for some hours with $(C^{12})^{6+}$ ions before the oxygen bombardment. Carbon dioxide was used as source gas for the production of both kinds of ions, and the selection of bombarding particle was made by adjusting the magnetic field to the corresponding resonance value.

The surface layer of the uranium target was dissolved and carriers were added. The separation of actinides and lanthanides was performed by lanthanum fluoride precipitation and ion exchange chromatography.[2] The identification of element 100 was established from its position relative to that of californium in the eluate.

The alpha activity was measured by means of an ionization chamber and a 16-channel pulse analyzer. The measurements were started about two hours after the end of the irradiations. In the element-100 eluate fraction, up to 20 alpha disintegrations of energy 7.7 Mev were usually found, decaying with a half-life of about half an hour. According to alpha systematics a probable mass number corresponding to these data is 250.

The first positive results were obtained on February 19. The work is still in progress.

We express our gratitude to the head of the institute, Professor Manne Siegbahn, for his continuous interest. Professor John O. Rasmussen, Jr., cooperated with us in the early development of this project during part of 1953, and his valuable advice is gratefully acknowledged. Our thanks are also due the cyclotron crew and other members of the technical staff.

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[1] H. Atterling, Arkiv Fysik 7, 503 (1954). This paper is a preliminary report on the acceleration of carbon, nitrogen, and oxygen ions in the 225-cm cyclotron.

[2] E.g., Street, Thompson, and Seaborg, J. Am. Chem. Soc. 72, 4832 (1950).

Interactions of High-Energy Neutrons in Molybdenum*

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In the past, decisive evidence obtained from stars induced by neutrons in nuclear emulsions was obscured by the ambiguity in the identification of the nucleus involved in the interaction.[1,2] To obviate this difficulty we have resorted to the use of thin filaments embedded in Ilford G5 electron sensitive emulsions.[3,4] The technique required the overcoming of various problems which will be discussed in a publication to appear elsewhere. In this letter we intend to present the results obtained from emulsions with embedded molybdenum wires of 28 microns diameter. We selected this material because of its favorable position between silver and bromine and for its desirable mechanical properties. The plates were exposed in good geometry to the neutron beam obtained by internal bombardment of a $\frac{1}{8}$-in. beryllium target with the proton beam of the 95-in. synchrocyclotron. The target was located at the 70-Mev radius and the neutrons were collimated in the forward direction and then passed through a hardener (32 cm of polyethylene) before impinging into the plates. We searched for events originating in molybdenum by scanning along the wires and measured the spatial angle and the true range, discriminating between particles with single and double charge. 250 events were analyzed. Each range was corrected for self absorption in the wire as a function of the azimuth and dip angles. The shrinkage was virtually eliminated from these emulsions and the residual amount was properly taken into account in computing both the range and the spatial angle. The range spectrum presented contains only singly-charged particles (Fig. 1). Under the reasonable assumption that they are protons, the two peaks appearing in our histogram would correspond to energies of about 3 and 6 Mev, respectively. The conventionally calculated Coulomb barrier for the molybdenum nucleus is of about 9 Mev. In addition, the range spectrum of the doubly-charged particles, assumed to be predominantly alphas, showed a similar

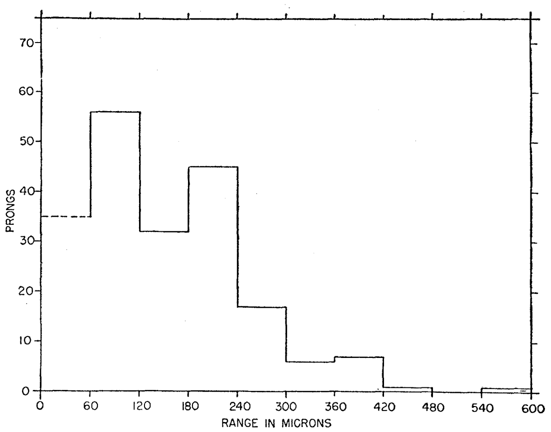

FIG. 1. Range histogram of singly-charged particles.

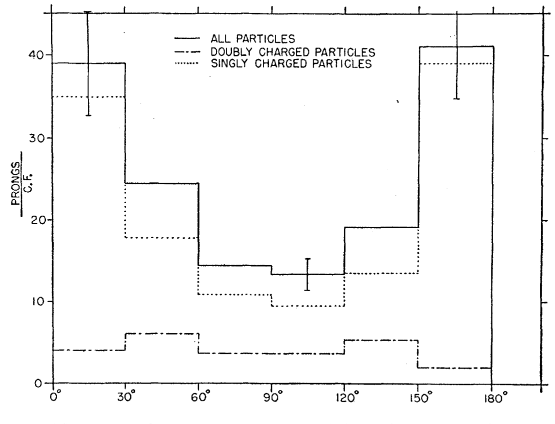

FIG. 2. Number of prongs *versus* spatial angle corrected for solid angle. (C.F. is the correction factor for the solid angle.)

distribution of particles emitted below the barrier. The angular distribution (Fig. 2) represents a histogram of the number of particles per unit solid angle plotted *versus* spatial angle. Calculations indicate that scattering in the wire for the lowest-energy protons emerging, should amount to no more than 8° in the average. Since self-absorption energy losses are a function of the azimuth and dip angle, we have considered the correction necessary to compensate for the loss of low-energy tracks emitted nearly parallel to the wire axis. We have found this correction to fall well within the statistics. Additional small corrections may be introduced due to the existence of a small "shadow volume" above and below the wire which is inaccessible to scanning.

Similar experiments with tungsten and Nylon filaments and at different energies are in progress.

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[1] R. W. Waniek and Taiichiro Ohtsuka, Phys. Rev. **89**, 1307 (1953).

[2] R. W. Waniek and Taiichiro Ohtsuka, Phys. Rev. **91**, 1574 (1953).

[3] G. P. S. Occhialini, Nuovo cimento **8**, 341 (1951).

[4] E. G. Silver and R. W. Waniek, Phys. Rev. **94**, 769 (1954).

Polarization of Nucleons Elastically Scattered from Nuclei*

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It has been shown by several authors[1–4] that the observed polarization[5–7] of protons of energy 200-400 Mev elastically scattered from nuclei can be accounted for by the assumption of a spin-orbit coupling of reasonable magnitude. In previous calculations[3] of the polarization of 316-Mev protons scattered from Be, it was found that the polarization P is positive inside the first diffraction minimum, becomes negative at ~17°, and becomes positive again for larger scattering angles θ (~21°). Although the order of magnitude of the observed P could be explained, the experiments of Marshall *et al.*[6] and of Chamberlain *et al.*[7] do not seem to give support to an oscillatory behavior of P. The previous calculations were carried out using a square well potential. It was suggested by E. Fermi and C. N. Yang that the oscillatory behavior of P may be directly connected with the assumption of a sharp nuclear boundary, and might disappear if one would use a nuclear potential with a more progressive falloff near the nuclear radius R.[8]

For this purpose, the following harmonic oscillator potential was used,

$$V=V_0(1-r^2/R^2), \tag{1}$$

where V_0 is a constant. The calculations were again carried out for 316-Mev nucleons on Be, using the same parameters of the optical model[9,10] as in I, i.e., $R=3.2\times10^{-13}$ cm, $k_1=0.86\times10^{12}$ cm^{-1}, $K=1.7\times10^{12}$ cm^{-1}, corresponding to a complex well of depth $\bar{V}=-(13+i25.6)$ Mev. V_0 was so chosen that the average $\langle V\rangle$ of (1) over the nuclear volume equals $\bar{V}$. We have

$$\langle V\rangle=(3/R^3)\int_0^R V_0(1-r^2/R^2)r^2dr=\tfrac{2}{5}V_0. \tag{2}$$

Thus V_0 was taken as $(5/2)\bar{V}=-(32.5+i64)$ Mev.

For the spin-orbit coupling, two models were assumed which correspond to those considered in I. The potential functions for these models will be written $-U_{1,2}(r)\mathbf{l}\cdot\boldsymbol{\sigma}$, where $\hbar\mathbf{l}$ and $\hbar\boldsymbol{\sigma}/2$ are the orbital and the spin angular momenta of the nucleon. $U_1(r)$ was taken proportional to the real part of $(1/r)(dV/dr)$ in accordance with the form of the Thomas precession. Thus U_1 is a constant u_1 independent of r. U_2 is assumed concentrated at the center of the nucleus. The approximate form of U_2 is

$$U_2(r)\cong u_2(R/r)^2(1-r^2/R^2). \tag{3}$$

The main term $\delta_{l,0}$ of the phase shift corresponding to V is given by

$$\delta_{l,0}=\frac{kV_0}{2T}\int_0^{(R^2-y^2)^{\frac{1}{2}}}\left(1-\frac{x^2+y^2}{R^2}\right)dx =\frac{V_0kR}{3T}\left(1-\frac{y^2}{R^2}\right)^{\frac{3}{2}}, \tag{4}$$

where k = wave number, T = kinetic energy, x and y are coordinates with respect to the center of the nucleus; x is along the incident direction of the nucleon, and $y=(l+\frac{1}{2})/k$. One obtains for the phase shifts $\delta_l^{\pm}$ of the two models,

$$(\delta_l^{\pm})_1=\frac{5}{3}R\left(\frac{iK}{2}+k_1\right)\left[1-\frac{(l+\frac{1}{2})^2}{k^2R^2}\right]^{\frac{3}{2}} \pm\frac{5k\epsilon_1(l+\frac{1}{2})}{6T(L+\frac{1}{2})}\left[R^2-\frac{(l+\frac{1}{2})^2}{k^2}\right]^{\frac{1}{2}}, \tag{5}$$

$$(\delta_l^{\pm})_2=\frac{5}{3}R\left(\frac{iK}{2}+k_1\pm\frac{k\epsilon_2}{2T}\right)\left[1-\frac{(l+\frac{1}{2})^2}{k^2R^2}\right]^{\frac{3}{2}}, \tag{6}$$

where L is the largest integer $<kR$, and $\epsilon_{1,2}$ are parameters which measure the strength of the spin-orbit coupling. We have $\epsilon_{1,2}=\frac{3}{5}u_{1,2}(L+\frac{1}{2})$.

The calculations of P from the $\delta_l^{\pm}$ were carried out using Eqs. (3)–(6) of I. Figure 1 shows $P(\theta)$ for the potential $U_1(r)$ with $\epsilon_1=4$, 7.5, 12, and 15 Mev. It is seen that P remains positive throughout the range of θ. The same is shown by Fig. 2 which presents $P(\theta)$ as obtained from $U_2(r)$ with $\epsilon_2=4$, 7.5, and 15 Mev. Thus