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1962

SovietRxiv

Fig. 1

Figure 1: Fig. 1

Abstract

Full Text

PHYSICS

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MEASUREMENT OF THE VELOCITY OF ULTRASOUND IN CERTAIN GASES IN A STATE OF HIGH DENSITY

It is known that certain approaches in the theory of the liquid state are based on the fact that a liquid is likened to a strongly compressed gas. It is therefore important to know the state and behavior of gases at high densities. The most effective method used for this purpose is the ultrasonic method.

The study of the influence of pressure on the propagation velocity of ultrasonic waves makes it possible to calculate certain thermodynamic functions for high pressures (the ratio of heat capacities $\gamma = c_p/c_v$ and the coefficient of adiabatic compressibility β_{ad}).

Up to now, comparatively few works have been known in the literature devoted to the study of the dependence of the velocity of sound on pressure. As a rule, in these works the pressures do not exceed one hundred atmospheres. Only Lakam and

Fig. 1

Nuri[1,2] measured the velocity of sound in argon, nitrogen, methane, and propane as a function of pressure up to 1000 atm. It is also necessary to note the work of M. P. Volarovich and D. B. Balashov[3], in which the velocities of sound in nitrogen up to 1000 atm were measured.

Michels[4,5], on the basis of data on isothermal compressibility, calculated the dependence of the velocity of sound and of all thermodynamic functions on pressure up to 5000 atm. The aim of the present work was to measure the velocity of sound in nitrogen, argon, and helium at pressures up to 3500 atm.

The method of measuring the dependence of the velocity of sound on pressure is based on the optical method of Debye and Sears[6]: through two side windows in a high-pressure vessel, monochromatic light was passed, which was diffracted by an ultrasonic grating produced in the fluid by means of a piezoquartz plate operating at its natural frequency of 3.5 MHz. From the diffraction pattern the velocity of sound was calculated. The pressure in the vessel was produced by a single-stage gas compressor up to 6000 atm.

All measurements presented in the present work were carried out at a temperature of 25°. The measurement error did not exceed 2%.

Figure 1 presents the dependence of the velocity of sound c on pressure p in argon, nitrogen, and helium.

As a result of the measurements carried out, it was established that the velocity of ultrasound in gases increases with increasing pressure; moreover, at first the curve of the dependence of the ultrasonic velocity on pressure is close to a straight line, and then it deviates toward the pressure axis. This regularity can be explained by the fact that the density of the substance is responsible for the change in the ultrasonic velocity, while the dependence of density on pressure in the pressure range studied is nonlinear.

The curves of the dependence of the sound velocity on pressure in nitrogen and argon deviate from a straight line as the pressure increases, whereas in helium this is clearly not observed—in the pressure region 1500–3500 atm the curve has a linear character.

The obtained values of the sound velocities for nitrogen and argon in the pressure region up to 1000 atm were compared with the data of Lacam and Noury [1,2]. In the indicated range they coincide completely.

From the obtained values of the ultrasonic velocity, the coefficients of adiabatic compressibility as functions of pressure were calculated for nitrogen and argon. The calculation was carried out by the formula

$$\beta_{\mathrm{ad}} = \frac{1}{c^2\rho},$$

where the dependence of the density ρ on pressure was taken from Michels' s works. The dependence of β_{ad} on pressure is presented in Figs. 2 and 3 for nitrogen and argon.

Fig. 2.
Fig. 2

Fig. 3.
Fig. 3

In addition, the data on the dependence of the sound velocity on pressure made it possible to calculate the ratio of heat capacities as a function of pressure. In the calculation the rigorous thermodynamic formula proposed by Hubbard and Hodgem [8] was used,

Fig. 4

Figure 2: Fig. 4

$$\gamma = \frac{c^2}{pV\left[1 + \frac{\rho}{pV}\left(\frac{\partial pV}{\partial \rho}\right)_T\right]}.$$

The values of the derivative were calculated from the Kamerlingh-Onnes equation of state

$$pV = A + B\rho + C\rho^2 + D\rho^3 + Z\rho^4 + F\rho^5 + E\rho^6 + M\rho^7.$$

Figure 4 presents the dependence of the heat-capacity ratio $\gamma = c_p/c_v$ on pressure for nitrogen, calculated by Michels. On the same curve are plotted the values corresponding to the experimental data obtained in the present work. Along the entire curve, the obtained values of γ coincide, within the limits of experimental error, with Michels' calculated curve up to pressures of 3500 atm. At higher pressures the experimental values diverge from Michels' curve, and this divergence exceeds the accuracy of our measurements.

Fig. 4

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Received
26 II 1962

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Note: Figure translations are in progress. See original paper for figures.