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THERMAL CONDUCTIVITY OF GASEOUS NEON AND KRYPTON AT REDUCED TEMPERATURES AND ATMOSPHERIC PRESSURE

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The results of an experimental and theoretical investigation of the thermal conductivity of neon and krypton at reduced temperature and atmospheric pressure are presented and discussed.

The thermal conductivities (λ) of krypton [1, 2, 15] and neon [1, 3-5, 15] have been investigated fairly completely at temperatures of 273°K and below and an atmospheric pressure, and preliminary values of the thermal conductivity of neon measured as a function of the temperature and pressure have been given in [6]. In view of the fact that existing methods of calculating the thermal conductivity do not describe the experimental data sufficiently accurately over a wide temperature range, the latter are of particular value both for the further development of molecular-kinetic theory and for use in calculations of heat-exchange apparatus and heat-transfer processes.

In this paper we present the results of experimental investigations of the thermal conductivities of neon and krypton at atmospheric pressure in the temperature range of 90-273°K and 120-273°K, respectively. The investigations were made using experimental equipment based on the use of the absolute heated-filament method described in [7].

For the investigation we used neon of high purity containing up to 0.11% of impurity, of which 0.1% was helium, and pure krypton with a krypton content of 99.97%.

Figure 1 compares the experimental values obtained for the thermal conductivities of neon and krypton as a function of temperatures with existing experimental and theoretical values calculated using the Lennard-Jones [8-10], Morse [11], and exp-6 [9-12] potentials.

Our experimental data on neon are in good agreement with the results obtained by other authors and with the preliminary values of the thermal conductivity given in [6], which indicates that they are reliable and independent of the pressure in the limits from 0.7 atm to 1 atm.

Calculation shows that for neon the values calculated for the Lennard-Jones potential with intermolecular interaction parameters $\varepsilon/k = 35.7°K$, $\sigma = 2.789$ Å [8]; $\varepsilon/k = 43°K$, $\sigma = 2.73$ Å [9]; $\varepsilon/k = 45.58°K$, $\sigma = 2.707$ Å agree best of all with the experimental data. The maximum disagreement between the data is 0.8, 1.5, and 1.6%, respectively.

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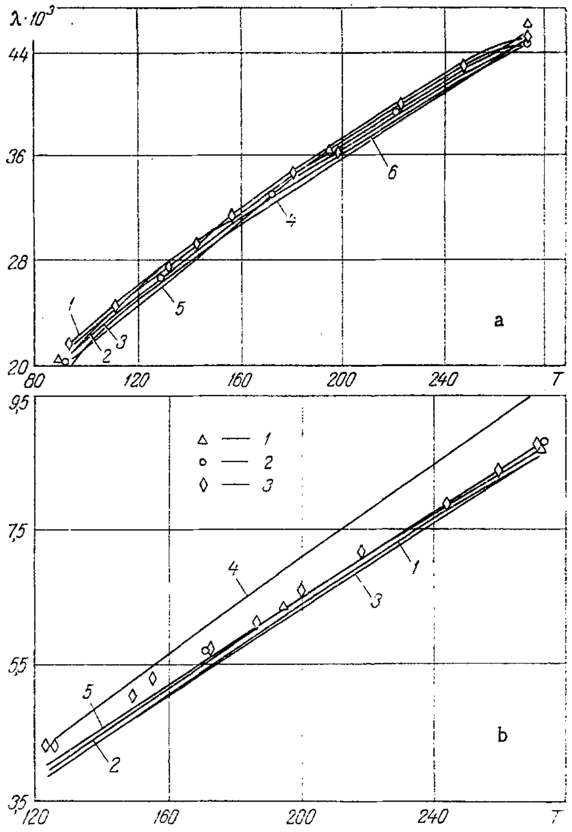

Fig. 1

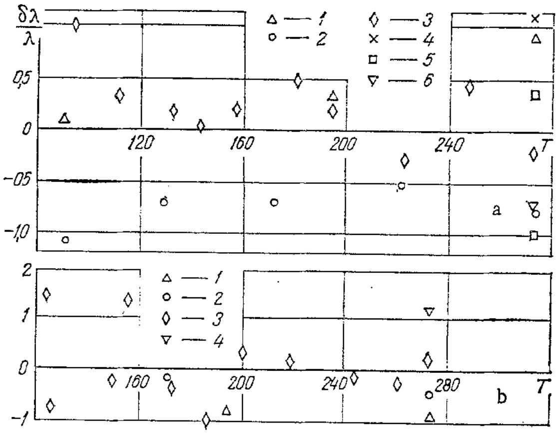

Fig. 2

Fig. 1. Thermal conductivity of: a) gaseous neon; b) gaseous krypton, as a function of temperature at atmospheric pressures. For a) the experimental data are: 1) [1]; 2) [6]; 3) our measurements. The theoretical data obtained using potentials: 1) Lennard-Jones [8]; 2) Lennard-Jones [9]; 3) Lennard-Jones [10]; 4, 5) Morse [11]; 6) exp-6 [12]. For b) the experimental data are: 1) [1]; 2) [2]; 3) our measurements. The theoretical data obtained using potentials: 1) Lennard-Jones [8]; 2) Lennard-Jones [9]; 3) Lennard-Jones [10]; 4) exp-6 [12]; 5) exp-6 [9].

Fig. 2. Differences between the experimental values of the thermal conductivity of neon (a) and the values calculated from Eq. (1) (1 – experimental data [1]; 2 – [6]; 3 – our measurements; 4 – [5]; 5 – [3, 4]; 6 – [15]) and krypton (b) calculated using Eq. (2) (1 – experimental data [1]; 2 – [2]; 3 – our measurements; 4 – [15]). $\delta\lambda/\lambda$, %; T, °K.

The experimental data [1, 2] for krypton agree fairly well with our results. The best agreement with experiment is obtained for values calculated using the Lennard-Jones potential (ε/k = 193°K, σ = 3.61 Å) [1] and the exp-6 potential (ε/k = 158.3°K, σ = 4.056 Å) [9]. The maximum disagreement between the experimental and theoretical data occurs in the temperature range close to the saturation line; for the Lennard-Jones potential it is 8.1%, and for the exp-6 potential it is 7.6%.

When processing the results of the measurements we took into account the correction for heat loss from the ends of the heater and radiation, the sum of which for neon did not exceed 2% and for krypton 3.1% of the amount of heat dissipated. The maximum values of the correction for the drop in temperature on the walls of the glass tube of the measuring cell of neon and krypton are 0.74 and 0.16%, respectively, of the measured temperature drop. The remaining corrections which affect the true value of the thermal conductivity were ignored due to their smallness. The error in the data obtained was ±1.2%. For a confidence coefficient of 0.95 the measurement error was ±0.5%.

On the basis of the experimental data obtained and existing experimental data on the thermal conductivities of gaseous neon at T = 90–273°K and krypton (T = 120–273°K) and atmospheric pressure, using the method of least squares, we obtained the equations

$$\lambda = a + bT + cT^2 + dT^3 \quad [\mathrm{W/m\cdot deg}], \qquad (1)$$

TABLE 1. Comparison of the Values of the Thermal Conductivity of Gaseous Neon and Krypton Obtained Using Eqs. (1) and (2) with the Values Recommended in [13, 14]

T, K	Krypton			Neon		
	$\lambda \cdot 10^3$ our work	$\lambda \cdot 10^3$ [13]	Δ	$\lambda \cdot 10^3$ our work	$\lambda \cdot 10^3$ [13]	Δ
90	—	—	—	20,41	20,4	+0,05
100	—	—	—	22,24	22,2	+0,18
110	—	—	—	23,99	23,9	+0,38
120	4,15	4,05	+2,41	25,67	25,6	+0,27
130	4,45	4,37	+1,80	27,30	27,2	+0,37
140	4,76	4,69	+1,47	28,86	28,8	+0,21
150	5,06	5,01	+1,00	30,38	30,3	+0,26
160	5,36	5,33	+0,56	31,84	31,8	+0,13
170	5,66	5,62	+0,71	33,25	33,3	—0,15
180	5,97	5,93	+0,67	34,62	34,7	—0,23
190	6,27	6,23	+0,64	35,95	36,1	—0,42
200	6,57	6,53	+0,61	37,25	37,5	—0,67
210	6,87	6,83	+0,58	38,52	38,8	—0,73
220	7,18	7,13	+0,70	39,76	40,1	—0,86
230	7,48	7,42	+0,80	40,97	41,4	—1,05
240	7,78	7,72	+0,77	42,17	42,6	—1,02
250	8,09	8,01	+1,00	43,35	43,8	—1,04
260	8,39	8,29	+1,19	44,52	44,9	—0,85
270	8,69	8,57	+1,38	45,69	46,1	—0,90
273,15	8,79	8,66	+1,48	46,05	46,4	—0,76
		[14]			[14]	
90	—	—	—	20,41	20,5	—0,44
125	4,30	4,20	+2,33	26,49	26,8	—1,17
175	5,81	5,85	—0,69	33,94	33,6	+1,00
225	7,33	7,20	+1,77	40,37	39,9	+1,16
273	8,78	8,85	—0,80	46,03	45,8	+0,50

<u>Note.</u> λ, W/m·deg; $\Delta = (\lambda_{\mathrm{our.work}} - \lambda_{\mathrm{rec}})/\lambda_{\mathrm{our.work}}$, %.

where $a = 0.216 \cdot 10^{-3}$; $b = 0.2682 \cdot 10^{-3}$; $c = -0.5451 \cdot 10^{-6}$; $d = 0.65 \cdot 10^{-9}$,

$$\lambda = a + bT \ [\mathrm{W/m \cdot deg}], \tag{2}$$

where $a = 0.5175 \cdot 10^{-3}$; $b = 0.3027 \cdot 10^{-4}$.

The differences between the experimental data and the theoretical data calculated from Eq. (1) for neon and that for krypton calculated from Eq. (2) are shown in Fig. 2. They do not exceed 1.1% for neon and 1.4% for krypton.

The values of the thermal conductivity of neon and krypton given in the table obtained from Eqs. (1) and (2), the error of which is estimated to be 1.4% for krypton and 1.1% for neon, are comparable with the recommended values [13, 14].

Since in our time four experimental values of the thermal conductivity of krypton at atmospheric pressure have been published (at temperatures of 194.65, 273.15°K [1], and 171.35 and 273.15°K [2]), an approximation for the smoothing of the data [1, 2] in the region close to the saturation line below 171.35°K is hardly legitimate, as is confirmed by the differences between the data obtained at temperatures below 150°K (up to 2.5% [13, 14]) and the values obtained using Eq. (2).

Our data for neon are in good agreement with the recommended values [13, 14] and, in our opinion, are to be preferred in view of the fact that they were obtained on the basis of a greater volume of experimental data.

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EFFECTIVE TRANSVERSE CONDUCTIVITY OF LAYERED MATERIALS WITH THROUGH CRACKS IN THE LAYERS

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The problem of the transverse conductivity of a multilayered packet when loaded in the same plane as the layers, which are mechanically independent, in the presence of or on the generation of a number of through cracks in the layers under load is analyzed.

1. For the sake of brevity we shall refer in this and the subsequent sections to thermal conductivity, but diffusion taking into account the influence of changes in concentration on changes in volume can be treated analogously.

1.1. Let us consider a packet of layers, parallel with the xy plane, containing a number of through cracks (see Fig. 1). The conductivity of unloaded layers with cracks will be treated as negligible compared with the conductivity of the medium in the exposed cracks and of the medium between the layers; the mean resistance of the medium between the layers will be neglected. The loading of the layers is determined by the conditions at the periphery of the packet. When the cracks are exposed by the action of extension, the layer acquires a finite effective conductivity and under certain conditions leakage may occur through the packet, i.e., it loses its insulating properties. A similar situation arises in many cases of practical importance. The problem of the loss of insulating properties in a multilayered packet is examined theoretically below.

The effective conductivity of the packet perpendicular to the layers at a certain point z under the conditions indicated is equal to

$$\lambda = \lambda' \sum_a S^{(a)}. \tag{1}$$

Here $S^{(a)}$ is the area of the exposed a crack (a jump in the normal component of displacement integrated along the length of the crack) and λ' is the coefficient of thermal conductivity of the medium in the cracks. Assuming that the layers with cracks are under plane stressed state conditions, we have (for derivation see [1, 2])

$$\varepsilon_{ik} = \varepsilon^0_{ik} + \frac{1}{2} \sum_a (n_i S^{(a)}_k + n_k S^{(a)}_i). \tag{2}$$

Here ε_{ik} is the effective strain tensor of the layer, ε^0_{ik} is the mean strain tensor of the material outside the crack (the strains are assumed to be slight), n_i is the vector of the unit line normal to the crack (the cracks are assumed to be rectilinear), and $S^{(a)}_i$ is the i-component of the displacement jump integrated along the length of the crack. Since $n_i S^{(a)}_i = S^{(a)}$ (recurrent index summing), it follows from (1) and (2) that

$$\lambda = \lambda' (\varepsilon_{ii} - \varepsilon^0_{ii}). \tag{3}$$

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