Applied Physics 1

Heat and Temperature — Concepts, Measurement, and Heat Transfer

1. Concept of Heat and Temperature

Heat and temperature are two closely related, yet fundamentally different, concepts in physics, and it is important to understand the distinction between them clearly.

Heat is a form of energy that is transferred from one body to another, or from one part of a body to another, as a result of a difference in temperature between them. Heat always flows naturally from a region of higher temperature to a region of lower temperature, and this flow continues until both regions reach the same temperature, a condition known as thermal equilibrium.

Temperature, on the other hand, is a physical quantity that indicates the degree of hotness or coldness of a body. It determines the direction in which heat will flow when two bodies are placed in contact — heat flows from the body at a higher temperature to the body at a lower temperature, regardless of the amount of heat energy each body may contain.

The key differences between heat and temperature are summarised in the table below:

Aspect	Heat	Temperature
Definition	A form of energy that is transferred between bodies due to a difference in their thermal states	A measure of the degree of hotness or coldness of a body
Nature	A form of energy	A physical quantity indicating thermal state (not a form of energy)
SI Unit	Joule (J)	Kelvin (K)
Measuring Instrument	Calorimeter	Thermometer
Depends on	Mass of the substance, its specific heat, and temperature change	Independent of the mass or amount of substance

2. Basic Concepts of Measurement of Heat and Temperature

2.1 Measurement of Temperature

Temperature is measured using a device called a thermometer, which works on the principle that certain physical properties of a substance (such as the length of a mercury or alcohol column, or the electrical resistance of a metal) change in a regular, predictable manner with a change in temperature.

Temperature scales are established by choosing two fixed reference points — the ice point (the temperature at which pure ice melts) and the steam point (the temperature at which pure water boils, under standard atmospheric pressure) — and dividing the interval between them into a fixed number of equal divisions. The most commonly used temperature scales are compared below:

Scale	Lower Fixed Point (Ice Point)	Upper Fixed Point (Steam Point)	Number of Divisions
Celsius (°C)	0°C	100°C	100
Fahrenheit (°F)	32°F	212°F	180
Kelvin (K)	273.15 K	373.15 K	100

The Kelvin scale is the SI scale of temperature and is widely used in scientific work, since it begins at absolute zero (0 K), the theoretical temperature at which molecular motion is at a minimum, avoiding the need for negative temperature values in most physical calculations.

2.2 Measurement of Heat

The quantity of heat absorbed or released by a substance is measured using a device called a calorimeter, based on the principle of calorimetry, which states that, in an isolated system, the heat lost by a hotter body is equal to the heat gained by a colder body, when the two are mixed or brought into thermal contact, until thermal equilibrium is reached.

The quantity of heat Q absorbed or released by a substance of mass m, when its temperature changes by $\Delta\theta$, is calculated using the relation:

- $Q = m\,c\,\Delta\theta$

where c is the specific heat capacity of the substance, defined as the quantity of heat required to raise the temperature of a unit mass of the substance through one degree. The SI unit of heat, like all forms of energy, is the joule (J), although the calorie is also commonly used as a practical unit, where 1 calorie ≈ 4.18 joules.

3. Modes of Heat Transfer

Heat can be transferred from one place to another, or from one body to another, through three distinct modes: conduction, convection, and radiation. Each mode operates on a different physical mechanism, and one or more modes may occur simultaneously in real physical situations.

Mode of Heat Transfer	Description	Examples
Conduction	Transfer of heat through a substance (usually a solid) from a region of higher temperature to a region of lower temperature, without any actual movement of the material particles themselves; heat is passed on from molecule to molecule.	Heating of a metal spoon left in hot tea; heat travelling along an iron rod when one end is heated; warmth felt when touching a heated utensil handle.
Convection	Transfer of heat through a fluid (liquid or gas) by the actual movement of the heated particles of the fluid from one place to another, forming convection currents.	Boiling of water in a pot; heating of a room by a room heater; formation of land and sea breezes; circulation of air in an oven.
Radiation	Transfer of heat from one place to another in the form of electromagnetic waves, without requiring any material medium; radiation can travel even through a vacuum.	Heat from the Sun reaching the Earth; warmth felt near a burning fire without touching it; heat radiated by a heated iron rod even without contact.

Of these three modes, conduction is most significant in solids, convection is the dominant mode of heat transfer in fluids (liquids and gases), and radiation is the only mode of heat transfer that can occur through a vacuum, since it does not require any material medium to carry the heat energy.

4. Coefficient of Thermal Conductivity

The coefficient of thermal conductivity (K) of a material is a measure of its ability to conduct heat through it. It is defined as the quantity of heat conducted per unit time, through a unit cross-sectional area of the material, per unit temperature gradient (temperature difference per unit thickness), under steady-state conditions.

For a slab of material of thickness d and cross-sectional area A, with its two faces maintained at temperatures θ_1 and θ_2 (with θ_1 greater than θ_2), the quantity of heat Q conducted through the slab in time t is given by:

- $Q = K A (\theta_1 - \theta_2) t / d$

where K is the coefficient of thermal conductivity of the material. Rearranging this formula gives the definition of K:

- $K = Q\,d / [A\,(\theta_1 - \theta_2)\,t]$

The SI unit of the coefficient of thermal conductivity is watt per metre-kelvin, W/(m·K). A material with a high value of K, such as copper or aluminium, is a good conductor of heat and is commonly used in cooking utensils, heat exchangers, and radiators, where efficient heat transfer is desired. A material with a low value of K, such as wood, glass wool, or air, is a poor conductor of heat and is used as a thermal insulator, where minimising heat transfer is desired, such as in the walls of a thermos flask or the insulation of a building.

Worked Example 1:
A metal slab of thickness 5 cm and area 0.02 m^2 has its two faces maintained at temperatures 100°C and 20°C. If the coefficient of thermal conductivity of the metal is 400 W/(m·K), calculate the quantity of heat conducted through the slab in 10 seconds.

Solution: Using $Q = KA(\theta1-\theta2)t/d$, with d = 0.05 m, A = 0.02 m^2, $(\theta1-\theta2)$ = 80 K, t = 10 s: Q = (400 × 0.02 × 80 × 10) / 0.05 = 6400 / 0.05 = 128000 J, or 1.28×10^5 J.

Worked Example 2:
A wall of thickness 25 cm and area 10 m^2 has a temperature difference of 15°C between its two surfaces. If the coefficient of thermal conductivity of the wall material is 0.5 W/(m·K), calculate the rate of heat flow through the wall.

Solution: Rate of heat flow, $Q/t = KA(\theta1-\theta2)/d$ = (0.5 × 10 × 15) / 0.25 = 75 / 0.25 = 300 W. The wall conducts heat at a rate of 300 joules per second.

5. Multiple Choice Questions (MCQs)

Answer the following questions by selecting the most appropriate option.

1. Heat is best described as:
A) A measure of the hotness of a body
B) A form of energy transferred due to temperature difference
C) A physical constant
D) A property measured only with a thermometer

2. Temperature is best described as:
A) A form of energy
B) A measure of the degree of hotness or coldness of a body
C) The total heat content of a body
D) The specific heat capacity of a substance

3. The SI unit of heat is:

A) Kelvin
B) Celsius
C) Joule
D) Calorie only

4. The SI unit of temperature is:

A) Joule
B) Kelvin
C) Calorie
D) Watt

5. Heat flows from a body at a higher temperature to a body at a lower temperature when they are in contact, until:

A) Both bodies reach the same mass
B) Both bodies reach thermal equilibrium (same temperature)
C) One body loses all its heat
D) The process never stops

6. The relation between the Kelvin scale and the Celsius scale of temperature is:

A) $K = °C + 100$
B) $K = °C + 273$
C) $K = °C - 273$
D) $K = °C \times 273$

7. Which of the following is the mode of heat transfer that does not require a material medium?

A) Conduction
B) Convection
C) Radiation
D) All three modes

8. The mode of heat transfer mainly responsible for boiling water in a pot is:

A) Conduction
B) Convection
C) Radiation
D) None of these

9. Heat reaches the Earth from the Sun mainly through:

A) Conduction
B) Convection
C) Radiation
D) All three equally

10. In conduction, heat is transferred:

A) By the actual bulk movement of the material
B) From molecule to molecule without bulk movement of the material
C) Only through empty space
D) Only in liquids

11. The coefficient of thermal conductivity of a material is a measure of:

A) Its capacity to store heat
B) Its ability to conduct heat through it
C) Its temperature
D) Its specific heat capacity

12. The SI unit of coefficient of thermal conductivity is:

A) J/(s·K)
B) W/(m·K)
C) J/kg
D) W/m²

13. The formula for the quantity of heat conducted through a slab is given by Q =

A) K A (θ1 − θ2) t / d
B) K A d / (θ1 − θ2) t
C) K (θ1 − θ2) / (A d t)
D) K d t / A(θ1 − θ2)

14. A material with a high coefficient of thermal conductivity is generally used as:

A) A thermal insulator
B) A good conductor of heat, such as in cooking utensils
C) A poor conductor of electricity
D) An electrical insulator only

15. Materials such as wood, wool, and air have a relatively low coefficient of thermal conductivity, making them good:

A) Conductors of heat
B) Thermal insulators
C) Radiators of heat
D) Absorbers of light

Answer Key

1. B) A form of energy transferred due to temperature difference | 2. B) A measure of the degree of hotness or coldness of a body | 3. C) Joule | 4. B) Kelvin | 5. B) Both bodies reach thermal equilibrium (same temperature) | 6. B) K = °C + 273 | 7. C) Radiation | 8. B) Convection | 9. C) Radiation | 10. B) From molecule to molecule without bulk movement of the material | 11. B) Its ability to conduct heat through it | 12. B)

W/(m·K) | 13. A) K A ($\theta 1 - \theta 2$) t / d | 14. B) A good conductor of heat, such as in cooking utensils | 15. B) Thermal insulators

6. Broad / Long Answer and Numerical Questions

1. Distinguish between heat and temperature, stating the SI unit and the instrument used to measure each.

2. Explain the basic principle used in measuring temperature with a liquid-in-glass thermometer, referring to the fixed points used to calibrate the scale.

3. Explain the basic principle used in measuring the quantity of heat given out or absorbed by a substance using a calorimeter.

4. Explain conduction as a mode of heat transfer, with two suitable examples from daily life.

5. Explain convection as a mode of heat transfer, with two suitable examples from daily life.

6. Explain radiation as a mode of heat transfer, with two suitable examples, and state how it differs fundamentally from conduction and convection.

7. Define the coefficient of thermal conductivity of a material. Write the formula used to calculate the quantity of heat conducted through a slab, explaining each term.

8. Explain why metals are generally good conductors of heat, while materials such as wood and air are poor conductors (thermal insulators), giving practical examples of each being used for this property.

9. A metal slab of thickness 5 cm and area 0.02 m^2 has its two faces maintained at temperatures 100°C and 20°C. If the coefficient of thermal conductivity of the metal is 400 W/(m·K), calculate the quantity of heat conducted through the slab in 10 seconds.

10. A wall of thickness 25 cm and area 10 m^2 has a temperature difference of 15°C between its two surfaces. If the coefficient of thermal conductivity of the wall material is 0.5 W/(m·K), calculate the rate of heat flow through the wall.