CHAPTER 3

HEAT

3.1 General precautions to be taken in the experiments on heat :

(a) In handling thermometers : (*i*) The bulb of the thermometer should *never be gripped* by hand.

(*ii*) It should never be introduced in a bath whose temperature is expected to be *higher than the maximum temperature* for which it is intended.

(*iii*) When the reading of thermometer is to be taken *parallax* should be avoided i.e., the line joining the eye and the mercury meniscus must be at right angles to the stem.

(*iv*) When determining the actual temperature of a bath, the *zero-error* of the thermometer should be previously determined.

(*v*) When two or more thermometers are employed to note the rise of temperature (but not the actual temperature) the *mean value of the rise of temperature* shown by different thermometers should be taken to avoid the different zero-errors of different thermometers.

(*vi*) To record the temperature of a solid substance the bulb of the thermometer should be kept *very close to the hot body* but not in contact with it.

(*vii*) When a substance of appreciable dimension or a substance confined in a non-conducting enclosure, is to be heated by introducing it in a hot liquid or vapour bath, the temperature of the bath (as indicated by a thermometer kept immersed in the hot liquid or vapour bath) should be maintained constant for an appreciable time (say, five minutes) so that the temperature of every part of the substance may be equal to that of the bath which is really measured.

(*viii*) When a badly conducting substance is to be heated, it should be preferably broken out into *small pieces*, so that the temperature throughout the mass of every piece may be the same.

(*ix*) The thermometer should be introduced in the hot bath in such a way that the length of the mercury column outside the hot bath may be as small as possible.

(*x*) To obtain greater accuracy in measurement of small changes of temperature, a thermometer, reading upto $\frac{1}{10}$°C should be employed.

(*xi*) When noting the temperature of a room, the bulb of the thermometer

must not be moist and the thermometer should be kept at a place which is far away from the hot or cold body and where there is no current of air.

(b) In Heating a chamber or a bath of liquid : (*i*) When a chamber is to be heated by steam, water taken in the boiler for producing steam must *not be too small or too large*.

(*ii*) If a moderately long chamber is to be heated by steam, two thermometers are to be employed—one near the entrance pipe and the other near to the exit pipe of steam. The *mean value of the changes of temperature shown* by the two thermometers should be accepted.

(*iii*) When a solid is heated in hot air, as in steam heater steam should be passed for an appreciable time until the temperature of the hot air is *nearly the same* as that of steam.

(*iv*) When a substance is heated by introducing it in a liquid bath heated from below, the liquid should be *stirred continually* to have a uniform temperature throughout the mass of the liquid.

(*v*) If the vapour of the hot bath is inflammable, proper care should be taken *not to bring the flame in direct contact with the vapour* and the vessel containing the liquid should be long enough to keep the vapour at a safe distance from the flame.

(c) In minimising the transference of heat from or to the body : Transference of heat from or to the body is an important source of error in experiments on heat. So proper care should be taken to minimise such heat losses.

3.2 To determine the thermal conductivity of a bad conductor by Lees and Chorlton's method :

• **Apparatus :** The arrangement of the apparatus is shown in Fig 3.2-1. C is a circular metal disc over which the badly conducting circular sheet S, of uniform thickness, is placed. A steam chamber A is placed on S. The bottom B of this steam chamber is a thick circular metal plate. The diameters of the slabs B and C as well as of the bad conducting sheet S are all equal.

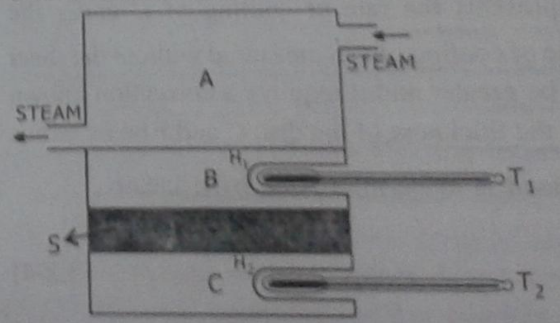

Fig. 3.2-1

To record the temperatures of B and C two holes H_1 and H are respectively drilled in them to introduce thermometers T_1 and T_2. T_1 shoul read up to 0·2°C while T_2 should read up to 0·1°C. The whole apparatus is kept suspended by three strings from a support.

- **Theory :** Let, θ_1 = temperature of upper slab B in the steady state

θ_2 = " " lower slab C " " " "

A = area of cross-section of the badly conducting sheet S

k = thermal conductivity of the material of the sheet S

d = thickness of the sheet S.

Quantity of heat conducted per second through the badly conducting sheet S in the steady state is

$$Q = \frac{kA(\theta_1 - \theta_2)}{d} \quad \text{... (3.2-1)}$$

In the steady state, this heat Q is radiated through the exposed surface of the slabs C and S. Since the thickness of S is made very small compared to its diameter, the radiation loss through its curved surface can be neglected. If m be the mass and s be the sp. heat of the material of C and $\left(\frac{d\theta}{dt}\right)_{\theta_2}$ be its rate of cooling at its temperature θ_2 then the heat radiated per second from

C is, $Q = ms\left(\frac{d\theta}{dt}\right)_{\theta_2}$ ... (3.2-2)

From (3.2-1) and (3.2-2) we get, $k = \dfrac{msd\left(\frac{d\theta}{dt}\right)_{\theta_2}}{A(\theta_1 - \theta_2)}$ ... (3.2-3)

In this equation $\left(\frac{d\theta}{dt}\right)_{\theta_2}$ represents the rate of cooling of C under the experimental condition. If the rate of cooling of C is measured without the sheet S on it, the measured value will be greater and it requires a correction known as *Bedford's correction*. If d' be the thickness of the disc C and r be its radius then the value of $\frac{d\theta}{dt}$ so determined is to be multiplied by a factor

$$f = \frac{r + 2d'}{2r + 2d'} \quad \text{... (3.2-4)}$$

to get the correct value of $\left(\frac{d\theta}{dt}\right)_{\theta_2}$.

Hence the relation (3.2-3) is modified as

$$k = \frac{m.s.d.\left(\frac{d\theta}{dt}\right)_{\theta_2}}{A(\theta_1 - \theta_2)} \times \frac{r + 2d'}{2r + 2d'} \quad \text{... (3.2-5)}$$

where $\left(\frac{d\theta}{dt}\right)_{\theta_2}$ is the rate of cooling of C without the experimental disc S on it.

In Eq. (3.2-5) if m is in kg, s in J.kg.$^{-1}$.K^{-1}, θ in ^{0}C, t in sec, r and d' in m, A in m^2 then k will be in W. m^{-1}. K^{-1}.

- **Procedure :** To measure m, A and d : (*i*) The mass m of the disc C can be found out by a spring balance or by an ordinary rough balance.

(*ii*) The area $A = \pi r^2$ of the disc C (or of the sheet S, for both are equal) is obtained by measuring its circumference L with the help of a thread and a metre scale. Total length of thread wound around the periphery of the disc C 4 to 5 times is measured by the metre scale and dividing this length by the number of turns we can get L. Then $r = L/2\pi$ and $A = \pi\ (L/2\pi)^2$. The sp. heat s of the material of C is found out from a table.

(*iii*) To find the thickness d of the sheet S, a microscope is taken whose vernier constant (*v.c.*) is first determined. Then several cross-marks are made at different places on a paper attached to the upper slab B. Preferably these cross-marks should be made at least at three different places (roughtly at 120^0 interval) to average out the non-uniformity in the thickness. Keeping the sheet S within the discs B and C, the microscope is focussed on one of the cross-marks and the reading R_1 is taken. This reading R_1 corresponding to other cross-marks is also noted by rotating the support from which the discs are suspended and bringing the cross-marks within the focus of microscope. The sheet S is then removed and the readings (R_2) corresponding to those cross-marks are again successively noted. The thickness d of the sheet S at different places is given by $d = (R_1 \sim R_2)$. The mean value of d is to be taken. By this method, the exact focussing of cross-mark is possible but care should be taken to maintain the relative positions of the discs B and C intact.

(*iv*) The thickness d' of the disc C is measured by a slide callipers at its different places and their mean value is determined. Thus we get d'.

(*v*) After determining the *initial error* (if any) of the thermometers T_1 and T_2, steam is passed in the chamber A and the temperatures of B and C are respectively noted at intervals of five minutes, until they remain steady for at least three consecutive intervals. Note that the apparatus should be adjusted with a slight downward tilt of the steam outlet. Otherwise there may be accumulation of water and it would be difficult to get steady state. Knowing the steady temperatures of B and C and initial errors of thermometers T_1 and T_2 the correct value of $(\theta_1 - \theta_2)$ is obtained.

(*vi*) By raising the steam chamber A a little (the steam is continued to pass in A) the sheet S is then removed to make the bottom B of chamber A to touch the surface of the disc C. The temperature of the disc C then begins to rise (as indicated by T_2) and this temperature is allowed to rise to a value which is nearly 10°C higher than its steady temperature θ_2. The steam chamber A is then removed. When the temperature of C falls to a value which is nearly 5° or 6°C above its steady temperature θ_2^0C a stop-watch is started to note its fall of temperature with time.

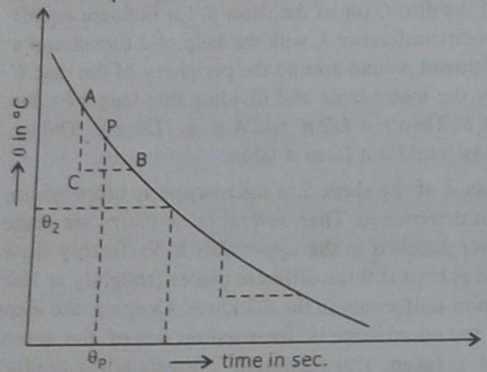

Fig. 3.2-2

(*vii*) The fall of temperature of the disc C is now noted at intervals of half-a-minute (or better after an interval of 15 seconds if the cooling is rapid) until its temperature falls below its steady temperature θ_2^0C by about 5° or 6°C. For convenience of recording, the stop-watch can be held adjacent to the thermometer.

(*viii*) From these data a cooling curve is now drawn by plotting time (t) along x-axis and the corresponding temperature (θ) of the disc C along y-axis. The nature of the curve will be as shown in Fig. 3.2-2.

(*ix*) From this cooling curve $\frac{d\theta}{dt}$ can be computed at three points

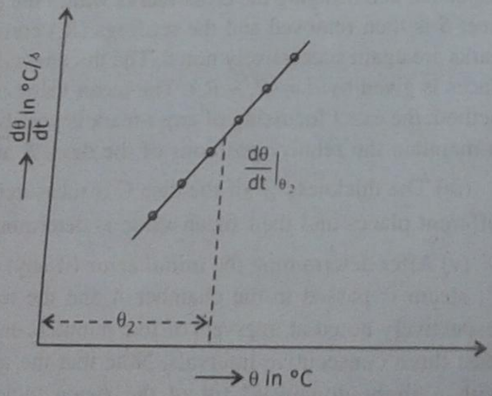

Fig. 3.2-3

above θ_2 and at three points below θ_2 by drawing small triangles as shown in Fig. 3.2-2. For example at the point P, $\theta = \theta_P$ and $\frac{d\theta}{dt} = \frac{\Delta\theta}{\Delta t} = \frac{AC}{BC}$. Then another graph between $\frac{d\theta}{dt}$ versus θ is plotted from which the value of $\frac{d\theta}{dt}$ at θ_2 can be found out [see, Fig. 3.2-3].

Alternatively, a tangent can be drawn to the cooling curve at the steady temperature θ_2 and measuring the slope of this tangent line we can find $\left.\frac{d\theta}{dt}\right|_{\theta_2}$.

(*x*) Knowing m, s, $(d\theta/dt)_{\theta_2}$, A, d and $(\theta_1 - \theta_2)$ the thermal conductivity k of the bad conducting sheet S can be calculated from the relation (3.2-5).

- **Experimental data :**

(A) *Mass (m) of the disc (C) and its sp. heat :*

Mass of the disc = ... kg 1.5 kg

Specific heat of the material of the disc $C = s = ...$ J . kg^{-1} . K^{-1}.

[**N.B.** : If s is given in c.g.s., multiply it by 4200 to get s in SI units]

(B) *Radius (r) and area (A) of the disc C or of the sheet S :*

TABLE I

No. of obs.	Length of thread for n turns L' in cm	Mean L' in cm	Circumference $L = \frac{L'}{100n}$ in m	Radius $r = \frac{L}{2\pi}$ in m	Area $A = \pi r^2$ in m^2
1.					
2.					
3.					

(C) *Thickness (d) of the sheet (S) by microscope :*

TABLE II

No. of obs.	Reading of a cross-mark on B with sheet S between B and C			Reading of a cross-mark on B without sheet S between B and C			Thickness in cm = $d = (R_1 - R_2)$	Mean d in m
	Scale (S) in cm	Vernier (v.r.)	Total in cm $R_1 = (S + v.r. \times v.c.)$	Scale (S) in cm	Vernier (v.r.)	Total in cm $R_2 = (S + v.r. \times v.c.)$		
1.								
2.								
3.								
4.								

(D) *To find the thickness d′ of the disc C by slide callipers :*

[Calculate v.c. and zero error of slide callipers as in Art. 2.2]

TABLE III

No. of obs.	Reading of			Mean d' in cm	d' in m
	Scale (S) in cm	Vernier (v.r.)	Total $d' = S + v.r. \times v.c.$ in cm		
1.					
2.					
3.					
4.					
5.					

(E) *To find the initial errors of thermometers T_1 and T_2 :*

TABLE IV

Initial readings in °C of thermometers		Correction to be added algebraically to $(\theta_1 - \theta_2)$ is $x = (t_2 - t_1)$	$\theta_1 - \theta_2$ in °C from TABLE V (y)	Corrected $\theta_1 - \theta_2$ in °C (y + x)
T_1	T_2			
...	...			
...	...	...	...	
$= t_1$	$= t_2$			

(F) *Time-temperature records of B and C for steady state :*

TABLE V (Room temperature =...°C)

Time in minutes →	0	5	10	15	20	25	30
Temp. of B in °C →	...	...	...	...	...	...	... $= \theta_1$
Temp. of C in °C →	...	...	...	...	...	...	... $= \theta_2$

(G) *Time-temperature records of C during its cooling :*

TABLE VI (Room temperature =...°C)

Time in sec →	0	15	30	... etc.
Temp. of C in °C →				... etc.

(H) *Calculation of* $\left.\dfrac{d\theta}{dt}\right|_{\theta_2}$:

TABLE VII ($\theta_2 = ...^\circ C$)

$\frac{d\theta}{dt}$ from cooling curve				$\left.\frac{d\theta}{dt}\right\vert_{\theta_2}$ in °C/s form $\frac{d\theta}{dt}$ vs θ graph
Ave. temp. θ in °C	$\Delta\theta = AC$ in °C	$\Delta t = BC$ in sec	$\frac{d\theta}{dt} = \frac{AC}{BC}$ in °C/s	
.....				
.....				
.....				.....
.....				
.....				
.....				

- **Calculation :**

$$k = \frac{msd\left(\frac{d\theta}{dt}\right)_{\theta_2} \times \frac{r+2d'}{2r+2d'}}{A(\theta_1 - \theta_2)} = \ldots \text{ W. m}^{-1}\text{ K}^{-1}.$$

- **Precautions and Discussions :** (*i*) Noting of temperatures θ_1 and θ_2 of B and C should be discontinued only when they remain steady for at least 15 minutes.

(*ii*) The temperature of the lower disc C during cooling, should be noted after an interval of 15 seconds or after half-a-minute if the rate of cooling be very slow.

(*iii*) To make the loss of heat by radiation from the sides of the sheet S minimum, the diameter of the sheet S should be made large in comparison with its thickness.

(*iv*) In this method the rate of cooling of the disc C is determined without the experimental disc S on it. To obtain rate of cooling under experimental condition the Bedford correction is used.

(*v*) The lower disc C should not be directly heated by a burner. This may change the emissivity of the lower surface. So heating should be done by the steam chamber.

(*vi*) Direct heat from boiler should be screened off by means of a wooden partition.

(*vii*) Initial error of the thermometers should be noted and $\theta_1 - \theta_2$ should be properly corrected.

(*viii*) The steam chamber should be adjusted with a slight downward tilt of the steam outlet. Otherwise there may be accumulation of water and it would be difficult to get steady state.

(*ix*) Room temperature during cooling and steady state experiments should be noted to see whether the temperature of the surroundings is remaining the same during the two experiments.

(*x*) The diameter of the sheet S should be made equal to those of B and C.

- **Maximum proportional error :**

If the lower disc C cools by radiation from θ' to θ'' °C in time interval Δt sec then $\left.\frac{d\theta}{dt}\right\vert_{\theta_2} = \frac{\theta' - \theta''}{\Delta t}$. Now putting $A = \pi r^2$ in Eq. (3.2-5) we get

$$k = \frac{m.s.d(\theta' - \theta'')}{\pi r^2(\theta_1 - \theta_2).\Delta t} \times \frac{r+2d'}{2r+2d'}$$

Therefore,

$$\frac{\delta k}{k} = \frac{\delta m}{m} + \frac{\delta d}{d} + \frac{\delta(\theta' - \theta'')}{\theta' - \theta''} + \frac{\delta(\theta_1 - \theta_2)}{\theta_1 - \theta_2} + \frac{\delta(\Delta t)}{\Delta t} + 2\frac{\delta r}{r}$$

$$+ \frac{\delta r + 2\delta d'}{r + 2d'} + \frac{2\delta r + 2\delta d'}{2r + 2d'} \quad \text{...(3.2-6)}$$

As m is large its contribution towards the proportional error in k is negligible. Other errors are as follows :

$\delta d = 2 \times$ v.c. of microscope

$\delta(\theta' - \theta'') = \delta(\theta_1 - \theta_2) = 2 \times 1$ div. of thermometer

$\delta(\Delta t) = 2$ sec.

$\delta d' =$ v.c. of slide callipers.

As the radius r is obtained by measuring circumference, from TABLE I we can write

$$\frac{\delta r}{r} = \frac{\delta L'}{L'}$$

$$\text{or, } \delta r = \frac{\delta L'}{L'}.r$$