X-Ray Scattering at Very Small Angles*

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July 21, 1947

DUMOND[1] has recently proposed a method of using the double crystal spectrometer for the measurement of x-ray scattering at very small angles. The scattering material is to be placed between the two crystals. The second crystal is then rotated, scanning a small angular region near the parallel position. Because the parallel position rocking curves with good crystals are only a few seconds of arc wide one hopes to detect scattered x-rays within a few seconds of the forward direction.

DuMond suggests in his letter[1] that the method may have occurred to others independently. This is indeed the case. At this laboratory some preliminary work was done over a year ago. Intense scattering from fibrous materials at right angles to the fiber axis was observed. A survey of the literature revealed that I. Fankuchen (whose interest in the problem was mentioned by DuMond) and M. H. Jellinek[2] had tried the method in 1944. They used the second or analyzing crystal in both the anti-parallel and parallel positions. No experimental results are given in the abstract. These authors attribute the suggestion of the parallel crystal arrangement to H. Friedman. In 1926 Slack[3] observed a considerable broadening of the parallel-position rocking curve when graphite was placed between the two crystals. He suggested that a multiple refraction of the wavefront by the graphite grains was responsible for the broadening. Von Nardroff[4] discussed the idea of multiple refraction quantitatively, and successfully explained Slack's results.

In view of the current speculation, a few comments on the double crystal method may be in order. Figure 1 is typical of the rocking curves which we have obtained with fibrous materials. Close to the central maximum (the region pictured) it is similar to the curves obtained by Slack with granular materials. We were able to continue the curve to several minutes of arc and still detect an increase of intensity with the specimen in place. With ground crystals, measurements might be extended to a degree or two. One can conveniently correct for absorption by running a rocking curve with the specimen before the first crystal.

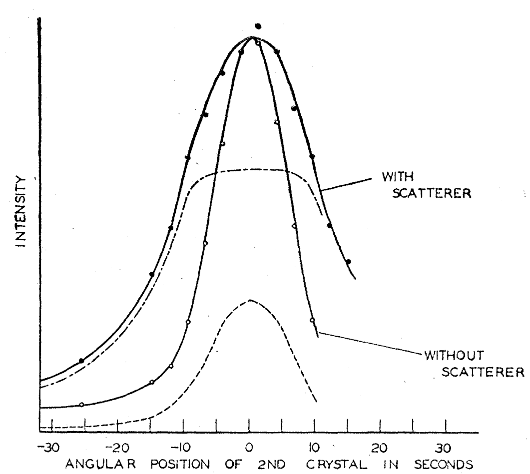

FIG. 1. Parallel-position rocking curves, wood scatterer 0.16 cm thick, tungsten L second order. The two curves are plotted to the same vertical scale.

The refraction effects obscure scattering at very small angles and may somewhat limit the usefulness of the method. Both refraction and scattering from randomly arranged particles[5] (the diffuse small angle scattering that has been so extensively investigated photographically) give an intensity *versus* angle distribution of the form

$$I(\theta)=Ce^{-\theta^2/k^2}.$$

In the case of scattering k is proportional to the x-ray wave-length divided by the particle size, and in the case of refraction to the unit decrement of the refractive index multiplied by the square root of the number of particles traversed. Thus refraction effects may be minimized by using a thin specimen and ignored if one is more than three or four half-widths away from the central maximum. In most cases we found more intensity at two or three minutes of arc than could be accounted for by refraction. The broadening of the central maxima of our curves is apparently due to refraction. The broadening increases with increasing specimen thickness, as predicted by the theory. This was first observed by Slack. Multiple scattering might, of course, cause such an effect.

It will also be noticed that the wave-length dependence of scattering differs from that of refraction. k is proportional to the wave-length for scattering, but to the wave-length squared for refraction.

* This research was supported in part by the Research Committee of the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.
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[2] I. Fankuchen and M. H. Jellinek, Phys. Rev. **67**, 201 (1945).
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Compatibility of Primary Protons with the Atom-Annihilation Hypothesis

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July 31, 1947

THE main objection to Millikan's theory for the origin of cosmic radiation appears to be his belief[1] that electrons are the principal components of the primary rays. This belief is based on his interpretation of the Lemaitre-Vallarta curves[2,3] when used for particles possessing the energy due to a helium atom-annihilation process. According to this interpretation, helium-produced electrons with an energy of 1.87×10^9 ev would first penetrate to the earth at about 54 degrees geomagnetic north, while helium-produced portions with an energy of 0.93×10^9 ev would be first detected somewhere north of 60 degrees geomagnetic north. This utilizes the same scale for protons as for electrons. The fact that there is an increase in total intensity