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Velocity of Sound in Nitrogen and Argon at High Pressures

A. S. EL-HAKEEM*

Department of Mechanical Engineering, University of Wisconsin, Madison, Wisconsin

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Measurements of the velocity of sound in N_2 and Ar are reported at the ice point and 294.26°K (70°F) and at pressures between 1 and 70 atm. The ratio of the specific heats as a function of pressure and temperature was calculated from the experimental results.

INTRODUCTION

PRECISE measurements of the sound velocity in real gases at different temperatures and pressures offer a useful tool for studying the equation of state. Recently, Gyorog[1] developed a generalized equation of state derived from experimental measurements of compressibility factor and enthalpy and internal energy deviations. To gain insight into the validity of this equation of state for N_2 and Ar, velocity measurements were made in these gases at the ice point and 294.26°K and at pressures from 1 to 70 atm. Also, knowledge of the molecular weight and the specific heat, along with the Gyorog equation, enabled velocity values to be calculated. The experimental data are compared with these calculated values, as well as with the data of van Itterbeek.[2,3]

TABLE I. Sound velocity and ratio of specific heats in nitrogen.

Temperature (°K)	Pressure (atm)	V_0(exptl.) (m/sec)	V_0(Gyorog) (m/sec)	γ
273.15	1.00	337.04	336.95	1.4029
	10.00	338.17	338.01	1.4229
	30.00	341.37	341.25	1.4660
	50.00	345.88	345.76	1.5089
	70.00	351.55	351.58	1.5483
294.26	1.00	349.72	349.76	1.4014
	5.00	350.44	350.37	1.4097
	10.00	351.22	351.20	1.4185
	30.00	355.11	355.12	1.4552
	50.00	359.98	360.09	1.4900
	70.00	366.06	366.10	1.5246

METHOD

The experimental method is based on the apparatus developed by the author and described in a previous paper.[4] The N_2 and Ar had purity of 99.95% or better. Temperature stability was achieved by running the tests in an air-conditioned room, the temperature of which did not change from 294.26°K by more than ±2 C° in a 24-h period. The entire sound tube was immersed in a water bath to ensure that no drastic changes in temperature (not more than ±0.1 C°) occurred during the test period. The ice-point temperature was controlled by immersing the sound tube in a bath of pure ice and distilled water.

Pressures of 1 and 5 atm were measured on a 130-in. manometer, while calibrated Heise absolute-pressure gauges measured the 10- to 70-atm points.

Extensive initial tests[4] showed that the apparatus was compatible with the Helmholtz–Kirchoff (H–K) equation. Thus the H–K constant for the tube (β_T) was equal, within experimental accuracy, to the theoretical value (β) and, therefore, could be calculated. The velocity of sound in the tube was then measured at one or more frequencies and corrected with the calculated β to yield the Laplacian free-gas velocity V_0.

The sound velocities were also calculated with the aid of Eq. (1), using the generalized virial coefficients of Gyorog[1] (or the generalized virial coefficients derived from the Lennard-Jones potential)[5,6]:

$$V_0=\{(RT/M)[\phi+(\Psi/x)(\gamma^0-1)]\}^{\frac{1}{2}}, \qquad (1)$$

where

$$\phi=1+2B^*\rho^*+3C^*\rho^{*2}+4D^*\rho^{*3},$$

$$\Psi=\left[1+\left(B^*+T^*\frac{dB^*}{dT^*}\right)\rho^*+\left(C^*+T^*\frac{dC^*}{dT^*}\right)\rho^{*2}+\left(D^*+T^*\frac{dD^*}{dT^*}\right)\rho^{*3}\right]^2,$$

$$x=1-(\gamma^0-1)\left[\left(2T^*\frac{dB^*}{dT^*}+T^{*2}\frac{d^2B^*}{dT^{*2}}\right)\rho^*+\left(T^*\frac{dC^*}{dT^*}+\frac{1}{2}T^{*2}\frac{d^2C^*}{dT^{*2}}\right)\rho^{*2}+\left(\frac{2}{3}T^*\frac{dD^*}{dT^*}+\frac{1}{3}T^{*2}\frac{d^2D^*}{dT^{*2}}\right)\rho^{*3}\right],$$

γ^0 is the ratio of heat capacities for the ideal gas state;

* On leave from Department of Mechanical Engineering, University of Khartoum, Khartoum, Sudan.

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[3] A. van Itterbeek, W. van Dael, and W. Grevendonk, Physica **25**, 7, 640–644 (1959).

[4] A. S. El-Hakeem, "A Refined Tube Method for Measuring the Sound Wavelength in Gases," Am. J. Phys. (to be published).

[5] J. O. Hirschfelder, C. F. Curtiss, and R. B. Bird, *Molecular Theory of Gases and Liquids* (John Wiley & Sons, Inc., New York, 1954).

[6] For the range of the reduced temperatures covered in this paper, the sound velocity values calculated with these virial coefficients are essentially identical to those calculated from Gyorog's equation.

TABLE II. Sound velocity and ratio of specific heats in argon.

Temperature (°K)	Pressure (atm)	V_0(exptl.) (m/sec)	V_0(Gyorog) (m/sec)	γ
273.15	1.00	308.14	308.06	1.6715
	10.00	308.42	308.48	1.7030
	30.00	310.02	309.95	1.7822
	50.00	312.29	312.23	1.8647
	70.00	315.33	315.42	1.9485
294.26	1.00	319.90	319.88	1.6714
	10.00	320.49	320.53	1.6978
	30.00	322.64	322.67	1.7628
	50.00	325.65	325.48	1.8325
	70.00	328.95	329.04	1.8985

R, T, M are the gas constant, absolute temperature, and molecular weight, respectively; B^*, C^*, D^* are the generalized virial coefficients (Refs. 1 and 5); and ρ^*, T^* are the reduced density and reduced temperature. Equation (1) is the form of the generalized virial equation given by Hovi[7] (but the fourth virial coefficient and its derivatives were added to Hovi's equation by the author).

The ratio of the heat capacities γ as a function of pressure and temperatures was calculated from

$$\gamma=\frac{V_0^2}{(R/M)T(1+2B^*\rho^*+3C^*\rho^{*2}+4D^*\rho^{*3})}. \quad (2)$$

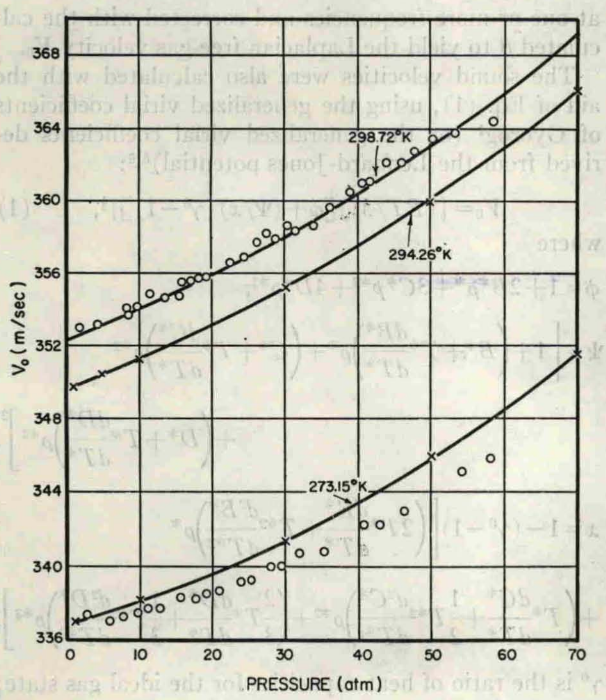

FIG. 1. Sound velocity in nitrogen as a function of pressure. (×, present data; ——, Gyorog's equation; ○, van Itterbeek's data[2].)

[7] V. Hovi and R. Nasanen, Ann. Acad. Sci. Fennicae Ser. AVI, No. 35 (1959).

RESULTS AND CONCLUSIONS

The free-gas sonic velocities and the specific-heat ratios are listed in Tables I and II. The data of this paper, the calculated values from Gyorog's equation, and van Itterbeek's data are compared in Figs. 1 and 2. Note that the agreement between the present data (×) and the values calculated by Gyorog's equation (solid line) is excellent in all cases. However, van Itterbeek's data for nitrogen at the ice point are lower than those of the present paper. The deviation increases from about 0.5 m/sec at low pressures to about 2.3 m/sec at high pressures.

Also presented in Fig. 1 is a comparison between velocity values for N_2 calculated at 298.72°K by Gyorog's equation and those of van Itterbeek[2] at the same temperature. Here it is seen that the van Itterbeek data agree with the predicted values except for his highest test pressure.

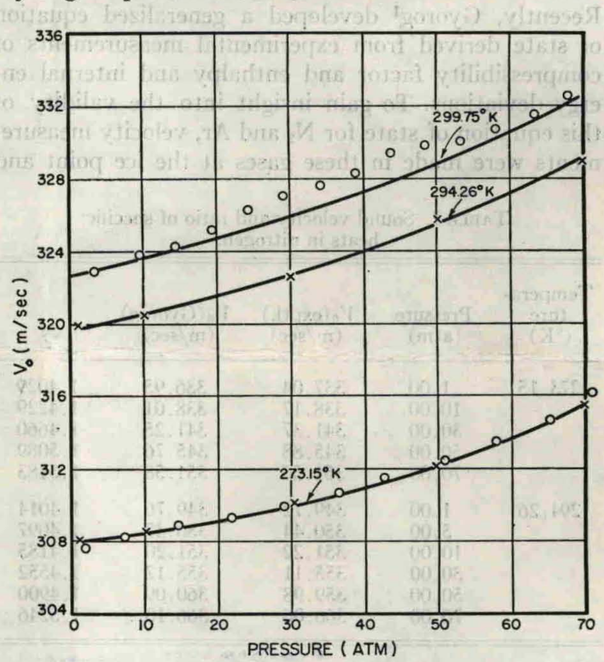

FIG. 2. Sound velocity in argon as a function of pressure. (×, present data; ——, Gyorog's equation; ○, van Itterbeek's data[3].)

In Fig. 2, the data of this paper for argon at the ice point are in very good agreement with those of van Itterbeek.[3] But comparison between the calculated values for argon at 299.75°K and those of van Itterbeek at the same temperature shows some deviation from the predicted curve in the pressure range of 20 to 50 atm. The author's data at 294.26°K, however, agree with the calculated values.

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