range investigated, one finds that there are about 1.2 neutrons in coincidence with every proton from carbon. The fact that this is greater than unity could be explained by poor statistics, or by the fact that the solid angle subtended by the neutron counter is no doubt due to a lead housing surrounding it. Further investigations are being made of this phenomenon with better geometry; however, the authors feel that most of the time neutrons and protons are emitted simultaneously from carbon and oxygen at these high energies.

* This work was supported in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

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[2] J. S. Levinger, Phys. Rev. **84**, 43 (1951).

Diffuse Surface Optical Model for Nucleon-Nuclei Scattering*

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We report some first results of calculations of the differential cross section for the elastic scattering of 20-Mev protons by medium and heavy nuclei, assuming that the nuclear part of the interaction is described by a spinless, spherically symmetric, complex potential. These calculations, which are accomplished by numerical integration of the partial wave radial equations for values of L up to 13, are performed on SWAC, the National Bureau of Standards Western Automatic Computer. The time required to obtain a

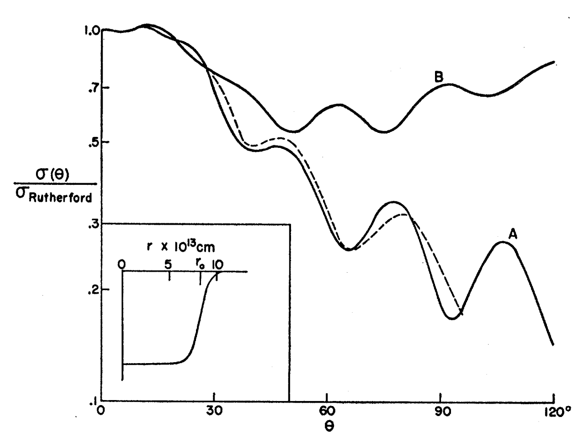

FIG. 1. Elastic scattering of 22-Mev protons by Pt relative to Rutherford scattering. The dashed curve is the experimental result of Cohen and Neidigh (see reference 3), the normalization of which is somewhat uncertain. Curve A is calculated for a diffuse surface model with $V=38$ Mev, $W=9$ Mev, $r_0=8.24\times10^{-13}$ cm, and $a=0.49\times10^{-13}$ cm. The shape of the well is shown in the small drawing at the lower left. Curve B is calculated for a square well of comparable size and depth.

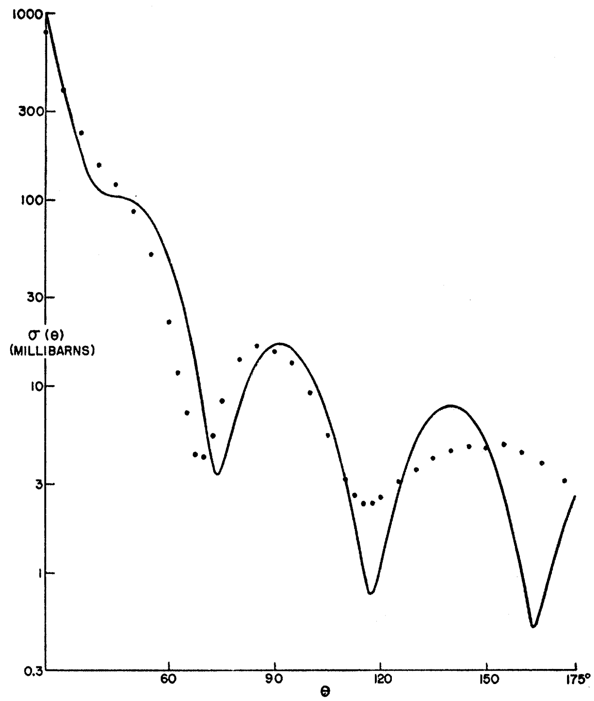

FIG. 2. Elastic scattering of 18-Mev protons by Ni. The experimental points are those of Dayton (see reference 1). The curve was calculated for a diffuse surface model with $V=40$ Mev, $W=10$ Mev, $r_0=5.3\times10^{13}$ cm, and $a=0.35\times10^{-13}$ cm.

complete differential cross section, tabulated at 5° intervals, is 15 to 20 minutes.

Initially, the complex potential was taken to be a square well with all of the nuclear charge essentially on the nuclear surface; this because of the simplicity of the model and because of its apparent success for Al.[1] However, for heavier nuclei, the square well results are in marked disagreement with the experimental cross sections of Gugelot,[1] Burkig and Wright,[2] and Cohen and Neidigh.[3] In particular, the square well predicts scattering at larger angles which is considerably too large as illustrated in Fig. 1 for the case of Pt. This disagreement, which has also been noted by others,[4] persists even if the square well parameters are permitted to vary over an extensive range and if the nuclear charge is assumed to be distributed over the nuclear volume.

Consequently, a nuclear potential which decreases smoothly to zero is now being studied, the assumed form of this potential being

$$V(r)=\frac{V+iW}{1+e^{(r-r_0)/a}},$$

where r_0 is a measure of the nuclear size and a determines the diffuseness of the nuclear surface. The Coulomb part of the interaction is taken to be that arising from a uniform charge distribution over a sphere of radius r_1 (not necessarily equal to r_0).

Computations for Al, Ni, and Pt for different values of the parameters V, W, r_0, and a, with $r_1=r_0$, show that rounding the nuclear potential significantly modifies the cross sections. As a increases and the rounding becomes greater, the large-angle cross sections decrease for the heavier elements and, as shown in Fig. 1, for the particular parameter values $V=38$ Mev, $W=9$ Mev, $r_0=8.24\times10^{-13}$ cm and $a=0.49\times10^{-13}$ cm, the computed cross sections are actually very close to the experimental ones. Also shown in Fig. 1 is a plot of the potential for this set of parameters. The results are *not* sensitive to the radius of the nuclear charge distribution; there is essentially no change when r_1 decreases from r_0 to 0.8 r_0, this latter value being of the order of that indicated by the experiments on x-rays from the mu-mesonic atoms.[5] However, information about the shape of the nuclear potential itself yields some information on the charge radius. Indeed, a rough calculation, assuming neutron and proton gases which fill states to the same Fermi level, indicates that the value of a quoted above is in the region required to give the observed charge radius.

Results for lighter elements are not yet so satisfactory, as indicated in Fig. 2 for Ni, although the results are at least qualitatively correct. However, only a limited range of the parameters has so far been investigated. Further computations are now in progress.

It is planned to extend the calculations to other elements and to other energies. It is also planned to calculate differential cross sections for the elastic scattering of neutrons in this energy region[6] using the same model.

* The preparation of this paper was sponsored (in part) by the Office of Naval Research.

[1] R. E. Le Levier and D. S. Saxon, Phys. Rev. **87**, 40 (1952); P. C. Gugelot, Phys. Rev. **87**, 525 (1952). Later results of I. E. Dayton, kindly communicated to us by Professor Gugelot prior to publication, showed that this success was fortuitous since the Al cross sections contained much deeper and narrower minima than had previously been reported.

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[5] V. L. Fitch and J. Rainwater, Phys. Rev. **92**, 789 (1953); L. N. Cooper and E. M. Henley, Phys. Rev. **92**, 801 (1953).

[6] Some preliminary results of experiments by J. H. Coon on the elastic scattering of 14-Mev neutrons from several elements have been kindly supplied prior to publication by Dr. J. H. Coon and Dr. R. Thomas.

Neutron-Proton Scattering at 300 Mev*

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A WILSON cloud chamber,[1,2] containing only hydrogen and water vapor, was photographed stereoscopically in a magnetic field[3] of strength 22 000 gauss to obtain data[2,4] on the protons scattered by 300-Mev neutrons. Certain selection criteria were adopted for the measurements of the tracks, which were obtained in two runs at the Berkeley cyclotron. A lower limit of 155 Mev was set on the neutron energy for a track to be accepted. Definite regions of the cloud chamber were chosen for the measurements in each of the two runs. Tracks whose dip angles exceeded 50° were excluded from measurement. The scatter angle was generally limited to 85°, although a few trackes were measured with angles up to 86° to make sure no 85° tracks were missed.

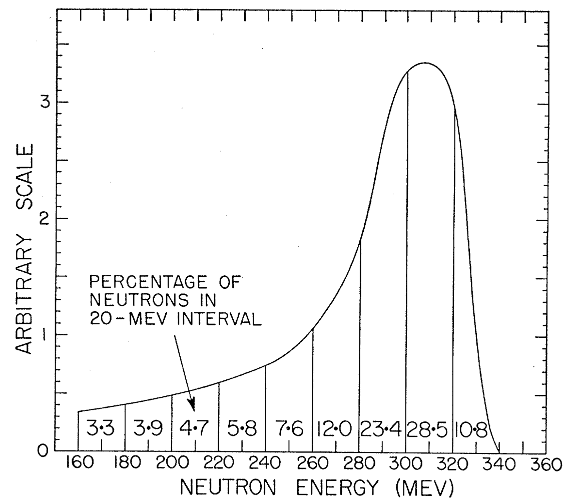

FIG. 1. The unfolded neutron energy spectrum from 340-Mev protons in a $1\frac{3}{4}$-in. thick LiD target. Errors of measurement were taken from the original data by an error-unfolding process.

The energy spectrum for the neutrons that were produced in a LiD target, $1\frac{3}{4}$ in. thick, by 340-Mev protons inside the cyclotron is shown in Fig. 1. This spectrum was derived from the original histogram of the cloud-chamber data by an error-unfolding process. A total of 1435 tracks were selected from the angular group (scatter angles less than 85° and dip angles less than 25°) for which the energy measurements are best. The omission of tracks with dip angles exceeding 25° is accounted for by applying a geometrical correction factor,[5] based on the assumption of azimuthal symmetry. The effect of the variation[6] of the total n-p scattering cross section with the neutron energy was included in the error-unfolding process.

In order to justify the assumption of uniform distribution of the protons in the azimuthal angle (measured in a plane perpendicular to the direction of the neutron beam), tabulations[2] of the data were made. Figure 2 shows the azimuthal distribution for dip angles less than 40° and for neutron energies above 200 Mev. Tracks with dip angles greater than 40° fall into the excluded region and are not tabulated. The number of tracks for any square or partial square is given inside the square. The numbers within any vertical column