PHYSICAL REVIEW VOLUME 119, NUMBER 4 AUGUST 15, 1960

Pressure Variation of the Elastic Constants of Sodium

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(Received April 6, 1960)

The pressure variation of the single crystal elastic constants of sodium has been measured using a modified ultrasonic pulse echo method. The values found for the pressure derivatives of the elastic constants are:

$$dC_{44}/dP=1.63,\quad dC'/dP=0.226,\quad dB_s/dP=3.60.$$

The notation $C'=(C_{11}-C_{12})/2$ and $B_s=(C_{11}+2C_{12})/3$ has been used. The experimental observation that the elastic anisotropy ratio C/C' ($C\equiv C_{44}$) does not depend on pressure indicates that one can positively neglect interaction of ion cores as a contribution to the elastic stiffness of sodium. The results are interpreted in terms of Fuchs' theoretical calculation of the Coulomb contribution to the shear stiffnesses of the alkali metals. The interpretation indicates that as sodium is compressed, the value of the electronic wave function at the boundaries of the atomic polyhedra increases more rapidly than $\Omega^{-\frac{1}{2}}$, where Ω is the volume of the atomic polyhedron. The volume variation of the value of the wave function of the lowest electronic state at the boundaries of the atomic polyhedra is found to be:

$$\left[\frac{d\ln\mu_0(r_s)}{d\ln\Omega}\right]_{\Omega=\Omega_0}=-0.27.$$

INTRODUCTION

As Benedek and Kushida[1] have shown, it is possible to evaluate the volume dependence of the electronic wave function of a solid at the position of the atomic nucleus, using the pressure variation of the Knight Shift. However, as far as cohesive properties of a solid are concerned, one is considerably more interested in the volume dependence of the value of the wave function at the boundaries of the atomic polyhedra. Fuchs[2] has shown for the case of the alkali metals, where one can neglect ion core interactions and Brillouin zone effects which contribute to the stiffness of multivalent metals, that the elastic shear stiffnesses are proportional to the square of the electronic charge density at the boundaries of the atomic cells. We have measured the pressure variation of the single crystal elastic constants of sodium and have computed from these data the volume dependence of the value of the electronic wave function at the boundaries of the atomic polyhedra.

EXPERIMENT

High-Pressure System

The high-pressure system has been described in detail in a recent article,[3] and needs little further elaboration here except for mention of the modifications of technique necessitated by the mechanical softness and high chemical reactivity of sodium.

The sample mount must be designed such that the crystal is not subjected to even moderate nonhydrostatic stresses; venting of the regions near the crystal helps to ensure that large viscous forces will not be applied to the sample during pressure changes. The mount design problem is further complicated by the large compressibility of sodium because a change of sample dimensions must not cause the electrode on the quartz transducer to lose contact with the rf input lead. In the present experiment these problems were met by resting the crystal on a long coil spring of very low stiffness, which maintained electrode contact but exerted only very small forces on the sample. Electrical contact to the crystals proper was made by pushing a 0.04-cm diameter wire a short distance into the sodium in a region outside the acoustic path. Octoil *S*, previously used as the pressure transmitting fluid, is unsatisfactory for use with a material as reactive as sodium. It was found that about a 50–50 mixture of mineral oil and isopentane performed satisfactorily in this respect if kept in the presence of sodium shavings for a week or so before use.

The high pressure fixed point used to calibrate the Manganin wire hydrostatic pressure gage was the freezing pressure of mercury at 0°C, taken to be 7640 kg/cm² following Bridgman.[4]

Sample Preparation

The chemical activity, the mechanical softness and the low melting temperature of sodium force the experimenter to exercise caution in manipulating the material, particularly in single crystal form.

The sodium used was Mallinckrodt Analytical Reagent. The exact purity is not known, but a cooling curve run for the material gave a sharp transition at the freezing point.

Single crystals 0.75 inch in diameter and 5 inches long were grown by a modified Bridgman technique.

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[4] P. W. Bridgman, *The Physics of High Pressures* (G. Bell and Sons, London, 1952).