



LVIII. On the thermal conductivity of some solid insulators

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limited range) the specific heat at constant pressure, C_p . If we suppose the liquid to be initially at temperature 0° and at a pressure P_t equal to the saturation pressure for temperature t , the increase of entropy while the liquid is heated to its saturation temperature under that pressure is $\int_0^t \frac{C_p dT}{T}$. Using this expression we may apply known values of C_p to calculate the increase of entropy in the process of heating the liquid. This integral gives the quantity $\phi_w - [\phi_w]_0$ where $[\phi_w]_0$ is the entropy of the liquid at temperature 0° and pressure P_t . For the purpose indicated in the paper, namely, that of obtaining a "first approximation to the entropy-temperature diagram," the small quantity $[\phi_w]_0$ was ignored. Each constant-pressure line in the diagram, along which the heating of the liquid was supposed to take place, was treated as practically coinciding with the liquid boundary curve: it actually lies slightly to the left of that curve until the saturation temperature is reached.

Yours faithfully,
J. A. EWING.

P.S. There is apparently a clerical error in the second expression for K_w as printed on p. 212. It should read

$$K_w = C_v + T \left(\frac{\partial p}{\partial T} \right)_v \frac{ds}{dT}.$$

LVIII. *On the Thermal Conductivity of some Solid Insulators.* By J. R. CLARKE, M.Sc. (Sheffield) *.

IN a paper in the Philosophical Magazine for December 1919, Professor W. M. Thornton remarks that from an inspection of the recorded values of the physical constants of some heat insulators, it was observed that the thermal conductivity of a substance is equal to the product of the coefficient of elasticity and the density of the substance. The agreement between this product and the thermal conductivity was so pronounced, except in the case of some complex organic bodies, that it invited further investigation.

Among the substances which showed this agreement were various kinds of glass. The data used, however, were obtained from tables of physical constants, and it is not certain, nor even probable, that the sample of "flint glass,"

* Communicated by the Author.

the thermal conductivity of which is given by Landolt and Börnstein, was of the same composition as the "flint glass" whose density is recorded by Kaye and Laby. The same applies to the other substances mentioned. It is desirable, therefore, to ascertain if the relation observed holds good if the constants concerned are measured using the same glass.

The composition of an ordinary glass is liable to be different with each melt, and it may even vary throughout the same melt. In the case of optical glass, however, homogeneity throughout the melt is essential, and in order that the glass may possess definite optical properties, precautions are taken to ensure that the composition is always the same. Optical glasses are thus very suitable for testing the validity of the relationship $k = E\rho$.

The physical constants of a large number of these glasses made in the Jena Optical Works have been determined by various observers, and these results have been used to compile the following table. The figures are taken from Hovestadt's "Jena Glass," but the original papers are referred to:—

No. of Glass.	Density ρ^* .	Elasticity $\times 10^8$.		Thermal Conductivity $k \times 10^3$ §.	$E_1\rho \times 10^9$.	$E_2\rho \times 10^9$.	$k/E_{1,0} \times 10^{12}$.	$k/E_{2,0} \times 10^{12}$.
		$E_1 \dagger$.	$E_2 \dagger$.					
19	2.370	7296	7563	2.712	1.729	1.793	1.569	1.513
20	5.944	5088	—	1.595	3.025	—	0.527	—
21	2.758	5474	5468	2.103	1.510	1.508	1.393	1.394
22	2.243	4699	4906	1.927	1.054	1.100	1.828	1.752
23	3.532	7952	7972*	2.041	2.808	2.822	0.727	0.701
24	3.578	5389	—	2.044	1.929	—	1.059	—
25	2.572	6498	6766	2.458	1.670	1.740	1.471	1.413
26	3.879	5467	5461	2.003	2.120	2.118	0.944	0.945
27	2.588	6780	—	1.974	1.755	—	1.126	—
28	2.580	6626	6599	2.269	1.710	1.702	1.327	1.332
29	2.629	6514	6638	2.407	1.713	1.745	1.405	1.379
30	2.518	—	6014	2.128	—	1.515	—	1.405
31	3.070	6296	6373	1.819	1.933	1.956	0.920	0.909
32	2.668	5862	5843	2.016	1.564	1.559	1.289	1.293
33	4.731	5512	5477	1.715	2.608	2.592	0.657	0.662
38	2.585	—	7465	2.442	—	1.930	—	1.267

* Winkelmann & Schott, *Ann. d. Phys.* 1894, li. p. 730.

† *Loc. cit.* p. 697.

‡ Winkelmann, *loc. cit.* 1897, lxi. p. 119.

§ Focke, *loc. cit.* 1899, lxxvii. p. 132.

The two values of the elasticity given were obtained by Winkelmann at different times. He notes, in explanation of the differences, that glasses 19 and 22 were from different meltings, and glass 38 contained bubbles. The error in the

thermal conductivity also may be great. Paalhorn* made measurements with several glasses, including numbers 5, 23, and 27, and obtained for these three the values 2·267, 1·610, and 1·409 respectively. These are much lower than Focke's values, and the reason for the variation is discussed by Winkelmann†, who does not, however, decide which values are the more trustworthy. Focke's coefficients are employed because he used the glasses of which the elasticities are also known. It does not matter which values of k and E are selected, the relation $k=E\rho$ is not even approximately valid. The complexity of the substance cannot be adduced as the explanation of the discrepancy, as a very simple glass, number 20, the composition of which is 20 per cent. SiO_2 , 80 per cent. PbO , shows the largest deviation from the empirical relation. It will be observed that $k/E\rho$ is small for the heavy glasses—for example, numbers 20 and 33; but it has not been found possible to postulate a value of n such that $k=E\rho^n$. A survey of the other physical constants of these glasses, such as the coefficient of expansion and the specific heat, has been made in the hope that some empirical relation might be discovered as suggested by Prof. Thornton. The employment of the volume elasticity, calculated from the given values of Young's modulus and the values of Poisson's ratio obtained by Straubel, makes the deviations from the equation $k=E\rho$ even more pronounced; and no other connexion between the constants could be observed. Also, it does not seem probable that the variation of $k/E\rho$ is due to any particular constituent oxide, except that the presence of lead tends to make this quotient small, numbers 20, 24, 26, and 33 all containing large quantities of lead and being the only glasses in the list to do so. It may be that P_2O_5 has a similar effect, as numbers 27 and 31 both contain more than 50 per cent. of this oxide, and in both cases the value of the quotient is below the average. In general, however, the compositions are so varied that it is not possible to attribute an abnormal influence to any particular oxide.

It may be added that, although the empirical relation suggested by Prof. Thornton does not hold good, the statement that the thermal conductivity increases with the elasticity and with the density seems to be approximately correct, except for the heavy glasses, and may be of use as a rough guide when seeking for a heat insulator or for a good conducting glass.

Manchester,
12th June, 1920.

* Paalhorn, Dissertation, Jena, 1894.

† Winkelmann, *Ann. d. Phys.* 1899, lxvii. p. 794.