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Crystal Orientation in Al by Slow Neutron Diffraction*

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Investigations are described of crystal orientation effects in various forms of aluminum by measurement of total cross sections in the neutron energy range 0.003 to 0.05 ev approximately.

1. INTRODUCTION

THE elastic coherent scattering of neutrons has been discussed theoretically by Goldberger and Seitz.[1] Fermi *et al.*[2] have studied, theoretically and experimentally, the transmission of slow neutrons through microcrystalline materials and obtained excellent agreement of theory and experiment for crystal diffraction effects in Be and BeO.

Sachs *et al.*,[3] analyzed by a simple theory the effect on slow neutrons of non-random orientations of the microcrystals in extruded graphite and compared the non-random with the random effect (powdered graphite). Their experimental results were in good agreement with the theory.

The present experiments include neutron diffraction investigations of crystal orientation effects in samples of microcrystalline aluminum prepared in several ways that were designed to influence the orientation of their crystallites.

2. EXPERIMENTAL PROCEDURE

The experiments were carried out by measuring the total cross section in the thermal neutron region of the various aluminum samples by the transmission method.[4] The mechanical slow neutron velocity selector[5] in conjunction with the Argonne heavy-water pile was used. Figures 1 to 4 illustrate typically the results obtained. The following points are noted in addition to the explanatory legends. The Al samples for Figs. 1–3 were machined in the form of rectangular parallelepipedon, presenting a cross-sectional area of $\frac{3}{4}$ in. × 3 in. to the neutron beam with a depth of $2\frac{3}{4}$ in. in the direction of the beam. The Fig. 4 sample was made of "atomized alumina" [6] pressed with an hydraulic press into a right circular cylinder of $3\frac{1}{2}$-in. diameter and 4-in. length, arranged so that a $\frac{3}{4}$-in. × $3\frac{1}{4}$ in. cross-sectional area by a 4-in. depth was presented to the neutron beam.

The curves are either corrected for "dead-time" errors of the counter circuits[7] or were made with the improved circuits of the same instrument which automatically eliminate dead-time errors. Upon each of Figs. 1–4 the absorption cross section, assuming a $1/v$ relation, has been drawn as a dashed line. These absorption curves were located by the point shown circled, 0.23 barn at 0.025 ev.[8] Thus, the total ordinates of the curves of Figs. 1–4 represent total cross sections (coherent elastic scattering cross section plus absorption cross section plus incoherent scattering); the portions of the ordinate distances from the dashed absorption curves up to the solid line are the coherent elastic scattering cross sections plus some small incoherent scattering. The magnitude of the incoherent scattering is shown by the separation between the dashed and solid curves between about 0.002 and 0.0035 ev and is seen to be about 0.25 barn.

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[1] M. L. Goldberger and F. Seitz, Phys. Rev. **71**, 294 (1947).

[2] E. Fermi, W. J. Sturm, and R. G. Sachs, Phys. Rev. **71**, 589 (1947).

[3] R. G. Sachs, V. Myers, and G. Arnold (to be published).

[4] See, for example, W. J. Sturm, Phys. Rev. **71**, 757 (1947).

[5] T. Brill and H. V. Lichtenberger, Phys. Rev. **72**, 585 (1947).

[6] Composed of particles generally spherical in shape (approximately 80 percent processed through No. 325 mesh screen and 20 percent through No. 100 mesh screen), impurities (iron, silicon, copper) less than 1 percent. This material was a gift of the Aluminum Company of America.

[7] Report 4010, Argonne National Laboratory.

[8] L. Seren, W. Sturm, and W. E. Mayer, Report CP1175, Argonne National Laboratory.

The long wave-length cut-off positions[9] of principal Bragg planes for Al (f.c.c.) are shown on Figs. 1–4.

3. RESULTS, DISCUSSION

Figures 1 and 2, for cold-drawn half-hard Al, exhibit the principal orientation effects observed in these experiments. Figure 1 was obtained for the neutron beam incident parallel to the axis of the rod from which the sample was cut, and Fig. 2 was obtained for the neutron beam incident perpendicular to the rod axis. The considerable differences between the two curves establish at once the presence of orientation effects. The main features of the Figs. 1 and 2 cross-section curves can be explained by assuming preferential orientation of the [111] and [100] axes in the direction of the axis of the original aluminum rod. Figure 5 shows diagramatically the effect of the assumed preferential orientation of these axes on the principal Bragg planes[10] and will be found helpful in understanding the cross-section curves.

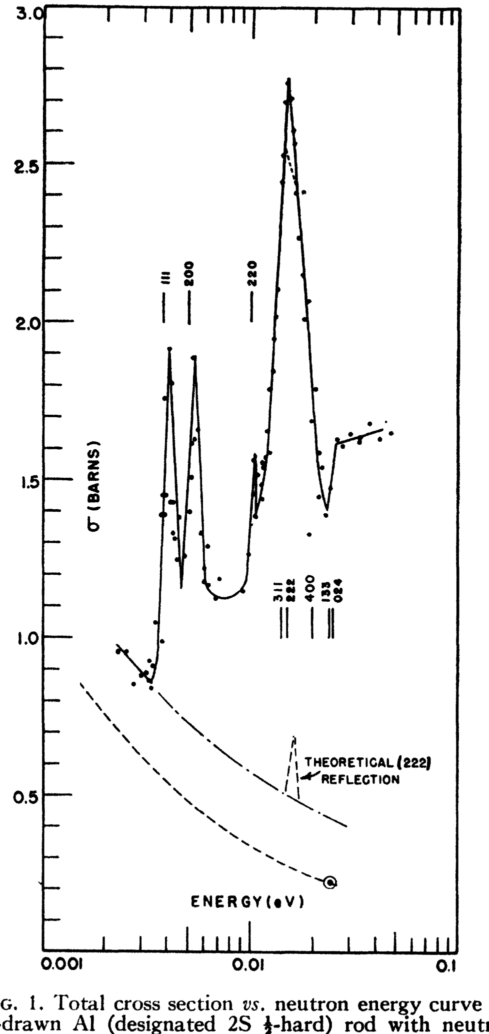

Fig. 1. Total cross section *vs.* neutron energy curve for cold-drawn Al (designated 2S ½-hard) rod with neutron beam incident *parallel* to the Al rod axis.

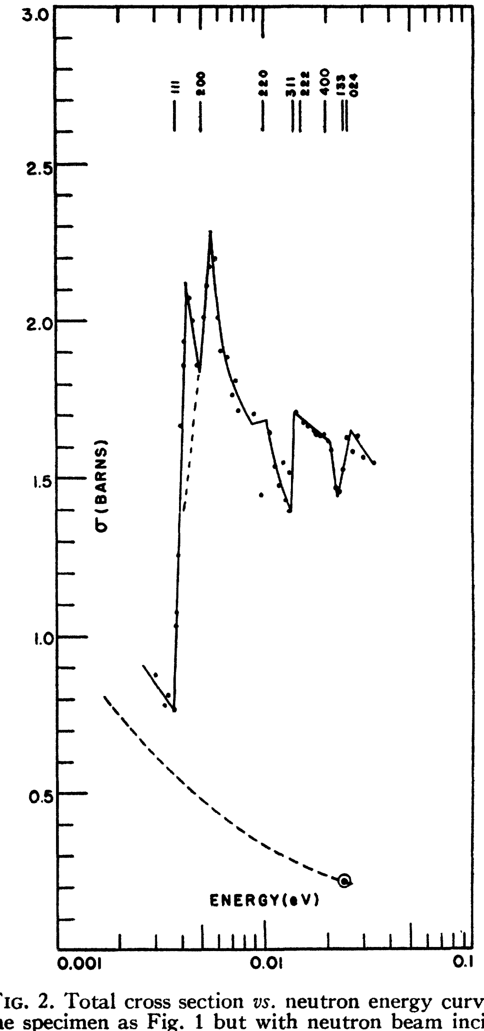

Fig. 2. Total cross section *vs.* neutron energy curve for same specimen as Fig. 1 but with neutron beam incident *perpendicular* to the Al rod axis.

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[9] Calculated by $\lambda = 2d$ in conjunction with

$$\lambda_{\text{in A}} = 0.285/(E_{\text{in eV}})^{\frac{1}{2}}$$

where E is the neutron energy and the other symbols have the conventional meaning.

[10] Compare W. T. Sproull, *X-Rays in Practice* (McGraw-Hill Book Company, Inc., New York, 1946), p. 454, Table 20–21.

Consideration of Figs. 1 and 5 shows that for the neutrons incident parallel to the Al rod axis, the [111] and [100] axes alignments in the rod direction produce, respectively, {111} and {200} type planes perpendicular to the incident neutrons. Hence, there should be the observed large coherent scattering at the long wave-length cut-off for these planes.

The large value of the cross section near the (222) cut-off (at about 0.015 ev, Fig. 1) appears at first an anomaly since (222) reflection is merely second-order (111) reflection, and since coherent scattering cross section varies directly as λ^2 (i.e., $1/E$),[11] σ_{111} should be about 4.5 times σ_{222}. It is considered, therefore, that the large observed cross section near the (222) cut-off is due chiefly to the nearby (113) and (220) planes. Figure 5 shows the several possibilities for the required (113) and (220) reflections and the conclusion is seen to be quite reasonable. Following this line of reasoning the theoretical σ_{222} was calculated from the experimental shape of the σ_{111} peak, assuming that the coherent scattering cross section varies directly as λ^2, and appears as the dashed peak labeled "theoretical (222) reflection" drawn from the dot-dashed absorption and incoherent scattering cross-section curve. Separating this experimental curve lowers the prominent peaks near the (222) plane cut-off to approximately the dashed line (at about 2.5 barns).

For neutrons incident perpendicular to the Al rod axis, Fig. 2 shows the importance of the {111} and {200} reflections. Consideration of Fig. 5 establishes the fact that some {200} planes only

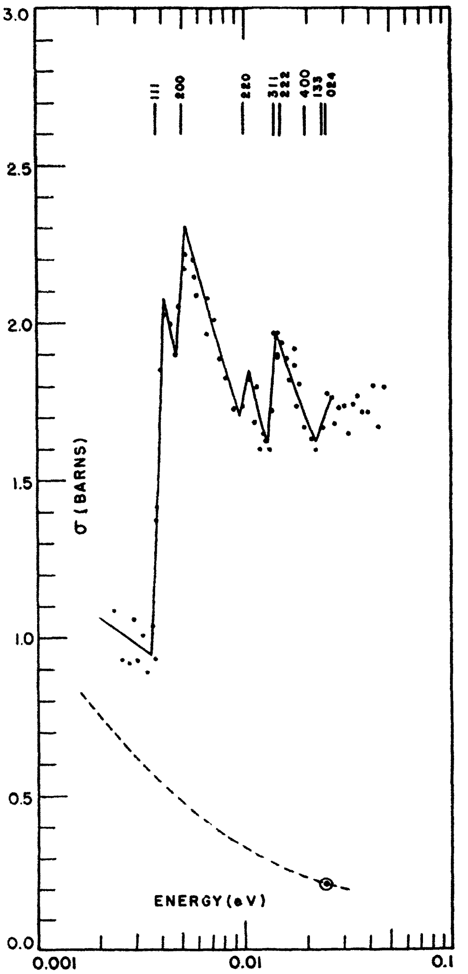

FIG. 3. Total cross section *vs.* neutron energy curve for a pellet pressed from Al powder with neutron beam incident parallel to compression direction.

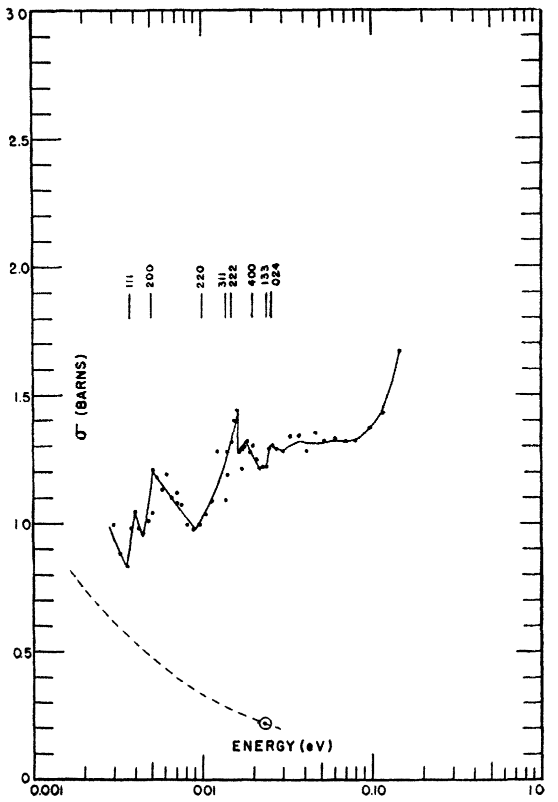

FIG. 4. Total cross section *vs.* neutron energy curve for cast Al.

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[11] Reference 2, Eq. (4).

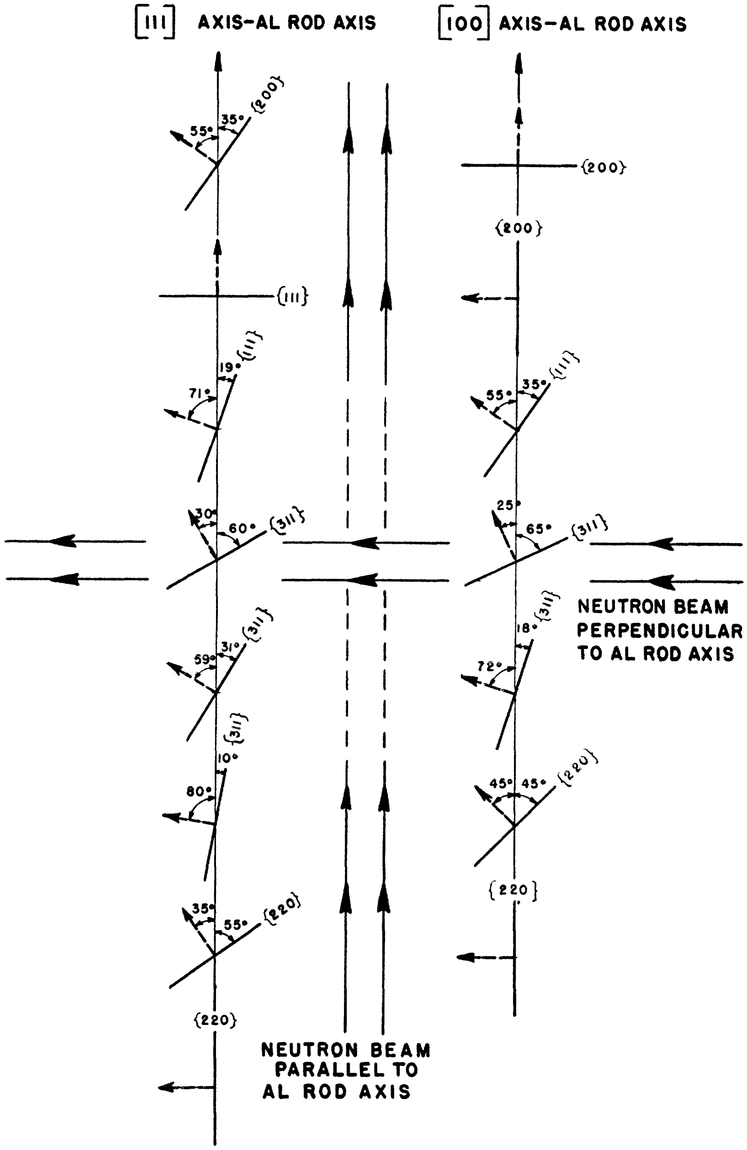

Fig. 5. Orientation of principal Bragg planes relative to [111] and [100] axes assumed in direction of Al rod axis and relative to the two directions of incident neutrons. The dashed arrows represent normals to the Bragg planes.

are presented perpendicular to incoming neutrons with the {111} planes at fairly large Bragg angles. Hence it is concluded that the dominant coherent scattering is by the {200} planes, with at least half of the steep rise associated in position with the nearby {111} planes being actually caused by the {200} reflection.[12] The dashed line located between about 1.4 and 1.85 barns is an approximate attempt to illustrate this conclusion. It is seen that this assumption diminishes considerably the apparently large {111} reflection. This is a likely result.

Inspection of Fig. 5 also should emphasize the possibility of limited preferential orientation of the Bragg planes shown about the two orientation axes, [111] and [100]. For neutrons incident parallel to the orientation axes, any limited orientation of Bragg planes about these axes will have no effect, but for the neutrons incident perpendicular to these axes, orientation of planes

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[12] In interpreting the curves shown it must be remembered that the mechanical velocity selector has finite resolution so that the rises in cross section in the vicinity of Bragg cut-offs are not infinitely steep, as is ideally required.

about the [111] and [100] axes would be important. Perhaps it is also obvious that alignment of crystals preferentially orientated is never perfect so that the angles shown by Fig. 5 vary somewhat in the actual samples.

It is seen that the total cross section *vs.* energy curve for the pressed Al powder, Fig. 3, with neutrons incident in the direction of compression, is closely similar to Fig. 2, and therefore the orientations for these two cases must be approximately the same.

The cross-section curve for the cast Al sample, Fig. 4, exhibits relatively weak Bragg scattering, although fairly large crystals could be seen in the specimen by visual inspection. Apparently the crystals are so orientated as to avoid any considerable Bragg reflection.

In addition to the cold-drawn half-hard Al, the pressed Al powder and the cast Al, two other types of Al, 2-SO (soft) aluminum, and a 99.95 percent pure Al casting which had been worked with several passes to reduce grain size, were measured. The soft Al specimen (cut from a drawn rod) yielded total cross section *vs.* neutron energy curves very similar to Figs. 1 and 2 for neutron beams parallel and perpendicular to the soft Al rod. Hence, crystal orientations in the soft Al are about the same as for the cold-drawn half-hard Al. The results for the pure casting established that the small impurities present in the specimens were of little significance in determining the shape of the Figs. 1–4 curves.

4. CONCLUSION

The results show that crystal orientation effects can be investigated conveniently with monoenergetic neutrons as well as with x-rays. It is to be noted that the neutron diffraction experiments yield intensities rather directly since total cross sections are obtained at once, and from these the coherent scattering cross sections can be separated ordinarily without difficulty. The required size of samples, much larger at present for neutron than for x-ray diffraction, has some definite advantages for investigations such as the present one since it is not necessary to work with a small volume of the material being measured.

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The Latitude Dependence of Neutron Densities in the Atmosphere as a Function of Altitude

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In order to study nuclear evaporation processes and the origin of neutrons in the atmosphere, a series of experiments was performed in B-29 aircraft which included the measurement of neutron densities for several altitudes at 0°, 19°N, 40°N, and 53°N magnetic latitude. The total vertical intensity of charged particles traversing 5 g/cm^2 and the vertical intensity of mesons traversing 20 cm of lead were also measured at the same time. The neutron detectors were BF_3 proportional counters surrounded by paraffin cylinders[1] which were covered with cadmium. Two of these detectors containing enriched boron were connected in parallel to a fast amplifier and scaling circuit; a second pair of these detectors containing normal boron was connected with an identical electronic system. These detectors had flat operating characteristic curves of at least 100 volts. They were mounted in the rear pressurized cabin of the plane approximately two feet from any equipment. The detectors respond to neutrons above the cut-off energy for cadmium but are essentially fast neutron detectors. Although they do not have an energy response curve identical with the "long" counters[1]

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[1] A. O. Hanson and J. L. McKibben, Phys. Rev. **72**, 673 (1947).