return cold water equatorward.

Heat distribution:
Transports enormous amounts of heat from the equator (where sun is intense) to polar regions.

Nutrient distribution:
Deep ocean water is rich in nutrients. Upwelling brings these nutrients up and fuels phytoplankton growth which supports rich fisheries and marine life.

Oxygen distribution
Surface water is oxygen-rich (from photosynthesis and air exchange). Thermohaline circulation mixes this oxygenated water downward into deep oceans. This supplies oxygen to deep-sea organisms that would otherwise suffocate.

9.3 Radiation

9.3.1 Define The Process Of Thermal Energy Transfer By Radiation

Thermal radiation (infrared radiation) is the transfer of thermal energy as electromagnetic waves (infrared rays), without requiring a medium (it can travel through a vacuum).

All objects continuously emit thermal radiation from their surface. When this radiation reaches another object, it can be absorbed (causing heating), reflected, or transmitted (passed through). Unlike conduction (particle contact) or convection (fluid movement), radiation requires no medium — that's why the Sun's heat reaches Earth through empty space. It is the only method of heat transfer that works in a vacuum.

9.3.2 Describe The Effect Of Surface Color (Black Or White) And Texture (Dull Or Shiny) On The Emission, Absorption And Reflection Of Infrared Radiation

Surface	Emission of IR	Absorption of IR	Reflection of IR	Explanation	Example
Black + Dull	Good emitter (emits a lot)	Good absorber (absorbs most)	Poor reflector (reflects little)	Closest perfect black body	charcoal, dark clothing in sun
Black + Shiny	Moderate emitter	Moderate absorber	Moderate reflector	Shiny surfaces reflect more	Glossy black car in sun
White + Dull	Poor to moderate	Moderate absorber	Moderate to good reflector	dull surfaces absorb less	White rough paper or unpainted wood.
White + Shiny	Poor emitter (emits little)	Poor absorber (absorbs little)	Good reflector (reflects most)	worst absorbers and emitters.	Polished teapot, aluminum foil

9.3.3 Describe That The Rate Of Emission Of Radiation Depends On The Surface Temperature And Surface Area Of An Object

The rate of emission of thermal radiation from an object increases dramatically with:

1. Surface temperature — hotter objects emit much more radiation.
2. Surface area — larger area means more surface emitting radiation.

Stefan-Boltzmann law

$$\text{Power radiated (P)} = \varepsilon \sigma A T^4$$

P = rate of emission of radiation (watts, W)
ε = emissivity (0 to 1; 1 for perfect black body, 0 for perfect white body)
σ = Stefan-Boltzmann constant = 5.67×10^{-8} W m^{-2} K^{-4}
A = surface area (m^2)
T = absolute temperature (in kelvin, K)

- Rate $\propto T^4$ → small temperature increase causes huge increase in radiation emitted (e.g., doubling T increases emission 16 times!).
- Rate $\propto$ A → double the area → double the power radiated (if other factors same).
- All objects also absorb radiation from surroundings, so net heat transfer = emitted – absorbed.

Examples
1. Filament of a light bulb (very hot, ~2500 K) emits intense visible + IR light.
2. Earth's surface radiates IR based on its temperature and area.
3. Larger animals (bigger surface area) lose heat faster by radiation if other factors are equal.

9.4 Effects of Heat Transfer

9.4.1 Discuss Everyday Applications Of Conduction, Convection And Radiation

Heating Objects Such As Kitchen Pans
When a pan is placed on a hot stove, heat is transferred to the pan mainly by conduction. The metal of the pan allows heat to flow quickly from the hot base to the sides and the food inside. The base of the pan is in direct contact with the heat source i.e., heat spreads throughout the pan. Handles are made of poor conductors (wood, plastic or insulated metal) to prevent burns.

Heating Of Room By Convection
Most household room heating relies on convection. Hot water or electric elements heat the air in contact with the heater. Heated air expands, becomes less dense and rises. Cooler, denser air sinks to take its place. This creates a convection current. Warm air circulates around the room, transferring heat to walls, furniture and people. Central heating radiators are placed near windows or under them to create a steady upward flow of warm air that counters cold draughts from windows.

Measuring Temperature Using An Infrared Thermometer
An infrared thermometer (non-contact thermometer) measures temperature using radiation. All objects emit infrared radiation (thermal radiation) depending on their temperature. The thermometer detects the intensity of infrared rays emitted from the surface (e.g., forehead, food, engine) using a lens and sensor. The device converts the radiation intensity into a temperature reading using the Stefan-Boltzmann law (power radiated $\propto T^4$). It is Quick, hygienic temperature check (e.g., during fever screening), measuring hot objects from a distance (e.g., oven interior, molten metal) without contact.

Using Thermal Insulation To Maintain The Temperature Of A Liquid
Thermal insulation uses materials that are poor conductors to reduce heat transfer by conduction, convection and radiation. Thermos flask has double-walled glass or steel with a vacuum between walls to prevent conduction and convection. Inner surfaces are shiny. They reflect radiation back inside. This reduces heat loss by radiation. Cork or plastic stopper is poor conductor. This reduces conduction through the top.

Using Thermal Insulation To Reduce Thermal Energy Transfer In Buildings
Cavity walls filled with foam, fibreglass or mineral wool traps still air reduces conduction and convection. Roof insulation with thick layers of mineral wool or cellulose reduces heat loss through the roof. Double-glazed windows have air gap (or vacuum) between panes. This reduces conduction and convection. All these keep houses warmer in winter (less heating needed) and cooler in summer (less air-conditioning needed) which saves energy and reduces bills.

The Mechanism Of A Household Hot-Water System
A typical household hot-water system (e.g., storage tank system with boiler) uses convection as the main heat transfer method. Cold water enters the boiler (usually at the bottom). The boiler heats the water (by gas flame, electric element or solar panels). Heated water becomes less dense and rises to the top of the boiler or storage tank. Hot water is drawn off from the top for use (taps, showers). Cooler water sinks to the bottom to be reheated → continuous convection current circulates water.

In modern systems (e.g., combi boilers), water is heated on demand, but convection still occurs within the heat exchanger.

9.4.2 Describe The Greenhouse Effect Based On Heat Radiation Emitted By The Sun

The greenhouse effect is a natural process that warms the Earth's surface by trapping heat radiation. It is caused mainly by the interaction of solar radiation and infrared radiation with the atmosphere. The greenhouse effect is essential for life — it keeps the planet habitable. Human activities (burning fossil fuels, deforestation) increase greenhouse gas concentrations → enhanced greenhouse effect → global warming.

- The Sun emits short-wavelength radiation (mainly visible light and some ultraviolet)
- This passes easily through the Earth's atmosphere and is absorbed by the Earth's surface (land, oceans).
- Earth's surface warms up and re-emits energy as long-wavelength infrared radiation (thermal radiation).
- Greenhouse gases in the atmosphere (e.g., carbon dioxide CO_2, methane CH_4, water vapour H_2O, nitrous oxide N_2O) absorb much of this outgoing infrared radiation.
- The gases then re-emit infrared radiation in all directions. Some is re-radiated back towards the Earth's surface. This downward radiation warms the surface more than if the infrared escaped directly to space.
- The Earth's average surface temperature is about 15 °C instead of the much colder –18 °C it would be without the greenhouse effect.