ACOUSTIC VELOCITY IN AND DENSITY OF BINARY HELIUM—ARGON MIXTURES

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UDC 533.27

The acoustic velocity in four different mixtures of the helium—argon system and the specific volume of two different mixtures of this system were measured over the 298.16-473.16°K temperature range under pressures from 50 to 400 MPa.

The properties of mixtures of nitrogen with methane and with helium had been studied earlier [1, 2]. It was also of interest to study a simpler system of monatomic gases useful for practical applications in aerodynamics.

Acoustic Velocity in Helium—Argon Mixtures. In another study [3] the acoustic velocity in helium—argon mixtures was measured under pressures below 10 MPa at 320.16 and 423.16°K. The study [4] covering the 50:50 helium—argon mixture at 298.16°K over a pressure range up to 1300 MPa was, in these authors' view, performed incorrectly and the reasons will be discussed here later on.

We have studied mixtures with molar fractions of helium 0.656, 0.734, and 0.952, respectively, at temperatures of 298.16, 323.16, 373.16, and 423.16°K as well as a mixture with the molar fraction of helium 0.314 at 373.16°K, all under pressures from 50 to 400 MPa. The acoustic velocities in pure helium and in pure argon have been determined in earlier studies [5, 6].

The acoustic velocity was measured by the pulse method [7], involving essentially determination of the time of travel of an ultrasonic pulse through a fixed distance between two quartz plates inside a vessel containing the given medium. The pressure was measured with several spring-type manometers of class 1 accuracy. The concentration in a mixture was determined accurately within 0.1% from its molecular mass. These measurements were made at frequencies from 1.4 to 4 MHz. No dispersion of the acoustic velocity was noted over the entire range of parameters.

The dependence of the acoustic velocity c on the pressure p in helium—argon mixtures at 298.16°K, shown in Fig. 1, indicates that helium in not very high concentrations has little effect on the acoustic velocity in such a mixture. In contrast, small additions

TABLE 1. Specific Volume v (m^3/kg) of Helium—Argon Mixtures under Various Pressures (MPa) at 373.16 and 473.16°K

p	Molar fraction of helium in a mixture			
	0,656		0,952	
	373,16 °K	473,16 °K	373,16 °K	473,16 °K
	$v\cdot 10^3$	$v\cdot 10^3$	$v\cdot 10^3$	$v\cdot 10^3$
50	4,625	5,568	12,815	15,949
60	4,032	4,798	11,136	13,593
80	3,247	3,823	8,916	10,685
100	2,779	3,236	7,502	8,951
120	2,456	2,833	6,503	7,806
140	2,225	2,558	5,848	6,944
160	2,055	2,347	5,397	6,276
180	1,925	2,183	5,008	5,722
200	1,821	2,051	4,685	—
220	1,726	1,941	—	—
240	1,647	1,848	—	—
250	1,614	1,805	—	—

M. V. Lomonosov Moscow State University. Institute of High-Pressure Physics, Academy of Sciences of the USSR, Moscow. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 39, No. 6, pp. 1090-1094, December, 1980. Original article submitted June 28, 1979.

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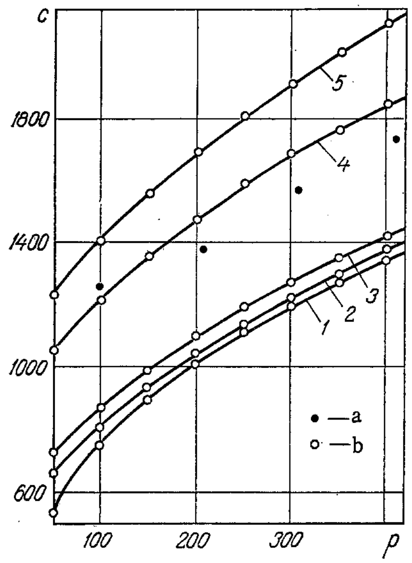

Fig. 1

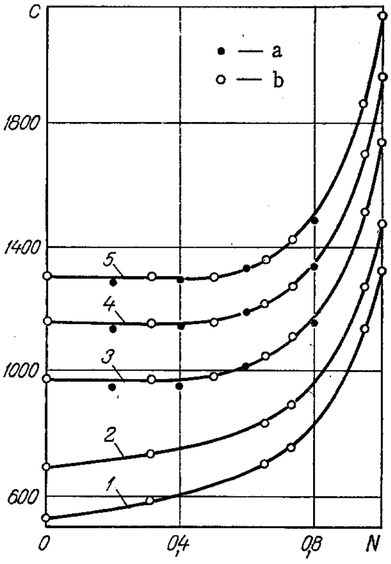

Fig. 2

Fig. 1. Dependence of the acoustic velocity c (m/sec) on the pressure p (MPa) in mixtures with molar fractions of helium: 1) 0 (pure argon); 2) 0.656; 3) 0.734; 4) 0.952; 5) 1.0 (pure helium) at 298.16°K; a) data in study [4]; b) data obtained in this study.

Fig. 2. Dependence of the acoustic velocity c (m/sec) on the molar fraction N of helium in a mixture at 373.16°K and pressures (MPa): 1) 50; 2) 100; 3) 200; 4) 300; 5) 400: a) data obtained by V. A. Abovskii; b) experimental data obtained in this study.

of argon to pure helium increase the acoustic velocity sharply. On the same diagram are also shown results of that questionable study [4]. A small addition of helium cannot increase the acoustic velocity to a level nearly as high as in pure helium, which would follow from that other study [4]. The curve depicting the pressure dependence of the acoustic velocity in a 50:50 mixture of the two components should lie between curves 1 and 2, corresponding, respectively, to pure argon and to a 0.656 molar fraction of helium. Inasmuch as the readings of acoustic velocity obtained in that study [4] agree with our readings, the error could possibly be due to insufficiently thorough mixing of helium and argon in that experiment, especially since those authors have not analyzed the mixture but proceeded on the basis of equal pressures of both components.

The dependence of the acoustic velocity in a mixture on the molar fraction N of helium at various pressures is shown in Fig. 2. On the same diagram have also been plotted data on the acoustic velocity according to calculations by Abovskii on the basis of his equation of state [8] for dense gases. The maximum discrepancy between theoretical and experimental data is 2%, but does not exceed 1% on the average, which can be regarded as a satisfactory confirmation of Abovskii's theory by our experiment.

The nonlinear trend of the curves in Fig. 2 is entirely explainable if one considers that in an ideal gas the acoustic velocity c is inversely proportional to the square root of the molecular mass $(c \sim 1/\sqrt{M})$. Upon eliminating this "ideal gas" relation, by changing to $(c\sqrt{M}, N)$ coordinates, we obtain the curves shown in Fig. 3. In addition to the curves for helium—argon mixtures, there are also shown here curves for nitrogen—helium and nitrogen—methane mixtures. All these relations can be approximated with straight lines, which suggests that the product $c\sqrt{M}$ is additive with respect to the molar fraction.

The trend of the temperature dependence of the acoustic velocity depends strongly on the concentration (Fig. 4). In the mixture with a molar fraction of helium 0.952, the acoustic velocity increases with rising temperature, while the slope of the straight lines representing this dependence (which is linear) decreases with rising pressure. Such a trend

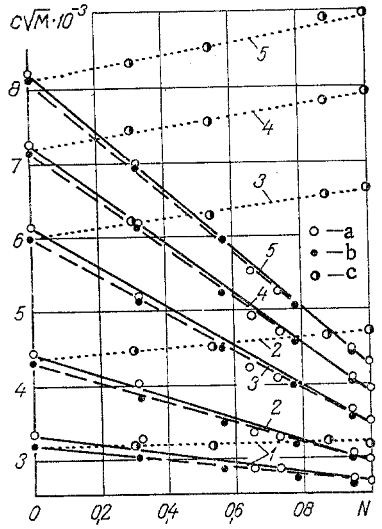

Fig. 3

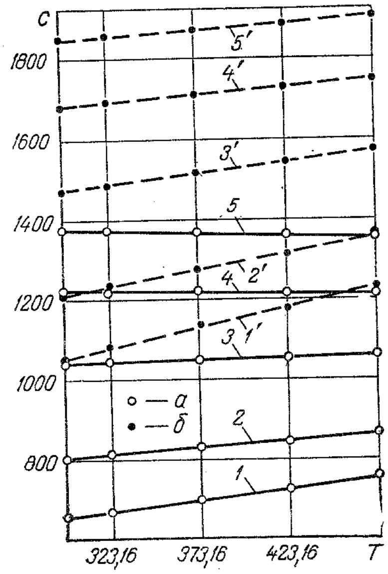

Fig. 4

Fig. 3. Dependence of $c\sqrt{M}$ on the molar fraction N of the light component at pressures (MPa): 1) 50; 2) 100; 3) 200; 4) 300; 5) 400 for mixtures: (a) helium—argon (373.16°K); (b) nitrogen—helium (373.16°K); (c) nitrogen—methane (348.16°K).

Fig. 4. Dependence of the acoustic velocity c on the temperature T, °K, for mixtures with molar fraction of helium 0.656 (1-5) — a and 0.952 (1'-5') — b for various pressures: 1, 1') 50; 2, 2') 100; 3, 3') 200; 4, 4') 300; 5, 5') 400 MPa.

is characteristic of pure helium too. In the mixture with a molar fraction of helium 0.656, the acoustic velocity increases with rising temperature at pressures below 200 MPa, does not depend on the temperature at 200 MPa, and decreases with rising temperature at pressures above 200 MPa. This trend is similar to the trend of the acoustic velocity in pure argon, except that there its temperature dependence changes at 40 MPa rather than at 200 MPa as in an argon—helium mixture.

Density of Helium—Argon Mixtures. The density of helium—argon mixtures has been measured by several authors, but of interest in this study were pressures above 50 MPa and these had been attained only by the authors of three studies: the compressibility of four helium—argon mixtures was measured by the Barnett method at 223.16, 273.16, and 323.16°K under pressures below 70 MPa [9], the compressibility of three helium—argon mixtures was measured at temperatures from 293.16 to 353.16°K under pressures from 30 to 60 MPa [10], and the compressibility of two helium-argon mixtures was measured at temperatures from 298.16 to 423.16°K under pressures up to 800 MPa [11].

In this study was measured the density of two helium—argon mixtures with a molar fraction of helium 0.656 and 0.952, respectively, at 373.16 and 473.16°K under pressures from 50 to 250 MPa each. The results are presented here in Table 1. The measurements were made by the weighing method [12] in a constant-volume piezometer. Deformation of the piezometer under pressure has been taken into account in the Lamé equation, according to the recommendations in study [13].

The molar volumes in the helium—argon mixtures obtained by these authors at 373.16°K agree, within experimental accuracy, with the data obtained by Maslennikova [11], where the two pressure ranges overlap. The molar volumes calculated by Abovskii for 373.16°K and 200 MPa differ from the experimentally determined ones by 1.5–1.8%. This discrepancy exceeds the experimental error.

NOTATION

c (m/sec), acoustic velocity; p (Pa), pressure; N, molar fraction of helium in a mixture; M, relative molecular mass of a mixture; T (°K), temperature; and v (m^3/kg), specific volume.

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