THERMAL CONDUCTIVITY OF KRYPTON AND XENON AT TEMPERATURES UP TO 5000°K

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The experimental data on the thermal conductivity of krypton and xenon at temperatures up to 5000°K are correlated. Computational equations are proposed.

Correlations of the thermal conductivity of krypton and xenon at temperatures up to 2000°K are available in [1-3]. New experimental data have recently appeared for these gases at temperatures up to 2500°K, obtained by the steady-state conductivity column method [4-6]. Shock tube measurements of the thermal conductivity at temperatures up to 5000°K are known also [7, 8].

Krypton. Experimental papers on the measurement of the thermal conductivity of krypton in the high-temperature region at atmospheric pressure are listed in Table 1. The log–log plot of these experimental results shown in Fig. 1 indicates that, within the limits of error (2-3%), the experimental data obtained by steady-state methods lie on a straight line for $T > 700$°K. Consequently, under the conditions indicated the temperature dependence of the thermal conductivity λ can be described by a simple power law. This relation does not hold at temperatures below 700°K, since the experimental points lie well below the straight line which describes the experimental results for $T > 700$°K.

Values of λ from shock tube measurements [7] in the temperature range 1500-2500°K, where there are reliable results, are systematically about 12% lower than the values obtained in [4, 5, 9] by steady-state methods. In all probability this difference results from the fact that in processing the results of measurements of the reflection of shock waves Collins and Menard [7] assumed that the temperature dependence of the thermal conductivity of krypton was given by a power law with a constant value of the exponent of T for the whole temperature range 300-5000°K. As noted above, this is not correct for krypton. Consequently, the Collins and Menard [7] values should be increased by ~12% over the whole temperature range investigated.

Analysis of the experimental data showed that in the temperature range 700-5000°K the thermal conductivity of krypton at atmospheric pressure can be represented by the power law

$$\lambda = 0.0194\,(T/700)^{0.69}, \tag{1}$$

where λ is the thermal conductivity in W/m·°K, and T is the temperature in °K.

Values of the thermal conductivity calculated from Eq. (1) can be in error by 3% for $T = 700\text{-}2500$°K, and by 5% for $T > 2500$°K. Table 2 lists values calculated from this equation.

Figure 2 shows the deviations from Eq. (1) of the experimental values available in the literature (Table 1) and results of known [1, 2] correlations of the thermal conductivity of krypton. The values recommended in [1] for temperatures up to 2000°K are higher than the values calculated from Eq. (1) by 2-3% in the temperature range 800-1500°K; for $T > 1500$°K the deviation is less than 1%. A combined analysis of the experimental data on viscosity and thermal conductivity of monatomic gases using the equations of rigorous kinetic theory is presented in [2]. For krypton the experimental results are correlated in the temperature range 120-1300°K. The values recommended in [2] are lower than those calculated from Eq. (1) by 1-1.5% up to 900°K; the deviation decreases with increasing temperature and reaches 0.3% at 1300°K.

Figure 2 shows the deviations from Eq. (1) of data from [6, 10, 11-14] calculated by using the Chapman–Enskog kinetic theory of gases [15]. The parameters of the potential functions used in these papers were determined from various sources. It is clear from the figure that the values calculated in [10, 11] by using data from experiments on the scattering of

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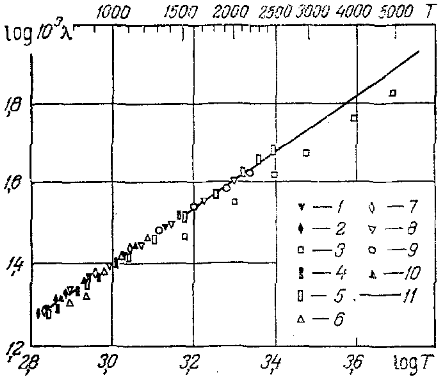

Fig. 1. Thermal conductivity of krypton from the following data: 1) [23]; 2) [24]; 3) [7]; 4) [17]; 5) [4]; 6) [25]; 7) [18]; 8) [9]; 9) [5]; 10) [26]; 11) (1). λ is in W/m•°K, and T in °K.

TABLE 1. Papers on the Thermal Conductivity of Krypton at High Temperatures (in chronological order)

Reference	Method of investigation	Temp. range, °K	Error in % estimated by author
[23]	Heated filament	273—1373	—
[24]	»	313—798	—
[7]	Shock tube	1500—5000	12
[25]	Conductivity column	796—1263	5—7
[17]	»	350—1500	2
[18]	Heated filament	318—1153	2,7
[9]	Conductivity column	800—2000	3—4
[4]	»	400—2500	2,2—3,6
[26]	Coaxial cylinders	600—1200	2—3
[5]	Conductivity column	1100—2200	3

atomic beams of various energies from stationary gas targets deviate from Eq. (1) by no more than 3%. Results of calculations [6] for temperatures up to 3000°K based on the same theory, but using the interatomic potential proposed by Buck et al. [16], practically agree with (1). Calculations by Watson [13] using a (12-6) Lennard-Jones potential with parameters found from high-temperature data on the viscosity of krypton deviate from Eq. (1) by no more than 2% for temperatures up to 2000°K. Sevast'yanov and Zykov [14] calculated the transport coefficients of monatomic gases by using a (12-7) Lennard-Jones type potential with parameters determined from experimental data on the second virial coefficient, compressibility, and viscosity. Up to 2000°K the results of these calculations deviate from Eq. (1) by no more than 1%; at 5000°K the deviation is 5%. The values which deviate most from Eq. (1) were calculated by Swehla [12] using a (12-6) potential with parameters determined from rather inaccurate low-temperature data on viscosity, and extended to temperatures up to 5000°K.

Xenon. The data on the thermal conductivity of xenon in the high-temperature region known at the present time are listed in Table 3, and Fig. 3 shows a logλ—logT plot of the experimental data on the thermal conductivity of xenon. The pattern is similar to that of Fig. 1 for krypton. For T < 800°K the experimental data for xenon lie well below the straight line which describes the results of measurements for T > 800°K. Consequently, the temperature dependence of the thermal condutivity of xenon is represented by a power law for T > 800°K.

In the temperature range 1000-1500°K the results in [17-20] are 3-4% larger than those reported in [5, 6, 21]. In [5, 6] the temperature ranges are appreciably wider — up to 2400°K. In the higher temperature region there is only the paper of Matula [8], where the shock tube measurements of the thermal conductivity of xenon up to 5000°K are reported. The results of this investigation, as for krypton in [7], are ≈11% below those obtained by steady-state methods over the whole region of overlap (1500-2500°K) of the temperature ranges investigated. It is believed that the cause of the underestimate of values in [8] is the same as in [7] for krypton. Therefore, the data in [8] have a systematic error, and should be increased by ≈11% over the whole temperature range investigated.

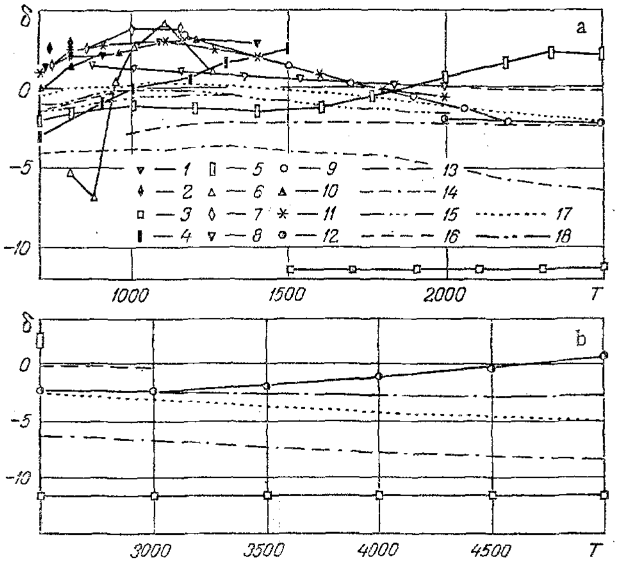

Fig. 2. Deviation $\delta = (\lambda - \lambda_{pow})/\lambda_{pow}$ in % from power law (1) for krypton according to the following data: 1-10) notation same as Fig. 1; 11) [1]; 12) [11]; 13) [10]; 14) [12]; 15) [13]; 16) [6]; 17) [14]; 18) [2].

TABLE 2. Thermal Conductivity of Krypton and Xenon. $\lambda \cdot 10^3$ is in W/m•°K

T, K	Kr	Xe	T, K	Kr	Xe
700	19,4	—	2400	45,4	28,8
800	21,3	13,5	2500	46,7	29,6
900	23,1	14,6	2600	48,0	30,4
1000	24,8	15,7	2700	49,3	31,2
1100	26,5	16,8	2800	50,5	32,0
1200	28,1	17,8	2900	51,8	32,8
1300	29,7	18,9	3000	53,0	33,6
1400	31,3	19,8	3200	55,4	35,1
1500	32,8	20,8	3400	57,7	36,6
1600	34,3	21,8	3600	60,1	38,1
1700	35,8	22,7	3800	62,4	39,5
1800	37,2	23,6	4000	64,6	41,0
1900	38,6	24,5	4200	66,8	42,4
2000	40,0	25,4	4400	69,0	43,8
2100	41,4	26,2	4600	71,1	45,1
2200	42,8	27,1	4800	73,2	46,5
2300	44,1	28,0	5000	75,3	47,8

TABLE 3. Papers on the Thermal Conductivity of Xenon at High Temperatures (in chronological order)

Reference	Method of investigation	Temp. range, °K	Error in % estimated by author
[24]	Heated filament	316—800	—
[8]	Shock tube	1400—5000	—
[17]	Conductivity column	350—1500	2
[18]	Heated filament	400—1100	2,8
[21]	Conductivity column	1000—1500	4
[19]	»	400—1400	2,5—3,5
[20]	Coaxial cylinders	700—1200	3—4
[5]	Conductivity column	1100—2200	3
[6]	»	500—2400	2,5—5

Analysis of the experimental data showed that the measured values of the thermal conductivity of xenon in the temperature range 800-5000°K at atmospheric pressure can be represented by the power law

$$\lambda = 0.0135\,(T/800)^{0.69}. \tag{2}$$

The values of the thermal conductivity calculated from Eq. (2) are in error by 3% in the temperature range 800-2000°K, and up to 6% for T > 2000°K. The values of the thermal conductivity calculated from Eq. (2) are listed in Table 2.

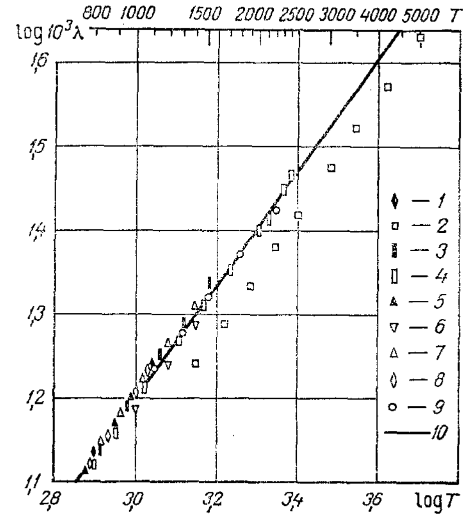

Fig. 3. Thermal conductivity of xenon according to the following data: 1) [24]; 2) [8]; 3) [17]; 4) [6]; 5) [18]; 6) [21]; 7) [19]; 8) [20]; 9) [5]; 10) (2). λ is in W/m·°K; T in °K.

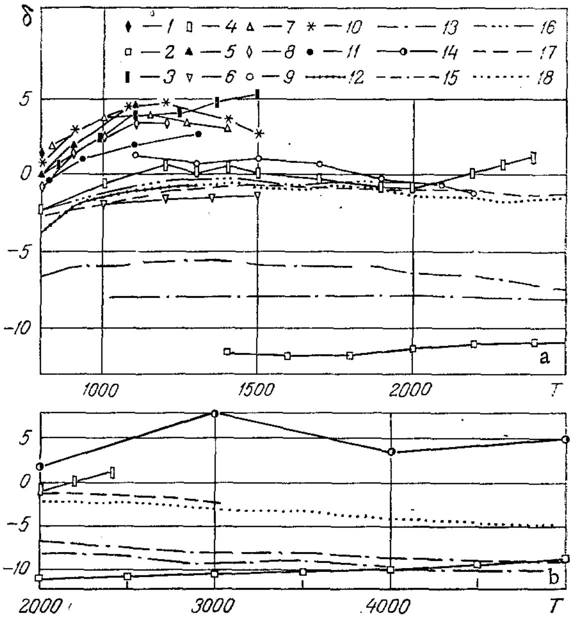

Fig. 4. Deviation $\delta = (\lambda - \lambda_{pow})/\lambda_{pow}$ in % from power law (2) for xenon according to the following data: 1-9) notation same as in Fig. 3: 10) [1]; 11) [3]; 12) [2]; 13) [10]; 14) [11]; 15) [12]; 16) [13]; 17) [6]; 18 [14].

Figure 4 shows the deviations of the available experimental data (Table 3) from the power law (2). It is clear from the figure that in the temperature range 1000-1500°K the results in [5, 6, 21] lie within 2% of our correlation, and those of [17-20] are 3-4% above, as are the values from the correlation for xenon cited in [1] for temperatures up to 1500°K. The correlated results for the thermal conductivity of xenon given by Bakulin and Ulybin [3] for temperatures from 1000 to 1300°K are 1.5-2.5% higher than the values found from Eq. (2).

The data recommended by Rabinovich [2], based on a combined analysis of experimental data on the viscosity and thermal conductivity of xenon at 800°K, are ≈4% lower than our correlation: the difference decreases rapidly with increasing temperature and is less than 1% in the range 1100-1130°K.

Figure 4 also shows the deviations from the power law (2) of results calculated in [6, 10-14] by using rigorous kinetic theory [15] with various interatomic potential functions.

Amdur and Mason [10] calculated values in the range 1000-15000°K by using a power-law potential found from scattering experiments. The authors estimated that their results are accurate to 10%. It is clear from the figure that, on the average, the data of [10] are lower than the values found from Eq. (2) by 9%. Similar investigations were performed later by Kamnev and Leonas [11] in the temperature range 2000-10,000°K. The results obtained for the thermal conductivity of xenon are 3-8% higher than our correlation. The authors estimated that their results are accurate to 5%. The values calculated by Swehla [12] are 7-9% below those found from Eq. (2). The deviation of the values calculated by Watson [13] is less than 1% for $T > 1000$°K, and about 2% for $T = 800$-1000°K. The values calculated in [6] by using the potential proposed by Barker et al. [22] are in good agreement with Eq. (2): the deviation is ~2% over the whole temperature range 800-3000°K. The values calculated by Sevast'yanov and Zykov [14] up to 3000°K are very nearly the same as those from [6]; for $T > 3000$°K the deviation of the values in [14] from Eq. (2) increases to 5% at 5000°K.

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THERMAL DIFFUSIVITY OF INHOMOGENEOUS SYSTEMS.

II. EXPERIMENTAL DETERMINATION OF THERMAL DIFFUSIVITY

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We investigated the methodical error in the measurement of the effective thermal diffusivity of inhomogeneous systems. We give the recommendation for the choice of the dimensions of the inhomogeneous specimen.

In [1] we established the conditions under which the nonstationary temperature field of a heterogeneous system can be calculated with an admissible degree of approximation by using the model of a quasihomogeneous body with effective thermal diffusivity

$$a = \lambda / c\rho. \quad (1)$$

In this paper we shall consider the problem of experimentally determining the effective thermal diffusivity. Measurements of thermal diffusivity use methods whose calculation formulas are based on the solution of the corresponding nonstationary problems for homogeneous bodies, and therefore there is a methodical error caused by the inhomogeneity of the representative element (specimen). By the error in the measurement of the effective thermal diffusivity we shall mean the difference between the value obtained from the experiment and the effective parameter determined in accordance with (1):

$$\delta a = \frac{a_{\text{m}} - a}{a}.$$

For systems with long-range order the problem of choosing a representative element of an inhomogeneous system consists in determining the number of elementary cells in the specimen for which the deviation of the temperature field from the field of a quasihomogeneous body will not lead to a methodical error δa that exceeds the admissible value. We use the following method of investigation:

a) the behavior of the measuring experiment is simulated by a numerical solution obtained on a computer for the corresponding boundary-value problem for an inhomogeneous system;

b) the value a_{m} of the thermal diffusivity obtained on the basis of the numerical solution by the calculation formula of the method is comparable to the effective parameter a;

c) a computer-empirical relation is constructed for determining the dimensions of a representative element.

The error in the measurement of the effective thermal diffusivity depends on the method of measurement, the structure of the system, the concentrations of the components and the

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