VIRIAL COEFFICIENTS OF NEON, ARGON, AND KRYPTON AT TEMPERATURES UP TO 3000°K

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The second and third virial coefficients are calculated for a (12-7, δ) pair model potential. With their help the fourth virial coefficient is determined from the experimental p, ρ, and T data. The limits of applicability of the equation of state obtained is indicated.

Over the past five years the range of measurements of transport properties [1-3] and virial coefficients [4] of gases has been significantly extended and data on these quantities have been refined and generalized as a result of improvements in the experimental procedure and technique, as well as deeper understanding of real physical processes occurring during measurements performed by stationary and nonstationary methods. These studies concern largely the simplest systems, such as the monatomic gases.

In this paper, based on a combined description of the data on the transport properties and the second virial coefficient, more accurate values are obtained for the force constants of the (12-7, δ) model pair potentials [5] for neon, argon, and krypton. For argon and krypton the new constants (see Table 1) differ from the previously published values by not more than ±1%; for neon they remain the same [5]. In Table 2 the computed values of the second virial coefficient are compared with the generalized experimental data [4]. As a rule, the results agree within the limits of error indicated in [4]. In the calculation of the third virial coefficient (see Table 3) both quantum effects and the nonadditivity of the potential energy of three-particle interactions were taken into account [6]. For all gases the computed values of the third virial coefficient agree with the experimental data [4] within the limits of disagreement between the measurements performed by different authors.

The computed values of the second and third virial coefficients were then used to determine the fourth virial coefficient from the p, ρ, and T data from the Amsterdam laboratory [7-9]. These measurements cover a wide range in the density (pressure) and are thought to be most reliable [10]. In the calculations the equation of state was given in the form of a polynomial of degree seven in the density. For the "true" leading virial coefficient the mean value of the corresponding polynomial on the section of stability was used. The values of the "true" fourth virial coefficients, obtained on the isotherms, were then used to determine by the method of least squares the coefficients α and β in the expression

$$D^* = \frac{D}{(b_0)^3} = \frac{\alpha(\delta)}{(T^*)^{3/4}} - \frac{\beta(\delta)}{(T^*)^{3/2}}, \qquad (1)$$

where $b_0 = (2/3)\pi N\sigma^3$ and $T^* = kT/\varepsilon$. This expression was used to approximate the temperature dependence of the fourth virial coefficient for $T > 0.7T_B$ [11]. For the monatomic gases

TABLE 1. Values of Constants for Neon, Argon, and Krypton

Substance	ε/k, K	σ·10⁸, cm	ν*	Λ*	T_B, K
Neon	45,5	2,717	0,060	0,532	122
Argon	150	3,315	0,075	0,171	407
Krypton	212	3,530	0,035	0,093	575

Note. $\Lambda^* = \frac{h}{\sigma\sqrt{m\varepsilon}}$ is a quantum-mechanical parameter; $\nu^* = \frac{3}{4} \times \frac{\alpha C_6}{\varepsilon\sigma^9}$ is the reduced coefficient of the nonadditive three-dipole interaction.

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TABLE 2. Comparison of the Computed (I) Values of the Second Virial Coefficient B, cm^3/mole, with the Generalized Experimental Data [4] (II)

T, K	Neon		Argon		Krypton	
	I	II	I	II	I	II
60	−25,5	−24,8±1,0				
81	−11,6	—	−276,2	−276±5		
110	−2,2	—	−154,6	−154,5±1	−364,0	−364±10
125	+0,8	−0,4±1,0	−121,9	−123,0±1	−283,4	—
150	4,1	+3,2±1,0	−86,4	−86,2±1	−200,8	−200,7±2
200	8,1	7,6±1,0	−47,8	−47,4±1	−117,2	−116,9±1
250	10,2	—	−27,5	−27,9±1	−75,4	−75,7±1
300	11,5	11,3±1,0	−15,0	−15,5±0,5	−50,6	−50,5±1
400	13,0	12,8±1,0	−0,5	−1,0±0,5	−22,6	−22,0±1
500	13,6	—	+7,3	+7,0±0,5	−7,4	−8,1±0,5
600	14,0	13,8±0,8	12,2	12,0±0,5	+2,2	+1,7±0,5
700	14,2	—	15,5	15,0±1	8,4	8,2±0,5
800	14,3	—	17,8	17,7±1	12,9	
900	14,3	—	19,6	20,0±1	16,3	
1000	14,3	—	20,9	22,0±1	18,9	
1500	14,1	—	24,2	—	26,0	
2000	13,7	—	25,4	—	28,8	
2500	13,4	—	25,9	—	30,2	
3000	13,1	—	26,0	—	30,9	

TABLE 3. Computed Values of the Third Virial Coefficient and the Limit of Applicability of the Proposed Equation of State

T, K	C, cm^6/$mole^2$			p_{max}, MPa		
	neon	argon	krypton	neon	argon	krypton
60	455	—	—			
81	331	—	—			
110	263	681	—			
125	248	1900	−11750			
150	233	2080	+834			
200	220	1560	3440	71,1	—	—
250	213	1220	2830	98,7	19,6	—
300	208	1030	2270	128	30,2	—
400	200	854	1660	190	53,5	31,1
500	192	786	1390	255	81,7	50,0
600	185	753	1260	322	110	69,7
700	179	732	1190	393	140	94,3
800	174	717	1140	466	171	118
900	169	705	1110	541	202	142
1000	164	695	1090	618	235	167
1500	146	651	1020	1030	408	299
2000	133	615	971	1480	593	443
2500	123	584	929	1950	789	593
3000	115	558	893	2450	996	750

studied ($\delta = 0$) the values $\alpha = 1.278$ and $\beta = 1.692$ were obtained. Thus the equation of state is unique for the indicated gases. In transferring from one gas to another only the values of the constants in the interparticle interaction potential are available (see Table 1).

Taking into account the fourth virial coefficient made it possible to more than double the region of applicability of the equation of state. The boundary of the region of applicability increases as the temperature increases and can be described approximately in the form

$$\rho \leqslant \frac{0.55}{B + T\frac{dB}{dT}}, \qquad (2)$$

where B is the second virial coefficient.

The values of the pressure corresponding to this density limit for neon, argon, and krypton are presented in Table 3. Within the limits of the indicated pressures the deviations between the computed values of the thermodynamic functions and the handbook data [10] do not exceed ±0.1% for the entropy and ±0.5% for the density and enthalpy.

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EFFECT OF THE CHARACTERISTIC MAGNETIC FIELD OF A HIGH-CURRENT ELECTRON BEAM ON ENERGY RELEASE IN TARGETS

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The character of the energy released by a high-current electron beam in metal targets is studied taking into account the self-action of the beam.

When an electron beam interacts with a metal barrier, matter is heated, melted, evaporated, and dispersed. The flow of the indicated processes is largely determined by the character of the energy release by fast electrons, i.e., the heat source, forming in the material. The distribution of energy losses by weak-current electron beams is usually calculated using the linear single-electron approximation [1, 2], when only the interaction of fast electrons in the beam with atoms and electrons in the material is taken into account. As experiments have demonstrated [3, 4], for high-current electron beams (HCEB, $I \geqslant 10$ kA), compared with weak-current beams, it is observed that the penetration depth of the electrons in the target decreases, energy release in thin targets increases, and the heating is more intense. To explain these facts the high-current electron beam must be regarded as a flux of charged particles, whose evolution is determined by the characteristic electromagnetic fields [5], i.e., it is necessary to take into account in addition (compared with the weak-current beam) the interaction of fast electrons in the beam with one another via the characteristic fields.

This paper is devoted to the study of the effect of the characteristic magnetic field of HCEB on the energy released in Al, Cu, and Au targets. The basic assumptions made in formulating the problem and the methodology are analogous to those presented in [6]:

1) since the relaxation time of a fast electron is much shorter than the characteristic time over which the parameters of the beam change, the kinetic equation is solved in the quasistationary approximation;

2) because of the high conductivity of the plasma formed the electric field of the thermalized electrons is neglected; and,

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