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## Polarized Neutron Beams

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(Received March 25, 1957)

THE partially polarized neutron beam used in the measurement of the free neutron-proton polarization[1,2] on the 110-inch Harwell cyclotron was obtained by irradiating an internal beryllium target with 165-Mev protons, the angle between the incident protons and the emitted neutrons being 26 degrees in the laboratory system as indicated in Fig. 1. The magnitude and the sign of the polarization were obtained[3,4] by measuring the asymmetry in small-angle scattering off uranium where the polarization due to the interaction between the nuclear Coulomb field and the neutron magnetic moment is large (Schwinger).[5] This experiment showed unambiguously that the neutron beam was a "spin-up" beam. The sign of the polarization corresponds to that expected if the neutron production is looked upon as a quasi-free *p-n* reaction. The magnitude of the polarization was 0.088±0.007 at an effective energy of 95±2 Mev although the measurement included neutrons in a triangular band from 75 Mev to 120 Mev.

Other partially polarized neutron beams have now been produced with the scattering angle $\theta$ changed to 55°. The results obtained are given in Table I. The effective energy at which these measurements were made was 75±2 Mev but neutrons in the energy range from 65 Mev to 100 Mev were involved. The most interesting fact to emerge from these measurements is that the sign of the beam polarization in all cases corresponds to a spin-up beam and is opposite to that expected at this angle if the neutron production process is considered as a quasi-free $(p,n)$ reaction (see Fig. 2). Moreover, the magnitude of the polarization, especially in the case of beryllium and carbon, is large. Marshall and Marshall,[6] and Brinkworth and Rose[7] have shown that in the elastic scattering of protons from nuclei a spin-up beam is produced by a "left" scattering, and it is tempting to interpret the $(p,n)$ results as providing evidence that the interaction of the incident protons with the nuclear surface provides a predominantly spin-up beam before any appreciable neutron production takes place. The results could provide a useful guide to the understanding of the production of neutrons at these energies.

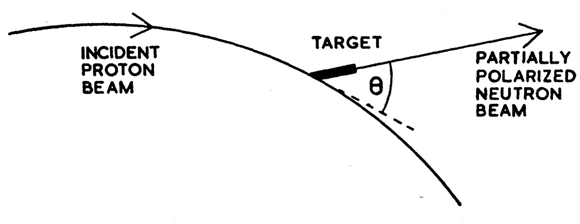


FIG. 1. Geometrical arrangement of apparatus.

TABLE I. Measured neutron beam polarization at 55°.

| Element | Asymmetry | Polarization |
|---|---|---|
| Be | 0.20±0.03 | +0.35±0.05 |
| C | 0.20±0.03 | +0.35±0.06 |
| Cu | 0.16±0.05 | +0.28±0.09 |
| W | 0.10±0.03 | +0.17±0.06 |

A similar effect, though of smaller magnitude, can be deduced from the experiment which Roberts, Tinlot, and Hafner[8] carried out to measure the polarization in free neutron-proton scattering; in this experiment the second scatterers were made of polythene and carbon, and it is possible to compare directly the sign of the asymmetry for carbon and for hydrogen targets. Two first scatterers, carbon and beryllium, were used. Taking the values quoted by Roberts *et al.* for the polarization ($P_1$) of the neutron beam from these two targets and assuming that the asymmetry $e=P_1P_2$, the two values obtained for the polarization from a carbon second scatterer at a laboratory angle of 55° are estimated as 0.11±0.02 and 0.17±0.04 which are in satisfactory agreement. These values are somewhat

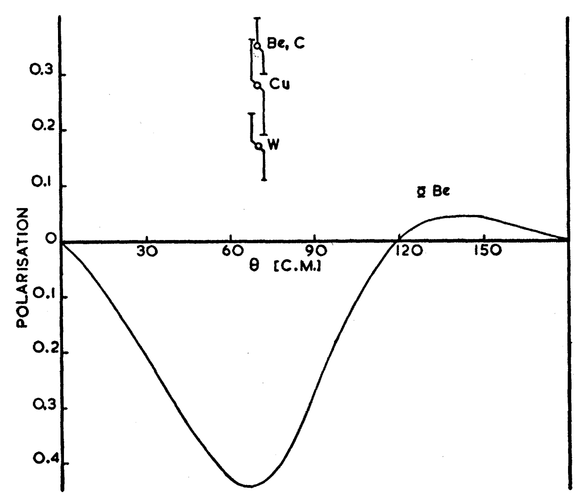


FIG. 2. The solid line shows the variation with center-of-mass scattering angle of the polarization of neutron beams expected in a free proton-neutron scattering process, with the geometry similar to that illustrated in Fig. 1. This has been derived from the measured neutron-proton polarization at an incident energy of 95 Mev. The points indicate the polarization of neutron beams produced by the irradiation of various target materials with 165-Mev protons.

lower than ours but this could be due to the fact that the initial proton energy was somewhat higher (230 Mev). The sign of the polarization is, however, the same and is opposite to the sign obtained by them for free neutron proton scattering.

We would like to acknowledge our thanks to Dr. G. Brown and Dr. T. H. R. Skyrme for valuable theoretical discussions.

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# Phenomenological Two-Nucleon Potential up to 150 Mev*

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(Received March 22, 1957)

THE large amount of experimental data bearing on the two-nucleon interaction in the energy region up to 150 Mev has thus far not been fitted by any type of meson-theoretic or even phenomenological potential. It is true that several meson-theoretic two-nucleon potentials give a reasonable fit of the low-energy parameters. However, all of these potentials (in particular, the Lévy[1] and Gartenhaus[2] potentials) fail conspicuously when an attempt is made to match the unpolarized and polarized scattering data at 100 and 150 Mev.[3] From this latest work one receives the distinct impression that no combination of central and tensor forces, making full allowance for an arbitrariness in the spin and isotopic spin dependence, will match the existing data up to 150 Mev.

On the other hand, from a purely phenomenological point of view, there is no reason why a spin-orbit two-nucleon interaction should not be added to the central and tensor forces. Case and Pais[4] first pointed out some of the virtues of the two-nucleon spin-orbit interaction but Goldfarb and Feldman[5] found that this interaction by itself (in triplet states) is incapable of explaining the experimental data. Recently, Ohnuma and Feldman[6] made a phase shift analysis of the experimental cross sections at 150 Mev and found that almost every set of acceptable phase shifts favors the inclusion of a spin-orbit potential. Other arguments for the existence of a spin-orbit component of the two-nucleon interaction can be adduced from the work of Wolfenstein[7] and Greene,[8] and of course from the success of the shell model for complex nuclei.

While none of the aforementioned arguments is conclusive, the contribution of a spin-orbit force to

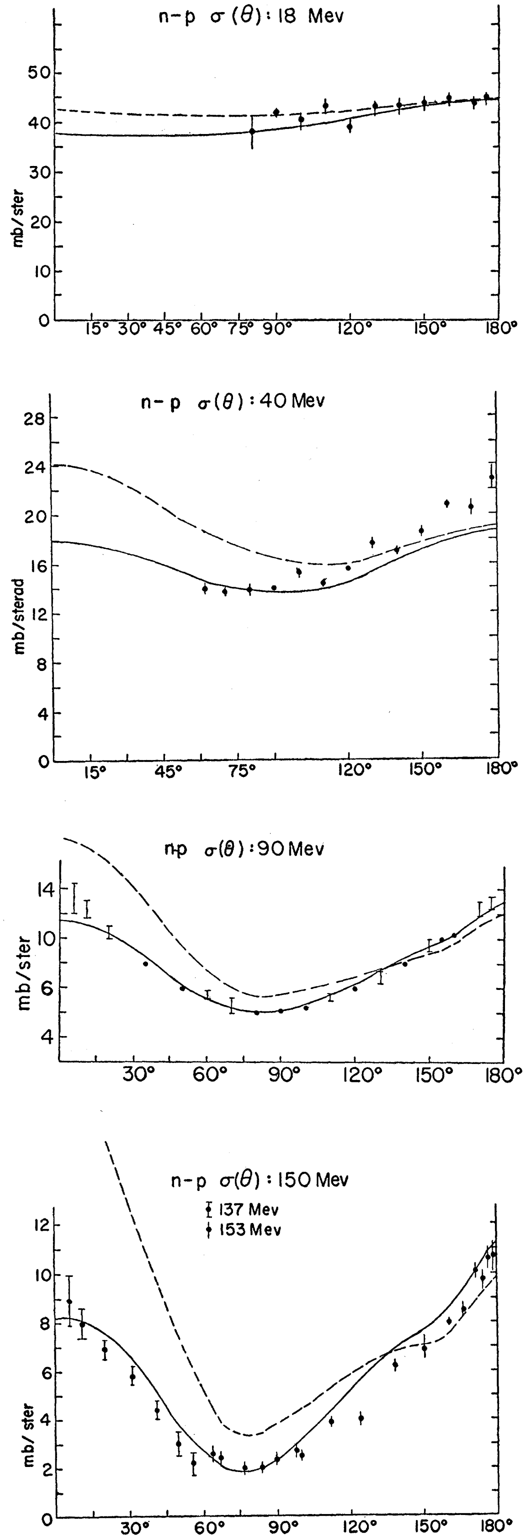


FIG. 1. Calculated $n-p$ scattering cross sections. The dashed lines represent the predictions of the Gartenhaus potential. Solid lines represent the cross sections calculated on the basis of Eq. (1). The points denote the best experimental data available.[10]