Chapter

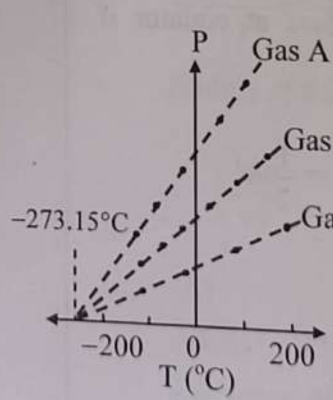
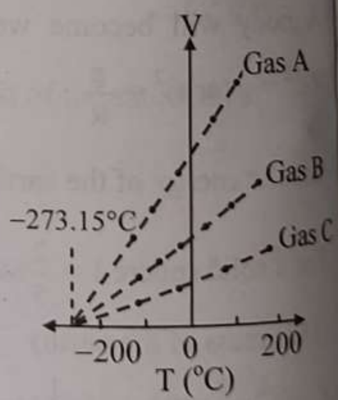
7 Thermal Properties of Matter

Quick Review

➢ **Measurement of temperature:**

Scale	Lower Fixed Point (LFP)	Upper Fixed Point (UFP)	No. of inter
Celsius scale	Melting point of ice = 0 °C	Boiling point of water = 100 °C	100
Fahrenheit scale	Melting point of ice = 32 °F	Boiling point of water = 212 °F	180
Kelvin scale (Thermodynamic scale)	Triple point of water = 273.15 K	Boiling point of water = 373.15 K	100

➢ **Absolute zero:**

Definition	Graphical Representation
The lowest attainable temperature is the absolute zero temperature. This can be understood by plotting the relation between pressure of the gas vs its temperature on the graph as shown beside. It is seen that all the lines for different gases cut the temperature axis at the same point at –273.15 °C. This point is termed as the **absolute zero of temperature.** **Caution** The point of zero pressure or zero volume does not depend on any specific gas.	 **Graph of P-T at constant volume for three ideal gases**  **Graph of V-T at constant pressure for three ideal gases**

The triple point is that temperature where solid, liquid and gas state of a material co exists in equilibrium and this occurs only at a unique temperature and a pressure.

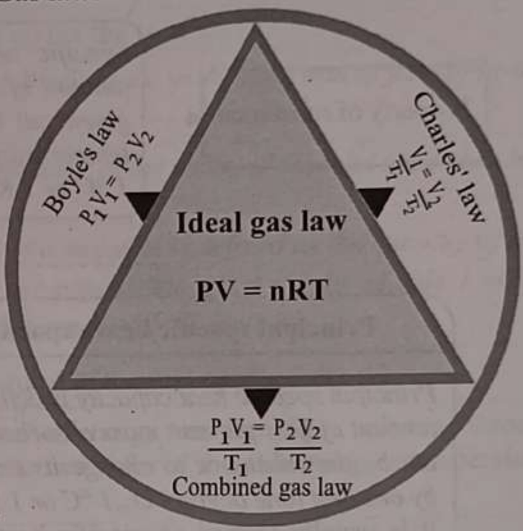
⇑

Triple point

⇓

Students can scan the adjacent Q. R. Code in Quill - The Padhai App to get conceptual clarity about ***phase diagram of water and triple point*** *with the aid of a linked video.*

➢ **Gas laws:**



➢ **Thermal Expansion:**

Thermal expansion ⇒ *The increase in the dimensions of a body due to an increase in its temperature is called thermal expansion.*

- **Thermal expansion in solids:**

	Linear expansion	**Superficial (areal) expansion**	**Cubical (volume) expansion**
Change in quantity	$\Delta L = L_0\alpha\Delta T$	$\Delta A = A_0\beta\Delta T$	$\Delta V = V_0\gamma\Delta T$
Final quantity after heating	$L = L_0(1 + \alpha\Delta T)$	$A = A_0(1 + \beta\Delta T)$	$V = V_0(1 + \gamma\Delta T)$
Coefficient of expansion	$\alpha = \frac{\Delta L}{L_0\Delta T}$	$\beta = \frac{\Delta A}{A_0\Delta T}$	$\gamma = \frac{\Delta V}{V_0\Delta T}$
Definition of coefficient of expansion:	*Coefficient of linear expansion is the increase in length per unit original length of a rod (at 0 ℃) per unit rise in temperature.*	*Coefficient of superficial expansion is the change in area per unit original surface area of a two-dimensional body (at 0 ℃) per unit rise in temperature.*	*Coefficient of cubical expansion is increase in volume of a body per unit original volume (at 0 ℃) per unit rise in temperature.*

•	**Thermal expansion of liquids**	•	**Thermal expansion of gases**
i.	Liquids do not have definite shape. They have shape of container. Therefore, liquids have only volume expansion.	i.	Gases have no definite shape; therefore, gases have only volume expansion.
ii.	Along with expansion of liquid, expansion of container also takes place.	ii.	The expansion of container is negligible in comparison to the gases.
iii.	As a result, coefficient of real expansion in liquids is, $\gamma_r = \gamma_a + \gamma_v$ where, γ_v is coefficient of cubical expansion of the container (vessel), γ_a is coefficient of apparent expansion	iii.	As a result, gases have only real expansion.

➢ **Specific heat capacity:**

Specific heat capacity

Specific heat capacity is defined as the amount of heat per unit mass absorbed or given out by the substance to change its temperature by one unit (one degree) i.e., 1 °C or 1 K.

Property of substance

Depends weakly on temperature

Types

Principal specific heat capacity (s)

Principal specific heat capacity is defined as the amount of heat per unit mass absorbed or given out by the substance to change its temperature by one unit (one degree) i.e., 1 °C or 1 K.
It is usually termed as specific heat capacity and is denoted by s.

Molar specific heat capacity (C)

If the amount of substance is specified in terms of moles (μ) instead of mass (m) in kg then the specific heat is called molar specific heat (C).

➢ **Calorimetry:**

i. Measurement of specific heat of a substance is carried out by using a calorimeter.
Principle of calorimetry:

Heat lost by hot body = Heat gained by cold body

ii. Principle of calorimetry represents the law of conservation of heat energy.

No change in temperature ⟸ **Change of state** ⟹ Solid $\underset{\text{Cool}}{\overset{\text{Heat}}{\rightleftarrows}}$ Liquid $\underset{\text{Cool}}{\overset{\text{Heat}}{\rightleftarrows}}$ Gas(vapour)

Caused by

Latent heat

The quantity of heat absorbed or given out by unit mass of a substance during change of state of the substance at a constant temperature is called the latent heat of the substance.

Characteristic of substance

at melting point → Solid $\underset{L_{\text{fusion}}\ \text{released}}{\overset{L_{\text{fusion}}\ \text{absorbed}}{\rightleftarrows}}$

at boiling point → Liquid $\underset{L_{\text{vaporisation}}\ \text{released}}{\overset{L_{\text{vaporisation}}\ \text{absorbed}}{\rightleftarrows}}$

Body at high temperature → **Heat transfer** → Body at low temperature

through

Conduction

Conduction is the process by which heat flows from the hot end to the cold end of a solid body without any net bodily movement of the particles of the body.

Convection

The process by which heat is transmitted through a substance from one point to another due to actual bodily movement of the heated particles of the substance is called convection.

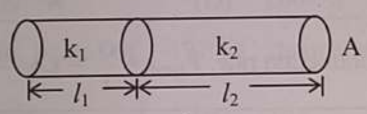
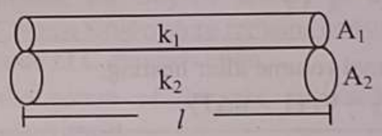
Radiation

The transfer of heat energy from one place to another via emission of EM energy (in a straight line with the speed of light) without heating the intervening medium is called radiation.

➢ **Terms related to thermal conduction:**

Term	More about the terms
Temperature gradient	*The rate of change of temperature with distance in the direction of flow of heat is called temperature gradient.*
Thermal conductivity	*Thermal conductivity of a solid is a measure of the ability of the solid to conduct heat through it.*
Coefficient of thermal conductivity	*Coefficient of thermal conductivity of a material is defined as the quantity of heat that flows in one second between the opposite faces of a cube of side 1 m, the faces being kept at a temperature difference of 1 °C (or 1 K).*
Thermal resistivity	Thermal resistivity (ρ_T) is the reciprocal of thermal conductivity (k).
Conduction rate	Conduction rate (P_{cond}) is the amount of energy transferred per unit time through a slab of area A and thickness x, the two sides of the slab being at temperatures T_1 and T_2 ($T_1 > T_2$).
Thermal resistance	Ratio $\dfrac{T_1 - T_2}{P_{cond}}$ is called as thermal resistance (R_T) of material.

➢ **Heat transfer through series and parallel combination of conductors:**

	Series combination of conductors	Parallel combination of conductors
i.	Two or more conductors are said to be connected in series if the same amount of heat flows through each conductor.	Two or more conductors are said to be connected in parallel if the same temperature difference is maintained across each conductor.
ii.		
iii.	The equivalent thermal resistance of a series combination of n conductors is given by, $R_s = R_1 + R_2 + R_3 + \ldots + R_n$ i.e. $R_s = \dfrac{l_1}{k_1A_1} + \dfrac{l_2}{k_2A_2} + \dfrac{l_3}{k_3A_3} + \ldots + \dfrac{l_n}{k_nA_n}$	The equivalent thermal resistance of a parallel combination of n conductors is given by, $\dfrac{1}{R_P} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3} + \ldots + \dfrac{1}{R_n}$ i.e. $\dfrac{1}{R_P} = \dfrac{k_1A_1}{l_1} + \dfrac{k_2A_2}{l_2} + \dfrac{k_3A_3}{l_3} + \ldots + \dfrac{k_nA_n}{l_n}$
iv.	Also, the rate of flow of heat through the series combination of conductors of **uniform cross-sections** is given by, $\dfrac{Q}{t} = \dfrac{\Delta\theta}{R_s} = \dfrac{A\Delta\theta}{\left(\dfrac{l_1}{k_1} + \dfrac{l_2}{k_2} + \dfrac{l_3}{k_3} + \ldots + \dfrac{l_n}{k_n}\right)}$	Also, the rate of flow of heat through the conductors in the parallel combination having **same length** l is given by, $\dfrac{Q}{t} = \dfrac{\Delta\theta}{R_P} = \dfrac{(k_1A_1 + k_2A_2 + k_3A_3 + \ldots + k_nA_n)\Delta\theta}{l}$

➢ **Newton's law of cooling:**

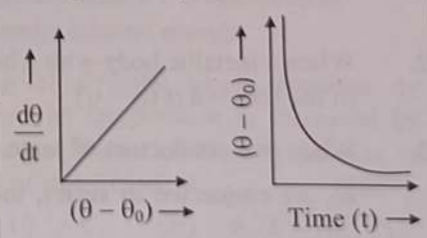
Statement:

The rate of loss of heat dT/dt of the body is directly proportional to the difference of temperature ($T - T_0$) of the body and the surroundings provided the difference in temperatures is small. Mathematically,

$\dfrac{dT}{dt} \propto (T - T_0)$

⇐ **Newton's law of cooling** ⇒

Graphical representation:



Formulae

1. Temperature scales:
$\frac{T_C - 0}{100} = \frac{T_F - 32}{180} = \frac{T_K - 273.15}{100}$

2. Relation between temperature and thermodynamic property: $T = \frac{100(P_T - P_1)}{P_2 - P_1}$

3. Ideal gas equation:
i. $\frac{PV}{T} = R$ for one mole of a gas.
ii. $PV = nRT$ for 'n' moles of gas.

4. Final length of a rod after heating:
$L_2 = L_1 (1 + \alpha \Delta T)$

5. Coefficient of linear expansion: $\alpha = \frac{L_2 - L_1}{L_1 \Delta T}$

6. Final area of plate after heating:
$A_2 = A_1 (1 + \beta \Delta T)$

7. Coefficient of superficial (areal) expansion:
$\beta = \frac{A_2 - A_1}{A_1 \Delta T}$

8. Final volume after heating:
$V_2 = V_1 (1 + \gamma \Delta T)$

9. Coefficient of volume expansion:
$\gamma = \frac{V_2 - V_1}{V_1 \Delta T}$

10. Relation between α, β and γ:
i. $\frac{\alpha}{1} = \frac{\beta}{2} = \frac{\gamma}{3} = \text{constant}$ ii. $\beta = 2\alpha, \gamma = 3\alpha$

11. Specific heat capacity: $s = \frac{\Delta Q}{m \Delta T}$

12. Molar specific heat: $C = \frac{1}{\mu} \frac{\Delta Q}{\Delta T}$
where, μ is number of moles.

13. Molar specific heat:
i. $C_P = M \times s_p$ at constant pressure
ii. $C_v = M \times s_v$ at constant volume
where, M is molecular weight.

14. Latent heat: $Q = mL$

15. Temperature gradient: $T_g = \frac{T_1 - T_2}{x}$

16. Rate of flow of heat: $\frac{Q}{t} = kA\left(\frac{T_1 - T_2}{x}\right)$

17. Heat energy conducted at a given temperature:
$Q = kA \frac{T_1 - T_2}{x} t$

18. Coefficient of thermal conductivity:
$k = \frac{Q}{At} \frac{T_1 - T_2}{x}$

19. Conduction rate: $P_{cond} = \frac{Q}{t} = kA \frac{T_1 - T_2}{x}$

20. Thermal resistance: $R_T = \frac{x}{kA} = \frac{T_1 - T_2}{P_{cond}}$

21. Thermal resistivity: $\rho_T = \frac{1}{k}$

22. Newton's law of cooling: $\frac{dT}{dt} = C(T - T_0)$
(provided excess temperature is small.)

Shortcuts

1. To convert Celsius temperature into Fahrenheit, apply the relation $t_f = \frac{9}{5} t_c + 32$ and to convert Fahren temperature to Celsius apply, $t_c = \frac{5}{9}(t_f - 32)$

2. When a metallic body with a hole of diameter (d) is heated then size of hole increases. Increase in diam of the hole $= d\,\alpha\,(t_2 - t_1)$

3. When two conductors of same length and same cross-section area but having thermal conductivities K_1 K_2 are connected in **series**, then temperature of interface is given as, $\theta = \frac{K_1\theta_1 + K_2\theta_2}{K_1 + K_2}$. This can als applied in case of a single slab made from layers of two different materials.