

Properties of Matter

CALORIMETRY

Section - 1

This is the branch of heat transfer that deals with the measurement of heat. The heat is usually measured in calories or kilocalories.

Heat :

It is form of energy which determines the change in thermal state of a body and is defined as the flow of energy from one body to the other body due to difference in the degree of hotness of two bodies ([temperature](#)). It flows from the body which is at a high temperature to the other at low temperature, by its own.

One Calorie :

1 calorie is the quantity of heat required to raise the temperature of 1 gram of water by 1°C .

Specific Heat :

The specific heat ([s](#)) of a substance is the quantity of heat in calories required to raise the temperature of 1 *gm* of that substance by 1°C . Its units are $\text{cal/gm}^{\circ}\text{C}$.

The heat lost by a body or gained from a body depends upon the difference in the temperature.

The heat lost or gained by a body = $m s \Delta\theta$

m : mass of the body; s : specific heat ; $\Delta\theta$: rise or fall in the temperature of body

Heat Capacity :

The heat capacity of a body is the quantity of heat required by the body to raise its temperature by 1°C . It is also known as [thermal capacity](#).

Heat Capacity = $m s$ (mass $\times$ specific heat)

Water Equivalent :

It is the quantity of water whose thermal capacity is same as the heat capacity of the body. It is denoted by [W](#).

$W = m s$ = Heat capacity of the body

Principle of Calorimetry :

When two bodies at different temperatures are placed in contact with each other or mixed with each other (*liquid-in-liquid*, *solid-in-liquid*), the heat will pass from the body at higher temperature to the body at lower temperature until both bodies reach a common temperature. This state is called as [thermal equilibrium](#).

At this state :

Heat lost by one body = Heat gained by the other body

Two bodies of masses m_1 and m_2 , specific heats s_1 and s_2 and at temperatures θ_1 and θ_2 are brought in contact with each other. Assuming $\theta_1 > \theta_2$, heat will flow from body 1 to body 2. If θ is the common temperature of two bodies at the state of thermal equilibrium, then (assuming no heat is gained or lost from or to the surroundings):

Heat lost by body 1 = Heat gained by body 2

$$m_1 s_1 (\theta_1 - \theta) = m_2 s_2 (\theta - \theta_2) \quad (\theta_2 < \theta < \theta_1)$$

or $m_1 s_1 (\theta - \theta_1) + m_2 s_2 (\theta - \theta_2) = 0$

Latent Heat :

The latent heat is the amount of heat that has to be supplied to (or taken from) the body during the change of state even though its temperature does not change. It is measured in terms of *cal/gm* or *kcal/kg*.

Latent heat of fusion :

It is the quantity of heat required to change the unit mass of a solid substance to the liquid state at its melting point. For ice, latent heat of fusion is 80 cal/gm .

Latent heat of vapourisation :

It is the quantity of heat required to convert unit mass of a liquid to gaseous state at the boiling point of the liquid. For water, latent heat of vapourisation is 540 cal/gm .

Illustration - 1 Calculate the heat of fusion of ice from the following data for water added to ice at 0°C kept inside calorimeter. Mass of calorimeter = 60 gm , mass of calorimeter + water = 460 gm , mass of calorimeter + water + ice = 618 gm , initial temperature of water = 38°C , final temperature of the mixture = 5°C . The specific heat of calorimeter = $0.10 \text{ cal/g}^\circ\text{C}$.

SOLUTION :

$$\begin{aligned} \text{mass of water} &= 460 - 60 = 400 \text{ gm.} & \Rightarrow & 400 \times 1 \times (38 - 5) \\ \text{mass of ice} &= 618 - 460 = 158 \text{ gm.} & & = 158 \times L + 158 \times 1 \times 5 + 60 \times 0.1 \times 5 \\ \text{Heat lost by water} &= \text{Heat gained by ice to melt} & & (\text{where } L \text{ is the latent heat of fusion of ice}) \\ + \text{Heat gained by (water + calorimeter) to reach } 5^\circ\text{C.} & & \Rightarrow & L = 78.35 \text{ cal/gm.} \end{aligned}$$

Illustration - 2 When a block of metal of specific heat $0.1 \text{ cal/g}^\circ\text{C}$ and weighing 110 gm is heated to 100°C and then quickly transferred to a calorimeter containing 200 gm of a liquid at 10°C , the resulting temperature is 18°C . On repeating the experiment with 400 gm of same liquid in the same calorimeter at same initial temperature, the resulting temperature is 14.5°C . Find :

- (a) specific heat of the liquid (b) the water equivalent of calorimeter.

SOLUTION :

$$\begin{aligned} \text{Let } s \text{ be the specific heat of the liquid and } W \text{ be the} & \Rightarrow 110 \times 0.1 \times (100 - 18) \\ \text{water equivalent of the calorimeter.} & = 200 \times s \times (18 - 10) + W \times (18 - 10) \\ \text{Heat lost by the block} & \Rightarrow 1600s + 8W = 902 \quad \dots (i) \\ = \text{Heat gained by (liquid + calorimeter)} & \end{aligned}$$

Heat lost by the block

= Heat gained by (liquid + calorimeter)

$$\Rightarrow 110 \times 0.1 \times (100 - 14.5) \\ = 400 \times s \times (14.5 - 10) + W \times (14.5 - 10)$$

$$\Rightarrow 1800s + 4.5W = 940.5 \quad \dots (ii)$$

On solving (i) and (ii), we get :

$$s = 0.48 \text{ cal/g/}^\circ\text{C and } W = 16.6 \text{ gm.}$$

Illustration - 3 The temperature of equal masses of three different liquids A, B, C are 12°C , 19°C and 28°C respectively. The temperature when A and B are mixed is 16°C while when B and C are mixed, it is 23°C . What would be the temperature when A and C are mixed?

SOLUTION :

Let m = mass of each liquid, when A and B are mixed,

Heat lost by B = Heat gained by A

$$\Rightarrow m s_B (19 - 16) = m s_A (16 - 12) \\ \Rightarrow 3 s_B = 4 s_A \quad \dots (i)$$

When B and C are mixed,

Heat lost by C = Heat gained by B

$$\Rightarrow m s_C (28 - 23) = m s_B (23 - 19) \\ \Rightarrow 5 s_C = 4 s_B \quad \dots (ii)$$

From (i) and (ii), we get :

$$16 s_A = 12 s_B = 15 s_C \quad \dots (iii)$$

When A and C are mixed, Let θ = final temperature.

Heat lost by C = Heat gained by A

$$\Rightarrow m s_C (28 - \theta) = m s_A (\theta - 12)$$

By using (iii), we get :

$$\Rightarrow 15 s_C (28 - \theta) = 15 s_A (\theta - 12) \\ \Rightarrow 16 s_A (28 - \theta) = 15 s_A (\theta - 12)$$

On solving for θ , we get :

$$\theta = \frac{16 \times 28 + 12 \times 15}{16 + 15} \\ \theta = 20.26^\circ\text{C}$$

Illustration - 4 A tube leads from a flask in which water is boiling under atmospheric pressure to a calorimeter. The mass of the calorimeter is 150 gm, its specific heat capacity is $0.1 \text{ cal/gm/}^\circ\text{C}$, and it contains originally 340 gm of water at 15°C . Steam is allowed to condense in the calorimeter until its temperature increases to 71°C , after which total mass of calorimeter and contents are found to be 525 gm. Compute the heat of condensation of steam.

SOLUTION :

Mass of calorimeter and contents before passing

$$\text{steam} = (150 + 340) = 490 \text{ gm.}$$

Mass after passing steam = 525 gm.

$$\Rightarrow \text{mass of steam which condenses} \\ = (525 - 490) \text{ gm} = 35 \text{ gm.}$$

Let L = latent heat of steam.

Heat lost by steam = heat gained by water + heat gained by calorimeter.

$$35L + 35 \times 1 (100 - 71) \\ = 340 \times 1 \times (71 - 15) + 150 \times 0.1 \times (71 - 15) \\ \Rightarrow L = 539 \text{ cal/gm.}$$

Illustration - 5 Determine the final result when 200 gm of water and 20 gm of ice at 0°C are in a calorimeter having a water equivalent of 30 gm and 50 gm of steam is passed into it at 100°C .

SOLUTION :

When steam is passed, the final temperature can be 0°C , between 0°C and 100°C , 100°C .

We will consider all three possibilities

Case I :

Final temperature = 0°C

In this case, all the steam condenses and then cools down to 0°C .

Heat given out by steam

$$= 50 \times 540 + 50 \times 1 \times (100 - 0) \\ = 32000 \text{ cal.}$$

Mass of ice which will melt by this heat

$$= \frac{32000}{80} = 400 \text{ gm}$$

But there are only 20 gm of ice in the calorimeter.

Hence final temperature can not be 0°C .

Case II :

Final temperature = θ and $0 < \theta < 100$

Heat lost by steam

$$= \text{Heat gained by (ice + water + calorimeter)}$$

$$\Rightarrow 50 \times 540 + 50 \times 1 \times (100 - \theta) \\ = 20 \times 80 + (20 + 200 + 30) \times 1 \times (\theta - 0)$$

$$\Rightarrow \theta = 101.3^\circ\text{C}$$

The assumption ($0 < \theta < 100$) is proved to be wrong.

Hence final temperature can not be between 0°C and 100°C .

$$\Rightarrow \text{The final temperature will be } 100^\circ\text{C}.$$

Final contents of mixture

Let m = mass of steam condensed.

Heat lost by steam = Heat gained by ice to melt + Heat gained by (water + water + calorimeter) to reach 100°C .

$$m(540) = 20 \times 80 + (20 + 200 + 30) \times (100 - 0)$$

$$\Rightarrow m = 26600/540 \approx 49 \text{ gm.}$$

$$\Rightarrow 49 \text{ gm of steam condense and the final temperature is } 100^\circ\text{C}.$$

Illustration - 6

What will be the final temperature, when 150 gm of ice at 0°C is mixed with 300 gm of water at 50°C ? Specific heat of water = $1 \text{ cal/gm}^\circ\text{C}$. Latent heat of fusion of ice = 80 cal/gm .

SOLUTION :

Let us assume that $T > 0^\circ\text{C}$

Heat lost by water = Heat gained by ice to melt
+ Heat gained by water formed from ice

$$300 \times 1 \times (50 - T) = 150 \times 80 + 150 \times 1 \times (T - 0)$$

$$\Rightarrow T = 6.7^\circ\text{C}$$

Hence our assumption that $T > 0^\circ\text{C}$ is correct.

Illustration - 7

In a calorimeter (water equivalent = 40 gm) are 200 gm of water and 50 gm of ice all at 0°C . Into this is poured 30 gm of water at 90°C . What will be the final condition of the system?

SOLUTION :

Let us assume that all ice melts and warms up. Thus we will assume that $T > 0$.

Heat lost by water added =

Heat gained by ice to melt + Heat to warm water formed from ice and water added + Heat gained by calorimeter can.

$$30 \times 1 \times (90 - T) \\ = 50 \times 80 \\ + (50 + 200) \times 1 \times (T - 0) \\ + 40 \times 1 \times (T - 0)$$

$$\Rightarrow 2700 - 30T = 4000 + 250T + 40T$$

$$\Rightarrow T = -4.1^\circ\text{C}$$

Hence our assumption that $T > 0$ is wrong, since hot water added is not able to melt all of the ice.

Therefore the final temperature will be 0°C .

Let m = mass of ice finally left in the can.

Heat lost by water = Heat gained by melting ice

$$30 \times 1 \times (90 - 0) = (50 - m) \times 80$$

$$\Rightarrow m = 16.25 \text{ gm.}$$

Finally there is 16.25 gm of ice and

$(200 + 30 + 33.75) = 263.75 \text{ gm}$ of water at 0°C .

Illustration - 8 If water at 0°C , kept in a container with an open top, is placed in a large evacuated chamber :

- (A) all the water will vaporize
 (B) all the water will freeze
 (C) part of the water will vaporize and the rest will freeze
 (D) ice, water and water vapour will be formed and reach equilibrium at the triple point

SOLUTION : (C)

Evacuation will greatly enhance evaporation leading to heat losses by water. As water is at 0°C , it begins to freeze. After some time, a part of water will vaporise and the remaining will freeze.

$\Rightarrow$ C is correct.

Illustration - 9 In the previous question, if the specific latent heat of vaporization of water at 0°C is η times the specific latent heat of freezing of water at 0°C , the fraction of water that will ultimately freeze is :

- (A) $\frac{1}{\eta}$ (B) $\frac{\eta}{\eta + 1}$ (C) $\frac{\eta - 1}{\eta}$ (D) $\frac{\eta - 1}{\eta + 1}$

SOLUTION : (B)

Let m_1 = mass which finally freezes

m_2 = mass of water vaporised

Heat gained by m_2 = Heat lost by m_1

$$m_2 L_{\text{vap}} = m_1 L_{\text{fusion}}$$

$$\frac{m_1}{m_2} = \eta \Rightarrow \frac{m_1}{m_1 + m_2} = \frac{\eta}{\eta + 1}$$

$\Rightarrow$ Fraction of total mass which freezes is

$$\frac{\eta}{\eta + 1}$$

B is the correct answer.

THERMAL EXPANSION

Section - 2

When a solid is heated, its length, surface area and the volume increase.

Linear expansion : (expansion in length of a solid)

Consider a rod of length ℓ_1 at a temperature T_1 . Let it be heated to a temperature T_2 and the increased length of the rod be ℓ_2 , then :

$$\ell_2 = \ell_1 (1 + \alpha \theta)$$

α : coefficient of linear expansion and $\theta = T_2 - T_1$