EXPERIMENT 6

DETERMINATION OF SPECIFIC HEAT CAPACITY OF A LIQUID USING THE METHOD OF COOLING

Structure

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6.1 INTRODUCTION

In your +2 physics classes, you learnt about the nature of heat. Initially, it was thought to be a perfectly invisible and weightless fluid called caloric. The transition from caloric theory to now accepted – ‘Heat is Motion’ – took several years and the best minds.

The SI unit of heat is Joule (J). In practice we normally use kilocalorie (kcal) which is defined as the quantity of heat required to raise the temperature of one kilogram of pure water from 14.5°C to 15.5°C. Moreover, 1 kcal = 4.2 × 10³ J.

The property of a body which determines the amount of heat in a body is called heat capacity. It is defined as the amount of heat required by a body to raise its temperature through 1°C. The SI unit of heat capacity is J°C⁻¹. If we consider m gram of a substance, the amount of heat required to raise its temperature through ΔT°C is given by

$$\delta Q = ms \Delta T$$

where s is specific heat capacity. It is defined as the amount of heat required to raise the temperature of unit mass of the substance through 1°C. Its SI unit is J kg⁻¹°C⁻¹. In this experiment, you will learn to determine specific heat capacity of a liquid using Newton’s law of cooling. This law states that the rate of loss of heat is directly proportional to the
temperature difference between the body and its surroundings, provided it is less than 40°C. As such, this law is based on everyday experience and unidirectional flow of heat.

Before presenting the procedure and underlining theoretical discussion, we state the expected skills you should acquire after performing this experiment.

**Expected Skills**

After performing this experiment, you should be able to:

- explain the concept of specific heat capacity;
- state Newton’s law of cooling and explain how it can be used for determining the specific heat capacity;
- draw cooling curves for water or any other experimental liquid; and
- explain the concept of water equivalent of heat.

We now list the apparatus that you will use in this experiment.

**Apparatus Required**

A calorimeter, wooden box, stirrer, thermometer, stop watch, Bunsen burner and tripod stand.

### 6.2 EXPERIMENTAL TECHNIQUE

The experimental technique used to determine amount of heat in a body is known as calorimetry. In calorimetry, heat is related to change in temperature through heat capacity of a substance. In all calorimetry experiments, conservation of heat forms the basis of measurement. That is, in all calorimetric measurements, it is necessary to prevent undesired loss of heat to the surroundings. For this purpose, a bad conductor, like cotton wool is used to prevent heat loss. Better isolation is possible by placing the system in vacuum. But it is not a cost-effective option for a college/university physics laboratory.

The specific heat capacity of a liquid can be measured by the following methods:

- Method of mixtures
- Bunsen ice calorimeter
- Method of cooling.

In this experiment, you will use the method of cooling, which is based on Newton’s law of cooling. Let us learn about it now.

### 6.3 METHOD OF COOLING

As mentioned earlier, Newton’s law of cooling states that the rate of cooling of a body is directly proportional to the temperature difference between the body
and its surroundings, provided it is small (< 40°C). Mathematically, we can write

\[
\delta Q = -K (T_b - T_s) \quad (6.1)
\]

where constant of proportionality \( K \) characterises the nature of the substance, \( T_b \) is temperature of the body and \( T_s \) is temperature of the surroundings.

If a body of specific heat capacity \( s \) and mass \( m \) cools through temperature \( \Delta T \) in time \( dt \), the amount of heat lost can be expressed as

\[
\delta Q = ms \Delta T \quad (6.2)
\]

On comparing Eqs. (6.1) and (6.2), we can write

\[
m s \Delta T = -K (T_b - T_s) \, dt
\]

On integrating both sides, we can relate the total time \( t \) taken by the body to cool from initial temperature \( T_1 \) say to final temperature \( T_2 \):

\[
\int_{T_0}^{T_1} \, dt = -\frac{ms}{K} \int_{T_1}^{T_2} \frac{dT}{T - T_s} \quad (6.3a)
\]

or

\[
t = ms \ln \left( \frac{T_1 - T_s}{T_2 - T_s} \right) \quad (6.3b)
\]

Note that in the denominator of the integrand in Eq. (6.3a), we have replaced \( T_b \) by \( T \).

If we consider another similar body of mass \( m' \), specific heat capacity \( s' \) and characteristic constant \( K \), the total time taken for change in its temperature in the same range can be expressed as

\[
t' = \frac{m's'}{K} \ln \left( \frac{T_1 - T_s}{T_2 - T_s} \right) \quad (6.4)
\]

On combining Eqs. (6.4) and (6.3b), we can write

\[
\frac{t}{t'} = \frac{ms}{m's'} \quad (6.5a)
\]

If water equivalent of the container is \( W \), then we can rewrite Eq. (6.5a) as

\[
\frac{t}{t'} = \frac{ms + W}{m's' + W} \quad (6.5b)
\]

Water equivalent is product of mass of the container and its specific heat capacity. It is numerically equal to mass of water that has the same heat capacity as the body.
If we take water as the second liquid \((s^* = 1)\), then Eq. (6.5b) can be rearranged as

\[
\frac{s}{m} = \frac{t}{t'^{\prime}} \left( m' + W - W \right)
\]

Eq. (6.6) forms the basis of determination of specific heat capacity of a liquid. We determine the times \(t\) and \(t'^{\prime}\) taken by the experimental liquid and water, respectively, between two known temperatures by plotting cooling curves. Then knowing \(m, m'\) and \(W\), we can easily determine \(s\).

Note that specific heat capacity is characteristic of the material of the container. (You should consult your Counsellor to get the value of specific heat capacity of the material of the container or refer Table 6.1.)

### Table 6.1: Specific heat capacity of some metals

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Substance</th>
<th>Specific heat capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(\text{J g}^{-1}\text{C}^{-1})</td>
</tr>
<tr>
<td>1.</td>
<td>Aluminium</td>
<td>0.921</td>
</tr>
<tr>
<td>2.</td>
<td>Copper</td>
<td>0.385</td>
</tr>
<tr>
<td>3.</td>
<td>Iron</td>
<td>0.460</td>
</tr>
</tbody>
</table>

You are now ready to perform this experiment using the procedure stated below.

### 6.3.1 Procedure

1. Take an empty calorimeter and weight it carefully to determine its mass. Let it be represented by \(M_c\). Note this value in Observation Table 6.2. Calculate the water equivalent of the container by multiplying this mass \((M_c)\) by its specific heat capacity \((s_c)\). (You should consult your Counsellor to get the value of specific heat capacity of the container or refer to Table 6.1.)

2. Fill calorimeter \(C\) with water up to a defined mark, as shown in Fig. 6.1. Weigh the calorimeter with water and subtract the mass of empty calorimeter from it to know the mass of water.
3. Place the calorimeter on a Bunsen burner and heat it to about 60°C.

4. Next, place the calorimeter in a perfectly insulated wooden box, B. Pack the wooden box with a non-conducting material such as cotton wool to minimise heat loss by radiation.

5. Insert an accurate thermometer, T in calorimeter and allow it to cool.

6. Note temperature of water at intervals of say 60 s, with the help of thermometer. Record your readings in Observation Table 6.2.

7. Repeat steps 2-6 with the liquid whose specific heat capacity is to be determined.

**Observation Table 6.2: Variation of temperature with time**

<table>
<thead>
<tr>
<th>Least count of stop watch</th>
<th>= ........... s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Least count of thermometer</td>
<td>= ........... °C</td>
</tr>
<tr>
<td>Mass of empty calorimeter ($M_C$)</td>
<td>=...............kg</td>
</tr>
<tr>
<td>Water equivalent ($W$) of the container ($M_C \times s_C$)</td>
<td>=..............kg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Time (s)</th>
<th>Temperature of water (°C)</th>
<th>Temperature of experimental liquid (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>180</td>
<td></td>
<td></td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
8. Plot temperature versus time graphs for water as well as the experimental liquid. You should obtain curves as shown in Fig. 6.2.

![Diagram of temperature versus time graphs for water and experimental liquid]

**Fig. 6.2**: Cooling curves for water and experimental liquid.

9. Now you know all the quantities required to determine specific heat capacity using Eq. (6.6). Calculate the value.

**Result**: The specific heat capacity of given liquid is ............ \( \text{Jkg}^{-1}\text{C}^{-1} \).