EXPERIMENTAL STUDY OF THERMAL CONDUCTIVITY IN KRYPTON AT HIGH TEMPERATURES

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The coaxial cylinder method is used to measure thermal conductivity of krypton in the temperature range 100-1200°K at a pressure $p \approx 1$ bar. Results are compared with experimental data of other authors.

Until recently, measurements of the thermal conductivity of krypton have been performed mainly by some variant of the heated-filament method [1-10]. Thus, it is of interest to measure this quantity by some other method.

In the present study the coaxial-cylinder method was employed. In order to reduce the fraction of radiation in the total thermal flux, the cylinders used were made of nickel, which has a low emissivity.

Dimensions of the measurement cylinders were as follows (mm): working diameter of inner cylinder, 12.91; working diameter of outer cylinder, 14.09; intercylinder gap, 0.59; cylinder wall thickness, 1.0; length of working, section, 100.3; length of cylinder, 200.

The inner heater which creates a radial heat flux was constructed of 0.3-mm platinum wire wound on a quartz tube. The heater had three windings: the main winding and two guard windings. Voltage drop on the operating winding and the coil of a reference resistor was measured by an R-307 potentiometer.

Platinum — platinum/rhodium thermocouples were used to measure cylinder wall temperature. Three thermocouples each were installed along the working length of both inner and outer cylinders, held to the surface by rings. Temperature drop during the experiments was within the limits 20-35°K. In the steady state the difference between the indications of the thermocouples along each cylinder was 0.1°K.

The measurement cylinders were installed in a thermostat with one main and two guard heaters.

The coefficient of thermal conductivity was calculated from the equation

$$\lambda = \frac{\ln \frac{D}{d}}{2\pi l} \cdot \frac{W - W_{\text{rad}}}{\Delta T_{\text{gas}}}. \tag{1}$$

For determination of W_{rad} with the apparatus used, the emissivity of the nickel cylinders was determined experimentally at a pressure of 10^{-5} mm Hg. Correction for the temperature jump in experiments did not exceed 0.5%.

It was also necessary to introduce a correction for the temperature change ΔT_c at the point of thermocouple contact. This was done by using the same apparatus to measure thermal conductivity or argon and nitrogen, for which λ values are well known [11]. By using the differences of results with the present apparatus from the data of [11] it is possible to find the value ΔT_c and consider it in determining the thermal conductivity of krypton. The value of ΔT_c should depend on total thermal flux W and the temperature of the experiment, which affects contact conditions.

The results of the measurements of the thermal conductivity of krypton and ΔT_c values are presented in Table 1. Figure 1 shows the function $\Delta T_c = f(W, T)$ determined from experiments on argon and nitrogen.

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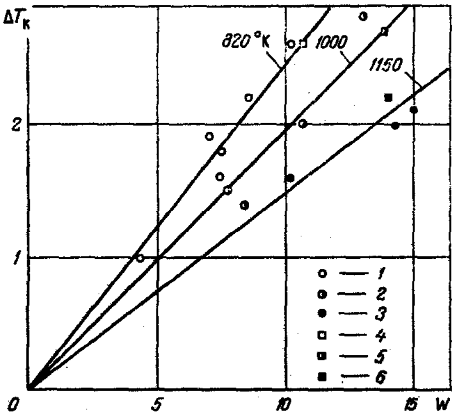

Fig. 1

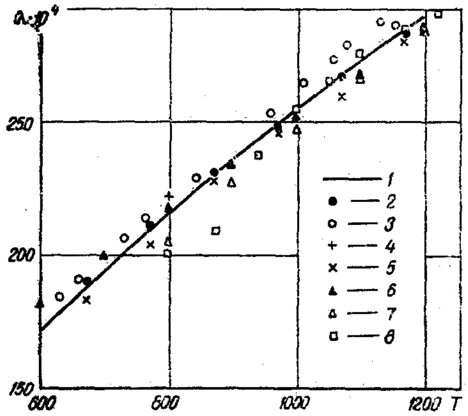

Fig. 2

Fig. 1. $\Delta T_C = f(W, T)$: 1) argon, 820°K isotherm; 2) argon, 1000°K; 3) argon, 1150°K; 4) nitrogen, 820°K; 5) nitrogen, 1000°K; 6) nitrogen 1150°K.

Fig. 2. Thermal conductivity of krypton according to data of: 1) present study; 2) [1]; 3) [2]; 4) [3]; 5) [7]; 6) [8]; 7) [9]; 8) [10].

Using this function the value of ΔT_C was determined for each experimental point for krypton and the temperature drop in the gas layer ΔT_{gas} was found.

As is evident from Table 1, the fraction of heat transmitted by radiation reached 40% at the highest experimental temperature. To decrease the ratio W_{rad}/W, another measurement cell was constructed with a smaller gap between the nickel cylinders. The dimensions of the second cell were (mm): working diameter of inner cylinder, 10.70; working diameter of outer cylinder, 11.10; gap between cylinders, 0.20; cylinder wall thickness, 1.0; working section length, 78.7; cylinder length, 230.

A second and third series of experiments were performed with this new apparatus to determine λ krypton. To obtain the ΔT_C correction, measurements were made with argon only, considering the linear

TABLE 1. Experimental Data on Thermal Conductivity of Krypton (series I experiments)

T, °K	$\Delta T'$, °K	W, W	W_λ, W	$\lambda' \cdot 10^4$ W/(m·deg)	$\lambda'' \cdot 10^4$ W/(m·deg)	$\Delta T''$, °K	ΔT_C, °K	ΔT_{ras}, °K	$\lambda \cdot 10^4$ W/(m·deg)
				Argon					
795	25,5	7,510	6,488	349	372	23,9	1,6		
807	28,9	8,539	7,313	348	376	26,7	2,2		
813	14,7	4,418	3,773	351	378	13,7	1,0		
816	34,2	10,187	8,719	351	379	31,6	2,6		
822	23,5	7,073	6,002	351	381	21,6	1,9		
832	24,4	7,487	6,319	354	384	22,6	1,8		
987	20,3	7,769	5,885	398	430	18,8	1,5		
1003	33,4	13,026	9,723	399	436	30,6	2,8		
1009	21,2	8,379	6,316	409	437	19,8	1,4		
1011	27,0	10,721	7,978	406	438	25,0	2,0		
1091	31,8	14,336	9,984	431	460	29,8	2,0		
1160	20,6	10,221	6,632	442	479	19,0	1,6		
1163	30,0	15,061	9,777	446	480	27,9	2,1		
				Nitrogen					
832	25,6	10,725	9,504	510	566	23,0	2,6		
997	26,6	13,927	11,360	585	652	23,9	2,7		
1167	21,3	13,977	10,186	657	731	19,1	2,2		
				Krypton					
591	30,2	3,960	3,574				1,2	29,0	169
615	29,3	4,092	3,655				2,2	28,1	178
786	27,3	5,089	4,041				1,25	26,05	213
976	21,2	5,538	3,660				1,1	20,1	250
1058	19,7	5,925	3,526				1,1	18,6	260
1162	21,1	7,779	4,085				1,2	19,9	282

TABLE 2. Experimental Data on Thermal Conductivity of Krypton

T, °K	ΔT_{gas}, °K	W, W	W_{λ}, W	ΔT_c, °K	$\lambda \cdot 10^4$ $\frac{W}{m \cdot deg}$
		Series II			
1089	28,0	11,175	9,268	2,6	278
854	22,7	6,928	6,333	2,3	234
719	22,1	5,680	5,382	2,2	203
971	21,5	7,442	6,507	2,2	254
792	28,1	7,827	7,278	2,8	217
		Series III			
1096	23,3	8,826	7,174	2,8	267
1096	22,9	8,841	7,217	2,8	274
1107	30,2	11,882	9,653	3,7	277
872	22,9	6,689	6,029	2,6	224
684	24,5	5,761	5,489	2,6	187
690	24,2	5,773	5,494	2,6	191

character of the function $\Delta T_c = f(W, T)$, and the ΔT_c values were calculated as in the first series of experiments. The value of W_{rad}/W in the determination of λ in krypton with the second apparatus did not exceed 15%. Correction for temperature change did not exceed 1%. Results of these measurements are presented in Table 2. Maximum measurement error in the first series of experiments was 4%, and 3% in the second and third series.

The thermal conductivity of krypton over the temperature range 600-1200°K may be represented by the equation

$$\lambda = a + bT + cT^2. \tag{2}$$

The coefficients in this equation, obtained by the method of least squares, are as follows: $a = 1.40 \cdot 10^{-3}$ W/m · deg; $b = 0.297 \cdot 10^{-4}$ W/m · deg^2; $c = -0.56 \cdot 10^{-8}$ W/m · deg^3.

Scattering of the experimental data with respect to Eq. (2) does not exceed 2%.

Smoothed values of thermal conductivity for krypton, calculated from Eq. (2) are presented below:

T, °K	600	700	800	900	1000	1100	1200
$\lambda \cdot 10^4$ W/m · deg	172	194	216	236	255	273	290

Figure 2 compares the present results with data from other authors. The values of [1] have been corrected by not more than 2% for temperature change, as recommended in [2].

Scattering of the main mass of points obtained by the classical variant of the heated-filament [1-6] and the modified method [7-10] is within the limits of 2-3%. An exception is individual points at low temperatures in [10].

Thus, the experimental data obtained in the present study by the coaxial-cylinder method support the available results and in the temperature range 600-1200°K they may be described by Eq. (2) to within an accuracy of 2-3%.

NOTATION

λ, thermal conductivity; W, total thermal flux; W_{rad}, radiant heat flux; $W_{\lambda} = W - W_{rad}$, heat flux transferred by conduction; ΔT_{gas}, temperature drop across gas layer; D, working diameter of outer cylinder; d, working diameter of inner cylinder; l, length of working segment; T, gas temperature; $\Delta T'$, temperature drop measured by thermocouples; λ', thermal conductivity measured without consideration of correction for temperature drop at point of thermocouple contact; λ'', values of argon and nitrogen thermal conductivity from the literature; $\Delta T''$, temperature drops corresponding to λ'' in argon and nitrogen; $\Delta T_c = \Delta T' - \Delta T''$, temperature drop at point of thermocouple contact.

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