Experiment 7
Lee's Method

Aumshree P. Shah
20231059[a)]

(Dated: 7 April 2025)

Synopsis

In this experiment the thermal conductivity of a bad conductor is measured.

I. THEORY AND PROCEDURE

A. Apparatus

- Lee's Apparatus
- Bad conductor discs
- Two thermometers
- Boiler and Induction
- Stop watch
- Weighing balance
- Vernier Caliper
- Screw gauge

B. Theory

Fourier's law of heat conductance gives the rate of transfer of heat between two objects at temperatures T_1 and T_2 connected by a conductor with conductivity k, uniform cross-sectional area A, and length l as

$$\frac{\Delta Q}{\Delta t} = k\,A\,l\,(T_2 - T_1)\,.$$

This equation governs the rate of heat transfer from disc D_2 to disc D_1 (the bottom and top discs of Lee's apparatus, respectively).

The instantaneous rate at which a warm body loses heat to its surroundings is given by Newton's law of cooling,

$$\frac{dT}{dt} = -b\,(T - T_a),$$

where T_a is the ambient temperature. This law governs the rate at which disc D_1 cools in the second half of the experiment. If m is the mass of disc D_1 and s is the specific heat of its material, then the rate at which heat is lost by the disc is

$$\frac{\Delta Q_1}{\Delta t} = m\,s\,\frac{dT_1}{dt}.$$

In the steady state achieved in the first half of the experiment, the heat supplied by the steam is balanced by the cooling of disc D_1. Combining the two heat transfer equations gives the heat balance

$$m\,s\,\frac{dT}{dt} = k\,A\,l\,(T_2 - T_1)\,. \tag{1}$$

The value of $\frac{dT}{dt}$ for disc D_1 can be determined from the cooling curve obtained in the second part of the experiment. As an approximation, a single value of $\frac{dT}{dt}$, calculated at T_1 during the cooling of disc D_1 from $T_1 + 10\,°\mathrm{C}$ to $T_1 - 7\,°\mathrm{C}$, is used. From the known value $s = 0.380\,\mathrm{J\,g^{-1}\,K^{-1}}$ for brass, the conductivity k can be determined. Note that if the two thermometers do not initially show the same reading, the temperature difference $T_2 - T_1$ must be corrected by the quantity T' determined at the beginning of the experiment.

[a)] aumshree.pinkalbenshah@students.iiserpune.ac.in

C. Procedure

1. Fill the boiler with water to nearly half and heat it to produce steam. In the meantime, weigh the disc D_1 on which the apparatus rests.
2. Measure the diameter of specimen disc d with a vernier calliper and its thickness using a screw gauge at several points, and determine the mean thickness.
3. Clamp the glass specimen between the base disk D_2 of the steam jacket and the auxiliary brass disc D_1. Insert the thermometers (either mercury thermometer or thermocouples) in the two brass disks D_1 and D_2.
4. Check if they show the same readings at room temperature. If not, note the difference T'.
5. Connect the boiler outlet with the inlet of the steam chamber by a rubber tube. Continue passing steam until the two brass disks reach a steady temperature. Note down the temperatures T_1 and T_2 of the two discs.
6. The second part of the experiment involves the determination of the cooling rate of disc D_1 alone. Remove the sample disc. Heat the disc D_1 directly by the steam chamber until its temperature is about $T_1 + 10\,^\circ$C.
7. Remove the steam chamber and place the insulating disk on it. Record the temperature of the brass disc at half-minute intervals. Continue until the temperature falls to about $T_1 - 7\,^\circ$C.

1. Precautions

- Use thermal gloves while working with the instrument.
- Make sure all the contacts are proper.

II. OBSERVATIONS

Least count of weighing scale: 1 g
Least count of thermometer: 0.5 °C
Least count of vernier calliper: 10^{-4} m
Least count of screw gauge: 10^{-5} m
$T' = 0$ °C
$M_{D_1} = 905$ g
$T_a = 23$ °C

Material	Width (d) (10^{-5}m)	Diameter (l) (cm)
Glass	410-376-376-376-376	11.80
Ebonite	203-199-197-201-199	11.20-11.30
Rubber	331	9.88-10.00

TABLE I. Data taken on 19 Mar 2025, the different observations are separated by '-'.

Material	T_1(°C)	T_1(°C)
Glass	86.0	95.0
Ebonite	76.0	94.5
Rubber	84.0	95.0

TABLE II. Data taken on 19 Mar 2025.

T °C	t (sec)
91.5	7
90.5	8
89.5	11
88.5	11
87.5	-
86.5	-
85.5	16
84.5	17
83.5	-
82.5	21
81.5	21
80.5	19
79.5	23
78.5	22
77.5	22

TABLE III. Data taken on 21 Mar 2025, the rate of cooling for D_2 where T is the mean of floor and ceiling of the one degree temperature range.

III. UNCERTAINTIES AND ERROR SOURCES

A. Measurement Uncertainties

- **Weight Measurements:** All weight measurements have an uncertainty of 0.5 g.
- **Length Measurements:** Vernier caliper has an uncertainty of 5×10^{-5}m while screw gauge measurements having uncertainty of 5×10^{-6}m.
- **Temperature Measurements:** Uncertainty of ± 0.25 K due to instrument resolution.

B. Systematic Errors

- Improper thermal contact between disk and thermometer.
- Incomplete contacts between disks.
- Non ideal insulating material for calculate the rate of cooling of D_2

IV. CALCULATION AND ERROR ANALYSIS

A. Error Propagation

Using Equation-1 we get:

$$k = \frac{4ms\dot{T}}{\pi d^2 l(T_2 - T_1)}$$

From the length, temperature and mass uncertainty, the error to k will travel using the formula for error propagation as **?**:

$$\delta k = k\sqrt{\left(\frac{\delta m}{m}\right)^2 + \left(\frac{\delta \dot{T}}{\dot{T}}\right)^2 + \left(\frac{2\delta d}{d}\right)^2 + \left(\frac{\delta l}{l}\right)^2 + \left(\frac{\sqrt{2}\delta T}{T_1 - T_2}\right)^2} \tag{2}$$

B. Calculation

We calculate the value of k of all data points and their uncertainty from the above formula, we get (Refer to [3] for calculations):

Material	k $(\mathrm{W\,m^{-2}\,K^{-1}})$
Glass	(50.4 ± 0.3)
Ebonite	(42.7 ± 0.2)
Rubber	(64.4 ± 0.4)

TABLE IV. Calculated heat transfer coefficients

V. RESULT

The final heat transfer coefficient values [1]

Material	k $(\mathrm{W\,m^{-2}\,K^{-1}})$
Glass	(50.4 ± 0.3)
Ebonite	(42.7 ± 0.2)
Rubber	(64.4 ± 0.4)

Appendix A: Theoretical Values

The theoretical values of k are highly different from the ones found, the source of this errors are described in systematic errors.