6.2. HEAT CAPACITY

The heat capacity, C, of an object is the quantity of heat which must be transferred to it to give it one degree rise in temperature. The SI unit for heat capacity is **joule per degree Celsius (J/°C)** or **Joule per Kelvin (J/K)**. The heat capacity is found using the following formula: $C = \frac{Q}{\Delta T}$ or $Q = C\Delta T$; Where Q is the quantity of heat transferred or supplied and ΔT is the temperature change.

The amount of heat required to change the temperature of a body depends on:

- The material the substance is made of;

- Mass of the body; the larger the mass, the smaller the temperature rise.

6.2.1. SPECIFIC HEAT CAPACITY

The specific heat capacity of a substance is defined as the amount of heat energy required to raise the temperature of a unit mass of a substance by 1 °C or 1K. It is used to describe the heat capacity of a substance per unit mass. The SI unit for the specific heat capacity **'c' is** $\boldsymbol{J \cdot kg^{-1} \cdot {}^\circ C^{-1}}$ or $\boldsymbol{J \cdot kg^{-1} \cdot K^{-1}}$ (or simply $\boldsymbol{J/kg \cdot {}^\circ C}$ *and* $\boldsymbol{J/kg \cdot K}$). The specific heat capacity of a substance is a property of the substance and does not depend on the size or shape of the substance.

Specific heat capacity can be written as $c = C/m$, where m is the mass of the object and C is its heat capacity. Combining the above equation with the one for heat capacity, we get: $Q = mc\Delta T$.

Note: Since the temperature interval on the Kelvin scale is the same as that on the Celsius scale, the temperature change can be expressed in *either* unit.

6.2.2. MEASURING SPECIFIC HEAT CAPACITY OF SOLIDS AND LIQUIDS.

Experiment 6.1: Specific heat capacity of liquid

Aim: To find the specific heat capacity of liquid using electric method

Apparatus: a laboratory thermometer, a calorimeter (lagged copper can), a low-voltage immersion heater, a stirrer, voltmeter, ammeter, stopwatch.

Precaution: When determining heat exchange, the experiment must be carried out under controlled conditions to prevent heat loss to the surroundings

Procedure:

Set up the apparatus as shown in the figure below.

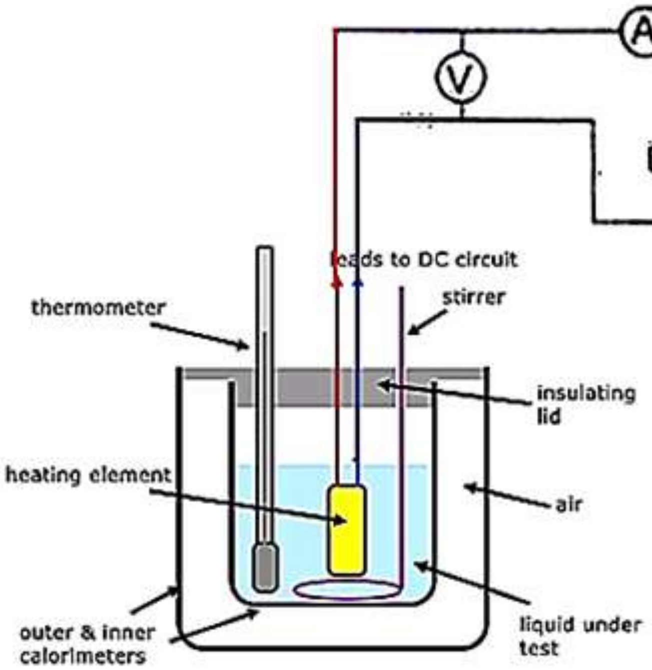

Figure 6.1: Apparatus used to measure the specific heat capacity of liquid

Place 250g of water at room temperature in the calorimeter and record its temperature. Switch on the immersion heater for exactly five minutes. Turn it off, stir the water and record the highest temperature reached.

Results:

Supposing that no energy was lost to the surroundings, which means all the heat energy produced by the heater went to rise the temperature of the water, we can say:

Heat lost by heater = heat gained by the water

This is called the heat equation. The heat produced by the heater is given by:

$E = VIt$, where V is the voltage measured by the voltmeter, I is the current measured by ammeter and t is the time in second measured by the stopwatch.

If we call VI the electrical power then the energy will be given by:

$$E = power \times time$$

But the heat energy received by the water is given by:

$$Q = mc\Delta T$$

So, the heat equation will now become: $VIt = mc\Delta T$ and we can therefore deduce the specific heat capacity equation as: $c = \frac{VIt}{m\Delta T}$

Your result may be found to be a little higher than 4500J/kg°C because of heat losses, which cause more heat to be needed for any temperature rise.

Experiment 6.2: To measure the specific heat capacity of metals

Aim: *To measure the specific heat capacity of metals*

Apparatus: a laboratory thermometer, a calorimeter (lagged copper can), a low-voltage immersion heater, a stirrer, voltmeter, ammeter, stopwatch.

Precaution: When determining heat exchange, the experiment must be carried out under controlled conditions to prevent heat loss to the surroundings

Procedure:

Take a 1kg cylindrical block of metal and drill two holes in it; one for a thermometer and the other for the immersion heater, as shown in the figure below. Lag the block. Insert the thermometer and the heater in their holes, switch on the current and simultaneously start the stopwatch. Keep the current constant by adjusting the rheostat.

Record the voltmeter and ammeter readings. When the temperature has risen by about 5°C, switch the current off and simultaneously stop the watch. Record the time taken but wait for a short moment before taking the final temperature reading because heat may still be travelling from the heater to the thermometer and the block. Record the highest temperature reached.

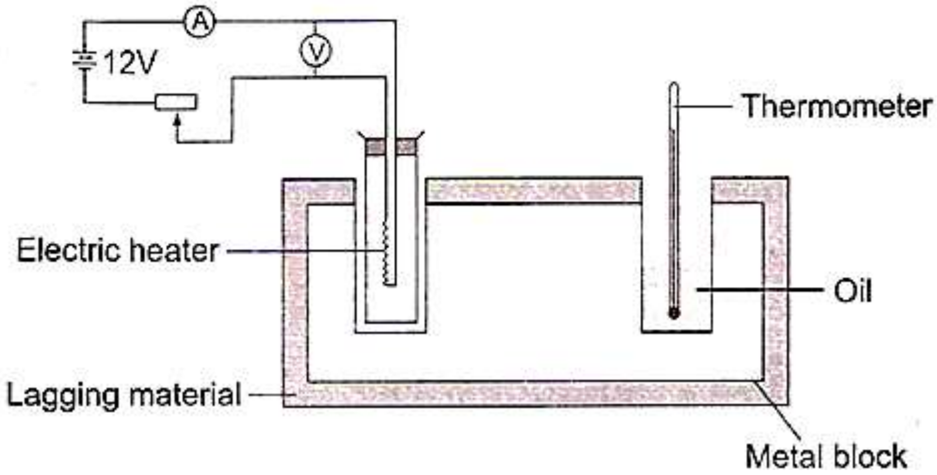

Figure 6.2: Determining the specific heat capacity of a solid

The specific heat capacity is obtained as $c = \frac{VIt}{m\Delta T}$

Specific heat capacities of various substances are given in the table below

Substance	Specific heat capacity J/kg°C
Water	4200
Brine	2900
Alcohol	2500
Glycerine	2400
Paraffin	2200
Ice	2100
Cork	2000
Sulphuric acid	1382
Aluminium	880
Glass	670
Silver	230

Mercury	140

Table 6.1: Specific heat capacities of some substances

Examples:

1. Calculate the heat required to raise the temperature of 10kg of brass from 10°C to 90°C. Specific heat capacity of brass is 377J/kg°C.

    Answer:

$$Q = mc\Delta T = 10 \times 377 \times (90 - 10) = 301600J$$

2. 1kg of a metal at 100°C is placed into two kilograms of water at 2°C and the resulting temperature of the water and the metal is 5°C. Find the specific heat capacity of the metal.

    Solution:

    Heat lost = heat gained

$$1 \times (100 - 5) \times c = 2 \times 4200 \times (5 - 2)$$

    $c = 265.26J/kg°\text{C}$.

3. It takes 5 minutes for a heater rated 12A, 5A to raise the temperature of 2kg of liquid by 3°C. calculate the specific heat capacity of the liquid

    Solution:

    Heat lost = heat gained

$$c = \frac{VIt}{m\Delta T} = c = \frac{12 \times 5 \times 30}{2 \times 3} = 3000J/kg°\text{C}$$

Importance of the high specific heat capacity of water

1. The temperature of water rises and falls more slowly than of land due to its high specific heat capacity.

2. The high specific heat capacity of water renders it a good coolant. It is used in car radiators because it absorbs a large amount of heat before its temperature rises to a higher value.

Note: when two objects having different temperatures are allowed to mix, transfer of heat energy occurs. Two principles have to be taken into account during heat transfer:

1. Law of conservation of energy: in any transformation of energy, the total amount of energy remains constant.

2. Principle of heat exchange: *When two objects with different temperatures mix, heat is transferred from the hotter object to the cooler one.* The amount of heat lost by the hotter object is equal to the amount of heat gained by the cooler object, as long as no heat is lost the surrounding. The transfer of energy continues until both objects reach the same temperature.

6.2.3. DETERMINATION OF SPECIFIC HEAT USING THE METHOD OF MIXTURE

Specific heat of a substance can be determined by the "Method of Mixture". This method is based on the law of Heat Exchange and the law of energy conservation.

These laws imply the fact that when a hot substance is mixed with a cold substance, the hot body loses heat and the cold body absorbs heat until thermal equilibrium is attained. This means: $\boldsymbol{Heat\ lost = Heat\ gained; E_H lost = E_H gained}$. At equilibrium, final temperature of mixture is measured.

Let us consider the following information in order to calculate the specific heat of a substance:

Mass of substance = M_s/kg
Mass of liquid = m_l/kg
Mass of calorimeter = m_c/kg
Initial temperature of the substance = T_s/K
Initial temperature of the liquid = T_l/K
Initial temperature of the calorimeter = Tc/K
Specific heat of substance = C_s =?
Specific heat of liquid = C_l
Specific heat of the material of the calorimeter = c_c
Final temperature of the mixture = T /K
According to the law of heat exchange

$$\boldsymbol{Q\ lost\ by\ substance\ =\ Q\ gained\ by\ liquid\ +\ Q\ gained\ by\ calorimeter}$$

$$M_s\ C_s\ (T_s - T) = m_l C_l (T - T_l)\ +\ m_c C_c (T - T_c)$$

$$C_s = \frac{m_l C_l (T - T_l)\ +\ m_c C_c (T - T_c)}{M_s (T_s - T)}$$

The required value of specific heat of solid is expressed in J/ kg K.

Example: How much water at 100°C must be added to 1.0kg of water at 10°C to give a final temperature of 37°C?

Solution:

Given

Warmer water:

$$\boldsymbol{m_w} = ?$$

$$\boldsymbol{C_w = 4.2 \times 10^3 J/kg} \cdot ℃$$

$$\Delta \boldsymbol{T_w = |T - T_1| = |37}℃ - \boldsymbol{100}℃| = \boldsymbol{63}℃$$

Cold water

$$\boldsymbol{m_c = 1.0kg}$$

$$\boldsymbol{C_c = 4.2 \times 10^3 J/kg} \cdot ℃$$

$$\Delta \boldsymbol{T_c = |T - T_1| = |37}℃ - \boldsymbol{10}℃| = \boldsymbol{27}℃$$

$$\boldsymbol{E_H \, lost \, by \, the \, warm \, water = E_H gained \, by \, the \, cold \, water}$$

$$\boldsymbol{m_w C_w \Delta T_w = m_c C_c \Delta T_c}$$

$$\boldsymbol{m_w = \frac{m_c C_c \Delta T_c}{C_w \Delta T_w} = \frac{(1.0kg) \times (4.2 \times 10^3 J/kg \cdot ℃) \times (27℃)}{(4.2 \times 10^3 J/kg \cdot ℃) \times (63℃)}}$$

$$\boldsymbol{m_w = 0.43kg}$$