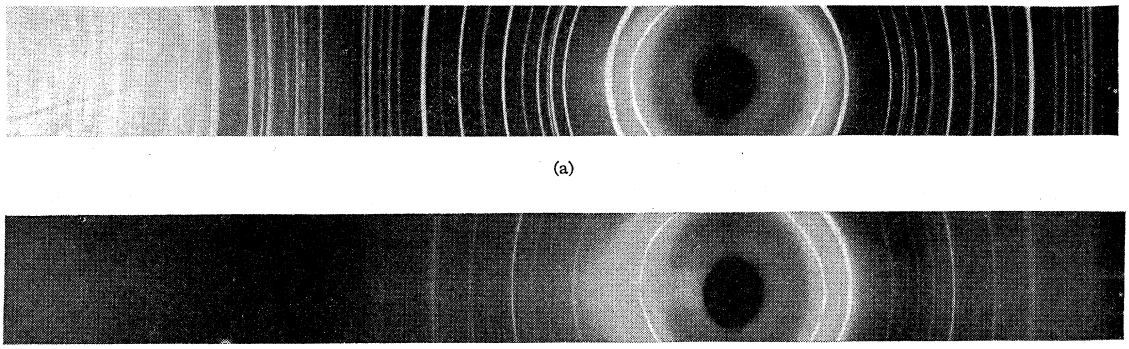
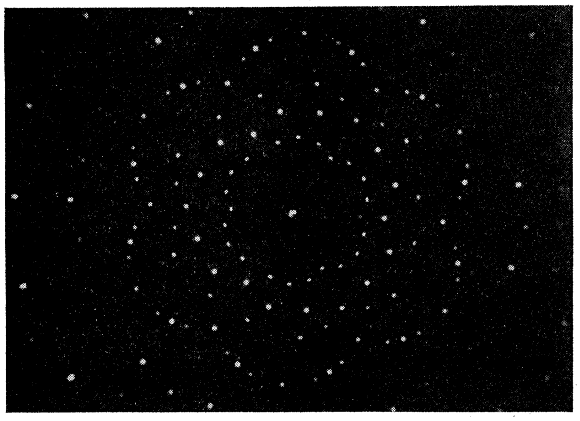


(a)

(b)

FIG. 1. Debye-Scherrer diffraction patterns of $\alpha$-quartz (a) before irradiation; (b) after irradiation.

The strain imposed on the lattice by this expansion is evidenced in the back-reflection region of the Debye-Scherrer diffraction pattern (Fig. 1b). All reflections at $2\theta > 90°$ have been "smeared out" so that they are indistinguishable above background level. The inaccuracies in determining precise lattice constants and x-ray densities are due to the absence of these reflections at large Bragg angles.



(a)

(b)

FIG. 2. Laue transmission photographs of $\alpha$-quartz parallel to $Z$ (a) before irradiation; (b) after irradiation.

The pseudo-hexagonal symmetry inherent in the Laue pattern of $Z$-cut quartz (Fig. 2a) is barely visible in the same pattern (Fig. 2b) of the irradiated crystal which shows its true trigonal symmetry. In addition, the apparent absence of many reflections in this latter pattern also indicates strain in the expanded lattice.

The thermal stability of this expanded lattice is of considerable magnitude. Annealing at 485°C for two hours produced no detectable relief from lattice strain, and no lattice contraction. Four hours of annealing at 650°C produced no lattice contraction, but the (33.1) and (23.4) reflections reappeared as broad, very weak peaks in the back-reflection diffraction pattern. The interest here lies in the fact that this annealing temperature is 77°C higher than the normal inversion temperature of $\alpha \rightarrow \beta$ quartz. Heating at 900°C for twelve hours relieved the lattice strain completely and contracted the lattice to normal parameters.

A model of the packing of atoms in $\alpha$-quartz indicates that the largest interstitial spaces in the lattice form long irregular channels parallel to the principal axis. It seems likely that these sites are the most probable positions in which the dislocated atoms could be trapped. On the basis of this premise, the anisotropic expansion in the $a$ direction is explained.

The writer is indebted to F. A. Sherrill, B. S. Borie, Jr., and G. E. Klein for valuable assistance during the course of the investigation.

## The Thermal Neutron Absorption Cross Section of Scandium

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WE have made a measurement of the thermal neutron absorption cross section of scandium in an attempt to resolve the inconsistencies in the published literature on the cross section of this element.

The thermal neutron cross section is quoted by Pomerance[1] as 11.8 barns, and the pile neutron cross section by Harris *et al.*[2] as 31.8 barns. $Sc^{45}$ is 100 percent abundant in natural scandium, and neutron capture in it leads to 85-day $Sc^{46}$, partly directly, and partly via a 20-second isomer of $Sc^{46}$.[3] The pile activation cross section for the production of 85-day $Sc^{46}$ is, therefore, also the pile absorption cross section of scandium. Seren, Friedlander, and Turkel[4] have measured this activation cross section as 22 barns (±20 percent).

We have made a rough measurement of the cadmium ratio for scandium in the G.L.E.E.P., which shows it to be approximately a $1/v$ absorber. This is confirmed by Harris *et al.*[5] For a $1/v$ absorber the pile neutron cross section is the same as the thermal neutron cross section. We would, therefore, expect the three values quoted above to be in agreement.

In view of the violent disagreement between these values a new measurement was undertaken. The scandium used was in the form of "spec-pure" $Sc_2O_3$. The measurement was made using the G.L.E.E.P. oscillator by the method described by Colmer and Littler,[6] and the value obtained for the pile cross section was 23.2 barns (±4 percent), assuming the absorption cross section of boron at 2200 m/sec to be 710 barns (±2 percent).

The sample was then analyzed by the Chemical Inspectorate, Chatham, for forty elements, including the rare earths. It was found that the contribution to the cross section from impurities was less than 2.4 barns. Allowing for this, our value for the pile neutron absorption cross section, and also the cross section at 2200 m/sec, becomes $23\binom{+1}{-3}$ barns.

As a result of this measurement we communicated with Pomerance, and have heard from him that he has remeasured his sample and now obtains a value of 23 barns.[7] Since Harris *et al.* state that their scandium was impure, their measurement can presumably be discounted, and the values obtained by the other experimenters are now in agreement with our value of 23 barns.

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[2] Harris, Muehlhause, Rasmussen, Schroeder, and Thomas, Phys. Rev. **80**, 342 (1950).
[3] M. Goldhaber and C. O. Muehlhause, Phys. Rev. **74**, 1877 (1948).
[4] Seren, Friedlander, and Turkel, Phys. Rev. **72**, 888 (1947).
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[6] F. C. W. Colmer and D. J. Littler, Proc. Phys. Soc. (London) **A63**, 1175 (1950).
[7] Private communication from H. Pomerance to D. J. Littler, October 3, 1952.

## Intensities of Nuclear Magnetic Resonances in Cubic Crystals

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A RECENT communication[1] reports puzzling results from attempts to determine the spin of $Si^{29}$ by comparing the intensity of its magnetic resonance absorption with that of $I^{127}$, of spin 5/2, in cubic crystalline KI. Some observations made a year ago on the shapes and intensities of the nuclear magnetic resonance lines of $Br^{79}$, $Br^{81}$, and $I^{127}$ in crystalline KBr and KI are briefly reported here because they seem particularly relevant to the interpretation of the above results. The intensities were determined relatively and absolutely by use of the calibrating circuit briefly described previously.[2]

In well-annealed single crystals of optical quality, narrow, symmetrical lines were observed. However, it was discovered that the integrated observable intensities were considerably smaller than would be expected for their respective spins. The observed intensities of $Br^{79}$ and $Br^{81}$, both of spin 3/2, were each only 0.4, and that of $I^{127}$, of spin 5/2, only 0.3 as large as expected. In powdered samples, or in single crystals which had been subjected to linear compression resulting in plastic flow and "work-hardening," the lines were found to be broader and unsymmetrical, with a stronger tail on the low frequency side. In these highly strained samples, the observed intensities of the resonances of bromine were still 0.4 of the full values and that of $I^{127}$ had decreased to about 9/35.

These effects have been interpreted as arising from the interaction of the quadrupole moments of the nuclei with electric field gradients of random position and orientation produced by internal strains in the crystals. A quadrupole interaction introduced as a first-order perturbation causes the normal magnetic resonance line to split into $2I$ lines equally spaced by an amount determined by the magnitude and orientation of the field gradient relative to the direction of the magnetic field.[3] For odd half-integral spin, the central line occurs at the unperturbed magnetic absorption frequency. Field gradients having a range of intensities and random orientations would smear the satellite lines over a wide frequency range, leaving only the central line as observable. The fractional intensity associated with the central line is just 4/10 for $I=3/2$, and 9/35 for $I=5/2$. This suggests that only the central lines were observed in the single crystal of KBr. In the single crystal of KI, we were evidently observing, as well as the central line, a small residual contribution from the satellites. A broadening of the central line, with an asymmetry in the same direction as that observed in the highly strained samples, can be explained by carrying the perturbation to second order as required for larger gradients.

An attempt has been made to estimate the magnitude of the internal strains associated with lattice imperfections of the dislocation type. The changes in line shape found to accompany plastic flow seem consistent with the increase in concentration of dislocations required to account for the flow. However, if a concentration of $10^8$–$10^{10}$ $cm^{-2}$ is assumed for the well-annealed crystal, using reasonable values for the nuclear quadrupole moments,[4] one finds that the field gradients at the nuclei must be a factor $\beta\sim 2$–20 times greater than would be produced by just the charged alkali neighbors displaced under strain. Another estimate of about 10 for this factor $\beta$ was made from observations of a small reversible effect of linear compression upon the line shape of $Br^{79}$ in a highly work-hardened crystal of KBr. Both of these observations indicate that the symmetry of the electronic wave function of the halogen ion itself is a larger contributant to the field gradient than is the direct effect of the displacement of the neighboring ions from cubic lattice sites. The details of this calculation as well as the experimental results quoted in this letter will be published later.

If this interpretation is correct, it is evident that a nucleus with a moderate quadrupole moment can serve as a very sensitive monitor of internal strains in crystals. The resonances observed here are poor for this because they are really too sensitive, the first-order smearing being almost completely effective even in the most perfect crystals. A nucleus with a smaller quadrupole moment (or smaller $\beta$) would be better. Detailed analysis of its line shape could give information about both the magnitude and distribution of internal strains in even the most "perfect" available single crystals. Intensity observations on $Li^7$ in LiF revealed no effects of this sort.

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## The Cross Section for $Ta^{181}(\gamma, 2n)Ta^{179}$ at 17.6 Mev

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THE variation with energy of the total nuclear absorption cross section of complex nuclei for gamma-rays has not yet been determined. The well-known "resonances" of the $(\gamma, n)$ cross section alone may or may not persist when competing reactions are taken into account; if they persist, then it may be that some specific nuclear model[1] is needed or that some specific aspect of nuclear forces is involved. It is also important to determine whether there exists the considerable cross section for higher order processes needed[2] in the interpretation of the total neutron yield through the dipole sum rule.[3]