THERMAL CONDUCTIVITY OF HEAVY-OXYGEN WATER H_2O^{18}

A. P. Bibik, I. V. Litvinenko, and I. V. Radchenko

UDC 536.22.08

The ratio of thermal conductivity coefficients of heavy-oxygen water H_2O^{18} with different percentages of enrichment to the thermal conductivity coefficient of ordinary water is measured in the range of 0-40°C. Differences in the thermal conductivities and the temperature coefficients of the thermal conductivity of heavy-hydrogen water D_2O and and heavy-oxygen water H_2O^{18} are indicated.

For clarification of the properties of the mechanism of thermal conduction of water it is of interest to study the thermal conductivity of water of different isotope compositions: H_2O, D_2O, H_2O^{18}. Molecules of D_2O and H_2O^{18} have almost identical masses but markedly different moments of inertia. Molecules of H_2O and H_2O^{18} with identical moments of inertia have different masses. A comparison of the thermal conductivities of these liquids can help to establish what role the translational and rotational motions of the

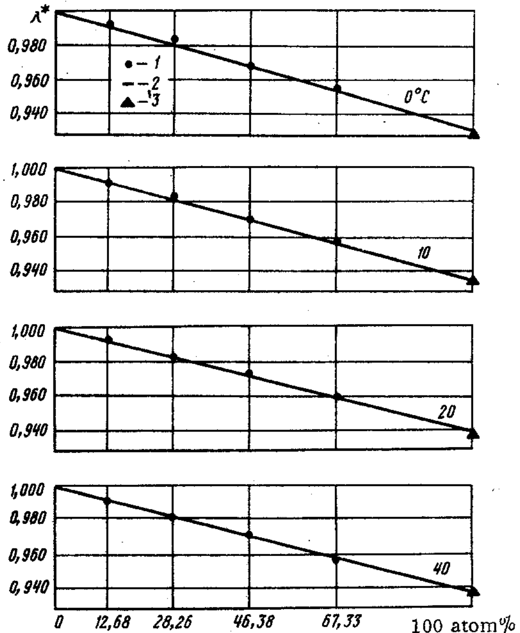

Fig. 1

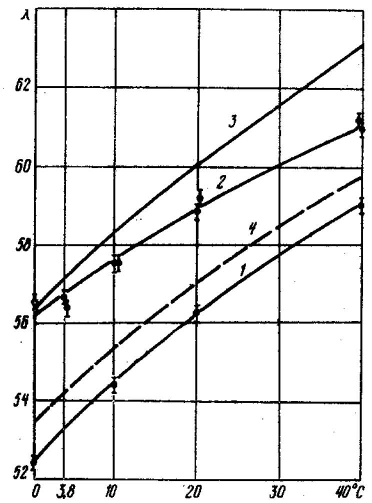

Fig. 2

Fig. 1. Ratio of thermal conductivity coefficients of heavy-oxygen water with different percentages of enrichment of thermal conductivity coefficient of ordinary water in range of 0-40°C: 1) experimental points; 2) isotherms according to Eq. (1); 3) extrapolation to 100% H_2O^{18}.

Fig. 2. Thermal conductivity of water of different isotope compositions ($\lambda \cdot 10^6$, $W \cdot m^{-1} \cdot deg^{-1}$): 1) H_2O^{18} (extrapolation to 100% according to Eq. (1)); 2) D_2O [1]; 3) ordinary water, recommended values of [2]; 4) H_2O^{18} and D_2O according to theory of [3].

Dnepropetrovsk Metallurgical Institute. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 26, No. 1, pp. 42-45, January, 1974. Original article submitted November 10, 1972.

TABLE 1. Ratios λ^* of Thermal Conductivity Coefficients of Heavy-Oxygen Water with Different Percentage Contents of H_2O^{18} to Thermal Conductivity Coefficient of Ordinary Water in Range of 0-40°C

T, °C	N (mole %)				100 (extrapolation)
	12,68	28,26	46,38	67,33	
0	0,991	0,982	0,968	0,956	0,931
10	0,991	0,981	0,968	0,959	0,936
20	0,992	0,984	0,974	0,961	0,939
40	0,992	0,981	0,973	0,955	0,937

water molecules play in the transport of heat, as well as to obtain certain information on the effect of the hydrogen bonds on thermal conductivity. Measurements of the thermal conductivity of D_2O were made in [1]. The present work is devoted to study of the thermal conductivity of H_2O^{18}. As far as the authors know, nobody has yet measured the thermal conductivity of H_2O^{18}.

The measurements were conducted by the method and on the instrument described in [1]. Heavy-oxygen water with an enrichment of 67.33 mole% H_2O^{18} and solutions with concentrations of 46.38, 28.26, and 12.68 mole % H_2O^{18} prepared from this water were studied. The solutions were prepared by the gravimetric method by dilution with doubly distilled H_2O. The same doubly distilled water was used as the standard liquid in the relative measurements of thermal conductivity. Experimental values of the ratios $\lambda(H_2O^{18})/\lambda(H_2O) = \lambda^*$ are presented in Table 1.

Values of λ^* extrapolated to 100% H_2O^{18} are given in the last column of Table 1. The extrapolation was carried out as follows. The experimental points (first four columns of Table 1) are used to find the coefficients of the equation

$$\lambda^* = 1 + A(1 + BT + CT^2)N, \tag{1}$$

where T is the temperature on the Celsius scale and N is the H_2O^{18} concentration in mole percent, and λ^* is calculated from this equation with N = 1.

The coefficients are:

$$A = -9.0690; \quad B = -0.0096 \ \text{deg}^{-1} \quad C = 1.9 \cdot 10^{-4} \ \text{deg}^{-2}.$$

Equation (1) is chosen as a linear equation relative to the concentration in accordance with the experimental data. The linearity is well seen in Fig. 1, where the dependences of λ^* on N are presented for four temperatures. The isotherms are plotted according to (1).

The coefficients of Eq. (1) were determined by the method of least squares. Minimization of the sum of the square deviations was conducted at once for the entire family of isotherms, i.e., simultaneously for all the temperatures and concentrations. The experimental data were represented in the form

$$Y_i = \frac{1}{N}(1 - \lambda_i^*) \tag{2}$$

and were approximated by the function

$$\hat{Y} = -A - AB \cdot T - AC \cdot T^2. \tag{3}$$

The standard deviation of the experimental points from the approximating curve (3)

$$S = \sqrt{\frac{\sum_{i=1}^{n} (\hat{Y}_i - Y_i)^2}{n - p}} \quad (n = 16, \quad p = 3)$$

is equal to S = 0.0044.

The absolute values of the thermal conductivity coefficient of H_2O^{18} are obtained by multiplying the thermal conductivity coefficient of the standard liquid (ordinary H_2O) by λ^* from (1) at N = 1. The thermal conductivity of H_2O^{18} is represented by curve 1 in Fig. 2. The values of $\lambda(H_2O)$ for the thermal conductivity coefficient of ordinary water are taken from the table of the review [2] (curve 3). Despite the equality of the masses of the H_2O^{18} and D_2O molecules the thermal conductivity coefficients of these liquids differ considerably from one another. The thermal conductivity of D_2O according to the results of [1] is represented by curve 2 in Fig. 2. The thermal conductivity of H_2O^{18} is $(93.6 \pm 0.4)\%$ of the thermal conductivity of ordinary water on the average and has the same temperature coefficient as ordinary water within the limits of the experimental errors. The thermal conductivity of D_2O practically coincides with the thermal conductivity of ordinary H_2O at 0°C but has a lower temperature coefficient so that it grows more slowly with an increase in temperature and at 40°C it is $(97.0 \pm 0.3)\%$ of the thermal conductivity of ordinary water.

The experimental results obtained are not in agreement with the theory of Horrocks, McLaughlin, and Ubbelohde [3] on the effect of an isotope substitution on the thermal conductivity. According to this theory the ratio of thermal conductivity coefficients of two liquids which differ only in the isotope composition of the molecules is equal to the square root of the inverse ratio of molecule masses. This value is equal to 0.949 for H_2O^{18} and D_2O with respect to ordinary water, i.e., the thermal conductivity of H_2O^{18} should coincide with the thermal conductivity of D_2O and comprise 94.9% of the thermal conductivity of ordinary water. The dashed curve 4 in Fig. 2 corresponds to the theoretical value $\lambda = 0.949 \cdot \lambda(H_2O)$.

The reasons for the disagreement may lie in the fact that certain effects which could play an important role in the thermal conductivity of such a peculiar liquid as water were not taken into account in the theory of [3]. Among them are: the rotational motion of the molecules which are the free spaces of the structure of water; the nonequivalence of the hydrogen and deuterium bonds between molecules; differences in the intermolecular structure.

NOTATION

A, B, C	are the coefficients of Eq. (1);
n	is the number of experimental points;
N	is the concentration, molar fractions;
p	is the number of coefficients in Eq. (1);
s	is the standard deviation of experimental points from approximating curve;
T	is the temperature on Celsius scale;
$y_i = N^{-1}(1-\lambda_i^*)$;	
$\hat{y}$	is the approximating function;
$\lambda^* = \lambda(H_2O^{18}/\lambda(H_2O)$;	
$\lambda(H_2O^{18})$ and $\lambda(H_2O)$	are the thermal conductivity coefficients of heavy-oxygen water and ordinary water, $W \cdot m^{-1} \cdot deg^{-1}$.

LITERATURE CITED

1. A. P. Bibik, I. V. Litvinenko, and I. V. Radchenko, Inzh.-Fiz. Zh., 25, No. 5, (1973).
2. E. McLaughlin, Chem. Rev., 64, No. 4, 389-428 (1964).
3. J. K. Horrocks, E. McLaughlin, and A. R. Ubbelohde, Trans. Faraday Soc., 59, No. 5, 1110-1113 (1963).