Sources of error and precautions:

1. The thermometers should be read only after they indicate steady temperatures.
2. Padding must be efficient.
3. Rate of flow of water should be slow and uniform.

ORAL QUESTIONS

1. *Does thermal conductivity depend upon temperature?*

Yes: it decreases as the temperature rises.

2. *What is the major source of error in this experiment?*

The lose of heat by radiation cannot be entirely eliminated, no perfect insulator of heat being known.

3. *What do you understand by the varsable and stationary states in respect of heat-flow?*

When a rod is heated at one end, for some time the temperature at every point in it goes on rising. This is the *variable state*. The rate of flow of heat depends on the **diffusivity** (K/ps, = sp. gr.) of the material. In the *stationary state* no part of heat received by any section of the rod is retained it is all lost by transmission or by radiation.

Experiment H-6. *To determine the thermal conductivity of a bad conductor by Lee's disc method.*

Apparatus. Lee and Charlton's apparatus, bad conductor in the form of a disc, physical balance, stop watch, vernier callipers, screw gauge, two thermometers, steam generator, and balance.

Formula.

$$K = \frac{msd}{\pi r^2(\theta_1 - \theta_2)}\left(\frac{d\theta}{dt}\right)_{\theta_2}\frac{r+2h}{2r+2h}$$

where,

m = mass of cylinder D

s = specific heat of material of D.

d = thickness of experimental disc S.

r = radius of cylinder D.

h = height of cylinsder D.

θ_2 = temperature of cylinder D recorded by thermometer T_2.

θ_1 = temperature of steam recorded by thermo meter T_1.

Theory. The thermal conductivity of a poorly conducting material like rubber, leather or card-board, when it is available in the form of a thin circular disc, can be determined as follows;

A thin disc S of the given material of about 10 cm diameter is placed in between a thick copper disc D of the same radius and a hollow cylindrical metal vessel C provided with an inlet and an outlet, for steam. The system is suspended *horizontally* from a stand by means of three threads attached to three small hooks provided symmetrically along the circumference of D, (Fig. 8.8).

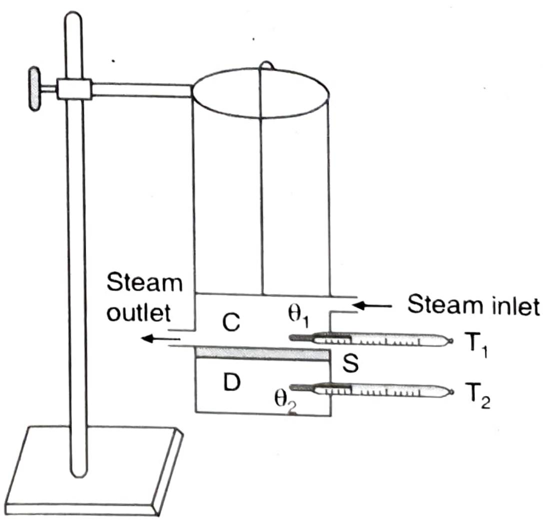

Fig. 8.8

Thermometers are inserted in the sides of C and D into holes provided for the purpose, so that they lie close to the faces of S. The surfaces of C and D are nickel plated to obtain uniform and good emissivity. Steam is passed through C. The flow of heat across S will be vertically downwards. While the upper thermometer will indicate throughout, the temperature θ_1 of steam, the temperature indicated by the lower thermometer will gradully increase till the steady state is reached and the temperature becomes consant at θ_2. If K be the thermal conductivity, d the thickness and A is the area of cross-section of S, the heat flowing through it per second is given by.

$$Q = K\frac{A(\theta_1 - \theta_2)}{d} \quad ...(i)$$

where letters have the meaning mentioned earlier.

In the steady state, all heat passing through S is lost by rediation from the surface of D. (Loss of heat from the curved surface of S can be neglected, because the thickness of S is very small). The rate of loss of heat due to radiation of disc D would be

$$= ms\left(\frac{d\theta}{dt}\right)_{\theta_2}\left(\frac{r+2h}{2r+2h}\right) \quad ...(ii)$$

where m is the mass of disc D and S is its sp. heat. In this expression, $\dfrac{r+2h}{2r+2h}$ is the fraction of the surface which is radiating heat as compared to total surface as mentioned in step (v) and (vi) of the procedure. Similarly, $\left(\dfrac{d\theta}{dt}\right)_{\theta_2}$ is the rate of cooling at temperature θ_2.

Equating Eq. (i) and (ii) and simplifying, we get

$$K = \frac{m.s.d}{\pi r^2(\theta_1 - \theta_2)}\left(\frac{d\theta}{dt}\right)_{\theta_2}\frac{r+2h}{2r+2h}$$

Procedure.

(i) Suspend the disc D horizontally by means of threads from a stand after its weight has been taken. Cut a piece of carboard (or any bad conduction material) of equal diameter. Determine its thickness carefully with a screw gauge at a number of points. Determine the diameter of the disc D with a callipers in two mutually perpendicular directions. Rest the carboard on the disc and place the vessel C on it. The vessel and disc should be nickelplated on the outside to obtain good and uniform emissivity. Apply glycerine on the faces in contact, to provide good thermal contacts.

(ii) Insert thermometers into holes provided in C and D for the purpose, such that they lie close to the cardboard S, one on either side. Connect C to a steam generator.

(iii) The upper thermometer will at once show the temperatures of steam $i.e.$, θ_1^0. As heat flows across S, the lower thermometer will indicate a higher and higher temperature (which is recorded every two minutes) till the stationary state is reached and it indicates a constant temperature θ_2^0. After this temperature has remained constant for 4 or 5 minutes, note the temperature θ_1^0 and θ_2^0 carefully.

(iv) All heat passing across S is lost from the lower face and from the curved surface of D by radiation. The loss from the curved surface of S may be ignored as S is very thin (1 mm or so in thickness), and therefore, the area of its curved surface is negligible. The heat lost from its surface per second is $Q = \dfrac{KA(\theta_1 - \theta_2)}{d}$ calories, where $A = \pi r^2$, is the face area of S and d is its thickness.

(v) Remove C and S from the top of D. Heat D by means of a Bunsen flame, by passing the flame under its surface, till it indicates a temperature of about $(\theta_2 + 10)°$.

(vi) Remove the flame and determine the temperature of D, every 30 seconds till its temperature falls to about $(\theta_2 - 10)°$.

(vii) Draw a cooling curve as shown in fig. 8.9 between time and temperature and draw carefully a tangent to the curve at temperature θ_2 and determine the slope of the tangent at temp. θ_2 *i.e,* $\left(\dfrac{d\theta}{dt}\right)_{\theta_2} = AB/BC.$

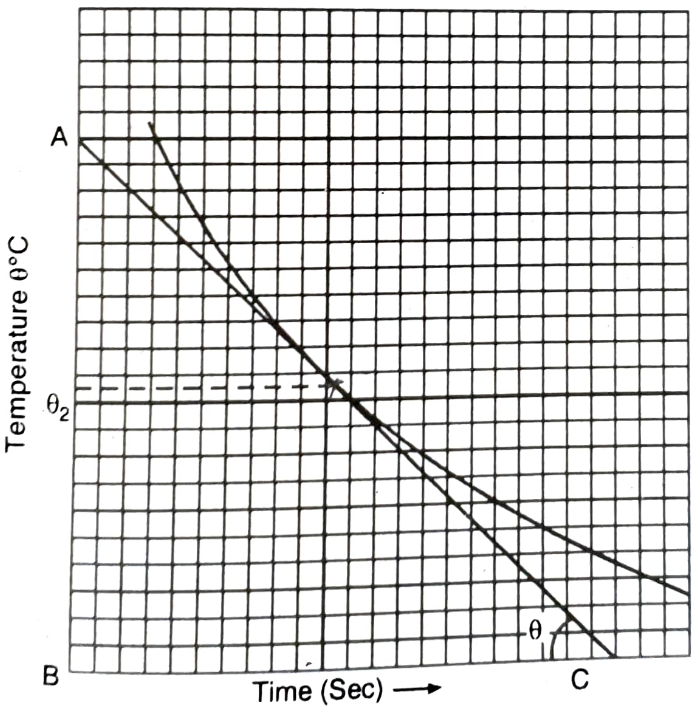

Fig. 8.9.

$\therefore$ Heat lost by D per second $= ms\left(\dfrac{d\theta}{dt}\right)_{\theta_2}$ ...(*ii*)

where m = mass and s = specific heat of the material of D. Thermal conductivity of bad conducting disc C is obtained by equating Eqs. (*i*) and (*ii*)

$$\frac{K(\theta_1 - \theta_2)}{d} = ms\left(\frac{d\theta}{dt}\right)_{\theta_2}$$

$\therefore$

$$K = \frac{m \cdot s \cdot d}{A(\theta_1 - \theta_2)}\left(\frac{d\theta}{dt}\right)_{\theta_2} \quad ...(iii)$$

Applying radiation correction, the corrected formula is

$$K = \frac{m.s.d}{A(\theta_1 - \theta_2)} \cdot \left(\frac{d\theta}{dt}\right)_{\theta_2} \frac{r + 2h}{2r + 2h} \quad ...(iv)$$

Observations.

1. Mass of the disc D ... ... = ...g
2. Diameter of disc D ... ... = ...cm

$\therefore$ radius of D ... ... = ... cm

3. Thickness of cardboard $= \dfrac{... + ... + ... + ... + ...}{5}$ = ...cm

4. Observations for θ_1 and θ_2

No.	Temp θ_1	Temp θ_2
1	98°C	25C
2	98	30
3	98	...
...	98	68
...	98	68
...	98	68

$\therefore$ Temperature $\theta_1 = 98°C$

Temperature $\theta_2 = 68°C$

5. Observations for the cooling curve.

No.	Time	Temp of D
1	30 s	70°C
2	1 min	72
3	1 – 30 s	...
...		...
...		...
...		...

$$\frac{d\theta}{dt} = \frac{AB}{BC} = ...$$

Calculations. $$\frac{KA(\theta_1 - \theta_2)}{d} = m.s.\left(\frac{d\theta}{dt}\right)_{\theta_2}$$

or $$K = m.s.\left(\frac{d\theta}{dt}\right)_{\theta_2} \frac{d}{A(\theta_1 - \theta_2)} = \frac{m.s.d}{\pi r^2(\theta_1 - \theta_2)} \cdot \left(\frac{d\theta}{dt}\right)_{\theta_2} \cdot \frac{r + 2h}{2r + 2h}$$

Result. The thermal conductivity of cardboard

= ...cal. cm^{-1} sec^{-1} degree C^{-1}

Weak points. 1. The thermometers, being a little away from the faces of S, may not indicat the correct temperatures of its faces.

2. Newton's law of cooling is not strictly applicable to the cooling body.

Sources of error and precautions:

1. The diameter of the cardboard must equal that of C and D. In thickness should be measured at a number of points on its surface.
2. The surface of C and D should be nickel-plated to obtain a uniform and good emissivity
3. The steady temperature θ_2^0 is that when three consecutive readings of the thermometer taken every two minutes, are the same.

4. D should be heated with a *non-luminous* flame so that the emissivity of the surfaces does not change by the deposition of soot on it.
5. Thermometers should be placed close to the faces of S, one on either side.
6. The tangent to the cooling curve, to determine $d\theta/dt$ should be drawn very carefully.
7. There should be no air-films between D and S and between S and C. For this, they should be pressed *tightly* together. Some glycerine may be applied to the faces in contact, to obtain good thermal contacts.

ORAL QUESTIONS

1. *What is thermal conductivity of a substance ?*
2. *What do you understand by stationary state?*
3. *What is the law of cooling? Does it hold correctly in the present case?*

   No. the difference of temperature between the hot body and surroundings is considerable.
4. *How do you make sure that the stationary state has been reached?*
5. *Why should the thermometer be placed very close to the faces of the cardboard?*

Notes 1. For most solids the value of K at any temperature t, may be determined from the linear relation $K = K + \alpha t$. where K_0 is the thermal conductivity at 0°C. If K increases with t, α is + ve. otherwise negative.

Many metals satisfy the relation $K = 2.5 \times 10 \times \sigma \times T$, where T is not °K and σ is the electrical conductivity of the material.

(i) For most gases, the ratio or conductivity K to viscosity η is constant for temperatures between – 89°C and 100°C.

(ii) The value of K for gases increases with increasing temperature, the rate of increase being different for different gases.

(iii) Maxwell showed that for gases $K = a\, \eta\, C_v$, where η is the Co-efficient of viscosity, C_v the specific heat of a gas at constant volume and α, a constant. This result is supported remarkably by experiment.

(iv) At normal pressure, K is independent of pressure over a wide range. It increases at high pressure and decreases at very low pressure *i.e.*, below 10 mm. The **Pirani gauge** is based on this fact. A constant current flows through a lamp-filament. The filament attains a steady temperature, and hence a constant resistance. The value of this resistance depends on the loss of heat through the gas by conduction and therefore on the pressure of the enclosed gas. When the pressure is lowered, using a vacuum pump, the conductivity diminishes while the temperature and therefore, the resistance of the wire increases. *From the change in resistance, the pressure of the gas can be calculated.*

Note. 2. *Metals are very good conductors of heat.* This high thermal conductivity is of great practical importance in the everyday uses of metals, alloys. Many of the more recent developments in high-speed machinary are really only possible because the thermal conductivity of metals is great enough to enable the heat generated in the machinery to be drawn away sufficiently rapidly and thus enable the machines to run safely and efficiently.

Note 3. In the modern age, thermal insulation has assumed great importance. To serve as an insulator, the material, in addition to being a poor conductor, should also have other properties. For high-temperature insulation, the material should not deteriorate at those temperatures, while for low-temperature work it must be damp-proof. The basic materials ~~are~~ cork, asbestos, magnesium carbonate, glass wool, diatomaceous silicon, etc. (By the way magnesium carbonate is the *whitest* substance known).