• C.J. Overbeck Northwestern University • R.R. Palmer Beloit College • Marsh W. White The Pennsylvania State University

THERMAL CONDUCTIVITY

OBJECT: To determine the thermal conductivity of a copper bar.

METHOD: One end of a uniform cylindrical copper bar is maintained at constant temperature by bathing it in steam while the other end of the bar is kept cool by passing a steady stream of water over it. The amount of heat conducted along the bar per second is found by measuring the rise in temperature of the water and the volume of water passing through per second. The temperature gradient of the bar is determined with two thermometers inserted in the bar at a known distance apart. The thermal conductivity of the copper bar is calculated from the quantity of heat conducted along the bar per second, the temperature gradient and the cross-sectional area of the bar.

THEORY: Consider a uniform bar of material of length l and cross section A whose ends are respectively kept at the constant temperatures T_2 and T_1 where T_2 is larger than T_1, Fig. 1. Heat is conducted along the bar from the end at high temperature to that at low temperature.

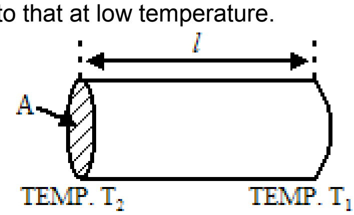

Fig. 1. Conduction of heat along a uniform bar.

Assuming that no heat escapes from the sides of the bar, the lines of heat flow are parallel to the axis of the bar. In this case the amount of heat conducted across any cross section of the bar is a constant. The rate of flow of heat R through the bar- that is, the quantity of heat conducted through the bar per unit time- is (a) directly proportional to the temperature difference (T_2 - T_1), (b) directly proportional to the cross-sectional area A, and (c) inversely proportional to the length l, or

$$R = \frac{KA\left(T_2 - T_1\right)}{l} \tag{1}$$

where K, the factor of proportionality, is called the thermal conductivity of the material of the bar. The thermal conductivity may be defined as numerically equal to the quantity of heat which is conducted per unit time through unit area of a body of unit thickness having unit temperature difference between its faces. The c.g.s. system of units is usually used for measuring K, so that R is measured in calories per second, A in square centimeters, l in centimeters and (T_2 - T_1) in degrees centigrade.

The quantity (T_2 - T_1)/l is the difference in temperature per unit length along the bar and is called the temperature gradient. If no heat escapes from the sides, the temperature gradient is constant along the bar. It is usual in any experiment on heat conductivity to measure the temperature gradient of a bar by inserting two thermometers in it at a known distance from each other. The rate of flow of heat R through the bar may be found by allowing a steady stream of water to flow over the cool end, and measuring the temperature difference of the incoming and outgoing water and the mass of water passing through per second. Suppose M grams of water flow uniformly over the end in r seconds and the rise in temperature of the water is (t_2 - t_1). If conditions are steady, such that the water conducts away all the heat transmitted through the bar per second, then

$$R = \frac{Mc\left(t_2 - t_1\right)}{r} \tag{2}$$

where c is the specific heat of water.

APPARATUS: The apparatus, which consists of a heavy copper bar with the ends enclosed in hollow brass caps, is designed for efficient heat transfer between the ends of the bar and the steam and water respectively. The bar with its brass caps fits snugly in a block of heat-insulating material divided in halves and mounted in a hinged metal case, holes being provided for the insertion of thermometers for measuring the temperature gradient of the bar and the temperature of the outgoing water, Fig. 2. A Bunsen burner and boiler for supplying steam, together with a constant temperature, constant pressure water supply must be at hand. The water supply may be obtained from a large tank elevated above the apparatus or from the faucet using a constant level tank as shown at the right in Fig. 2. Rubber hose for connecting the steam and water supplies and exits, a pair of calipers, four thermometers (two having ranges 0°-50°C and two 0°-100°C in 0.10 subdivisions), a meter stick, a watch or clock, a beaker. a graduate marked in cubic centimeters and a small quantity of oil are also needed. An ordinary clamp is frequently necessary to hold the exit tube for the water at a constant height so that the flow of water remains steady.

PROCEDURE:

Experimental: After the hose connections have been

Copyright, 2003, Sargent-Welch Scientific Company

properly made, fill the boiler full of water and start the Bunsen burner. The experiment usually takes one half to one hour before conditions become steady enough to take readings, so a large supply of steam is necessary. Insert a small amount of oil in the holes in the copper bar so that better thermal contact is possible between the bar and the thermometers. Place the copper bar in its insulating case as shown in Fig. 2. If a large tank of water is used for the water supply, it is necessary to fill this a day before the experiment is to be made so that the water may reach a constant temperature. If the water is taken directly from the faucet then usually after it has been allowed to run one half to one hour through the apparatus the temperature remains practically constant. In this case the constant level water tank arrangement is necessary as the water pressure at the faucet varies. The exit tube carrying the water from the apparatus should be kept at constant level by loosely holding it in a clamp stand, otherwise variations in its level would cause variations in the rate of flow of the water. After all the thermometers have attained a steady reading, which may take an hour, measure the amount of water flowing through the apparatus in, say, five minutes. Record the temperatures of each of the thermometers every minute. These temperatures should be read to tenths of a degree centigrade and if during the course of a five-minute run the temperatures should change by more than one tenth of a degree, discard the readings and take another set. When a reliable set of readings has been taken, the steam and water supplies should be cut off and the copper bar removed from the box. By means of the calipers measure the diameter of the bar in at least five places and from these measurements calculate the area of cross section of the bar. Measure the distance between the centers of the two thermometer wells in the bar.

Analysis and Calculations: Calculate the rate of flow of heat R through the bar by substituting the necessary data in Eq. (2). From the readings of the two thermometers inserted in the bar and their distance apart, calculate the temperature gradient in the bar. Using this value and the area of cross section of the bar, calculate $A(T_2 - T_1)/l$, Eq. (1). From these values find the thermal conductivity of the copper bar.

QUESTIONS: 1. Explain why it is necessary to surround the bar with heat-insulating material in this experiment.

2. Are the statements (a), (b), (c) in the first paragraph of the section on Theory (1) pure assumption or (2) justified by other experiments? Explain.

3. Would this type of apparatus be suitable for measuring the thermal conductivity of a poor conductor such as a glass bar? Explain.

4. Which temperature difference, (T_2 - T_1) in the bar or (t_2-t_1) of the water, should be more carefully measured?

5. Discuss the various sources of errors involved, for example, in the measurements of *R*, $(T_2 - T_1)/l, A$.

6. When the steam is first passed over one end of the bar and before a steady thermal condition is set up, explain what happens to the heat given to the bar by the steam. Are the lines of heat flow at this time parallel to the axis of the bar?

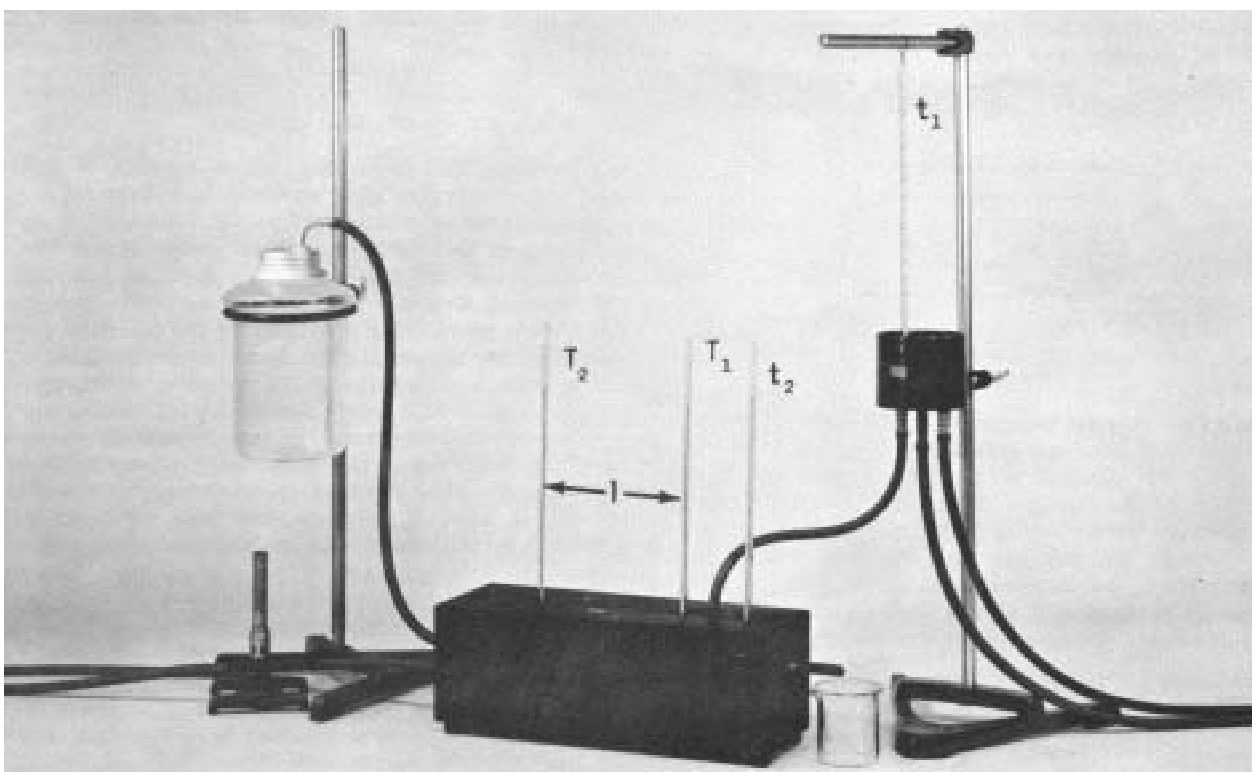

Fig. 2. Apparatus for measuring the thermal conductivity of a copper bar.