CHAPTER ELEVEN

SPECIFIC HEAT CAPACITY AND HEAT CAPACITY

The specific heat capacity:

- The specific heat capacity of a substance is defined as the heat required to raise a unit mass of it through 1^{0c}.
- Its S.I unit is J/Kg^0C, and the symbol used to represent it is C.
- This mass refers to a mass of 1kg.

The heat capacity:

- This is also known as the thermal capacity.
- The heat capacity of a substance or a body is defined as the heat required to raise it temperature by 1^0c.
- The S.I unit for the heat capacity is joule per degree Celsius i.e. $J/^0C$ or $J/^0k$.
- The heat capacity = mass × specific heat capacity.

(Q1) The specific heat capacity of copper is $400J/kg^0C$. Find the heat capacity of 5kg of copper.

Soln:

Since heat capacity = mass × specific heat capacity,

=> heat capacity = $5 \times 400 = 2000Jk^{-1} = 2000J/k = 2kJ/k$

N/B: 2kJ/ k is the same as $2kJk^{-1}$.

Also 40J/k can also be written as $40Jk^{-1}$.

(Q2) Calculate the heat capacity of a substance whose specific heat capacity is $25Jk^{-1}\,{}^0C^{-1}$, if it has a mass of 10kg.

Soln:

Mass = M = 10kg.

Specific heat capacity = C = 25J/kg^{0}C.

Heat capacity = MC = 10 $\times$ 25

= 250J/^{0}C.

(Q3) The mass of a substance is 4000g. If its specific heat capacity is 50J/kg^{0}C, determine its heat capacity.

Soln:

M = 4000g = 4kg.

C = 50J/kg^{0}C.

Heat capacity = MC

= 4 $\times$ 50 = 200J/^{0}C = 0.2Kj/^{0}c.

N/B: (1) 1kJ = 1000J and 1kg = 1000g.

(1) The heat gained by a substance = M $\times$ C $\times \triangle\theta$, where M = the mass of the substance in kg.

C = its specific heat capacity.

$\triangle\theta$ = the change in temperature.

(2) The heat lost by a substance or a body is also = M $\times$ C $\times \triangle\ \theta$.
$where \triangle\theta$ = the increase (rise) or decrease (fall) in temperature.

(Q1) The specific heat capacity of a substance is 20J/kg^{0}C. If the substance has a mass of 15kg and it temperature rises by 10^{0}C, calculate the heat gained by the substance.

Soln:

C = 20J/kg^{0}C.

M = 15kg.

$\triangle\theta = 10^{0C}$.

Heat gained = M $\times$ C $\times$ $\triangle\theta$

= 15 $\times$ 20 $\times$ 10 = 3000J = 3kJ.

(Q2) The mass of a metal is 7000g and its specific heat capacity is $30Jkg^{-1}c^{-1}$. If its temperature is raised from 4^{0c} to 6^{0C}, determine the amount of heat energy that it will gain.

Soln:

M = 7000g = 7kg.

C = $30Jkg^{-1}$ = 30J/kg.

$\triangle\theta = 6 - 4 = 2^{0C.}$

Amount of heat gained = M $\times$ C $\times$ $\triangle\theta$ = 7 $\times$ 30 $\times$ 2 = 420J.

N/B:

Heat gained or lost by a body = M $\times$ C $\times\triangle\theta$.

But since m $\times$ c = the heat capacity,

then heat lost or gained by a body = m $\times$ c $\times\triangle\theta$ = Heat capacity $\times\triangle\theta$.

(Q3) The heat capacity of a substance is $320J/^0C$. If its temperature is increased by 4^{0c}, determine the amount of heat gained.

Soln:

Heat gained = heat capacity $\times$ rise in temperature.

Therefore heat gained = 320 $\times$ 4 = 1280J = 1.28kJ.

(Q4) The temperature of a substance was decreased by 8^0C. If it has a mass of 50kg, and a specific heat capacity of $10J/kg^0C$, determine the amount of heat lost by the substance.

Soln:

$\triangle\theta = 8^0c$

$c = 10J/\ kg^0C.$

m = 50kg.

Heat lost = $m \times c \times \triangle\theta$

$= 50 \times 10 \times 8 = 4000J = 4kJ.$

(Q5) The heat capacity of a body is $200J/\ kg\ ^0C$. If its temperature falls from 22^0C to 20^0C, calculate the amount of heat lost.

Soln:

Heat capacity = $m \times c = 200J/\ ^0C.$

$\triangle\theta\ = 22 - 20 = 2^0C.$

Heat lost = Heat capacity x change in temperature = $200 \times 2 = 400J$

Soln:

Fall in temperature = $\triangle\theta$ = ?

M = 200g = 0.2kg.

$C = 10Jkg^{-10}c^{-1}$

Heat lost = 12J.

But since heat lost = $M \times C \times \triangle\theta$

N/B:

(I) $10J.kg^{-10}C^{-1}$ is the same as or equivalent to $10Jkg^{-10}k^{-1}$.

(II) Also $10Jkg^{-10}k^{-1}$ can also be written as $10J/kg^0k$.
(III)In short, degrees kelvin and degrees celcius are interchangeable.

(Q6) Given that the heat capacity of a metal is $80J/kg\ ^0k$, find its specific heat capacity, if it has a mass of 5kg.

Soln:

Heat capacity = $80J/^0k$.

M = 5kg, C = ?

Since heat capacity = m$\times c$,

=> heat capacity = 5 $\times$ c, => 80 = 5c,

=> c = $\frac{80}{5} = 16$.

The specific heat capacity = 1 $6J/kg^0k$.

N/B:

- The change in temperature (i.e. the increase or decrease in temperature) $\triangle\theta$ is also = $\theta_2 - \theta_1$, where θ_2 = the higher temperature and θ_1 = the lower temperature

Therefore heat lost or heat gained = m $\times$ c $\times\triangle\theta$ = m $\times$ c $\times$ $(\theta_2 - \theta_1)$.

(Q1) How many jouls of heat is given out, when a piece of iron of mass 2kg and specific heat capacity $460J/kg^0C$, cools from 30^0C to 20^0c.

Soln:

M = 2kg, C = $460J/kg^0C$, θ_2 = 30^0C and θ_1 = 20^{0c}.

Heat given out = m $\times$ c $\times$ $(\theta_2 - \theta_1)$

= 2 $\times$ 460 $\times$ (30 – 20)

= 2 $\times$ 460 $\times$ 10 = 9200J = 9.2kJ.

(Q2) Determine the amount of heat given out, when 50g of iron cools from 45^0C to 15^0C, if its specific heat capacity is 460J/kg^{0}C.

Soln:

$\theta_2 = 45^0$C, $\theta_1 = 15^0$C,

m = 50g = 0.05kg, c = 460J/ kg^{0}C.

Heat given out = m $\times$ c $\times$ $(\theta_2 - \theta_1)$

= 0.05 $\times$ 460 $\times$ (45 – 15)

= 0.05 $\times$ 460 $\times$ 30 = 690J

N/B:

- θ_2 may also be referred to as the final temperature.
- θ_1 may also be referred to as the initial temperature.
- $(\theta_2 - \theta_1)$ = the change in temperature.

(Q3) (a) Explain what is meant by the statement, the specific heat capacity of iron is 460J/kg^{0}C.

Soln:

This means that when the temperature of 1kg of iron changes by 1^{0c}, the heat given out or taken in is 460J.

(Q4) What will be the final temperature of the mixture, if 100g of water at a temperature 70^0C is added to 200g of cold water whose temperature is 10^{0c} and well stirred. Neglect the heat absorbed by the container. [Specific heat capacity of water = 4200J/kg^{0}C].

Soln:

Heat given out by hot water = Heat gained by cold water.

Let θ = the final temperature of the mixture.

With reference to the hot water, θ, the final temperature of the mixture will be lower than the temperature of the hot water (i.e. 70^0C).

=> For the hot water, the change in temperature = $(70^0 - \theta)$.

Heat lost by hot water when it cools from 70^0C to θ^0C = m $\times$ c $\times$ (70 - θ)

= 100g $\times$ 4200 $\times$ (70 - θ)

= 0.1kg $\times$ 4200 $\times$ (70 - θ).

With reference to the cold water, the final temperature of the mixture which is θ, will be higher that the temperature of the cold water, (10^0C).

=> The change in temperature of the cold water = (θ - 10).

The heat gained by the cold water in warming from 10^0C to θ^0C = m $\times$ c $\times$ (θ - 10)

= 200g $\times$ 4200 $\times$ (θ - 10)

= 0.2kg $\times$ 4200(θ - 10).

Since heat lost by hot water = heat gained by cold water,

=> $0.1 \times 4200 \times (70 - \theta) = 0.2 \times 4200 \times (\theta - 10)$,

=> $420(70 - \theta) = 840 (\theta - 10)$, => $29400 - 420\theta = 840\theta - 8400$,

=> $29400 + 8400 = 840\theta + 420\theta$,

=> $37800 = 1260\theta$

=> $\theta = \frac{37800}{1260} = 30^0$C.

The final temperature of the mixture = 30^0C.

(Q5) A piece of copper of mass 250g was heated to 100^0C, and then transferred into a well lagged aluminum can of mass 10.0g, which contained 120g of methylated spirit whose temperature was 10^0C. Determine the final steady temperature of the mixture, after the spirit had been well stirred. [The specific heat capacity of copper = 400J/kg^{0}C, of aluminum = 900J/kg^{0}C, of methylated spirit = 2400J/kg^{0}C].

N/B:

- Since the methylated spirit was contained within the aluminum can, => heat gained by the aluminum can + the heat gained by the methylated spirit = heat lost by the piece of copper.
- Secondly, since the methtylated spirit is within the aluminium can(i.e. in contact with each other), then they will also have the same temperature.
- Therefore if the temperature of the methylated spirit is 10^0C, then that of the aluminium can will also be 10^0C.

Soln:

Let θ = the final temperature of the mixture.

Sine the initial temperature of the copper (i.e. 100^0C) will be higher than this θ,

=> change in temperature = $(100 – \theta)$.

Heat lost by the copper in cooling from 100^0C to $\theta = m \times c \times (100 - \theta)$

$= 250g \times 400 \times (100 - \theta) = 0.25kg \times 400 \times (100 - \theta) = 100(100 – \theta) = 10,000 - 100\,\theta$.

Since the hot piece of copper was dropped into the aluminum can which contained the methylated spirit whose temperature was 10^0C, then the final temperature θ will be higher than this 10^0C, which is the initial temperature of both the aluminum can and the methylated spirit.=> For both the aluminium can and the methylated spirit, the change in temperature = (θ - 10^0C).Heat gained by the aluminum can = $m \times c \times (\theta - 10^0C)$

$= 10g \times 900\ (\theta - 10)$

$= 0.01kg \times 900 \times (\theta - 10)$

$= 9(\theta - 10) = 9\theta - 90$.

Lastly, heat gained by the methylated spirit = $m \times c \times (\theta - 10)$

$= 120g \times 2400 \times (\theta - 10)$

$= 0.12kg \times 2400 \times (\theta - 10)$

= 288(θ − 10) = 288 θ - 2880.

Since the heat lost by the copper = the heat gained by the aluminum can + the heat gained by the methylated spirit, then 10000 - 100θ= 9θ - 90 + 288 θ – 2880,

=> 10,000 + 90 + 2880 = 9θ + 288θ + 100θ,

=> 12970 = 397θ

=> $\theta = \frac{12970}{397} = 33$

=> The final temperature = 33^0C.

(Q6) 500g of a certain metal was heated to 100^0C, and then placed in a 200g of water whose temperature was 15^0C. If the final temperature of the mixture rose to 20^0C, calculate the specific heat capacity of the metal.

N/B: The final temperature will be the same for both the metal and the water.

[Specific heat capacity of water = 4200J/kg^{0}C].

Soln:

<u>For the metal:</u>

Let C = the specific heat capacity.

Mass = 500g = 0.5kg.

Initial temperature = 100^0C.

Final temperature = 20^0C.

Change in temperature = $\Delta\theta$

= 100 – 20 = 80^0C.

Heat lost by the metal = m $\times$ c $\times$ $\Delta\theta$ = 0.5$\times$c x 80 = 40cJ

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For the water:

Mass = 200g = 0.2kg.

Specific heat capacity = 4200J/kg^{0}C.

Initial temperature = 15^{0c}

Final temperature = 20^{0c}

Change in temperature = θ

= 20 – 15 = 5^{0c}

Heat gained by water = m $\times$ c $\times \Delta\theta$ = 0.2$\times$4200 $\times$ 5 = 4200J.

But since heat lost by metal = heat gained by water => 40C = 4200, => C = $\frac{4200}{40}$

=> C = 105J/kg^{0}C.

(Q7) A brass cylinder of mass 100g was heated to 100^{0}C, and then transferred into a thin aluminium can of negligible heat capacity, containing 150g of paraffin whose temperature was 11^{0}C. If the final steady temperature after stirring was 20^{0}C, calculate the specific heat capacity of the paraffin. [The specific heat capacity of brass = 0.38J/kg^{0}C].

N/B: - Since the aluminum can has negligible heat capacity, then we do not consider it during calculation.

- Therefore in this particular case, the heat lost by the brass = the heat gained by the paraffin only.

Soln:

For the brass:

Mass = 100g = 0.1kg.

Initial temperature = 100^{0}C.

Final temperature = 20^0.

$\triangle\theta = 100 - 20 = 80^0c$.

$c = 0.38J/kg^0C$.

Heat lost by the brass in cooling from 100^0C to $20^0C = m \times c \times \triangle\theta = 0.1 \times 0.38 \times 80 = 3.04J$.