CAPILLARITY

- The phenomenon of rise or fall of liquid in a capillary tube is called capillarity or capillary action.
- The rise or fall of liquid in a capillary tube is given by

$$h = \frac{2S\cos\theta}{r\rho g} = \frac{2S}{R\rho g} \qquad \qquad \left(\because \cos\theta = \frac{r}{R}\right)$$

where S is the surface tension of the liquid, θ is the angle of contact, ρ is the density of liquid, r is the radius of capillary tube, R is the radius of the meniscus and g is the acceleration due to gravity.

- If $\theta < 90^{\circ}$, *i.e.*, meniscus is concave, *h* will be positive, *i.e.*, the liquid will rise in the capillary.
- If $\theta > 90^\circ$, *i.e.*, meniscus is convex, *h* will be negative, *i.e.*, the liquid will fall in a capillary tube.
- If $\theta = 90^\circ$, *i.e.*, meniscus is plane, h = 0, so no phenomenon of capillarity.
- If a capillary tube is of insufficient length as compared to height to which liquid can rise in the capillary tube, then the liquid rises upto the full length of capillary tube but there is no overflowing of the liquid in the form of fountain. It is so because the liquid meniscus adjusts its radius of curvature so that hR = constant *i.e.* hR = h'R'.

Variation in Surface Tension

- The surface tension of the liquid decreases with rise in temperature and becomes zero at the critical temperature.
- A highly soluble substance like sodium chloride (common salt) when dissolved in water, increases the surface tension of water.
- When a sparingly soluble substance like phenol, dissolved in water, reduces the surface tension of water.
- When a detergent or soap is mixed with water, the surface tension of water decreases.

Illustration 16

Air is pushed into a soap bubble of radius r to double its radius. If the surface tension of the soap solution is S, the work done in the process is

- (a) $8\pi r^2 S$ (b) $12\pi r^2 S$
- (c) $16\pi r^2 S$ (d) $24\pi r^2 S$
- Soln. (d) : A soap bubble has two surfaces, hence its surface potential energy is

 $U_0 = 2(4\pi r^2)S = 8\pi r^2 \cdot S$

If the radius of the soap bubble is doubled, then its surface potential energy.

$$U_{s} = 2(4\pi(2r)^{2})S = 32\pi r^{2} \cdot S$$

The work done in this process is $\Delta U = U_f - U_o = 24\pi r^2 \cdot S$

 \Rightarrow (d) is correct.

Illustration 17

Two soap bubbles of radii a and b combine to form a single bubble of radius c. If P is the external pressure, then the surface tension of the soap solution is

(a)
$$\frac{P(c^3 + a^3 + b^3)}{4(a^2 + b^2 - c^2)}$$
 (b) $\frac{P(c^3 - a^3 - b^3)}{4(a^2 + b^2 - c^2)}$
(c) $Pc^3 - 4a^2 - 4b^2$ (d) $Pc^2 - 2a^2 - 3b^2$

Soln. (b) : As the total mass of the air inside the bubble and the temperature remains constant, we can say,

$$P_a V_a + P_b V_b = P_c V_c$$

As pressure inside the soap bubble is $\frac{4\sigma}{r}$ more than the external pressure, (here σ is the surface tension)

$$\left(P + \frac{4\sigma}{a}\right) \cdot \left(\frac{4}{3}\pi a^3\right) + \left(P + \frac{4\sigma}{b}\right) \cdot \left(\frac{4}{3}\pi b^3\right)$$
$$= \left(P + \frac{4\sigma}{c}\right) \cdot \left(\frac{4}{3}\pi c^3\right)$$
$$\Rightarrow P(a^3 + b^3 - c^3) = 4\sigma(c^2 - a^2 - b^2)$$
or
$$\sigma = \frac{P(c^3 - a^3 - b^3)}{4(a^2 + b^2 - c^2)}$$
$$\Rightarrow (b) \text{ is correct.}$$

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Illustration 18

How much work is done in doubling a soap bubble of radius r and surface tension T?

Soln.: $W = 2 \times T \times \Delta A = 2 \times T \times [4\pi \times (2r)^2 - (4\pi r^2)]$ = $2T \times 4\pi \times 3r^2 = 24\pi r^2 T$.

HEAT

- Heat is the form of energy that flows between a body and its surrounding medium by virtue of temperature difference between them.
- The SI unit of heat is joule.
- The practical unit of heat is calorie.
- 1 calorie is the amount of heat required to raise the temperature of 1 g of water from 14.5°C to 15.5°C.
- Joule found that when mechanical work (W) is converted into heat (Q), the ratio of W and Q is always constant, represented by J,

i.e.
$$\frac{W}{Q} = J$$
 or $W = JQ$

where J is Joule's mechanical equivalent of heat. J is not a physical quantity but a conversion factor involved when work is converted into heat or viceversa. The value of

J = 4.186 joule/calorie

i.e. 1 calorie = 4.186 joule.

TEMPERATURE

Temperature is basically a measure of degree of hotness or coldness of a body.

Properties of Bulk Matter

Different Temperature Scales

S.	Nameof	Symbol	Lower	Upper	Numberof
No.	the scale	for each	fixed	fixed	divisions
		degree	point	point	on the
			(LFP)	(UFP)	scale
1.	Celsius	•C	€°C	100°C	100
2.	Fahrenheit	•F	32•F	212°F	180
3.	Reaumur	°R	0°R	80°R	80
4.	Rankine	°Ra	460 Ra	672Ra	212
5.	Kelvin	K	273.15K	373.15K	. 100

Relationship between Different Temperature Scales

$T_C = 0$	$T_{F} - 32$	$T_R - 0$	$T_{Ra} - 460$	$T_{K} = 273.15$
100	180	80	212	100

Temperature on one scale can be converted into another scale by using the following identity.

Upper fixed point (UFP) - lower fixed point (LFP)

Thermometer is an instrument used to measure temperature of a body.

Type of Thermometers

- Liquid thermometers
- o Gas thermometers
- o Resistance thermometers
- Thermoelectric thermometers
- o Pyrometers
- O Vapour pressure thermometers

THERMAL EXPANSION

- All solids are found to expand on heating. Thermal expansion of solids is of three types:
 - Linear expansion
 - O Area expansion
 - Volume expansion

 $\alpha =$

• Coefficient of linear expansion of a solid,

increase in length

original length \times rise in temperature

Coefficient of area expansion of a solid,

increase in area

- original area × rise in temperature
- Coefficient of volume expansion of a solid,

increase in volume

original volume x rise in temperature

Relation between
$$\alpha$$
, β and γ

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

- The units of α , β and γ are the same. i.e. °C⁻¹ or K⁻¹.
- When temperature increases (during summer), the length of the pendulum increases due to which the time period increases and the clock loses time. On the other hand, when temperature decreases (during winter season), the length decreases and the time period decreases. The clock gains time.

The loss or gain of time $\Delta t = \frac{1}{2} \alpha(\Delta T)t$.

where α is the coefficient of linear expansion.

 ΔT = change in temperature and t = time interval in which we have to find loss or gain of time. If it is per day,

 $t = 24 \times 60 \times 60 = 8 \text{ h} 6400 \text{ s}.$

A bimetallic strip consists of two strips of equal length but of different metals, riveted together keeping one over the other.



When such a bimetallic strip is heated, it bends with metal of greater of on outer side, *i.e.*, convex side.

- There are two coefficients of expansion in case of liquids.
 - Coefficient of real expansion
 - Coefficient of apparent expansion
- Coefficient of real expansion of a liquid,

real increase in volume

original volume × rise in temperature

Coefficient of apparent expansion of a liquid

apparent increase in volume

- $\gamma_a = \frac{\alpha_{PP}}{\text{original volume } \times \text{ rise in temperature}}$
- $\gamma_{i} = \gamma_{a} + \gamma_{g}$, where γ_{g} is coefficient of volume expansion of the container.

Anomalous Expansion of Water

- Generally matter expands on heating and contracts on cooling. In case of water, it expands on heating if its temperature is greater than 4°C. In the range 0°C to 4°C, water contracts on heating and expands on cooling, (i.e., its coefficient of volume expansion in this range is negative). This behaviour of water in the range from 0°C to 4°C is called anomalous expansion.
- Water has a maximum density at 4°C. ٢

SPECIFIC HEAT OR SPECIFIC HEAT CAPACITY

- It is defined as the amount of heat required to raise the 徽 temperature of unit mass of the substance through 1°C:
- The specific heat of a substance is given by

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

- * where m is the mass of the substance and ΔQ is the heat required to change its temperature by ΔT .
- The SI unit of specific heat is J kg⁻¹ K⁻¹. ø
- 0 The practical unit of specific heat is cal/g °C.

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- Specific heat depends on the nature of the substance and its temperature.
- Specific heat for hydrogen is maximum (3.5 cal g⁻¹ °C⁻¹) and for water, it is 1 cal g⁻¹ °C⁻¹. For all other substances, the specific heat is less than 1 cal g⁻¹ °C⁻¹.
- Specific heat of a substance depends also on the state of the substance *i.e.*, solid, liquid or gas. For example, specific heat of ice = 0.5 cal. g⁻¹ °C⁻¹; specific heat of water = 1 cal g⁻¹ °C⁻¹ and specific heat of steam = 0.47 cal g⁻¹ °C⁻¹.

Molar Specific Heat or Molar Heat Capacity

- It is defined as the amount of heat required to raise the temperature of one mole of substance through 1°C.
- The molar specific heat of a substance is given by

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

where μ is the number of the moles of that substance.

- The SI unit of molar specific heat is $J \mod^{-1} K^{-1}$.
- Molar specific heat also depends on the nature of the substance and its temperature.

Gas has Two Types of Molar Specific Heats

- Molar specific heat at constant volume (C_{ν})
- Molar specific heat at constant pressure (C_p)

Thermal Capacity or Heat Capacity

- It is defined as the amount of heat required to raise the temperature of a substance through 1°C or 1 K.
- Thermal capacity, $S = s \times m$

where m is the mass of the substance and s is the specific heat of a substance.

- The SI unit of thermal capacity is J K⁻¹ while practical unit is cal •C⁻¹.
- Thermal capacity depends upon the nature of the substance and its mass.
- Water is used as a coolant in automobile radiators as well as a heater in hot water bags because water has high specific heat capacity.

CHANGE OF STATE

- Matter normally exists in three states, *i.e.*, solid, liquid and gas. A transition from one of these states to another is known as change of state.
- Melting : The change of state from solid to liquid is known as melting.
- Fusion : The change of state from liquid to solid is known as fusion.
- Melting point : The temperature at which the solid and liquid states of the substance are in thermal equilibrium with each other is called its melting point. It is the characteristic of the substance. It also depends on pressure. The melting point of a substance at standard atmospheric pressure is called its normal melting point.
- For substances (like wax and sulphur) which expand on melting, melting point rises with increase in pressure

and for the substances (like ice and rubber) which contract on melting, melting point is lowered with increase in pressure.

- **Vaporisation**: The change of state from liquid to vapour is known as vaporisation.
- **Boiling point :** The temperature at which the liquid and the vapour states of the substance co-exist is called its boiling point. It is the characteristic of the substance. It also depends on pressure. The boiling point of a substance at standard atmospheric pressure is called its normal boiling point.
- The boiling point of a substance increases with increase in pressure. Due to this fact, the cooking is easier in the pressure cooker. The boiling point of a substance decreases with decrease in pressure. Due to this fact, the cooking is difficult on hill station.
- **Sublimation :** The change from solid state to vapour state without passing through the liquid state is known as sublimation.

Phase Diagram

A graph between the temperature T and pressure P of the substance is known as phase diagram or P-Tdiagram as shown in the figure. A phase diagram divides the P-T plane into solid region, the vapour region and the liquid region. The regions are separated by the curves such as sublimation curve, fusion curve and vaporisation curve. The point on sublimation curve represent states in which solid and vapour phases co-exist. Points on the fusion curve represent states in which solid and liquid phases co-exist. Points on the vaporisation curve represent states in which the liquid and vapour phases co-exist. The temperature and pressure at which the fusion curve, the vaporisation curve and sublimation curve meet and all the three phases of a substance co-exist is known as the triple point of the substance.



For example, the triple point of water is represented by the temperature 273.16 K and pressure 6.11×10^{-3} Pa.

LATENT HEAT

• It is defined as the amount of heat required to change the state of a unit mass of the substance at a constant temperature.