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F. Kohlrausch

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LVI. *Intelligence and Miscellaneous Articles.*

ON THE THERMAL CONDUCTIVITY OF HARD AND SOFT STEEL.

BY F. KOHLRAUSCH.

WE know from Mousson*, and more particularly from the thorough investigations of Barus†, that the electrical conductivity of steel depends on its hardness, and, as Barus found, so closely that the hardening of a soft steel bar can increase its conductivity two or three times.

If, now, the relation proved by Wiedemann and Franz‡ to exist for different metals, that a metal conducts heat and electricity almost equally well, holds also for the influence of mechanical preparation, or molecular aggregation, it is to be expected that the thermal conductivity of steel will be powerfully influenced by its degree of hardness.

The probability of an affirmative answer to this question follows from the fact that the statements respecting the conductivity in iron and steel lie much further apart than with other materials. Kirchhoff and Hansemann find in three kinds the numbers 0.096, 0.137, and 0.142 grm. cal./cm. sec. The authors do not discuss the possible causes of this great difference, and seem to assign it principally to the different proportions of carbon and silicon. An observation, however, from which follows that the magnetic coercive force of the worse conducting iron was the greater, points to an influence of the hardness on the conducting power §.

I used two cylindrical-turned and well polished bars of 1.2 cm. diameter, 30 cm. in length, and 270 grammes in mass ||. They were cut from the same piece; one was heated and cooled slowly, while the other was glass-hardened.

Sensitive hands can at once tell by holding the cold bars, that the soft steel conducts better than the hard. A lecture-experiment on the rate of melting of wax or something similar is sufficient to show the difference ¶.

In order to determine the numerical relations approximately, I made a few measurements by Despretz's method, which was also that adopted by Wiedemann and Franz. The end of the bar was heated by steam, and after the temperature was stationary the excess of temperature u over the surrounding air was measured in three equidistant sections **.

* Mousson, *Neue Denkschr. der Schweiz. Gesellschaft.* xiv. p. 1 (1855).

† Barus, *Wiedemann Ann.* vol. vii. p. 399 (1879).

‡ Wiedemann and Franz, *Pogg. Ann.* vol. lxxxix. p. 531 (1853).

§ Kirchhoff and Hansemann, *Wied. Ann.* vol. xiii. p. 417 (1881).

|| The soft bars weighed 271, and the hard one 268 grammes.

¶ The following method is perhaps the most convenient. The bottoms of the bars to be compared are placed in a freezing-mixture, of alcohol and snow for instance, and the height is observed up to which a deposit of moisture or of ice takes place.

** As the conductivity of iron from 0° to 100° does not vary more than 2 per cent. according to Lorenz, it was needless for my purposes to take this into account.

For this purpose a thermoelement was used consisting of very thin German silver and iron wire soldered together; these wires loaded with a small weight were so laid above the horizontal bar that the junction was uppermost. At a distance of about 10 cm. from this place both wires were soldered to thin copper wires, which by means of a commutator were in connexion with a reflecting-galvanometer. When the thermoelement was in contact with the bars, the temperature of the junction was obviously proportional to that of the section in question.

Loss of heat by radiation was prevented by screens and coatings of wadding. The junction at the copper wires was sufficiently near to the temperature of the air for my purposes. As the element showed accidentally an electrical force nearly proportional to the difference of temperature, the deflection of the galvanometer was put for the difference of temperature.

In order to get an approximate statement as to the absolute conductivity, the loss of heat to the surroundings was measured by heating the entire bar and then observing its gradual decrease of temperature with the thermoelement suspended over it. These observations were made by Mr. Sheldon. According to this the temperature decreased in ten minutes in the ratio 1.67:1; the external conductivity for temperature in one second is therefore $1.67/600 - 1 = 0.00086$.

This number multiplied by the specific heat 0.117 *, and the density 7.9, gives the external thermal conductivity reduced to unit section = 0.00080, so that, denoting the internal conductivity by k , we have

$$\frac{d^2u}{dx^2} = \frac{0.00080}{k} u.$$

Considering now the temperatures u_1, u_2, u_3 of three sections distant from each other by the length l , putting

$$\frac{u_1 + u_3}{2u_2} = n,$$

the conductivity k is known to be

$$k = 0.0008 \left[\frac{l}{\log \text{nat} (n + \sqrt{n^2 - 1})} \right]^2.$$

We obtain:—

for l	=	4	5	8	8 cm.
k hard	=	0.063	0.062	0.061	0.062
k soft	=		0.106	0.118	0.111

Hence in the mean,

$$k \text{ hard} = 0.062 \text{ gram. cal./cm. sec.}$$

$$k \text{ soft} = 0.111 \text{ " " "}$$

The conductivity of soft steel is thus almost 80 per cent. greater than

* According to Regnault, who puts the specific heat of hard steel at one per cent. higher, and the density by as much lower than with soft steel.—Pogg. *Ann.* vol. lxxii. p. 73 (1877).

that of hard. And as heating to temperatures like that of boiling water produces an appreciable annealing, the conducting power of the hard steel determined at a lower temperature would have been even less.

The *electrical conductivity* of the two bars was further determined by transmitting a constant current, a branch of which was sent by means of two knife-edges through a sensitive galvanometer in a current of 5000 to 10,000 ohms resistance. The factor of reduction to absolute measure was determined by means of a Clark's element. The conductivities referred to mercury are, according to a measurement of Mr. Sheldon,

$$\kappa \text{ hard} = 3.3, \text{ soft} = 5.5.$$

A heated and slowly cooled bar of wrought iron of the same dimensions was investigated. Its conducting power was about 40 per cent. higher than that of soft steel:

$$\kappa \text{ soft wrought iron} = 7.6.$$

That its conducting power was greater in a similar ratio is shown by an experiment in the freezing mixture (see p. 448, note). The height of deposit in hard steel amounted to 72 mm., and in soft steel to 92 mm., and in soft iron to 110 millim.

We have thus found for the ratio of the thermal conductivity k to the electrical conductivity κ :—

$$\frac{k}{\kappa} = \frac{\text{Hard Steel. } 0.062}{3.3} = 0.019; \quad \frac{\text{Soft Steel. } 0.111}{5.5} = 0.02.$$

The corresponding numbers with Kirchhoff and Hansemaun are for 15°:—

$$\frac{k}{\kappa} = \frac{\text{Bar No. I. } 0.1418}{6.803} = 0.0208; \quad \frac{\text{No. II. } 0.0964}{4.006} = 0.0237; \quad \frac{\text{No. III. } 0.1375}{6.569} = 0.0209.$$

As my determinations of the thermal conductivity can only lay claim to an approximate measurement, the agreement of $\frac{k}{\kappa}$ cannot be expected to be closer.

While thus the conductivity of different and differently heated iron and steel may be different, the ratio of the conductivity for heat and for electricity seems to remain about the same.—Wiedemann's *Annalen*, No 4, 1888.

MOUNTAIN FORMATION.

To the Editors of the Philosophical Magazine and Journal.

GENTLEMEN,

In your issue of March (p. 210) Mr. T. Mellard Reade publishes a very suggestive paper on the "Geological Consequences of the Discovery of a Level-of-no-Strain in a Cooling Globe," in which he maintains the untenableness of the contractional theory of moun-