Expt-7
Thermal Conductivity By Lee's Disc

Objective
Measurement of thermal conductivity of a poor/bad conductor by electrically heated Lee's disc apparatus

Principle
The electrically heated Lee's disc apparatus for the measurement of thermal conductivity of an insulating sheet is shown schematically in *Fig. 1*, in which, a disc shaped heater is placed between two identical copper discs (1 and 2) and a thin disc of thickness *t* of the insulating sample is placed between the identical copper discs (2 and 3). All the discs, heater and the sample have nearly equal radii.

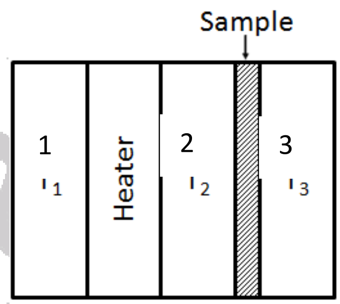

Fig.1: *Schematic design of a Lee's disc*

In steady state, the total heat emitted from the apparatus per unit time is equal to the electrical power, P supplied to the heater, given by

$$P = E\left(A_1T_1 + A_h\frac{T_1+T_2}{2} + A_2T_2 + A_s\frac{T_2+T_3}{2} + A_3T_3 \right) \qquad (1)$$

where, E is the energy emitted from the exposed surface per unit surface area, per sec, per ^{o}C temperature difference with the ambient temperature and is assumed to be the same constant for all the surfaces. The exposed surface areas of the discs are A_1, A_2, A_3, and those of the heater and sample are A_h and A_s, respectively. T_1, T_2 and T_3 represent the temperature difference with the ambient temperature for the three discs, respectively.

The rate of flow of heat through the sample of thermal conductivity λ is

$$H = \lambda\pi r^2\left(\frac{T_2 - T_3}{t_s}\right) \qquad (2)$$

where, r is the radius of the sample and t_s is its thickness

Considering that the average rate of heat transferred from disc 2 to the sample and the heat transferred from sample to disc 3 is equal to the rate of flow of heat through the sample:

$$\lambda \pi r^2 \left(\frac{T_2 - T_3}{t_s} \right) = \frac{1}{2}\left[E\left(A_S \frac{T_2 + T_3}{2} + A_3 T_3 \right) + E A_3 T_3 \right] = \frac{E}{2}\left(A_S \frac{T_2 + T_3}{2} + 2 A_3 T_3 \right) \qquad (3)$$

Using E from *Eqn.1*, and taking P as the product of the voltage V and current I used for heating we get,

$$\lambda = \frac{VIt_s}{\pi r^2 (T_2 - T_3)} \frac{\left(A_S \frac{T_2 + T_3}{2} + 2 A_3 T_3 \right)}{[2A_1T_1 + A_h(T_1 + T_2) + 2A_2T_2 + A_S(T_2 + T_3) + 2A_3T_3]} \qquad (4)$$

Experimental Set-Up And Apparatus Details

The electrically heated Lee’s apparatus is shown in Fig. 2. It consists of three nearly identical flat circular copper discs (1, 2 and 3) in which holes are drilled along their radii to insert metal shielded chromel-alumel thermocouples. The electrical heater, which is also sealed within a copper disc of similar dimensions, is sandwiched between the discs 1 and 2, while a thin disc of insulating material of the same radius is sandwiched between discs 2 and 3. This assembly of three copper discs, heater and the sample are clamped together within a metallic stand by using teflon spacers. The assembly is secured by placing on the small disc aligning tray and tightening the knob on the right side of the metallic stand. An extra thermocouple is placed on the side of the stand to measure the ambient temperature. A DC power supply is used to supply power to the heater. Coarse and fine voltage control knobs (3) are provided to set the output voltage. Coarse and fine current control knobs are used to set the upper limit of the current in the heater circuit. Digital voltmeter and ammeter are provided for displaying output voltage and current. The temperatures of the three discs and the ambient are displayed on a calibrated temperature monitor, which has provisions for connecting four chromel-alumel thermocouples (marked 1, 2, 3,

4) at the rear panel. A selector knob is provided on the front panel for displaying the temperature corresponding to each of the four thermocouples.

Fig.2: *Experimental setup*

Procedure

1. Measure the diameter and thickness of the three discs and the heater with vernier calipers. Take three readings for each measurement at different locations.
2. Measure the diameter (d) of the insulating sample with vernier calipers and thickness (t) with a screw gauge by taking three readings at different locations.

3. Place the disc aligning tray in between and parallel to the two rods at the base of the metallic stand. Sequentially arrange disc 1, heater, disc 2, sample and disc 3, as shown in *Fig. 1,* so as to form a cylindrical assembly and place this assembly on the disc aligning tray. Rotate the discs and the heater to bring the radial holes and the heater wire on the upper side and nearly aligned along a horizontal line.
4. Slightly adjust the position of the metallic stand to ensure that the teflon spacers touch the two extreme discs (1 and 3) at nearly their centres. Secure the disc and heater assembly between the teflon spacers by tightening the knob on the right side of the stand. Lift the stand with the disc assembly and remove the empty tray.
5. Insert the thermocouples (1, 2, 3) into the corresponding discs and leave the thermocouple 4 to rest on the side of the stand for measuring the ambient temperature.
6. Connect the heater wires to the output of the power supply. Check that the voltage control knob of the power supply is minimized and then maximize the coarse and fine current control knobs.

   At This Stage, Request The Instructor To Check The Circuit, Before Switching On The Power Supply.

7. Switch ON the DC power supply and turn the voltage knob to slowly increase the voltage and keep at 20 V. Note down the values of the applied voltage and the output current. These values should not be disturbed during the rest of the experiment.
8. At intervals of 5 *min*, note down the temperatures (θ_1, θ_2, θ_3 and θ) corresponding to discs 1, 2, 3 and the ambient temperature, respectively, till the temperatures stabilize to nearly constant values. This part of experiment will take about $1\frac{1}{2}\,hr$. Take two readings of the temperatures (at intervals of 5 *min*) after steady state is reached.
9. **Closing the experiment**: Minimize the voltage knob of the power supply and switch it OFF. Minimize the current control knobs. Disconnect the heater cable from the output connectors of the power supply. After the

temperature of the assembly decreases substantially, switch OFF the temperature monitor and carefully remove the thermocouples from the discs. Dismantle the discs and heater assembly and keep them safely on the table.

Results and Calculations

1. Tabulate the measured values of the diameter and thickness of the three discs and the heater. Calculate the average value in each case.
2. Tabulate the measured value of the diameter (d) of the sample and calculate its average value.
3. Tabulate the values of thickness (t) of the sample and calculate its average value.
4. Calculate the exposed areas of each of the three discs, the heater and the sample as follows:

$$A_1 = \pi d_1 t_1 + \frac{\pi d_1^2}{4}$$

$$A_h = \pi d_h t_h$$

$$A_2 = \pi d_2 t_2$$

$$A_S = \pi d_S t_s$$

$$A_3 = \pi d_3 t_3 + \frac{\pi d_3^2}{4}$$

   where, d's and t's , represent respective diameters and thicknesses.
5. Record the values of V and I.
6. Tabulate θ_1, θ_2, θ_3 and θ as a function of time and obtain

$$T_1 = \theta_1 - \theta$$

$$T_2 = \theta_2 - \theta$$

$$T_3 = \theta_3 - \theta$$

7. Plots the graphs of T_1, T_2 and T_3 on the same graph sheet (using different symbols), during the increase and stabilization of temperatures.
8. Write down the average of the last two values (in steady state) of T_1, T_2, T_3, $(T_1 + T_2)/2$ and $(T_2+T_3)/2$ and T $(= T_2 - T_3)$.
9. Using Eqn. 4, calculate the value of λ.

10. Estimate the error in λ as

$$\Delta\lambda = \left(\frac{\Delta T}{T}\right)\lambda$$

where, $\Delta T = \Delta T_2 + \Delta T_3$

ΔT_2 and ΔT_3 are equal to half the magnitude of the difference between the last two measured values of T_2 and T_3 in steady state, respectively. If ΔT_2 or ΔT_3 is zero, then take it as the $LC/2$ of the digital temperature monitor for error calculation. Neglect the errors in the other quantities.

Precautions

1. There should be no exposed surfaces other than those considered above. To ensure that, secure the discs, heater and sample in the stand in such a way that the assembly is nearly cylindrically aligned.
2. Insert and remove the thermocouples in and out of the discs with utmost care.
3. Before switching ON the power supply make sure that the voltage knobs are minimized and the current control knobs are maximized.

Suggested Reading: *Advanced Level Physics,* M. Nelkon and P. Parker