EXPERIMENT 14

AIM

To study the relationship between the temperature of a hot body and time by plotting a cooling curve.

APPARATUS AND MATERIAL REQUIRED

Newton's law of cooling apparatus that includes a copper calorimeter with a wooden lid having two holes for inserting a thermometer and a stirrer and an open double – walled vessel, two celsius thermometers (each with least count 0.5 °C or 0.1 °C), a stop clock/watch, a heater/ burner, liquid (water), a clamp stand, two rubber stoppers with holes, strong cotton thread and a beaker.

DESCRIPTION OF APPARATUS

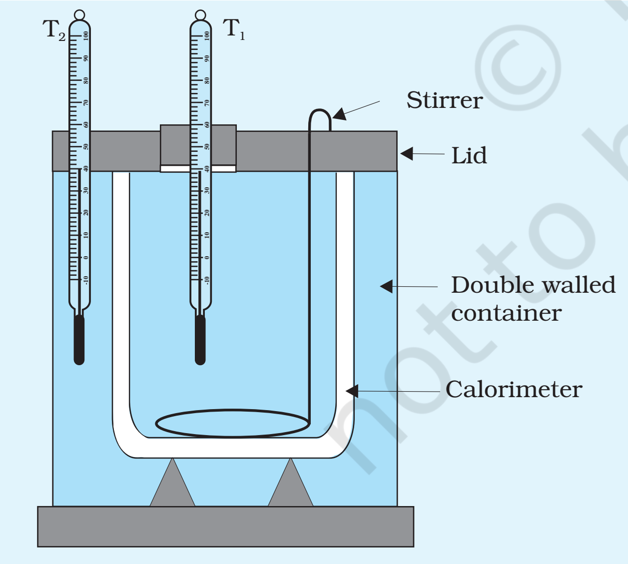

Fig.E 14.1: *Newton's law of cooling apparatus*

As shown in Fig. E 14.1, the law of cooling apparatus has a double walled container, which can be closed by an insulating lid. Water filled between double walls ensures that the temperature of the environment surrounding the calorimeter remains constant. Temperature of the liquid and the calorimeter also remains constant for a fairly long period of time so that temperature measurement is feasible. Temperature of water in calorimeter and that of water between double walls of container is recorded by two thermometers.

THEORY

The rate at which a hot body loses heat is directly proportional to the difference between the temperature of the hot body and that of its surroundings and depends on the nature of material and the surface area of the body. This is Newton's law of cooling.

For a body of mass m and specific heat s, at its initial temperature θ higher than its surrounding's temperature θ_o, the rate of loss of heat is $\frac{dQ}{dt}$, where dQ is the amount of heat lost by the hot body to its surroundings in a small interval of time.

Following Newton's law of cooling we have

Rate of loss of heat, $\frac{dQ}{dt} = -k\ (\theta - \theta_o)$ (E 14.1)

Also $\frac{dQ}{dt} = ms\ \frac{d\theta}{dt}$ (E 14.2)

Using Eqs. (E 14.1) and (E 14.2), the rate of fall of temperature is given by

$$\frac{d\theta}{dt} = -\frac{k}{ms}\ (\theta - \theta_o) \quad \text{(E 14.3)}$$

where k is the constant of proportionality and $k' = k/ms$ is another constant (The term ms also includes the water equivalent of the calorimeter with which the experiment is performed). Negative sign appears in Eqs. (E 14.2) and (E 14.3) because loss of heat implies temperature decrease. Eq. (E 14.3) may be re written as

$$d\theta = -k'\ (\theta - \theta_o)\ dt$$

On integrating, we get

$$\frac{d\theta}{\theta - \theta_o} = -k'\ dt$$

or $\quad \ln\ (\theta - \theta_o) = \log_e\ (\theta - \theta_o) = -k't + c$

or $\quad \ln\ (\theta - \theta_o) = 2.303\ \log_{10}(\theta - \theta_o) = -k't + c$ (E 14.4)

where c is the constant of integration.

Eq. (E 14.4) shows that the shape of a plot between $\log_{10}(\theta - \theta_o)$ and t will be a straight line.

PROCEDURE

1. Find the least counts of thermometers T_1 and T_2. Take some water in a beaker and measure its temperature (at room temperature θ_o) with one (say T_1) of the thermometers.
2. Examine the working of the stop-watch/clock and find its least count.
3. Pour water into the double- walled container (enclosure) at room temperature. Insert the other thermometer T_2 in water contained in it, with the help of the clamp stand.
4. Heat some water separately to a temperature of about 40 °C above the room temperature θ_o. Pour hot water in calorimeter up to its top.

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5. Put the calorimeter, with hot water, back in the enclosure and cover it with the lid having holes. Insert the thermometer T_1 and the stirrer in the calorimeter through the holes provided in the lid, as shown in Fig. E14.1.

6. Note the initial temperature of the water between enclosure of double wall with the thermometer T_2, when the difference of readings of two thermometers T_1 and T_2 is about 30 °C. Note the initial reading of the thermometer T_1.

7. Keep on stirring the water gently and constantly. Note the reading of thermometer T_1, first after about every half a minute, then after about one minute and finally after two minutes duration or so.

8. Keep on simultaneously noting the reading of the stop-watch and that of the thermometer T_1, while stirring water gently and constantly, till the temperature of water in the calorimeter falls to a temperature of about 5 °C above that of the enclosure. Note the temperature of the enclosure, by the thermometer T_2.

9. Record observations in tabular form. Find the excess of temperature $(\theta - \theta_o)$ and also $\log_{10} (\theta - \theta_o)$ for each reading, using logarithmic tables. Record these values in the corresponding columns in the table.

10. Plot a graph between time t, taken along x-axis and $\log_{10} (\theta - \theta_o)$ taken along y-axis. Interpret the graph.

OBSERVATIONS

Least count of both the identical thermometers = ... °C

Least count of stop-watch/clock = ... s

Initial temperature of water in the enclosure θ_1 = ... °C

Final temperature of water in the enclosure θ_2 = ... °C

Mean temperature of the water in the enclosure $\theta_o = (\theta_1 + \theta_2)/2$ = ... °C

Table E 14.1: Measuring the change in temperature of water with time

S. No.	Time (t) (s)	Temperature of hot water θ °C	Excess Temperature of hot water $(\theta - \theta_0)$ °C	$\log_{10} (\theta - \theta_0)$
1				
2				
.				
.				
20				

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PLOTTING GRAPH

(i) Plot a graph between $(\theta - \theta_o)$ and t as shown in Fig. E 14.2 taking t along x-axis and $(\theta - \theta_o)$ along y-axis. This is called cooling curve.

(ii) Also plot a graph between $\log_{10}(\theta - \theta_o)$ and time t, as shown in Fig. E 14.3 taking time t along x-axis and $\log_{10}(\theta - \theta_o)$ along y-axis. Choose suitable scales on these axes. Identify the shape of the cooling curve and the other graph.

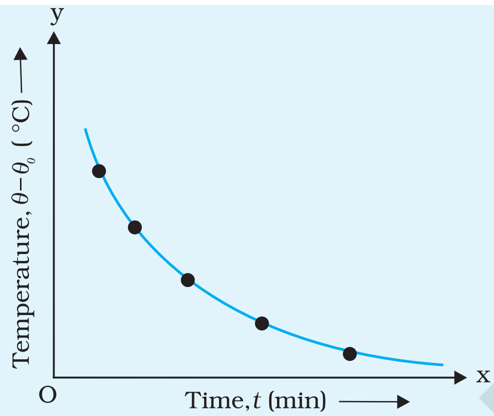

Fig.E 14.2: *Graph between $(\theta - \theta_o)$ and t for cooling*

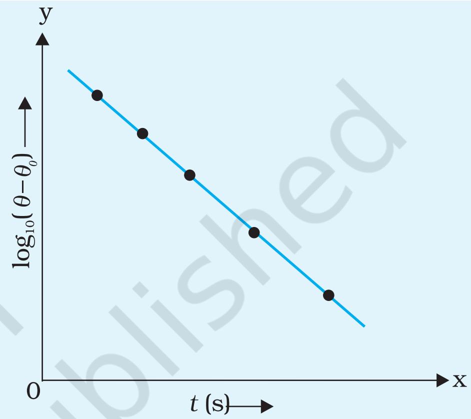

Fig.E 14.3: *Graph between $\log_{10}(\theta - \theta_o)$ and t*

RESULT

The cooling curve is an exponential decay curve (Fig. E 14.2). It is observed from the graph that the logarithm of the excess of temperature of hot body over that of its surroundings varies linearly with time as the body cools.

PRECAUTIONS

1. The water in the calorimeter should be gently stirred continuously.
2. Ideally the space between the double walls of the surrounding vessel should be filled with flowing water to make it an enclosure having a constant temperature.
3. Make sure that the openings for inserting thermometers are air tight and no heat is lost to the surroundings through these.
4. The starting temperature of water in the calorimeter should be about 30°C above the room temperature.

SOURCES OF ERROR

1. Some personal error is always likely to be involved due to delay in starting or stopping the stop-watch. Take care in starting and stopping the stop-watch.

2. The accuracy of the result depends mainly on the simultaneous measurement of temperature of hot water (decrease in temperature being fast in the beginning and then comparatively slower afterwards) and the time. Take special care while reading the stop-watch and the thermometer simultaneously.

3. If the opening for the thermometer is not airtight, some loss of heat can occur.

4. The temperature of the water in enclosure is not constant.

DISCUSSION

Each body radiates heat and absorbs heat radiated by the other. The warmer one (here the calorimeter) radiates more and receives less. Radiation by surface occurs at all temperatures. Higher the temperature difference with the surroundings, higher is rate of heat radiation. Here the enclosure is at a lower temperature so it radiates less but receives more from the calorimeter. So, finally the calorimeter dominates in the process.

SELF ASSESSMENT

1. State Newton's law of cooling and express this law mathematically.

2. Does the Newton's law of cooling hold good for all temperature differences?

3. How is Newton's law of cooling different from Stefan's law of heat radiation?

4. What is the shape of cooling curve?

5. Find the specific heat of a solid/liquid using Newton's law of cooling apparatus.

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Find the slope and intercept on y-axis of the straight line graph (Fig. E 14.2) you have drawn. Determine the value of constant *k* and the constant of integration *c* from this graph.

   [**Hint:** Eq. (E 14.4) is similar to the equation of a straight line: $y = m' x + c'$, with m' as the slope of the straight line and c' the intercept on y-axis. It is clear $m' = k'/2.303$ and $c' = c' \times 2.303$.]

2. The cooling experiment is performed with the calorimeter, filled with same volume of water and turpentine oil successively, by maintaining the same temperature difference between the calorimeter and the surrounding enclosure. What ratio of the rates of heat loss would you expect in this case?