In the experiments the monoenergetic incident neutrons were obtained from a crystal spectrometer and the energy distributions of the neutrons scattered at some particular angle ($\phi$) were measured by means of another crystal spectrometer.[8] In the first instance the angle of scattering and the incoming wave vector **k** were arranged so that the direction of the outgoing wave vector **k**′ passed close to a reciprocal lattice point and lay along a [111] direction with respect to that lattice point. Any neutron groups observed then represent phonons whose propagation vectors lie near [111] directions. Once an approximate $\nu(\mathbf{q})$ relation had been obtained it was improved by arranging conditions so that a desired phonon should appear. Then, utilizing the perhaps slightly different phonon which did appear, the $\nu(\mathbf{q})$ relation was improved. Conditions with respect to structure-factor, polarization, etc., were always arranged so that the intensity and resolution were especially favorable. Some of the results are shown in Fig. 1 on a reciprocal lattice diagram.

Neutron groups which represent **q**'s within $\pm 5°$ of a [111] direction on the reciprocal lattice diagram were selected from the complete experimental results. The frequencies $\nu$ of the phonons corresponding to these neutron groups are plotted against their wave numbers $q/2\pi$ in Fig. 2. The first-neighbor calculations of Hsieh are shown as dashed lines. The experimental points for the transverse modes are seen to diverge widely from the calculated curve. The values of MacFarlane *et al.*, shown as crosses, are in good agreement with our measurements for both the longitudinal and transverse branches. This agreement must be taken to add substantially to the certainty of the above-mentioned deductions from the infrared measurements.

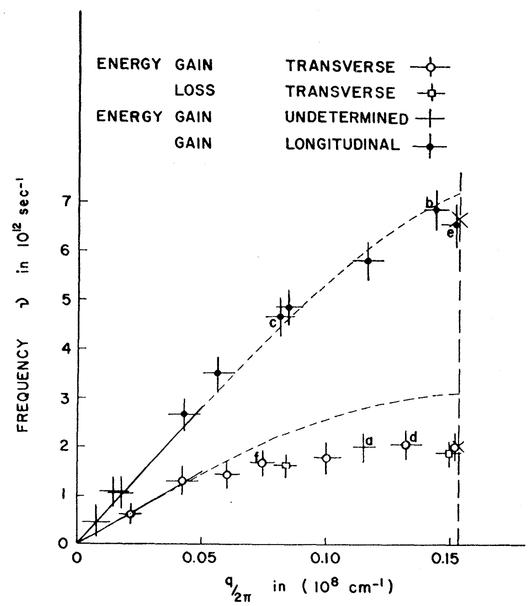


FIG. 2. The frequency ($\nu$) plotted as a function of the wave number $q/2\pi$ for the acoustic modes in the [111] direction. The dashed curves show Hsieh's calculations using first-neighbors interactions only. The crosses at the zone boundary are the results of MacFarlane *et al.* The solid lines have the slope of the velocities of sound as determined by McSkimmin. The phonons shown in Fig. 1 are identified by lower case letters.

The results for other directions and branches will be published on completion of the work.

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## Dispersion of Elastic Waves in Sodium Chloride*

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IT is well known that dislocations decrease the apparent elastic moduli of crystalline materials because the motion of dislocations under an applied stress decreases the rigidity of the specimen. It has been predicted[1] that, at megacycle frequencies, the dislocation motion would be sufficiently damped so that the dislocations would no longer be able to follow in phase with the applied stress and that a dispersion would appear. This effect has been found in the case of NaCl. The problem under discussion arose in connection with the examination of nuclear irradiation effects in alkali halides where it has been found that the radiation effects depend strongly on previous deformation.

The apparatus necessary for the measurement of velocities to two parts in $10^4$ is described elsewhere.[2] In these measurements, compressional waves were propagated along the [100] direction of an NaCl single crystal (obtained from Harshaw). The specimen was subsequently deformed in compression by 0.06% and remeasured. (The actual deformation may be slightly more since some pressure was applied in attaching the transducer.) The time of transit of the leading edge of the sound echoes is measured, and the velocities are computed from the measured thickness of the specimen. Before deformation, the velocities found at 20, 60, and 100 Mc/sec are 0.4763, 0.4771, and 0.4777 cm/$\mu$sec, respectively. After deformation the velocities were found to have the lower values 0.4608, 0.4672, 0.4729, and 0.4746 at 10, 30, 50, and 70 Mc/sec, respectively. The results are shown in Fig. 1.

It is to be noted that the deformation has increased the size of the dispersion from about 0.5% to 4% and the value of the frequency, at which the velocity change is half complete has decreased. The total change found in $C_{11}$ (approximately 8%) is larger than typical values found at kilocycle frequencies[3] for small deformations. Our deformations are not, however, strictly comparable with those of reference 3. For very high frequencies, the measured velocities approach each other.

It does not seem likely that the effect can be a vacancy pair reorientation or similar mechanism[4] because preliminary measurements have shown that the location of the dispersion shifts gradually to higher frequencies with increasing recovery time. If the effect is accepted as a dislocation effect, estimates of the dislocation density and average loop length can be made from the present data. According to the pinned dislocation loop theory,[1] the velocity change as a function of frequency should be given by

$$\frac{\Delta v}{v_\infty}=\left(\frac{\Delta v}{v_\infty}\right)_0\frac{1}{1+(\nu/\nu_0)^2}, \tag{1}$$

where

$$(\Delta v/v_\infty)_0=6\Omega\Lambda L^2/\pi^2, \tag{2}$$

and

$$\nu_0=(\pi C/2B)(1/L^2). \tag{3}$$

In these equations, $v_\infty$ is the velocity measured at infinite frequency and $\Delta v$ is the difference between the velocity at infinite frequency and the velocity at the measured frequency $\nu$. $\Omega$ is a factor relating the resolved shear stress on the slip systems to the applied stress, $\Lambda$ is the dislocation density, $L$ is the dislocation loop length, $C$ is the tension in the dislocation line, and $B$ is a damping constant. Equation (1) applies strictly only when all loop lengths are equal. For a distribution of loop lengths, a somewhat more complicated relation must be used. This calculation for a distribution of loop lengths has not yet been carried out, but by application of Eq. (1) to the present results, one should obtain the correct orders of magnitude. When the results are analyzed in this way, one finds $v_\infty$ to be 0.4786 and 0.4788 cm/$\mu$sec for the before and after deformation conditions, respectively. These values of $v_\infty$ may be regarded as coincident and equal to the velocity of a wave propagating in a medium with no dislocations. The corresponding value of $C_{11}$ is $4.961\times10^{11}$ dynes/cm² which compares well with the value[5] of $4.9\times10^{11}$ in the literature. Additional results are listed in the following table:

| | $\nu_0$ (Mc/sec) | $\Delta v/v_\infty$ | $\Lambda$ (cm$^{-2}$) | $L$ (cm) |
|---|---|---|---|---|
| Before deformation | 74 | $0.50\times10^{-2}$ | $7.8\times10^6$ | $1.5\times10^{-4}$ |
| After deformation | 35 | $4.1\times10^{-2}$ | $30.0\times10^6$ | $2.1\times10^{-4}$ |

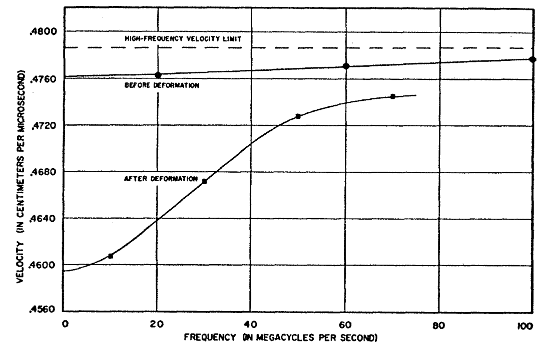


FIG. 1. Velocity dispersion for compressional elastic waves propagating in the [100] direction in NaCl. Deformation increases the magnitude of the dispersion from about 0.5% to 4%, and moves it to lower frequencies.

For these calculations the values $\Omega=1/10$, and $B=C=1.2\times10^{-4}$ (cgs units) were used.

The values found appear to be reasonable and indicate that the dislocation density increased by a factor of four as a result of the deformation.

Experiments are planned for which both the attenuation and velocity will be measured simultaneously. At present there are difficulties with the attenuation measurement since other sources of sound loss are present. Studies of the recovery of attenuation and velocity as a function of annealing time and temperature (in both salts and metals) are planned.

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## Hyperfine Coupling Specific Heat in Cobalt Metal

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THE investigations of the nuclear orientation[1] produced in cobalt crystals by the hyperfine interaction led us to suggest[2] the evaluation of the hyperfine coupling in transition metals by the measurement of the low-temperature specific heats. Preliminary measurements of the atomic heat of metallic cobalt between 0.6 and 3.0°K indicate the existence of this hyperfine coupling.

The sample consisted of 11.4 moles of cobalt metal of 99.9% purity, kindly supplied by the African Metals