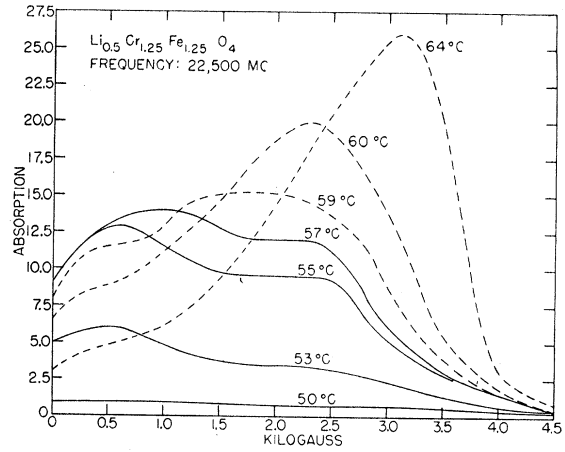

FIG. 1. Resonance absorption curves at various temperatures.

records are shown in Fig. 1. It is clear from the figure that a new peak at lower fields appears and vanishes as the temperature is increased. One is faced with a difficulty that the peaks overlap to some extent, but for purposes of further analysis the separate peaks were outlined as well as possible. Apparent g values were then calculated for each peak by the formula $h\nu = g\beta H$, where H is the magnitude of the applied field at the position of maximum absorption. The two sets of g values obtained in this way are shown as a function of temperature by the solid lines in Fig. 2. One set has extremely high values, while the other set, although high, never becomes larger than the value of 7 or 8 which can reasonably be expected for the lower branch near $S=0$.

The peak height of the lower branch resonance is shown by the open circles in Fig. 2; it is steadily increasing as the net magnetization is increasing again from the value $M=0$ which occurs at about 40°C. On the other hand, the peak height assigned to the upper branch resonance, which is shown by the open triangles, increases to a maximum and vanishes again in the range

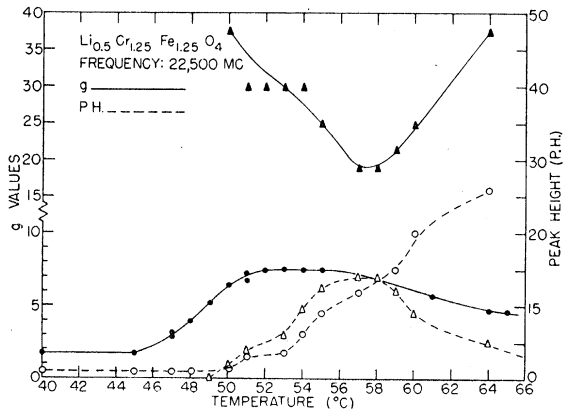

FIG. 2. g values and peak heights as a function of temperature.

of temperature shown. From these measurements the angular momentum compensation point is placed at 57 to 58°C.

The fact that the low-field resonance peak remains distinct over a wide temperature interval lends support to its identification as exchange resonance. If the specimen were porous, or contained a considerable number of local inhomogeneities in the chemical composition, it would show unduly broad resonance curves. The effect of such broadening would give poorer resolution and might conceivably merge the two peaks shown in Fig. 1 into one. It seems clear, therefore, that the material was sufficiently good to show exchange resonance in the region of a ferrimagnetic compensation point for angular momentum.

* A brief mention of these results was made at the Naval Ordnance Laboratory Conference on Ferrimagnetism on October 12, 1954.

[1] R. K. Wangsness, preceding letter [Phys. Rev. **97**, 831 (1955)].
[2] J. S. van Wieringen, Phys. Rev. **90**, 488 (1953).
[3] L. R. Maxwell and T. R. McGuire, Revs. Modern Phys. **25**, 279 (1953).

X-Ray Measurements of Pile-Irradiated LiF†

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X-RAY measurements have been made upon two LiF single crystals cleaved upon the (001) face and exposed to slow-neutron flux in the Argonne pile. The exposures were approximately 2.1×10^{17} and and 7.5×10^{17} nvt. Li^6 is 7.5 percent abundant in natural lithium, and slow neutrons react with this iostope according to $Li^6+n^1\rightarrow H^3+He^4+4.8$ Mev with a cross section of 950 barns. The tritium receives 2.74 Mev, and the α particle 2.06 Mev of kinetic energy. The major radiation effects are presumed to be caused by this reaction with slow pile neutrons. A Seitz calculation for the exposure 7.5×10^{17} nvt gave 4300 displacements per million atoms.[1]

Five orders, (002), (004), (006), (008), and (0010) were examined with x-rays. Table I gives the integrated reflections for three samples. Each reflection for the unirradiated sample is set equal to 100 percent. Irradia-

TABLE I. Integrated reflections of irradiated LiF relative to unirradiated LiF (expressed in percent).

Reflection	Unirradiated	Irradiated 2.1×10^{17} nvt	Irradiated 7.5×10^{17} nvt
002	100	216	206
004	100	90	95
006	100	83	86
008	100	105	93
0010	100	89	100

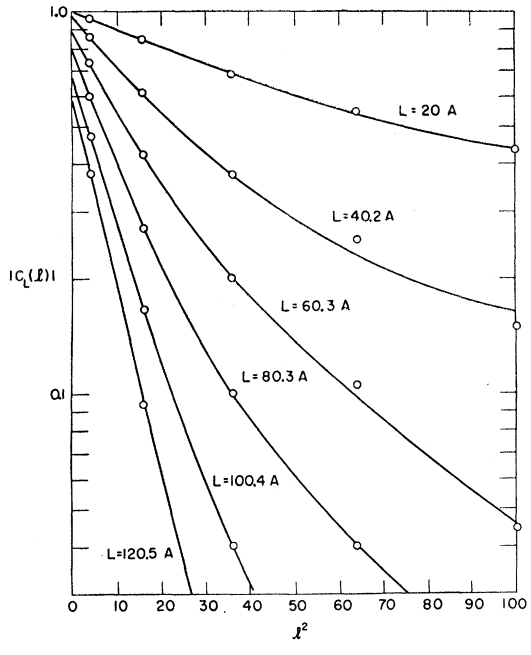

FIG. 1. Semi-log plot of $|C_L(l)|$ *versus* l^2 for the first five orders of (00l), measured on a single crystal of LiF irradiated 7.5×10^{17} nvt.

tion produced a twofold increase in the integrated reflection of (002). This increase for (002) is presumably by a reduction in extinction upon irradiation. Reflections (004), (006), (008), and (0010) do not show any definite correlation between integrated intensity and exposure or intensity and order.

The line shapes of the five orders were analyzed in terms of Fourier coefficients, corrected for instrumental broadening by the Stokes' method.[2] The breadth from the unirradiated crystal was assumed to be entirely instrumental. From the plots of the Fourier coefficients for the five orders, semilog polts of $|C_L(l)|$ *versus* the square of the order, l, were made. For small values of l the curves approach a straight line, and the intercept gives the particle size coefficient.[3] The plot for the crystal with exposure 7.5×10^{17} nvt is given in Fig. 1. The intercepts gave values of the particle size coefficients corresponding to a particle size of 500 A or more for both irradiated crystals.

The integral breadths, B, of the reflections expressed in terms of $\sin\theta/\lambda$ were closely proportional to the order of the reflection. The integral breadths corrected for instrumental broadening are tabulated in Table II. When properly corrected, the peak positions as measured by their centers of gravity gave an expansion of about 0.012 percent for both irradiated samples, but the shifts were so small that the value is scarcely outside of experimental error. The integral breadths were larger than the shifts in peak position by a factor of nearly 100. The predominant effect of the pile irradiation was to broaden the reflections rather than shift their positions.

TABLE II. The integral breadths for five orders of LiF, corrected for instrumental broadening.

Reflection	2.1×10^{17} nvt B	2.1×10^{17} nvt B/l	7.5×10^{17} nvt B	7.5×10^{17} nvt B/l
002	0.00170	0.000853	0.00219	0.001093
004	0.00349	0.000873	0.00427	0.001067
006	0.00530	0.000882	0.00653	0.001089
008	0.00718	0.000897	0.00872	0.001090
0010	0.00853	0.000853	0.01114	0.001112

In terms of a length, L, perpendicular to the (00l) planes the strain $\epsilon=\Delta L/L$ is defined for the change in L due to the damage. Distribution functions, $P_L(\epsilon)$, were synthesized from the Fourier coefficients of the reflections for the distances $L=40.2$ A, 80.3 A, and 120.5 A.[4] It was found that the strain distribution functions $P_L(\epsilon)$ were independent of the distance L up to 120 A, the largest distance considered. When allowance is made for the small expansion of 0.012 percent, the distributions were symmetrical corresponding to equal probabilities of expansion or compression. They could be fitted by $P_L(\epsilon)=(\frac{1}{2}\sigma)[\cosh\pi(\epsilon-\bar{\epsilon})/2\sigma]^{-1}$, where $\bar{\epsilon}$ is the average strain of 0.012 percent, and $\sigma=\langle\epsilon^2\rangle^{\frac{1}{2}}$ is the root mean square strain. $\sigma=0.00350$ and 0.00438 for the samples irradiated 2.1×10^{17} and 7.5×10^{17} nvt, respectively. Figure 2 gives points from the synthesized distributions for the sample 7.5×10^{17} nvt. The solid curve was fitted by using the analytical expression with $\bar{\epsilon}=0.00012$ and $\sigma=0.00438$.

The important features of the damage produced in LiF single crystals by pile irradiation are pronounced broadening of the x-ray reflections and no marked change in the integrated reflections. There are small shifts in the positions of the reflections corresponding to expansions which are scarcely outside of experimental error. The broadening is due primarily to strains rather than to small particle size. The constant values of the strain over such large distances indicate that rather

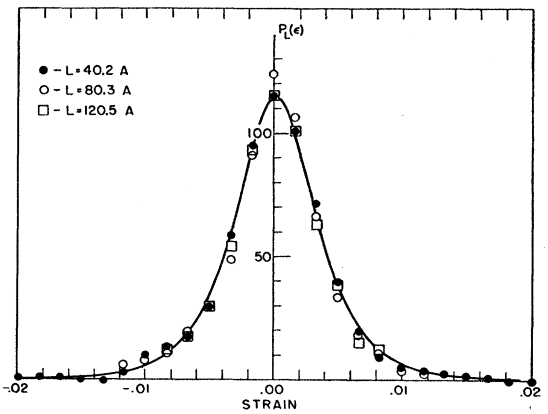

FIG. 2. Points from the synthesized strain distributions for $L=40.2$ A, 80.3 A, and 120.5 A in a single crystal of LiF irradiated 7.5×10^{17} nvt, and the function $P_L(\epsilon)=(\frac{1}{2}\sigma)[\cosh\pi(\epsilon-\bar{\epsilon})/2\sigma]^{-1}$ with $\bar{\epsilon}=0.00012$ and $\sigma=0.00438$.

large regions of the crystal must be in uniform compression or expansion. This suggests that the distortion cannot be due to isolated vacancies or interstitials. These results suggest that the imperfections collect in patches along certain (00l) planes, spreading these planes apart over areas whose diameters may be several hundred angstroms, and which are separated vertically by distances of 500 A or more. The regions directly above and below such imperfections would be in uniform vertical compression while regions near the periphery of such a collection of imperfections would be in vertical tension. For ionic crystals such as rock salt, the ratio of the breaking strength to Young's modulus, S/E, varies between a theoretical value of 0.1 and measured values as low as 2×10^{-4}. The measured root mean square strains fall in this range. The migration of imperfections would be a way of partially relieving strains and might be expected to proceed to such an extent that strains are kept down to values corresponding to S/E. From this picture it is not surprising that strains for the crystal irradiated 7.5×10^{17} nvt are only slightly greater than those irradiated 2.1×10^{17} nvt.

Since compressions and extensions normal to the cleavage planes have been postulated, additional measurements on samples cut parallel to (110) and (111) should be made before definite conclusions as to the nature of radiation damage in LiF can be drawn. It is conceivable that the effects in powdered LiF might differ from those in single crystals.

The author is indebted to Professor B. E. Warren for his suggestion of this research and for his counsel through the course of this work, and to Dr. Gerhart Hennig of the Argonne National Laboratory for the irradiated samples of LiF.

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[1] F. Seitz, Discussions Faraday Society **5**, 271 (1949).
[2] A. R. Stokes, Proc. Phys. Soc. (London) **61**, 382 (1948).
[3] B. E. Warren and B. L. Averbach, J. Appl. Phys. **23**, 497 (1952).
[4] B. E. Warren and B. L. Averbach, J. Appl. Phys. **21**, 595 (1950).

Domains of Reverse Magnetization in Ferromagnetic Metals

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In a recent communication, Goodenough[1] has calculated the nucleation energies for domains of reversed magnetization at grain boundaries and at crystal surfaces. He concludes that the probability for creation of such nuclei is largest at grain boundaries and depends on the relative angles of orientation of the axes of magnetic symmetry of the two grains subject to his particular assumptions regarding geometry and crystal symmetry.

We have been studying magnetic powder patterns in polycrystalline grain-oriented silicon steels. On the basis of extensive studies of the patterns obtained, we believe that Goodenough's calculations are not applicable to the types of material and sample geometry that one usually encounters in power transformer applications, i.e., laminated $3\frac{1}{4}$ percent silicon steel, with laminations of the order of 0.014 in. thick having grain sizes in the neighborhood of 5×10^{-3} cm^2.

A typical set of patterns we obtained on well oriented material is shown in Fig. 1. The patterns were obtained by the technique employed by Williams *et al.*[2] The orientation of each of the grains included in the figure was separately obtained by means of an optical goniometer using the etch pit technique.[3] It is evident from Fig.

Fig. 1. Domains of reverse magnetization on well-oriented material, showing that in the demagnetized state these domains are not influenced by the orientation of the adjacent grains.

1 that the spikes which form along the lower boundary of grain A are characteristic of the absolute orientation of the grain itself and are not related to the orientation of the neighboring grain. It has been ascertained that these spikes are nuclei of reversed magnetization. In fact, on the basis of an intensive investigation of the orientation and magnetic domain texture of more than 200 grains on like materials, it is possible to establish that the pattern of observed closure and reversed magnetization domains corresponds very closely to the orientation of the grain relative to the plane of the sheet and the direction of rolling.

The type of pattern observed on demagnetized material is found to depend exclusively on the angle of tilt out of the plane of the direction of easy magnetization ([100] direction) nearest the rolling plane. This angle we call ϕ. Typical patterns obtained on demagnetized material for various values of ϕ are shown in