Phys 235 Thermodynamics Experiment

Thermal Conductivity of a Bad Conductor

References

1) Tipler, 4th Edition, Section 21.4.

2) Kittel, "Introduction to Solid State Physics", Sixth Edition, page 116 and page 150.

Aim

To measure the thermal conductivity of a bad conductor, e.g. cardboard, using Lee's disc.

Apparatus

- Three thermometers (preferably $0 - 50°C$)
- Lee's disc, consisting of:
- Three copper discs and a heater on a wooden stand;
- 6 Volt transformer; and
- Multimeter.

Important: Apply the 6V to the heater as soon as possible; the system heats up very slowly and may take up to two hours to reach equilibrium.

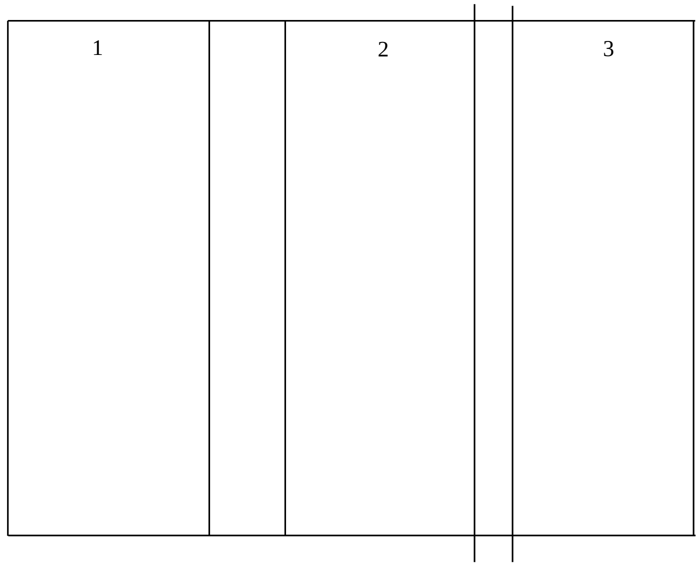
Introduction

The Thermal Conductivity of any substance is given by the equation

$$\frac{dQ}{dt} = \kappa A \frac{dT}{dx} \tag{1}$$

where dQ/dt is the quantity of heat flowing in Joules per second; κ is the thermal conductivity in $JK^{-1}m^{-1}sec^{-1}$; dT/dx is the temperature gradient in Km^{-1}, across a sample of the material of uniform cross-section A m^2.

When the electrical heater is turned on, heat will flow from the heater into discs 1 and 2 and from 2 across the cardboard to 3. The heat will be lost to the room by emission and convection from the rim and end of 1 and 3 and from the rim of 2 and the rim of the heater. The rate of heat loss from the cardboard is small compared with the heat loss from the copper discs.



The rate of loss of heat of a particular disc will be proportional to the temperature difference between the disc and its surroundings, provided this temperature difference is small (Newton's law of cooling).

The temperature of the three discs will increase till the rate of heat loss to the room is equal to the rate of heat generation in the electrical heater. When this occurs equilibrium has been reached and

$$VI = e[A_1(t_1 - t) + A_2(t_2 - t) + A_3(t_3 - t) + A_h(t_h - t)] \tag{2}$$

where e is a constant which measures the heat loss per unit area of copper. A_1, A_2 and A_3 are the emitting areas of the three discs. t_1, t_2 and t_3 are the temperatures of the three discs. t_h is the temperature of the heater. t is the room temperature. VI is the power generated in the heater. t_h is not directly measured. Make a reasonable estimate; since the rim area is small this should be good enough. Allow for uncertainty in t_h in your error estimate. The amount of heat crossing the cardboard sample is the amount of heat emitted from disc 3 which is

$$\frac{dQ}{dt} = e[A_3(t_3 - t)]$$

which from Equation (1) is

$$= \frac{\kappa(A(t_2 - t_3)}{d}$$

where d is the thickness of the cardboard. Combining these two equations leads to the result,

$$\kappa = \frac{ed(A_3(t_3 - t)}{A(t_2 - t_3)}$$

where A is the area of cardboard disc in contact with a copper disc.

Experimental Procedure and Data Analysis

To ensure that equilibrium has been reached record the readings of the three thermometers at one minute intervals until steady values for these readings are obtained for a period of five minutes.

Record (before switching off);
(i) readings on all three thermometers, (ii) room temperature, (iii) voltage across heater, (iv) ammeter reading and/or resistance of heater. (Note: these quantities depend on temperature.)

Record (after switching off);
(i) thickness of copper discs and of heater, (ii) diameter of copper discs, (iii) thickness of sample.

Calculate e, and hence κ, with error estimates. Check your value for κ with those in Figure 21.8 of reference 1) above.

Questions

1) Using kinetic theory it can be shown that the contribution that "particles" make to the thermal conductivity of a substance is given by

$$\kappa = \frac{1}{3}Cvl.$$

Give the meaning of the symbols in this expression and their S.I. units.

2) From Figure 21.8 of reference 1) it can be seen that metals have a higher thermal conductivity than the other materials in the table. Suggest reasons for this.

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