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Simultaneous sound velocity and density measurements of NaCl at high temperatures and pressures: Application as a primary pressure standard

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Abstract

The elastic compressional (P) and shear (S) wave velocities in NaCl were measured up to 12 GPa at 300 K, and up to 8 GPa at 473 and 673 K, by combining ultrasonic interferometry, in situ synchrotron X-ray diffraction, and X-ray radiographic techniques in a large-volume Kawai-type multi-anvil apparatus. The simultaneously measured sound velocity and density data at 300 K and high pressures up to 12 GPa were corrected to transform the adiabatic values to isothermal values and then used to estimate the 300 K equation of state (EOS) by a least-squares fit to the fourth-order Birch-Murnaghan finite strain equation, without pressure data. For a fixed isothermal bulk modulus K_{T0} of 23.7 GPa at 0 GPa and 300 K, we obtained the first and the second pressure derivatives of K_{T0}, $K'_{T0} = 5.14 \pm 0.05$ and $K''_{T0} = -0.392 \pm 0.021$ GPa^{-1}, respectively. A high-temperature and high-pressure EOS of NaCl was then developed using the Mie-Grüneisen relation and the Debye thermal model. To accomplish this, the simultaneously measured sound velocities and densities up to 8 GPa at both 473 and 673 K, as well as previously reported volume thermal expansion data of NaCl at 0 GPa were included in the fit. This resulted in a q parameter of 0.96, while holding the Grüneisen parameter and the Debye temperature, both at 0 GPa and 300 K, fixed at 1.56 and 279 K, respectively. Our EOS model accurately modeled not only the present measured K_T data at pressures up to 12 GPa and temperatures between 300 and 673 K, but also the previously reported volume thermal expansion and the temperature dependence of K_T, both at 0 GPa. The new temperature-pressure-volume EOS for NaCl, presented here, provides a pressure-independent primary pressure standard at high temperatures and high pressures.

Keywords: Sound velocity, equation of state, NaCl, pressure standard, high pressure, high temperature, synchrotron X-ray