NCERT SHORT NOTES

THERMAL PROPERTIES OF MATTER

PHYSICS

KENDRIYA VIDYALAYA,
Masjid Moth, Sadiq Nagar, New Delhi

www.chishant.vaisesika.org.in

{This document is prepared only to benefit the CBSE 10+2 students. }

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TEMPERATURE AND HEAT

Heat

- Heat is the transfer of energy from one object to another object as a result of a difference in temperature between the two.
- we assume that two objects are in thermal contact with each other if energy can be exchanged between them.

Thermal equilibrium

- It is a situation in which two objects in thermal contact with each other cease to exchange energy by the process of heat.
- **S.I. Unit of heat** is **Joule(J)**, **CGS unit** of heat is **Calorie**

Temperature

- Temperature of a body is the degree of hotness or coldness of the body.
- **SI unit** of temperature is **Kelvin (K)**, and **°C** is a commonly used unit of temperature.

MEASUREMENT OF TEMPERATURE

- A measure of temperature is obtained using a thermometer.
- The ice point and the steam point of water are two convenient fixed points and are known as the freezing and boiling points.
- These two points are the temperatures at which pure water freezes and boils under standard pressure.

Temperature Scales

- The three temperature scales are:

Scales	Freezing points	Boiling points
Fahrenheit temperature scale	32 °F	212 °F
Celsius temperature scale	0 °C	100 °C
Kelvin temperature scale	273.15 K	373.15 K

- **Conversion** between these scales can be done using the relation

$$\frac{T_C}{100} = \frac{T_F - 32}{180} = \frac{T_K - 273.15}{100}$$

Where, T_C = Temperature of the body on Celsius Scale
T_F = Temperature of the body on Fahrenheit Scale
T_K = Temperature of the body on Kelvin scale
$T_K = T_C + 273.15$

IDEAL-GAS EQUATION

Ideal gas law

$$\frac{PV}{T} = Constant$$

Ideal-Gas Equation

$$\frac{PV}{T} = \mu R$$

$$PV = \mu RT$$

Where, μ is the number of moles in the sample of gas and R is called universal gas constant: $R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$

ABSOLUTE TEMPERATURE

- The absolute minimum temperature for an ideal is found to be – 273.15 °C and is designated as **absolute zero**.
- Absolute zero is the foundation of the Kelvin temperature scale or absolute scale temperature

THERMAL EXPANSION

All solids are found to expand on heating. This is called Thermal Expansion.

When a solid is heated, the amplitude of vibration of the atoms and molecules increases. Therefore effective interatomic separation increases.

Thermal expansion is of three types:

1. Linear expansion
2. Area expansion
3. Volume expansion

Linear expansion

- ➢ The expansion in length of a rod on heating is called linear expansion.
- ➢ If the substance is in the form of a long rod, then for small change in temperature, ΔT, the fractional change in length, $\Delta L/L$, is directly proportional to ΔT.

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

Where, α is known as the **coefficient of linear expansion** and is characteristic of the material of the rod and ΔL is the change in length.

Area expansion

- ➢ The expansion in surface area of a solid on heating is called area expansion.
- ➢ If the solid has a surface area A, then for small change in temperature, ΔT, the fractional change in area, $\Delta A/A$, is directly proportional to ΔT.

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

Where, β is known as the **coefficient of area expansion** and ΔA is the change in area.

Volume expansion

- ➢ The expansion in volume of a solid on heating is called volume expansion.
- ➢ If the solid has a volume V, then for small change in temperature, ΔT, the fractional change in volume, $\Delta V/V$, is directly proportional to ΔT.

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

Where, γ is known as the **coefficient of volume expansion** and ΔV is the change in volume.

Relation between α, β and γ

$$\alpha = \frac{\beta}{2} = \frac{\gamma}{3}$$

Or

$$6\alpha = 3\beta = 2\gamma$$

ANOMALOUS BEHAVIOUR OF WATER

- Water exhibits an anomalous behaviour; it contracts on heating between 0 °C and 4 °C.
- The volume of a given amount of water decreases as it is cooled from room temperature, until its temperature reaches 4 °C.
- Below 4 °C, the volume increases, and therefore the density decreases

Environmental effect:

- Lakes and ponds freeze at the top first. As a lake cools toward 4 °C, water near the surface loses energy to the atmosphere, becomes denser, and sinks; the warmer, less dense water near the bottom rises.
- However, once the colder water on top reaches temperature below 4 °C, it becomes less dense and remains at the surface, where it freezes.
- If water did not have this property, lakes and ponds would freeze from the

bottom up, which would destroy much of their animal and plant life.

SPECIFIC HEAT CAPACITY

Heat Capacity

- heat capacity, S of a substance is defined as

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

- Where ΔQ is the amount of heat supplied to the substance to change its temperature from T to $T + \Delta T$.

Specific Heat Capacity

- It is defined as the amount of heat per unit mass absorbed or rejected by the substance to change its temperature by one unit.
- Mathematically

$$s = \frac{S}{m} = \frac{1}{m}\frac{\Delta Q}{\Delta T}$$

- It depends on the nature of the substance and its temperature.
- The **SI unit** of specific heat capacity is J kg^{-1} K^{-1}.

Molar Specific Heat Capacity

- If the amount of substance is specified in terms of moles μ, instead of mass m in kg, we can define heat capacity per mole of the substance by

$$C = \frac{S}{\mu} = \frac{1}{\mu}\frac{\Delta Q}{\Delta T}$$

- Where C is known as **molar specific heat capacity** of the substance. Like S, C also depends on the nature of the substance and its temperature.
- The **SI unit** of **molar specific heat capacity** is **J mol^{-1} K^{-1}.**

- If the gas is held under constant pressure during the heat transfer, then it is called the **molar specific heat capacity at constant pressure** and is denoted by C_p.
- If the volume of the gas is maintained during the heat transfer, then the corresponding molar specific heat capacity is called **molar specific heat capacity at constant volume** and is denoted by C_v.

CALORIMETRY

- Calorimetry means measurement of heat.

Principle of Calorimetry

- When a body at higher temperature is brought in contact with another body at lower temperature, the heat lost by the hot body is equal to the heat gained by the colder body, provided no heat is lost to the surroundings.

Calorimeter

- A device in which heat measurement can be made is called a **calorimeter**.

Construction

- It consist a metallic vessel and stirrer of the same material like copper or aluminium.
- The vessel is kept inside a wooden jacket which contains heat insulating materials like glass wool etc.
- The outer jacket acts as a heat shield and reduces the heat loss from the inner vessel.
- There is an opening in the outer jacket through which a mercury thermometer can be inserted into the calorimeter.

CHANGE OF STATE

- A transition from one of these states to another is called a change of state.
- The change of state from solid to liquid is called **melting** and from liquid to solid is called **fusion**.

Melting

- The temperature remains constant until the entire amount of the solid substance melts.
- **Both the solid and liquid states of the substance coexist in thermal equilibrium during the change of states from solid to liquid.**
- The temperature at which the solid and the liquid states of the substance in thermal equilibrium with each other is called its **melting point**. It also depends on pressure.
- The melting point of a substance at standard atmospheric pressure is called its **normal melting point**.

Regelation

- The phenomenon of refreezing is called **regelation**.
  - **Example**: Skating is possible on snow due to the formation of water below the skates. Water is formed due to the increase of pressure and it acts as a lubricant.

Vaporisation

- The change of state from liquid to vapour (or gas) is called **vaporisation**.
- Temperature remains constant until the entire amount of the liquid is converted into vapour.
- Both the liquid and vapour states of the substance coexist in thermal equilibrium, during the change of state from liquid to vapour.
- The temperature at which the liquid and the vapour states of the substance coexist is called its **boiling point**.
- The boiling point of a substance at standard atmospheric pressure is called its **normal boiling point**.

Sublimation

- The change from solid state to vapour state without passing through the liquid state is called **sublimation**, and the substance is said to sublime.
  E.g. Dry ice (solid CO_2), iodine.
- During the sublimation process both the solid and vapour states of a substance coexist in thermal equilibrium.

LATENT HEAT

- The amount of heat per unit mass transferred during change of state of the substance is called **latent heat** of the substance for the process.

For example, if heat is added to a given quantity of ice at –10 °C, the temperature of ice increases until it reaches its melting point (0 °C).

- At this temperature, the addition of more heat does not increase the temperature but causes the ice to melt, or changes its state
- Similar situation occurs during liquid gas change of state at the boiling point. Adding more heat to boiling water causes vaporisation, without increase in temperature.

Latent heat

- If mass m of a substance undergoes a change from one state to the other, then the quantity of heat required is given by

$$Q = m L$$

$$\text{or } L = Q/m$$

- Where L is known as latent heat and is a characteristic of the substance. Its SI unit is J kg^{-1}. The value of L also depends on the Pressure.

Latent heat of fusion (L_f)

- The latent heat for a solid liquid state change is called the **latent heat of fusion** (L_f).

Latent heat of vaporisation (L_v).

- The latent heat for a liquid-gas state change is called the **latent heat of vaporisation** (L_v).

These are often referred to as the heat of fusion and the heat of vaporisation.

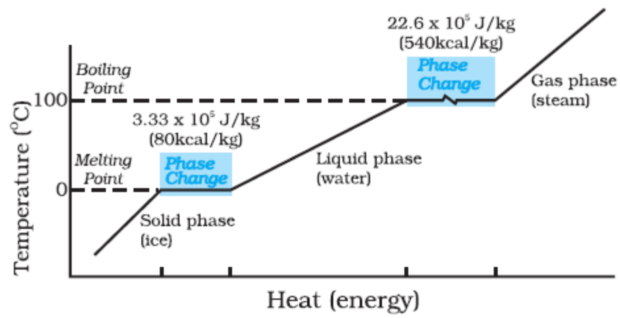
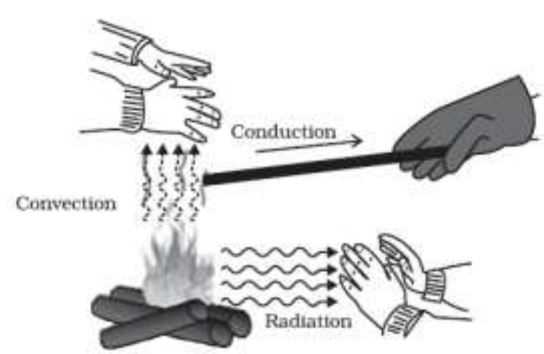


Figure 1 ***Temperature versus heat for water at 1 atm pressure (not to scale).]***

HEAT TRANSFER

There are three distinct modes of heat transfer:
Conduction, convection and radiation

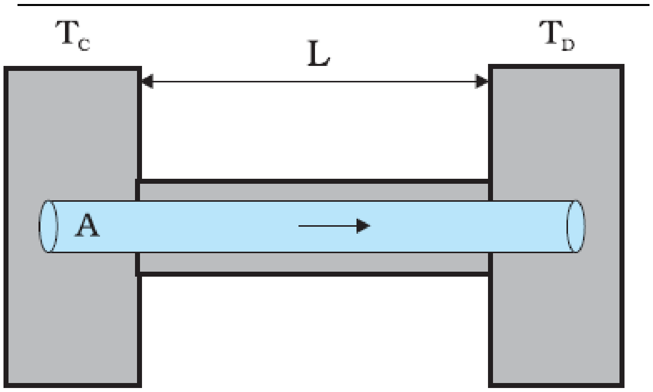


Conduction

- Conduction is the mechanism of transfer of heat between two adjacent parts of a body because of their temperature difference.

Thermal conductivity

- Consider a metallic bar of length *L* and uniform cross section *A* with its two ends maintained at *T*C and *T*D respectively.



[Fig. 3 Steady state heat flow by conduction in a bar with its two ends maintained at temperatures T_C and T_D; ($T_C > T_D$).]

- After sometime, a steady state is reached; the temperature of the bar decreases uniformly with distance from T_C to T_D; ($T_C > T_D$). The reservoir at C supplies heat at a constant rate, which transfers through the bar and is given out at the same rate to the reservoir at D.

At the steady state, the rate of flow of heat (or heat current) *H* is proportional to the temperature difference ($T_C - T_D$) and the area of cross section *A* and is inversely proportional to the length *L:*

$$H = \frac{KA\,(T_C - T_D)}{L}$$

The constant of proportionality *K* is called the **thermal conductivity** of the material. The greater the value of *K* for a material, the more rapidly will it conduct heat. The SI unit of *K* is J S^{-1} m^{-1} K^{-1} or W m^{-1} K^{-1}.

Convection

- Convection is a mode of heat transfer by actual motion of matter. It is possible only in fluids.
- Convection involves bulk transport of different parts of the fluid. In forced convection, material is forced to move by a pump or by some other physical means.

Examples of forced convection systems:

- Forced-air heating systems in home, the human circulatory system, and the cooling system of an automobile engine. In the human body, the heart acts as the pump that circulates blood through different parts of the body, transferring heat by forced convection and maintaining it at a uniform temperature.

Radiation

The mechanism for heat transfer needs no medium; it is called **radiation** and the energy so radiated by electromagnetic waves is called **radiant energy**.

- The electromagnetic radiation emitted by a body by virtue of its temperature like the radiation by a red hot iron or light from a filament lamp is called **thermal radiation**.
- When this thermal radiation falls on other bodies, it is partly reflected and partly absorbed.
- The amount of heat that a body can absorb by radiation depends on the colour of the body.
- Black bodies absorb and emit radiant energy better than bodies of lighter colours.

Stefen's Law

When the temperature difference between body and surroundings is large, then Stefen's law for cooling of body is obeyed.

According to it, the total electromagnetic energy radiated by a body at absolute temperature T is proportional to its size, its ability to radiate (called emissivity) and most importantly to its temperature. For a body which is a perfect radiator. The energy emitted per unit time (E) is given by

$$E = \sigma e A T^4$$

Where A is the area and T is the absolute temperature of the body, σ is a constant of proportionality and is called Stefan-Boltzmann constant, e = emissivity = 1 (for perfect radiator).

$\sigma = 5.67 \times 10^{-8}\ Wm^{-2}K^{-4}$

A body at temperature T, with surroundings at temperatures T_0, emits as well as receives energy. For a perfect radiator. The net rate of loss of radiant energy is

$$E = \sigma A\,(T^4 - T_0^4)$$

For a body with emissivity e,

$$\Rightarrow \quad E = \sigma e A\,(T^4 - T_0^4)$$

BLACK BODY RADIATIONS

Black Body

A black body is an object that absorbs all electromagnetic radiations.

BLACK BODY RADIATION CURVES

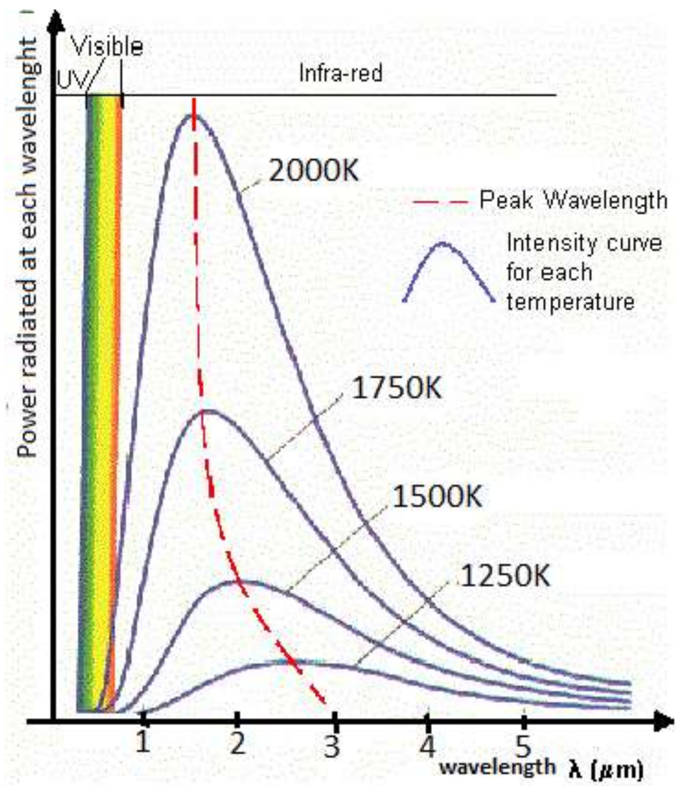


Fig 2: Black body radiation curves showing peak wavelengths at various temperatures

The graph shows:

- As the temperature increases, the peak wavelength emitted by the black body decreases. i.e.

$$\lambda_m \propto \frac{1}{T}$$

Or $\quad \boldsymbol{\lambda_m T}$= a constant

- It therefore begins to move from the infra-red towards the visible part of the spectrum. Again, none of the graphs touch the x-axis so they emit at every wavelength.
- This means that some visible radiation is emitted even at these lower temperatures and at any temperature above absolute zero, a black body will emit some visible light.

The graph also shows:

- As temperature increases, the total energy emitted increases, because the total area under the curve increases.
- It is found that the area enclosed by a curve is directly proportional to the fourth corresponding absolute temperature, As the area under the curve represents the total energy (E) emitted per sec. per unit area corresponding to all wavelengths at a given temperature, hence $E \propto T^4$
  This is Stefan's Boltzmann law
- Also the relationship is not linear as the area does not increase in even steps. The rate of increase of area and therefore energy increases as temperature increases

Wien's Displacement Law

The wavelength (λ_m) of maximum intensity of emission of black body radiation is inversely proportional to the absolute temperature (T) of the black body.

$$\lambda_m \propto \frac{1}{T}$$

$$\lambda_m = \frac{b}{T}$$

Where, $b = 2.892 \times 10^{-3} mK$ = Wien's constant.

- This law accounted for the change in colour of a body from red to yellow and then to white as its temperature is increased.
- This law is used to find the temperature of celestial bodies (moon, sun and other stars)

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