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Experimental Study of the Ultrasonic Velocity in Liquid Cesium at High Temperatures and Pressures[1]

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The sound velocity in liquid cesium under pressures up to 60 MPa and temperatures to 1500 K is measured using a modified-pulses phase-sensitive technique. The sound velocity (at frequency 10 MHz) is determined by means of the pulse propagation time measurement through the cesium sample. The experimental error is 0.2%. The results obtained are discussed.

KEY WORDS: cesium; equation of state; heat capacity; high temperature; pulse method; sound velocity; ultrasonic.

1. INTRODUCTION

The majority of sound velocity data in liquid alkali metals of various authors has been taken near the saturation curve [1]. In sodium the sound velocity was measured up to 1773 K [2], and to 1100 K for other alkali metals. At higher pressures, the sound velocity was measured for sodium and rubidium in a narow temperature range near the melting point: at pressures to 140 MPa and at temperatures to 473 K in liquid rubidium [3], for example.

In this paper, we present the results of sound velocity experiments in liquid cesium up to 1500 K and to 60 MPa. From the data obtained and equation-of-state data [4] the heat capacity at constant pressure C_p and the heat capacity ratio C_p/C_v have been calculated.

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2. MEASUREMENT TECHNIQUE AND EXPERIMENTAL APPARATUS

Sound velocity measurements have ben made by means of a modified ultrasonic (US)-pulsed phase-sensitive technique. The schematic and photograph of the cell are shown in Fig. 1. Let us consider the essence of the technique.

If a radiofrequency pulse is applied to the first piezoelectric transducer, the delay between the transmitted US pulse to the second transducer and the reflected echo pulse from the hot end of the first rod is measured

$$\Delta\tau_1 = \tau_1 + \tau + \tau_2 - 2\tau_1 \tag{1}$$

where τ_1 is the propagation time of the US pulse in the first rod; τ_2, in the second rod; and τ, in the investigated medium.

If a radiofrequency pulse is applied to the second transducer, the time of delay $\Delta\tau_2$ is masured:

$$\Delta\tau_2 = \tau_2 + \tau + \tau_1 - 2\tau_2 \tag{2}$$

Hence,

$$\tau = (\Delta\tau_1 + \Delta\tau_2)/2 \tag{3}$$

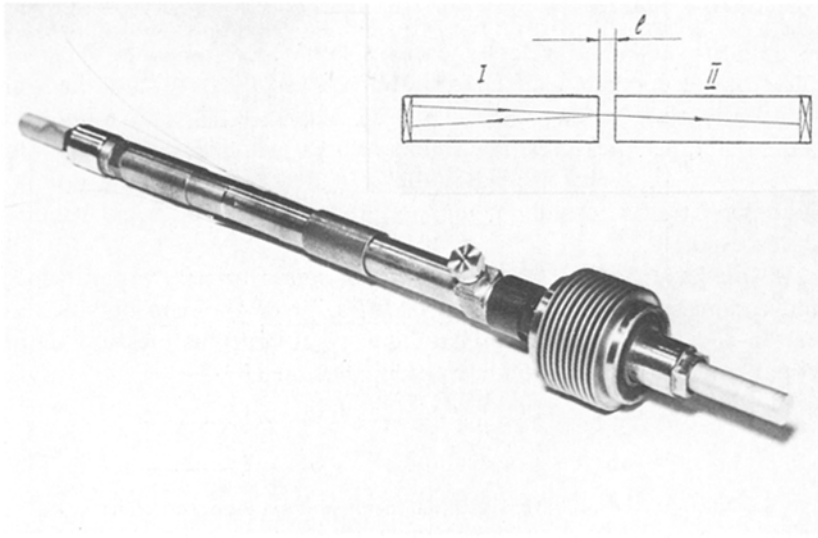

Fig. 1. Schematic and photograph of the cell.

Then the sound velocity U is calculated:

$$U = l/\tau \tag{4}$$

where l is the gap between the rods.

The time $\Delta\tau$ is measured by a calibrated pulse delay generator using the coincidence of phases of analogous periods for the transmitted and echo pulses on the oscilloscope screen (the error of this procedure in our

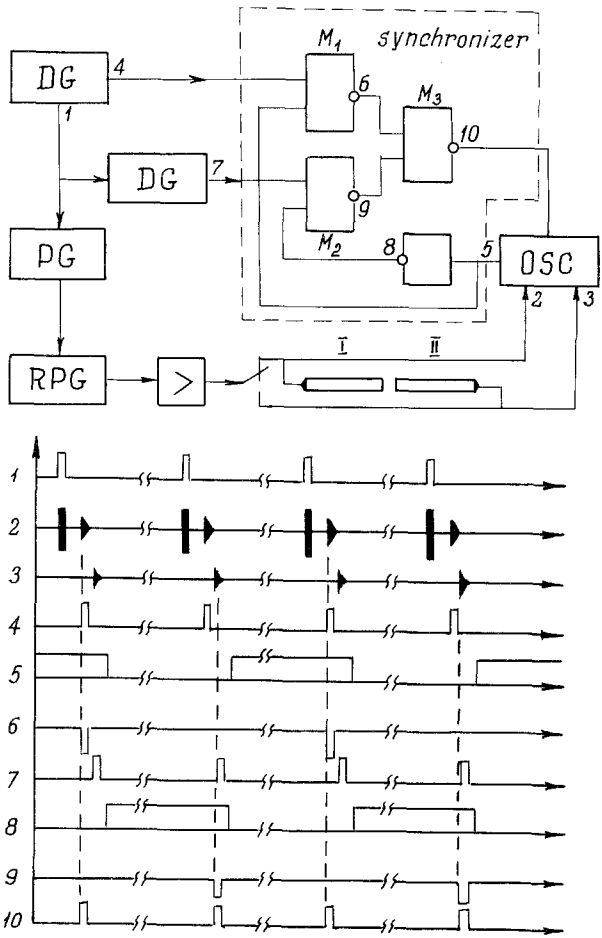

Fig. 2. Block and time diagrams of the electroacoustics part of the apparatus. DG, calibrated delay generator of pulses; PG, generator of pulses; RPG, generator of radiofrequency pulses; OSC, oscilloscope.

experiments was $\pm 1 \times 10^{-9}$ s). We used a two-channel one-beam oscilloscope in the mode "alternately." The oscilloscope was triggered by a homemade synchronizer and the scanning was synchronized with the switching of the channels. The block and time diagrams of the electro-acoustics part of the apparatus are shown in Fig. 2. The apparatus is described in detail in Ref. 5.

The high-pressure vessel and the US cell are shown in Fig. 3. The cell consists of an ampule (2) (the tube of stainless steel) and two rods (3) (sound guides). The length of the rods is 180 mm, and the diameter is 10 mm. The size of the gap between rods (length of sample) is determined by the calibrated ring (4). The length of the ring is ≈ 2 mm. The rods and the ring were made of stainless steel.

A litium niobate (36°-rotated Y-cut) transducer (9) of 10 MHz was bonded to the cold ends of the rods. The outward rod ends were cooled by means of Cu rings (6) and pressurizing medium (argon gas).

Pressure was transferred to the cesium by means of a bellows expansion reservoir (7), which is necessary for the pressure unloading of the cell and to preveent cesium pollution. The reservoir was made of two thin-wall (0.08-mm) stainless-steel bellows placed coaxially. The pressure difference between the inner and the outer parts of the reservoir was $\lesssim 0.05 \times 10^5$ Pa.

The cesium sample between the rods was heated by a resistance graphite furnace (14). The temperature of the sample was automatically controlled and measured by two W-5% Re: W-20% Re thermocouples, located in the outward channels of the cell ampule near the gap.

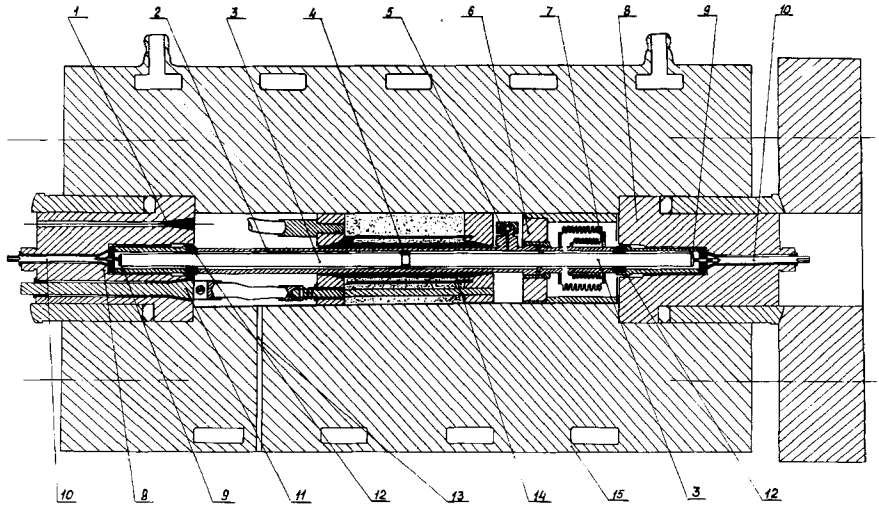

Fig. 3. High-pressure vessel and ultrasonic cell.

The cell together with the furnace was placed in a high-pressure vessel; the vessel was sealed by water-cooled plugs (8) carrying radiofrequency (10), high-current (11), and thermocouple (1) feedthroughs.

3. RESULTS AND DISCUSSION

In our experiments the change of propagation time $\Delta t(T, P)$ of the US pulse in liquid cesium as a function of temperature T and pressure P against a reference point ($T_r = 350$ K, $P_r =$ atmospheric pressure) was measured. The sound velocity at the reference point was taken as $U_r = 950\ \mathrm{m \cdot s^{-1}}$. It is the man value of sound velocity in liquid cesium at 350 K from varous authors' data [1]. The sound velocity $U(T, P)$ was calculated from the following equation:

$$U(T, P) = l_0[1 + \alpha(T, P)(T - T_0)]/[l_r/U_r + \Delta t(T, P)] \tag{5}$$

where $\alpha(T, P) \approx \alpha(T)$ is the linear thermal expansion coefficient of stainless steel, l_0 is the length of the gap at $T_0 = 293$ K, and l_r is the length of the gap at $T = T_r$.

The experimental error of the sound velocity change is 0.2%. The difference of the literature sound velocity data at the reference point is $\approx 1\%$. The temperature measurement error is 5 K; the pressure measurement error varies from 20 kPa for $P \leqslant 10$ MPa up to 0.1 MPa for 10 MPa $\leqslant P \leqslant 60$ MPa.

Sound velocity data obtained experimentally at constant pressures are shown in Fig. 4. The dispersion of experimental points does not exced the

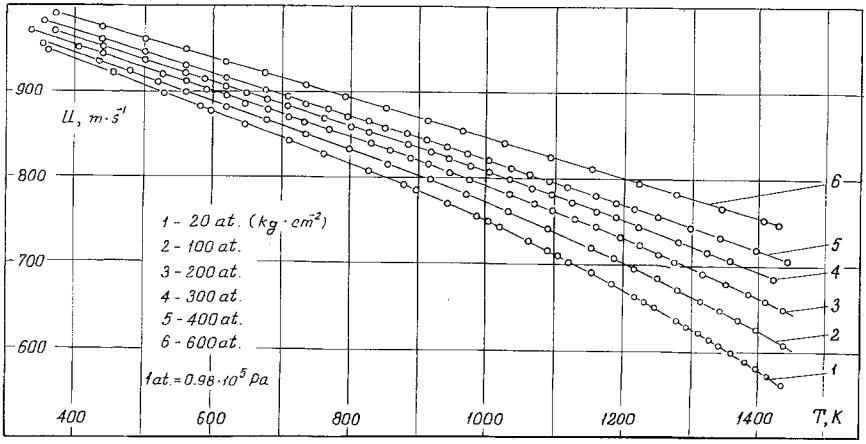

Fig. 4. Sound velocity isobars in liquid cesium as a function of temperature.

claimed error (0.2%). At low pressures the data are in satisfactory agreement with the sound velocity data along the saturation curve obtained up to 1100 K [6].

The sound velocity data obtained $U(T, P)$ and initial density data $\rho(T, P)$ [4] were used for the calculation of the heat capacity at constant pressure C_p and heat capacity ratio $\gamma = C_p/C_v$ of liquid cesium at parameters of state studied from the following equations:

$$C_p = \frac{\alpha_p^2 T}{\rho(\beta_T - \beta_S)} = \frac{\alpha_p^2 T}{(\partial\rho/\partial P)_T - U^{-2}} \tag{6}$$

$$\gamma = C_p/C_v = \beta_T/\beta_S = U^2(\partial\rho/\partial P)_T \tag{7}$$

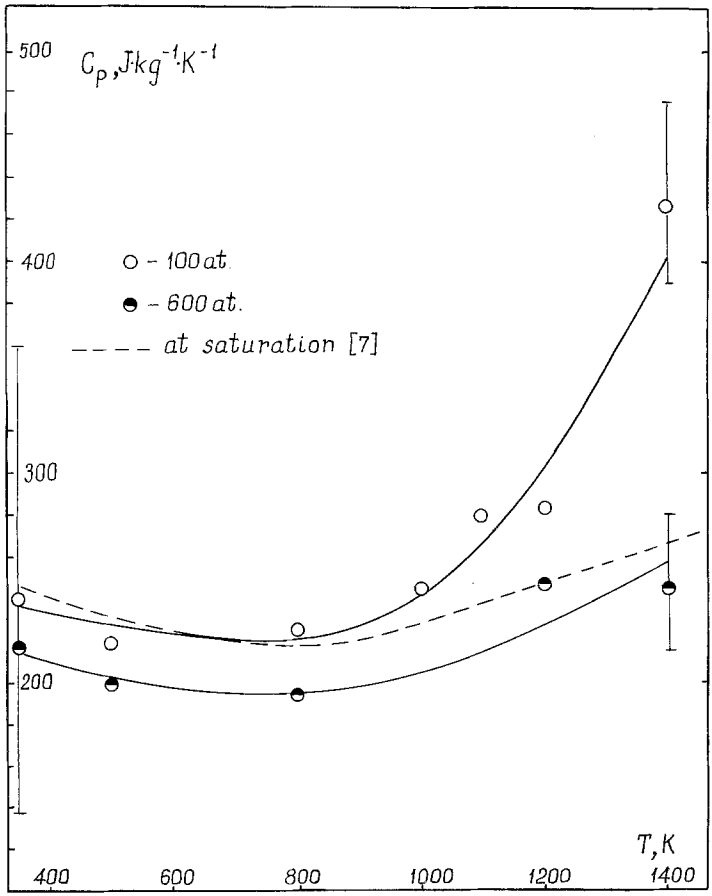

Fig. 5. Heat capacity at constant pressure of liquid cesium as a function of temperature.

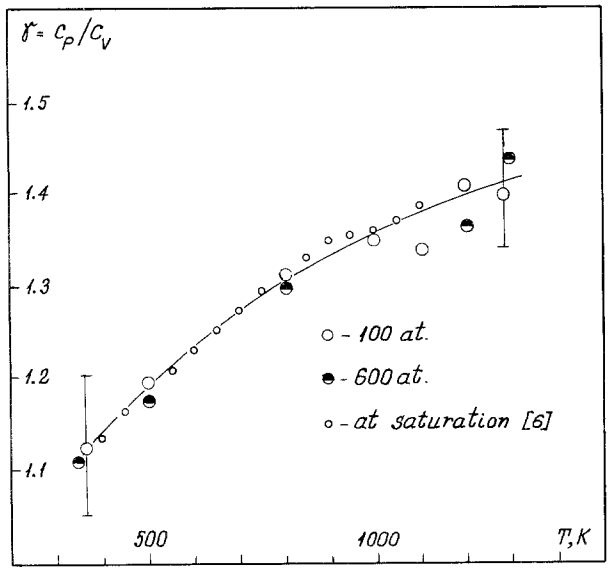

Fig. 6. Heat capacity ratio of liquid cesium as a function of temperature.

where $\alpha_p = -\rho^{-1}(\partial\rho/\partial T)_p$ is the volumetric isobaric thermal expansion coefficient, $\beta_T = \rho^{-1}(\partial\rho/\partial P)_T$ is the isothermal compressibility, and $\beta_S = \rho^{-1}(\partial\rho/\partial P)_S$ is the adiabatic compressibility.

Derivatives $(\partial\rho/\partial T)_p$ and $(\partial\rho/\partial P)_T$ were calculated from the initial equation-of-state data [4], which were smoothed and then numerically differentiated.

Figure 5 shows the plot of the heat capacity C_p of liquid cesium versus T along two isobars: 9.8 MPa (100 kg · cm^{-2}) and 58.8 MPa (600 kg · cm^{-2}). The errors due to the change in density ± 0.001 g · cm^{-3} (0.1 % relative) are shown in the plot. One can notice the satisfactory agreement of calculated C_p values with literature C_p data at saturation [7], which were obtained at temperatures $T \geqslant 900$ K by linear extrapolation. The plot of the heat capacity ratio $\gamma = C_p/C_v$ of liquid cesium versus T is shown in Fig. 6. The ratio γ is pressure independent, with the error 5 % for the parameters of state studied.

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