amount of carbon and manganese being added subsequently in the forms of grey iron, spiegel, or ferro-manganese.

I propose to continue this work by extending my observations to the flame from the basic Bessemer process and the gases in the Siemens steel furnace.

VI. "On a Method for determining the Thermal Conductivity of Metals, with Applications to Copper, Silver, Gold, and Platinum." By JAMES H. GRAY, M.A., B.Sc., 1851 Exhibition Scholar, Glasgow University. Communicated by LORD KELVIN, P.R.S. Received May 24, 1894.

(Abstract.)

The object of this investigation was to obtain a method for determining thermal conductivities of metals, which would not require either elaborate preparations or large quantities of the substances to be tested, and by means of which a test could be made in a few hours.

The method about to be described was suggested by Lord Kelvin thirty years ago, and is the experimental realisation of the theoretical conditions implied in the fundamental formula

$$Q = kA\frac{v-v_0}{l}t,$$

where the symbols have their usual meaning.

The apparatus was made so as to be suitable to test the metals in the form of wires of circular section.

The diameters found most convenient were from 2 to 4 mm., the lengths from 4 to 8 cm.

One end of a given length of the wire is kept at a constant known temperature. The rise of temperature of the other end of the wire is noted every minute, and, if proper precautions be taken to prevent loss by radiation from the sides, the data are obtained for calculating the thermal conductivity.

The wire to be tested is soldered at one end into the bottom of a copper box, 16 cm. long, 6 cm. wide, and 7 cm. deep. The bottom of the box is made of copper 3 mm. thick, the sides of thin sheet copper. In the box, immediately above the hole into which the wire is soldered, there is a large block of copper, in which a hole has been made sufficiently large to admit a small thermometer.

The box is filled with water and supported at its middle by being fitted into an asbestos-lined wooden screen, 24 × 24 cm. The water is heated by a Bunsen burner placed on the other side of the screen

from that on which the wire is. No heat can therefore be communicated directly to the wire from the lamp. In the bottom of the box above the lamp a number of thick copper pins is fixed, so as to catch and distribute the heat. 3 mm. length of the other end of the wire is soldered into a solid copper ball, diameter 5·5 cm. In the ball a hole 3 cm. deep is made, so as to admit the bulb and part of the stem of a small and very sensitive thermometer. This thermometer is graduated from 5° C. to 20° C., and can be easily read to within one-fortieth of one degree. The bulb is surrounded by water.

To prevent radiation from the surface of the wire, a tube of circular section, diameter 1 cm., made of several layers of thin paper, surrounds the wire all along its length. The air inside this tube soon takes up the temperature of the part of the wire with which it is in contact, and so practically eliminates radiation.

A rough calculation gives for the maximum value of the loss due to radiation, 5·5 per cent. when the surface of the wire is exposed to the air, the length being 4 cm. Unless the paper tube is effective, the error due to radiation ought to be greater, the greater the length. Exhaustive trials, however, proved that different lengths gave practically the same value for the conductivity.

The other possible errors, besides radiation, to be tested for are:—

(1) The thermometer in the hot water may not indicate the temperature of the end of the wire.
(2) The solder may cause some error.
(3) The thermometer in the ball may not indicate the average temperature.
(4) There may be a lag in the thermometer.
(5) The temperature of the ball may not be the same throughout, and the thermometer may not indicate the temperature of the wire where it enters the ball.

All these errors are practically tested by using different lengths or diameters of the wire, and the results obtained in the present investigation indicate that the errors have been eliminated.

To test whether the thermometer in the hot water indicated the temperature at the end of the wire, a thermo-electric junction, made of very thin platinoid and copper wires, was soldered to the wire just where it entered the box. The other junction was tied to a thermometer and immersed in water, which was heated till there was no deflection in the sensitive mirror galvanometer which was used. The temperature indicated by the thermometer was then found to be the same as that of the thermometer in the hot water.

An approximate calculation for the other end of the wire shows that the temperature of that end is somewhat lower than that of the ball, the greatest difference being 1·5 per cent. This difference was

always allowed for by applying an approximate formula to each different length.

In order to make a complete test of a metal it is only necessary to take a wire of 5 or 6 cm. length and solder it firmly, the one end into the bottom of the heating box, the other into the calorimeter ball. The water in the heating box is kept boiling briskly, and readings are taken every half minute from the thermometer in the ball. These readings are then put upon a curve as ordinates, with the time in minutes as abscissæ. From this curve the rise of temperature per unit time can then be accurately read off, and, the thermal capacity of the ball being already determined, the flow of heat per unit time is obtained.

In order to eliminate radiation from the surface of the calorimeter ball, the latter is, at the beginning of the experiment, cooled to about 6° or 7° C. below the temperature of the air, or rather of the water-jacket which surrounds the ball.

Let α be the quantity of heat that passes from the surface of the ball, when the latter is $\theta°$ above or below the temperature of the water-jacket; Q_1 the quantity of heat that flows into the ball at the temperature $\theta°$ *above* that of the water-jacket; Q_2 the quantity that flows in when the ball is $\theta°$ below that of the jacket; T the temperature of the hot end of the wire.

Then if κ is the mean conductivity,

$$Q_1 = \kappa\,(T-\overline{t+\theta})-\alpha,$$

$$Q_2 = \kappa\,(T-\overline{t+\theta})+\alpha,$$

$$\therefore\ \tfrac{1}{2}\,(Q_1+Q_2) = \kappa\,(T-t).$$

If, therefore, the rise in temperature per half minute at $\theta°$ *above* that of the water-jacket be taken from the curve and added to the rise for $\theta°$ *below* the temperature of the jacket, the quantity $\frac{1}{2}(Q_1+Q_2)$ is obtained, and is the flow of heat when the temperatures of the ends of the wire are T° and $t°$ C., the radiation from the ball being thus eliminated. If ten or fifteen of these values be taken from the curve and the mean found, a very accurate result is obtained. It is thus immaterial whether the surface of the ball changes between each test, as long as it remains constant during the test.

The metal which was chiefly used for the exhaustive tests of the method was copper wire, of diameter 0·21 cm., density 8·85, volume specific (electrical) resistance at about 13° C. 1834 in absolute units.

The number obtained for the absolute value of the thermal conductivity was 0·88838 C.G.S. units, which was the mean of the values for different lengths of from 4 to 7 cm., the greatest variation being a little over 1 per cent.

The greatest value obtained for copper was 0·9594 C.G.S. units, which was for wire obtained from Messrs. Glover and Sons. The specific (electrical) resistance was found to be 1730.

It must be noted that these values are the means of the conductivities corresponding to the temperatures at the ends of the wire. When compared with the values obtained by other experimenters, the results of the latter must be taken for the mean of 97° C. and 10° C., that is 53° C.

For this temperature Ångström gives 0·9208.

Several qualities of copper were tested, as well as pure gold, silver, and platinum, kindly lent for the investigation by Messrs. Johnson, Matthey, and Co.

The values are given below:—

Mean Conductivity between Temperatures 10° C. and 97° C.

	Thermal conductivity in C.G.S. units.	Diameter.
Copper, Specimen 1	0·9594	2·00 mm.
,, ,, 2	0·88838	2·11 ,,
,, ,, 3	0·8612	3·09 ,,
,, ,, 4 (very impure)	0·3497	2·04 ,,
,, ,, 5 ,, ..	0·3198	2·04 ,,
Silver (pure)	0·9628	2·02 ,,
Gold ,, ...	0·7464	2·00 ,,
Platinum ,, ...	0·1861	2·00 ,,

Experiments to find out if there is any relation between the electrical and thermal conductivities confirmed what has been found by previous investigators, that if one metal is a better conductor for heat it is also a better conductor for electricity. The results did not, however, prove that the ratios were always the same, although in some cases they agreed very closely.

For example—

$$\frac{\text{Conductivity of Specimen 2 in above table}}{\text{Conductivity of Specimen 5 in above table}} = 2{\cdot}78 \text{ for heat.}$$

$$= 2{\cdot}86 \text{ for electricity.}$$

$$\frac{\text{Conductivity of Specimen 2}}{\text{Conductivity of Specimen 4}} = 2{\cdot}54 \text{ for heat.}$$

$$= 2{\cdot}56 \text{ for electricity.}$$

$$\frac{\text{Conductivity of Specimen 1}}{\text{Conductivity of Specimen 2}} = 1{\cdot}08 \text{ for heat.}$$

$$= 1{\cdot}066 \text{ for electricity.}$$

While, however, these numbers agree very closely, other wires were tested in which the numbers varied considerably.

It is intended to go on with tests of alloys, such as platinoid and German silver; also, by using liquids other than water, to obtain values of the variation of conductivity with temperature.

Presents, June 14, 1894.

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