relative to acoustic vibrations, shows that the peak is associated with an optical mode of vibration, in which the atoms of a unit cell vibrate "against" each other, relatively independently of other atoms.

Since the scattering from zirconium hydride is primarily the result of the hydrogen, the inelastically scattered neutrons that have gained energy from acoustic vibrations form a continuous spectrum typical of incoherent scattering. In this case, a gain of energy from an optical vibration can be easily identified if present, for only an optical mode can produce a sharp peak. Such a peak is observed with a sample of polycrystalline ZrH at 0.134 ev (Fig. 2) with an energy of ±0.015 ev, of which ±0.005 results from resolution and incident energy spread. The corresponding energy of the lattice vibration is $E=0.130$ ev. It is interesting to note that this transition, which is so prominent in the present measurements, does not appear in infrared absorption measurements. Further discussion of the ZrH results is contained in the accompanying Letter by Andresen, McReynolds, Nelkin, Rosenbluth, and Whittemore.

Thus the cold neutron energy gain technique appears to be a useful method of detecting optical lattice vibrations up to energies of about 0.25 ev, this limit being set by the characteristics of the present chopper. Experiments with other materials are planned to investigate the value of these measurements to solid state investigations.

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† On leave from Weizmann Institute, Rehovoth, Israel and the Israel Atomic Energy Commission.

[1] Carter, Palevsky, and Hughes, Phys. Rev. **106**, 1168 (1957).

[2] Pelah, Eisenhauer, Hughes, and Palevsky, Bull. Am. Phys. Soc. Ser. II, 2, 43 (1957).

[3] A study of the scattering of cold neutrons from vanadium has been completed and will be submitted for publication shortly.

[4] We wish to thank H. P. R. Frederikse of the National Bureau of Standards and S. M. Christian of RCA laboratories for supplying single crystals of Ge for this measurement. A detailed analysis of the Ge data in cooperation with F. Herman of RCA is now under way.

Neutron Investigation of Optical Vibration Levels in Zirconium Hydride*

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We have investigated certain properties of zirconium hydride by studying the spectrum of neutrons scattered elastically and inelastically from polycrystalline samples. A consideration of the zirconium hydride lattice shows that its thermal vibration spectrum should include in addition to the usual band of acoustical frequencies also a sharp "optical" frequency, ν, corresponding approximately to vibrations of the individual hydrogen atoms in an isotropic harmonic well. This implies a set of optical energy levels for the lattice, $E_n=nh\nu$. Peaks corresponding to transitions between these optical energy levels are seen in Fig. 1, which shows the spectrum of neutrons scattered at 90° from zirconium hydride. The average incident energy was 0.004 ev. Measurements were made in collaboration with Pelah, Eisenhauer, Hughes, and Palevsky on the Brookhaven Laboratory slow chopper, which they described in the preceding Letter. The $ZrH_{1.5}$ sample for Fig. 1 was heated to 393°C to make evident the second level (Channel No. 23), as well as the first level (Channel No. 30). Still higher levels should exist but the equipment discriminates so severely against neutrons of these higher energies that the levels do not appear.

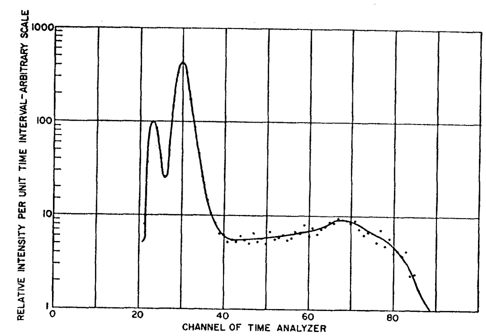

FIG. 1. Distribution of flight time for neutrons scattered by $ZrH_{1.5}$. Channel number 6 is zero time, each channel is 40 μsec, and flight path is 487 cm.

By transforming the coordinate from time of flight to energy, we obtain Fig. 2. From this figure, we can see the shape of the optical levels and their location as well as the acoustical Debye cutoff which occurs at about 0.02 ev. For comparison, we have shown the results obtained at $T=24$°C and 393°C. At 393°C the width of the first level at half its maximum value is about 0.037 ev. The Doppler broadening of the level due to simultaneous acoustical and optical transitions has been estimated to be 0.031 ev, a value about three

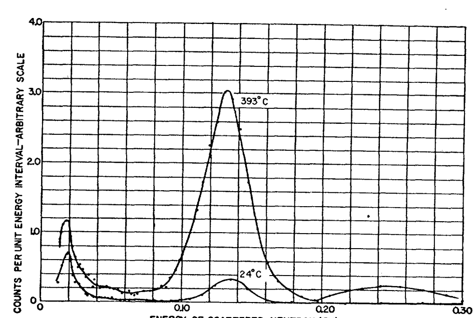

FIG. 2. Energy distribution of neutrons scattered by $ZrH_{1.5}$ at 90° angle. The average incident neutron energy is 0.004 ev.

times the instrumental resolution. The observed level is somewhat broader than these combined widths, but not significantly so. The level width is predicted to vary as $\sqrt{T}$, as it appears to do within the accuracy of the measurements.

To good accuracy, the population of the first level (and hence scattering from this level) varies with temperature according to the Boltzmann function $e^{-E/kT}$, where E is the energy of the level. In order to determine this energy, the intensity of the neutrons scattered from the first optical level has been measured as a function

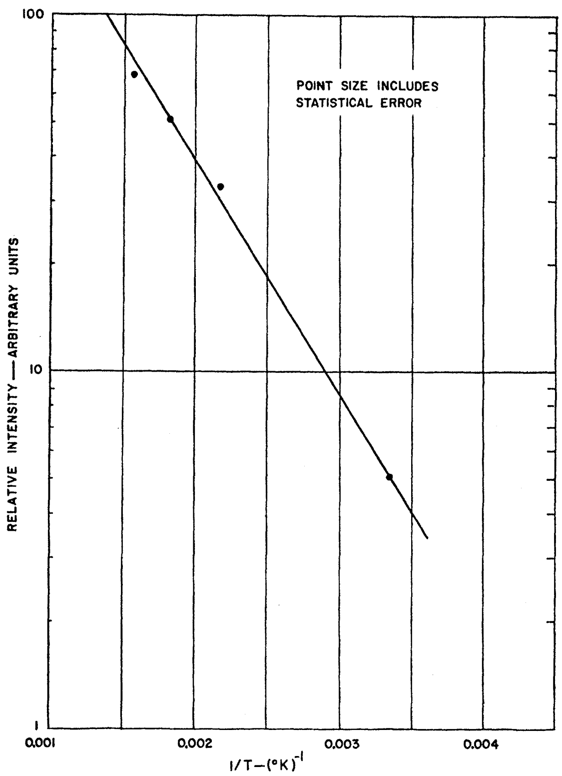

FIG. 3. Intensity of neutrons scattered from the optical level of $ZrH_{1.5}$ as function of sample temperature. Slope of curve gives optical energy level as 0.130±0.005 ev.

of temperature. These data are plotted in Fig. 3 and yield a value of $E=0.130\pm0.005$ ev.

The cross section for energy gain from the optical level can be readily calculated for a one-phonon process. This yields a cross section of about 0.9 barn at 24°C for neutrons incident with 0.004 ev. The experimental determination of this cross section for the present samples of zirconium hydride is rendered difficult because of the multiple scattering in the thick samples. From the data we can determine the ratio of the inelastic to the elastic cross section, taking account of the multiple scattering. Since one can assume that the elastic cross section for this case is 80 barns, we find that the total inelastic cross section is about 2 barns. Of this the experiment shows that between 35% to 50% is due to the optical level at 24°C. This yields a cross section of 0.7 to 1.0 barn in good agreement with the theoretical value.

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Mechanism for Production of X-Rays by Ion Clouds Striking the Earth*

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IN this letter we point out a mechanism, based on the Chapman-Ferraro[1,2] model for geomagnetic storms, for the production of x-rays in auroras, of energies comparable to those of the incoming protons.

We here give an argument which applies not to the initial stages of the phenomenon as discussed by Chapman and Ferraro, but to a steady state established sometime after the beginning of the phenomenon. For simplicity we consider a very large uniform cloud incident along the direction of the earth's magnetic axis. The mechanism will also clearly work for clouds incident in other directions, and also for clouds with nonuniform density. We neglect the thermal and turbulent motion of the cloud particles. If the density of the cloud is very low, then the particles will not affect each other, and the electrons and protons will follow the orbits investigated by Størmer. This means that the protons will be able to penetrate $(1836)^{\frac{1}{2}}$ times closer to the earth before being turned away by the earth's magnetic field. This situation is sketched (not to scale) in Fig. 1, where

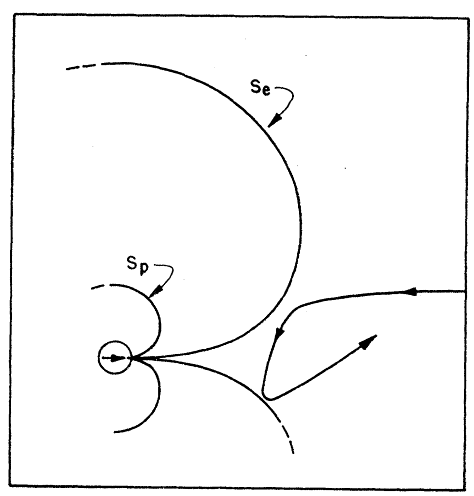

FIG. 1. Approach of electrons and positrons to the earth. For explanation see text.