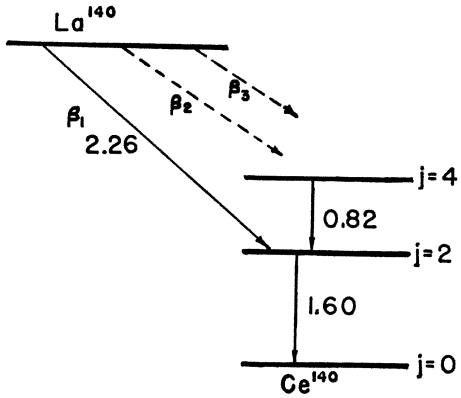

FIG. 1. Partial decay scheme of La^{140} with spins assigned on the basis of angular correlation experiments.

which is shown in Fig. 1. This scheme is similar to the decay schemes[8] of other odd-odd beta-emitters such as Co^{60}, Na^{24}, Cs^{134}, Sc^{46}, Y^{88}. On this assumption, the results of the angular correlation experiment may be used to assign spins to the 1.60-Mev and 2.42-Mev excited states of Ce^{140}. Table I shows the correlation function W to be expected with finite geometry for the assignment of spins 4, 2, 0 and quadrupole radiation.[7,8] This would be in accordance with the rule[9] for the spin of the first excited state of even-even nuclei.

There is some uncertainty[10] in the assignment of the 0.093-Mev gamma-ray in the decay scheme proposed by Beach *et al.*[1] If this gamma-ray does indeed occur between the 0.82- and 1.60-Mev gamma-rays, then the interpretation of the angular correlation experiment must be made on the basis of the triple correlation theory.[11] Further investigation of this isotope by means of precision coincidence spectrometry is necessary in order to determine the decay scheme unambiguously.

The authors are indebted to Professor George E. Owen of this university for helpful discussions of this problem.

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† AEC Predoctoral Fellow, 1950–1952.
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The Symmetry of Graphite

JOSEPH S. LUKESH
Knolls Atomic Power Laboratory, General Electric Company, Schenectady, New York*

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THE writer has discussed the symmetry of graphite in an earlier communication.[1] At that time there was suggested a fundamental twofoldness of the c-axis. Evidence for this was presented in the form of a c-axis precession-type photograph of the zero-level of the reciprocal lattice. Because of the small size of the unit cell of graphite and the wavelength employed (Cu K_α), only the six reflections of the $10\bar{1}0$ group appeared on the film. Four of these were accompanied by satellite reflections which were symmetrically related among themselves by the operation of two perpendicular mirror planes rather than by rotation about the c-axis. The satellites were separated from the parent reflections by a distance one-fifteenth of the reciprocal a-axis.

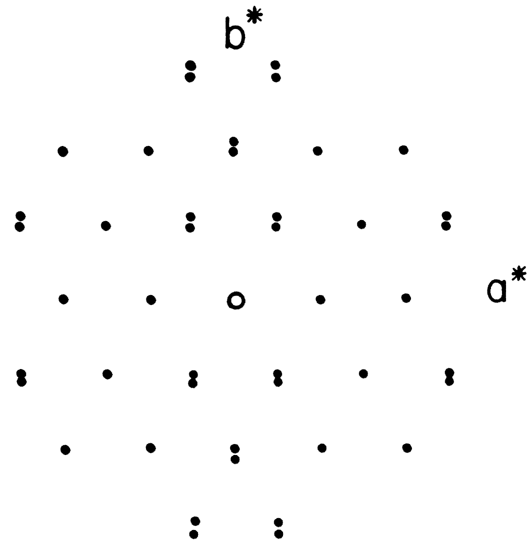

FIG. 1. Schematic representation of the c-axis, zero-level of the reciprocal lattice of graphite showing array of satellite reflections.

Since there were insufficient data to permit interpretation of the satellite reflections when copper radiation was used, experiments are being conducted with Mo K_α radiation monochromatized with rocksalt. Although these experiments are incomplete, it is believed that the accompanying illustration, Fig. 1, of the c-axis, zero-level of the reciprocal lattice, drawn schematically, is of considerable interest, since it extends and confirms the earlier results.

The inner ring of Fig. 1 represents that part of the reciprocal lattice illustrated in Fig. 3(b) of the earlier communication.[1] As mentioned before, the satellites are separated from their parent reflections by one-fifteenth of the reciprocal a-axis (conventional hexagonal graphite cell). This separation is maintained as one proceeds out the reciprocal a-axis of the orthorhombic supercell. The separation doubles and then triples in the direction of the reciprocal b-axis. The intensities of the satellites are of the order of one-fiftieth that of the parents.

Work on the n levels is continuing. Preliminary results indicate that satellites associated with reflections on the first level lie on the opposite side of the parent reflection from those on the zero-level.

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Polarization Effects in n-p Scattering*

DON R. SWANSON
Radiation Laboratory, Department of Physics, University of California, Berkeley, California

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THE expected azimuthal asymmetry in a double scattering of high energy neutrons by protons has been calculated using the "half-exchange" n-p interaction of Christian and Hart.[1]

If the first incident beam and both targets are unpolarized, then the intensity of the twice-scattered neutrons is given by

$$J(\theta_1, \theta_2, \phi_2) = I_1(\theta_1)I_2(\theta_2) + Q_1(\theta_1)Q_2(\theta_2)\cos\phi_2.$$

$P_y(\theta_1, \phi_1=0) = [Q_1(\theta_1)/I_1(\theta_1)]$ is the component of polarization normal to the plane of the first scattering of the once scattered neutron beam. $Q_2\cos\phi_2$ is the I_P defined by Wolfenstein.[2]

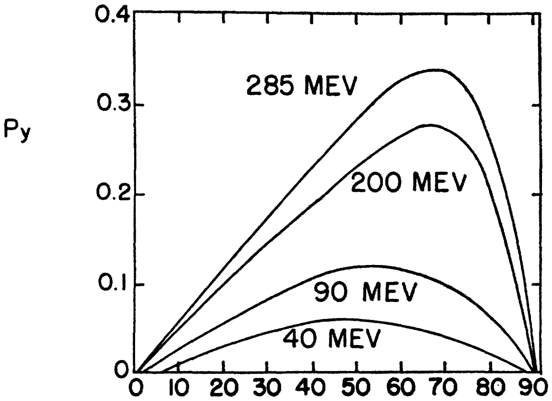

FIG. 1. The polarization $P_y(\theta, \phi=0) = [Q(\theta)/I(\theta)]$ as a function of scattering angle θ (c.m. system) for a single n-p collision at laboratory energies of 40, 90, 200, 285 Mev.

$(\theta_1, \phi_1=0)$ are the coordinates of the second target with the first target as origin and the incident beam as z-axis. (θ_2, ϕ_2) are the coordinates of the twice-scattered neutrons with the second target as origin and a z-axis defined by the two targets; ϕ_2 is measured from the plane of the first scattering. $I_1(\theta_1)$, $I_2(\theta_2)$ are the differential cross sections with polarization terms omitted.

Although polarization effects vanish in the Born approximation, the higher angular momentum states in a partial wave analysis can profitably be so calculated since interference terms with states of lower angular momentum (computed exactly) do not vanish. Accordingly, the calculations were carried out using the phase shifts of Christian and Hart in the $^3S_1$, $^3D_1$, $^3D_2$, and $^3D_3$ states, with all higher states included in the Born approximation.

Q_1 and Q_2 are equal (at the same angle and energy), provided that, in a partial wave analysis, all Wronskian conditions on the phase shifts of the coupled equations are satisfied. In Fig. 1, values of $Q(\theta)/I(\theta)$ are plotted as a function of center-of-mass angle for any single n-p scattering. One can see from the equations of Wolfenstein[3] that $Q(\theta)$ is antisymmetric about $\pi/2$ for odd or even parity states alone (hence zero at $\pi/2$), but symmetric for odd-even interference terms. Detection of azimuthal asymmetry at $\pi/2$ would therefore indicate the presence of both odd and even terms, and so disprove the "even" exchange hypothesis. In the case of p-p scattering, the $\pi/2$ point should of course give no polarization regardless of the assumed interaction since the even triplet states are not present.

It is of interest to note that almost the entire energy dependence of the polarization $Q(\theta)/I(\theta)$ lies in the differential cross section $I(\theta)$. This behavior is not entirely surprising since $Q(\theta)$ is determined principally by the $^3S-{}^3D$ interference terms; the S phase shifts decrease and the D increase with increasing energy apparently in such a way as to leave $Q(\theta)$ almost independent of energy between 90 Mev and 285 Mev.

With energies of 220 Mev and 160 Mev for the two scatterings, respectively, the ratio $J(\phi_2=0)/J(\phi_2=\pi)$ is 1.12 ± 0.03 at $\theta_1=65°$, $\theta_2=60°$. The ±0.03 is based on an estimate of the accuracy to which the phase shifts are known.

Although the problem has been formulated for two scatterings of a neutron beam, the first scattered beam could just as well have arisen from a (p,n) reaction. This follows from the equality of polarization of the two scattered particles and from the invariance of the scattering amplitude under the substitution $\theta\rightarrow\pi-\theta$ and $\phi\rightarrow\phi+\pi$ because of the exchange dependence assumed. A similar argument for the second scattering shows that the scattered intensity of the protons at any angle is the same as that of the neutrons. In an accompanying letter, Wouters[4] reports an experiment in which a beam of polarized neutrons was produced by a (p,n) reaction in LiD and detected by means of an n-p scattering. The resulting asymmetry agrees in sign and order of magnitude with the foregoing calculations. The experiment was also carried out with LiH as first target; for this case no significant asymmetry was detected.

A more refined interpretation of the results could be obtained by calculating the polarization from the $D(p,n)$ reaction, here assumed equivalent to a scattering of protons by free neutrons. The failure to detect asymmetry with the LiH target does not seem particularly disturbing since scattering from neutron bounds in Li^7 might reasonably be expected to yield less polarization than would scattering from free neutrons, sufficiently less to escape detection in Wouters' experiment.

The experimental results, although consistent with the "even" theory, are not of sufficient precision to allow one on this basis to rule out interaction in the odd triplet states. This point is under further investigation in the hope that a quantitative argument can be made.

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Detection of the Azimuthal Polarization of the n-p Interaction at 150 Mev

L. F. WOUTERS
Radiation Laboratory, Department of Physics, University of California, Berkeley, California
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A DOUBLE-SCATTERING experiment for the purpose of measuring the polarization due to the noncentral n-p interaction at high energy is in progress at this laboratory. The azimuthal effect appears notably as a change in the right/left ratio of second scattered flux intensity as the scattering angles are altered; the concurrent paper[1] presents the theoretical predictions concerning the magnitude of the effect in an ideal experiment.

The principal problem encountered in a double-scattering experiment in the 150-Mev region is the large accidental background in the azimuthal counter array caused by single scattered particles. In order to circumvent this, the first scattering (p,n) is performed inside the 184-inch cyclotron vacuum tank, utilizing the excellent neutron collimating features of the concrete shielding. The "neutron" target is a cast LiD block, which can be moved along the center line of the emergent neutron beam by means of a sliding probe. It thus intercepts the circulating proton beam at various radii corresponding to a range of first scattering angles of 0° to 45°. This geometrical arrangement has the advantage that the emergent neutron beam has almost the same energy at any angle; it also makes possible normalizing the system to 0°, where clearly no polarization is to be expected. LiH has also been used to show that the predominent contribution to the polarization effect is indeed a result of the relatively "free" deuteron neutron.

The second scattering (n,p) is performed by the orthodox carbon-paraffin difference method; the proton detectors consist of coincidence scintillation counter telescopes subtending a wide aperture ($\sim$8°). Four such telescopes detect the second scattered particles at the azimuthal angles 0° (right), 90° (up), 180° (left), and 270° (down). The scattering angle for all four is fixed at 30°, the theoretically optimum angle, throughout the experiment. Thus, the external second scattering apparatus operates under essentially constant conditions, and the independent variable is the first scattering angle.

The theory of the concurrent paper predicts no polarization at 45° lab angle, with a maximum asymmetry at 30°; quantitatively, this is expressed as a right/left second-scattered flux ratio of 1.12 or, as is more convenient, 12 percent polarization. Experimentally,