SOUND VELOCITIES IN CESIUM CHLORIDE AND SODIUM CHLORIDE AT PRESSURES UP TO 100 kbar

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Abstract

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SOUND VELOCITIES IN CESIUM CHLORIDE AND SODIUM CHLORIDE AT PRESSURES UP TO 100 kbar

(Presented by Academician L. F. Vereshchagin, 15 V 1970)

The elastic characteristics of solids under high-pressure conditions are presently determined from the velocities of propagation of elastic waves. Such studies have been carried out under hydrostatic pressures up to 10 kbar ([1,2]) and quasi-hydrostatic pressures up to 20 kbar ([3,4]) and 40 kbar ([5,6]). A substantial expansion of the pressure range is associated with difficulties in generating very high pressures in large volumes.

At the Institute of High Pressure Physics of the Academy of Sciences of the USSR, studies have been begun of the velocities of propagation of ultrasonic waves in solids at pressures up to 100 kbar ([7]) in a chamber that makes it possible to use specimens 5-10 mm long and up to 15 mm in diameter.

Typical representatives of ionic crystals—sodium chloride and cesium chloride—were chosen as objects of study, since comparison with the results of theoretical calculations is possible for them. Of great interest are data on the sound velocities in sodium chloride, which is adopted as the standard substance of the high-pressure scale and whose equation of state was calculated by Decker ([8]).

Both of these substances have a sufficiently low resistance to shear and ensure quasi-hydrostatic conditions in the high-pressure chamber.

The experimental procedure was briefly described in ([7]). The deformations of the pistons under the action of the load, which enter into the measured height of the specimen, were calculated with the aid of elasticity theory ([9,10]) and were determined experimentally by two independent methods: by special loading of the chamber simulating the real experiment, and from ultrasonic measurements on specimens of different lengths. The experimentally determined deformation values agreed with one another within 1% and amounted to 0.18 mm at 100 kbar, while their deviation from the calculated value did not exceed 10%.

The experimental dependences obtained for the specimen length, the transit time of elastic waves, and the pressure in the chamber on the press force exhibited a large hysteresis between the direct and reverse runs, typical of solid-body

Fig. 1. Velocities of longitudinal v_l and transverse v_t ultrasonic waves in cesium chloride (a) and sodium chloride (b) at pressures up to 100 kbar (the region of experimental values of v_t in NaCl is hatched)

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chambers of this type. The velocities of propagation of elastic waves are calculated from these data by the formula

$$v_s = (l_s + 4\Delta l)/(t_p + \Delta t_s),$$

where l_s is the specimen length, determined during the experiment with an accuracy of ± 0.01 mm; $4\Delta l$ are corrections for the elastic deformation of the pistons; Δt_s is the change with pressure in the transit time of elastic waves in the specimen, measured with an accuracy of $\pm 5 \div 10$ nsec; t_p is the transit time of elastic waves at the pressure corresponding to the reference point, for which the transition point $\mathrm{Bi_I} \rightarrow \mathrm{Bi_{II}}$ (25.5 kbar) was taken.

The sound velocities in cesium chloride and sodium chloride determined in this way showed a monotonic dependence on pressure. The results, averaged over the direct and reverse runs, of processing 6 independent experiments for the longitudinal sound velocity v_l and 9 experiments for the transverse velocity ···

of sound v_t are given for CsCl in Fig. 1a, and for NaCl in Fig. 1b. The errors in determining the velocities of longitudinal and transverse ultrasonic waves are $\sim 0.6\%$ for NaCl and $\sim 1\%$ for CsCl.

The propagation velocities of elastic waves in CsCl increase monotonically with pressure, and at 90 kbar the velocity of longitudinal waves increases by 44%, while the velocity of transverse waves increases by 30%; for NaCl these quantities are equal to 26 and 10%, respectively.

Thus, in this case, as in previous works ([1,11]), a greater effect of pressure on the propagation velocities of sound is observed in the more compressible substance (at 100 kbar $\Delta v/v_0 = 0.223$ for CsCl and $\Delta v/v_0 = 0.197$ for NaCl (Bridgman' s data ([12]))).

Fig. 1. Velocities of longitudinal v_l and transverse v_t ultrasonic waves in cesium chloride (a) and sodium chloride (b) at pressures up to 100 kbar (the region of experimental values of v_t in NaCl is hatched)

By the method of least squares, equations were found for the curves $v_l(P)$ and $v_t(P)$ for both substances in the form of third-degree polynomials: for CsCl

$$v_l = 2850.5 + 24.96P - 0.1551P^2 + 0.0002749P^3,$$

$$v_t = 1596.1 + 10.50P - 0.07857P^2 + 0.000208P^3;$$

for NaCl

$$v_l = 4594.4 + 22.94P - 0.1315P^2 + 0.0002175P^3,$$

$$v_t = 2624.2 + 5.058P - 0.04605P^2 + 0.000209P^3,$$

where v is in m/sec, and P is in kbar on the adopted pressure scale ([7]).

It should be noted that the curvature of the dependences $v_l(P)$ and $v_t(P)$ for CsCl increases, which, upon extrapolation to the pressure region above 100 kbar, may lead to saturation of the curves, which is physically unjustified. Apparently, this is caused by overestimation of the pressure values of the phase transitions of the reference metals $Ba_{II\to III}$ and $Bi_{III\to IV}$ ([13]).

The weak increase with pressure ($\sim 10\%$) in the velocity of transverse waves in NaCl can be associated with the previously observed slight increase in the constant c_{44} at pressures ~ 10 kbar ([14]) and with a possible decrease in c_{44} toward the point of the phase transformation ($P = 300$ kbar), analogous to the behavior of c_{44} for KCl and PbCl ([14,15]), since the contribution of this elastic constant to the shear modulus of the polycrystal is $\sim 80\%$.

The authors state that, within the accuracy of their experimental method, no anomalies were found in the dependences $v_l(P)$ and $v_t(P)$ for

NaCl that could be identified with the phase transition found in works [16,17], which is apparently explained by the specific nature of the experiments in the cited works.

The calculation of the elastic moduli will be carried out after the pressure values of the phase transitions of the reference metals have been refined.

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CITED LITERATURE

[1] F. F. Voronov, L. F. Vereshchagin, *Fiz. met. i metalloved.*, **11**, 443 (1961).
[2] F. F. Voronov, L. F. Vereshchagin, V. A. Goncharova, *DAN*, **135**, No. 5, 1104 (1960).
[3] F. F. Voronov, O. V. Stal' gorova, *ZhETF*, **49**, issue 3 (9), 755 (1965).
[4] F. F. Voronov, V. A. Goncharova, *ZhETF*, **50**, issue 5, 1173 (1966).
[5] T. J. Ahrens, S. Katz, *J. Geophys. Res.*, **67**, 2935 (1962).
[6] M. P. Volarovich, A. I. Levykina, *DAN*, **165**, No. 6, 1287 (1965).
[7] F. F. Voronov, S. B. Grigor' ev, *DAN*, **182**, 304 (1968).
[8] D. L. Decker, *J. Appl. Phys.*, **36**, 7, 157 (1965).
[9] I. E. Shterman, *Contact Problem of the Theory of Elasticity*, 1949.
[10] A. I. Lur' e, *Spatial Problems of the Theory of Elasticity*, 1955.
[11] F. F. Voronov, *Fiz. met. i metalloved.*, **11**, 620 (1961).
[12] P. W. Bridgman, *Proc. Am. Acad. Arts Sci.*, **76**, 1, 1 (1945).
[13] R. N. Jeffery, J. D. Barnett et al., *J. Appl. Phys.*, **37**, 8, 3712 (1966).
[14] G. R. Barsch, Z. P. Chang, *Phys. Stat. Solidi*, **19**, 1, 139 (1967).
[15] F. F. Voronov, V. A. Goncharova, T. A. Agapova, *FTT*, **8**, 11, 3405 (1966).
[16] V. V. Evdokimova, L. F. Vereshchagin, *ZhETF*, **16**, 855 (1963).
[17] D. B. Larson, R. N. Keeler et al., *J. Phys. Chem. Solids*, **27**, 476 (1966).

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