THERMAL CONDUCTIVITY OF D_2O VAPOR

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Results are shown of an experiment in which the thermal conductivity of D_2O vapor was measured and the $\lambda_{D_2O}/\lambda_{H_2O}$ ratio was determined at temperatures up to 760°C under a pressure of about 1 bar.

This report follows earlier ones and concerns the thermal conductivity of D_2O vapor.

The first tests had been performed under atmospheric pressure by the hot-wire method over the 100-500°C temperature range by N. B. Vargaftik and L. S. Zaitseva [1], then over the 108-250°C temperature range by C. E. Bekker and R. S. Brockaw [2]. The values in [1] and [2] differed by up to 3% for λ_{D_2O} and up to 1% for λ_{H_2O} at the lower temperatures.

The thermal conductivity of D_2O vapor was measured by N. B. Vargaftik and O. N. Oleshchuk [3] by the hot-wire method under pressures from 1 to 250 bars over the 145-500°C temperature range, and by B. LeNeidre [4] by the coaxial-cylinders method under pressures from 1 to 125 bars over the 100-330°C temperature range. All these authors measured the thermal conductivity of D_2O vapor and of H_2O vapor in the same apparatus. It appears from all these tests that the $\lambda_{D_2O}/\lambda_{H_2O}$ ratio for the vapors is a function of the temperature.

It was of interest to study the thermal conductivity of D_2O at higher temperatures and, especially, close to the range where the thermal conductivity of H_2O vapor had already been determined.

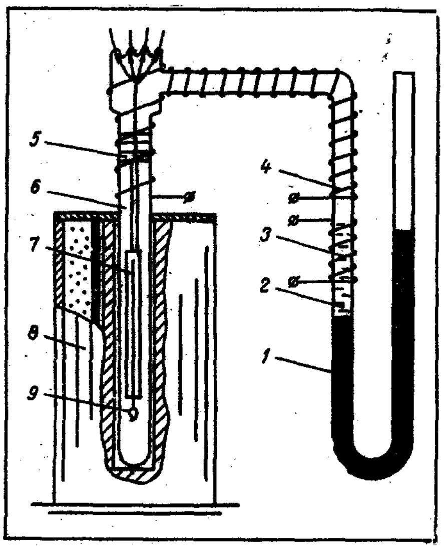

Fig. 1. Schematic diagram of the test apparatus: 1) manometer; 2) vapor generator; 3) boiler; 4) oven; 5) adapter; 6) quartz case; 7) test tube; 8) thermostat; 9) weight of 4 g.

The thermal conductivity of D_2O vapor was measured by the hot-wire method in an apparatus shown in Fig. 1. This tube was placed inside a quartz case 6. The rest of the apparatus was made of glass. The quartz case was connected to the glass part through a special quartz-to-glass adapter tube 5. The quartz case 6 and the test tube 7 were both placed inside a thermostat 8. The test tube 7 was connected to a vapor generator 2. The vapor pressure was set according to the temperature in boiler 3. In order to prevent vapor condensation, the entire system from boiler to thermostat was heated in an oven 4.

The tube had an inside diameter $D_i = 4.07$ mm and an outside diameter $D_o = 5.67$ mm, the diameter of the platinum heater wire along the tube axis was $d_h = 0.157$ mm, and the test segment was $l = 160$ mm long. The resistance thermometer on the outer surface of the test tube was made of platinum wire $d = 0.1$ mm in diameter. This platinum wire was of high-purity grade PL-1 material with a resistance ratio $R_{100}/R_0 = 1.3923$.

The thermal conductivity was determined according to the relation

$$\lambda = \frac{Q \ln (D_i/d_n)}{2\pi l \Delta t_v} = A \frac{Q}{\Delta t_v},$$

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TABLE 1. Test Data for λ_{D_2O}

p	Q	$(t_{wi}-t_{wa})$	δt_{qu}	δt_{wa}	Δt_v	q_{rad}	$(Q-q_{rad})$	λ'	$\delta\lambda$	λ	t_m
370	0,1483	17,31	0,04	—	17,27	0,0014	0,1469	0,0276	0,0003	0,0273	127,55
370	0,3297	36,59	0,09	—	36,50	0,0037	0,3260	0,0289	0,0003	0,0286	141,26
370	0,2329	24,46	0,06	—	24,40	0,0029	0,2300	0,0305	0,0003	0,0302	159,74
263÷500	0,2302	23,86	0,06	—	23,80	0,0030	0,2271	0,0309	0,0003	0,0306	163,22
322÷533	0,2459	20,90	0,06	—	20,84	0,0045	0,2413	0,0375	0,0005	0,0370	230,47
180÷555	0,3689	25,77	0,09	—	25,68	0,0092	0,3597	0,0454	0,0005	0,0449	301,08
117÷540	0,3647	25,16	0,09	—	25,07	0,0094	0,3553	0,0459	0,0005	0,0454	308,23
259÷506	0,3622	20,08	0,08	—	20,00	0,0130	0,3491	0,0566	0,0006	0,0560	392,14
362÷543	0,5870	29,07	0,13	—	28,94	0,0259	0,5610	0,0628	0,0007	0,0621	451,55
341÷500	0,5841	27,93	0,13	—	27,80	0,0261	0,5581	0,0650	0,0007	0,0643	463,14
210÷556	0,7700	30,66	0,15	0,18	30,33	0,0454	0,7247	0,0776	0,0008	0,0766	552,46
115÷530	1,1448	41,47	0,22	0,29	40,96	0,0716	1,0730	0,0849	0,0009	0,0840	600,03
240÷503	1,2036	42,79	0,22	0,35	42,22	0,0791	1,1245	0,0863	0,0009	0,0854	618,78
232÷513	0,7920	25,55	0,14	0,35	25,06	0,0633	0,7287	0,0942	0,0010	0,0932	663,32
148÷256	1,1671	37,46	0,20	0,52	36,74	0,0876	1,0795	0,0952	0,0010	0,0942	678,61
453÷543	0,7563	23,16	0,13	0,35	22,68	0,0711	0,6852	0,0979	0,0010	0,0969	686,97
313÷558	1,3418	36,50	0,21	1,12	35,17	0,1597	1,1820	0,1089	0,0012	0,1077	769,70

TABLE 2. Test Data for λ_{H_2O}

p	Q	$(t_{wi}-t_{wa})$	δt_{qu}	δt_{wa}	Δt_v	q_{rad}	$(Q-q_{rad})$	λ'	$\delta\lambda$	λ	t_m
400	0,0751	8,06	0,02	—	8,04	0,0008	0,0743	0,0299	0,0003	0,0296	156,78
460	0,1615	16,93	0,04	—	16,89	0,0020	0,1595	0,0306	0,0003	0,0303	162,58
170÷300	0,1636	16,55	0,04	—	16,51	0,0024	0,1612	0,0316	0,0003	0,0313	182,32
253÷540	0,6286	60,47	0,17	—	60,30	0,0100	0,6186	0,0332	0,0005	0,0327	192,15
206÷410	0,3668	25,83	0,09	—	25,74	0,0093	0,3575	0,0450	0,0005	0,0445	303,04
350÷600	0,5896	34,88	0,15	0,09	34,64	0,0197	0,5700	0,0533	0,0006	0,0527	372,98
370÷540	0,6212	34,41	0,14	0,16	34,11	0,0254	0,5958	0,0566	0,0006	0,0560	412,64
130÷540	0,6072	25,74	0,12	0,17	25,45	0,0354	0,5718	0,0728	0,0008	0,0720	537,50
357÷502	0,6058	23,29	0,11	0,35	22,83	0,0408	0,5650	0,0802	0,0008	0,0794	604,06
170÷550	0,5895	21,01	0,11	0,27	20,63	0,0426	0,5470	0,0859	0,0009	0,0850	636,74
130÷350	0,5795	18,21	0,10	0,49	17,62	0,0513	0,5282	0,0971	0,0010	0,0961	724,52

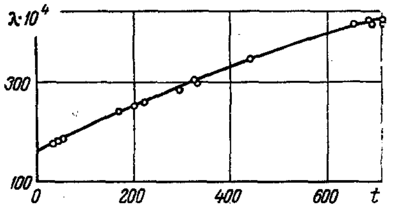

Fig. 2

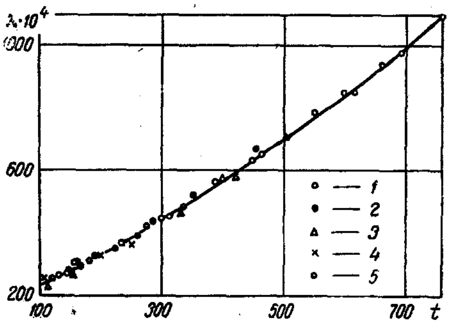

Fig. 3

Fig. 2. Thermal conductivity λ of gaseous argon as a function of the temperature t: the dots represent our data, the curve represents data in [6].

Fig. 3. Thermal conductivity λ of D_2O vapor as a function of the temperature: 1) our data; 2) data from [3]; 3) data from [1]; 4) data from [2]; 5) data from [4].

with the instrument constant A depending on the apparatus geometry and on the operating temperature, Q denoting the amount of heat transmitted from the wire to the vapor by conduction, and Δt denoting the temperature drop across the vapor layer from wire to wall.

The calculations were corrected for heat radiation from the heater to the tube wall, for heat leakage through the heater ends, for the temperature drop across the tube wall, and for a temperature jump.

In order to account for the effect of a temperature jump, the tests were performed under various vapor pressures about the 1 bar level (from 100 to 600 mm Hg). The correction for a temperature jump did not exceed 3% under the highest pressure. There was no heat convection, inasmuch as $Gr \cdot Pr < 1000$ in all tests.

Prior to measuring the thermal conductivity of heavy water, we had measured the already well known thermal conductivity of argon in the same apparatus. The results are shown in Fig. 2, along with the values recommended in [6]; the deviation of our values from those recommended ones are within the limits of measurement error, i.e., do not exceed 1.0-1.5%.

The tests were performed with D_2O containing 99.8% deuterium isotope.

Our test results pertaining to the thermal conductivity of D_2O vapor are shown in Table 1 and Fig. 3. In Fig. 3 are also shown data according to other authors. Deviations from the averaging curve do not exceed ±2%.

It seemed worthwhile, as had been in earlier studies, to measure in the same apparatus also the thermal conductivity of normal water vapor. This would eliminate any systematic error and would yield

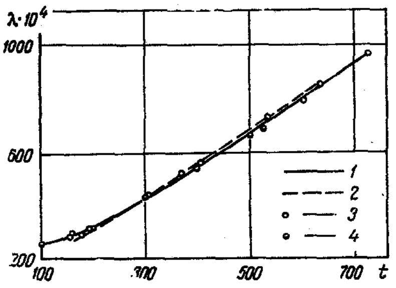

Fig. 4

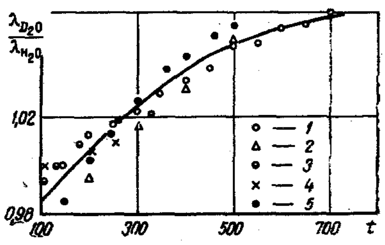

Fig. 5

Fig. 4. Thermal conductivity λ of H_2O vapor as a function of the temperature: 1) recommended values [6]; 2) data from [7]; 3) our data; 4) data from [4].

Fig. 5. Ratio $\lambda_{D_2O}/\lambda_{H_2O}$ as a function of the temperature: 1) our data; 2) data from [1]; 3) data from [4]; 4) data from [2]; 5) data from [3].

accurate values for the $\lambda_{D_2O}/\lambda_{H_2O}$ ratio. Our test data for H_2O vapor are shown in Table 2 and Fig. 4. The deviations of our values from those in λ_{H_2O} tables [6] does not exceed 1%. On the same diagram are also shown values recently obtained by other authors. They agree with those for λ_{H_2O} in [6] within ±2%.

In Fig. 5 are shown values of the $\lambda_{D_2O}/\lambda_{H_2O}$ ratio, according to our tests and those by other authors under a pressure of about 1 bar.

It is characteristic that, although the values of λ_{H_2O} and λ_{D_2O} according to various authors deviate by up to 2% from the respective averaging curves, the values of the $\lambda_{D_2O}/\lambda_{H_2O}$ ratio according to all available data agree within 1%. This is so, because all the authors measured the thermal conductivity of D_2O and H_2O vapors with exactly the same apparatus and thus eliminated any systematic errors.

NOTATION

p	is the pressure, mm Hg;
Q	is the thermal flux transmitted by the hot platinum wire, W;
t_{wi}	is the wire temperature, °C;
t_{wa}	is the wall temperature, °C;
t_m	is the mean temperature, °C;
δt_{qu}	is the temperature drop across the wall of the quartz tube, °C;
δt_j	is the correction for a temperature jump, °C;
Δt_v	is the temperature difference across the vapor layer, °C;
q_{rad}	is the amount of heat radiated from the hot wire, W;
λ	is the thermal conductivity, W/m · °C;
λ'	is the thermal conductivity of vapor without considering the heat leakage through the tube ends, W/m · °C;
$\delta\lambda$	is the correction for heat leakage through the tube ends, W/m · °C.

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