which is the product of a deuteron plane wave and the wave function $\psi_1(\rho)$ of the initial nucleus. In the Butler theory,[4] one effectively does the same thing but for the exclusion of the range of integration $r_n \leqslant r_0$, where r_0 is the range of the interaction N between the picked-up neutron and the target nucleus.[5]

As remarked in reference 2, both approaches neglect the reaction effects of the various outgoing waves on the stripping process. In this letter, we report on calculations taking into account one of the most important of such effects, namely, the reaction of the proton outgoing wave itself. It is more convenient to consider the matrix element $I=\langle d|N+P|\Psi\rangle$ for the time-reversed process $\mathfrak{N}_2(p,d)\mathfrak{N}_1$. Both matrix elements are related in a well-known fashion. Ψ is the exact wave function for a stationary state of collision $p+\mathfrak{N}_2$. An approximate value for I is obtained by:

(a) neglecting V in the Schrödinger equation for Ψ;
(b) replacing P everywhere by a fixed average potential $\mathcal{P}$ with the effect that Ψ becomes the product of ψ_2 by a proton plane wave plus a wave elastically scattered by potential $\mathcal{P}$.

Then, using the Schrödinger equation, one gets for I an expression amenable to computation. In approximation (a), one treats the formation of the deuteron as a perturbation, as was already done in the Born approach. Approximation (b) still takes correctly into account the reaction effect of the elastically scattered wave provided $\mathcal{P}$ is properly chosen, but neglects the effect of all the other outgoing waves.

We have examined the case where $\mathcal{P}$ is a hard sphere potential with a radius r_0 equal to the range of the interaction P (and N).[6] Numerical calculations have been made with the shapes "$l=0$" and "$l=1$" for several values of the incident energy, the Q value and the parameter r_0, and the results have been compared with Butler's theory.

They are summarized as follows:

(1) The *angular distribution* predicted at low angles are much the same in both theories. For the same r_0, the peak occurs at rather smaller angles in this modified theory. This effect can be simulated by taking Butler's formula with a radius r_0 increased by about 25 percent. The reported discrepancy,[7] between the orthodox nuclear radii and the radii derived from the interpretation of stripping data through Butler's formula, is thereby explained.

(2) The *magnitude of the cross section* is much smaller. Our peak values are from 2 to 6 times smaller than those predicted by Butler's theory. Conversely, the values of the reduced widths obtained from these peak values are larger than those obtained from Butler's theory by the same factor, which explains at least qualitatively the reported discrepancy[7,8] in reduced width determination from resonance reactions and from stripping data.

(3) The stripped-off particle gets *partially polarized* provided $l>0$, in agreement with Newns' prediction.[9]

(4) In the $(d, p\gamma)$ *angular correlation*, although the over-all anisotropy remains as important as in the Butler theory, the actual shape of the distribution is completely different. In particular it does not possess any more the transferred momentum as axis of symmetry.

A fuller account of this work will be published in the *Journal de physique et le radium.*

[1] We neglect Coulomb corrections throughout. Accordingly the results on (d, p) reactions are readily extended to (d, n) by interchange of the roles of the proton and the neutron.
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[3] Bhatia, Huang, Huby, and Newns, Phil. Mag. **43**, 485 (1952).
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[6] The (p, d) amplitude that one gets this way could be called the amplitude for "pick-up proper," namely the amplitude that one gets when compound nucleus formation is neglected. It should fit best at energies far from the resonances of the compound nucleus $(p+\mathfrak{N}_2)$.
[7] Report of the Birmingham Conference on Nuclear Physics (Birmingham University Press, Alabama, 1953).
[8] R. G. Thomas, Phys. Rev. **91**, 453 (1953); also private communication.
[9] H. C. Newns, Proc. Roy. Soc. (London) **B66**, 477 (1953).

The Signs of the Phase Shifts for Pion-Proton Scattering

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In principle, it is possible to determine the sign of the pion-proton nuclear interaction by measuring the effect of interference between the nuclear and Coulomb amplitudes in pion-proton scattering. Under the usual assumptions[1] that only S and P states are effective and that the charge independence hypothesis is valid, the reactions

$$\pi^+ + p \rightarrow \pi^+ + p, \quad (1)$$

$$\pi^- + p \rightarrow \pi^- + p, \quad (2)$$

$$\pi^- + p \rightarrow \pi^0 + n \quad (3)$$

are described by the six nuclear phase shifts[2] α_1, α_{11}, α_{13}, α_3, α_{31}, and α_{33}, and by the Coulomb amplitude in the manner given by Van Hove.[3] The angular distribution of reaction (1) has been investigated[4,5] at energies sufficiently low so that Coulomb effects should be detectable; however, due to the experimental uncertainties, the relative signs of the nuclear and Coulomb amplitudes could not be determined unambiguously.

Recently, Woodruff[6] has pointed out that if the phase shifts α_{11}, α_{13}, and α_{31} are taken to be negligibly small, as the evidence indicates, then the magnitudes of the other three phases α_1, α_3, and α_{33} can be determined from the total cross sections for reac-

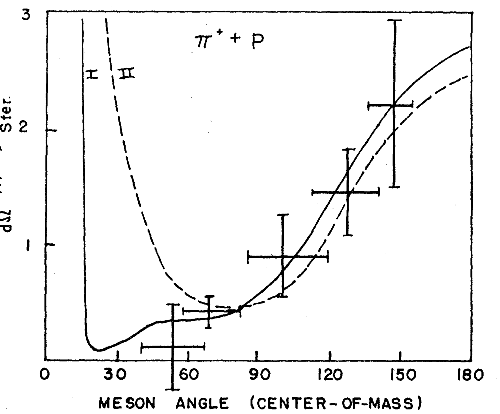

FIG. 1. Differential scattering cross section of hydrogen for π^+ mesons at 40 Mev. Curve I: $\alpha_3=-2.6°$, $\alpha_{33}=+5.7°$. Curve II: $\alpha_3=+2.6°$, $\alpha_{33}=-5.7°$.

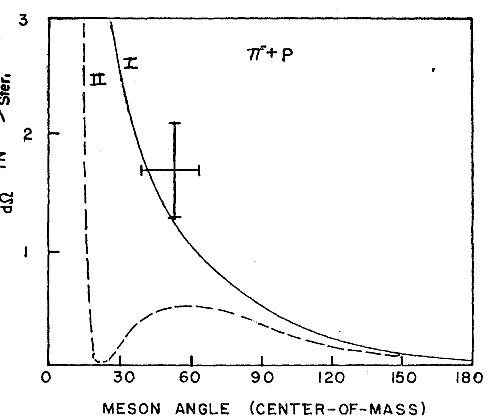

FIG. 2. Differential scattering cross section of hydrogen for π^- mesons at 40 Mev. Curve I: $\alpha_1=+9.7°$, $\alpha_3=-2.6°$, $\alpha_{33}=+5.7°$. Curve II: $\alpha_1=-9.7°$, $\alpha_3=+2.6°$, $\alpha_{33}=-5.7°$.

tions 1, 2, and 3. These have been measured at a pion energy of of about 40 Mev.[7,8] We have now obtained a value of $(1.7\pm0.4)\times10^{-27}$ cm^2/sterad for the differential cross section at a laboratory angle of 45° for reaction 2 at 40 Mev. Together with the three total cross sections and the five differential points for reaction (1),[5] and under the assumption that α_{11}, α_{13}, and α_{31} are negligible, this determines the following ranges of values for the other phases:

$$\alpha_1=+9.7°\pm1.2°;\quad \alpha_3=-2.6°\pm1.4°;\quad \alpha_{33}=+5.7°\pm1.2°.$$

No solution exists with reversed signs.

The phases shifts so obtained are consistent with the strong backward maximum found recently at this energy for reaction 3.[9]

Figures 1 and 2 give the experimental points along with the curves calculated from the above three phase shifts.

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Nuclear Configurations Inferred from High-Energy Pickup-Deuteron Distributions*

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THE production of high-energy pickup deuterons, first observed by York,[1,2] using 90-Mev neutrons, has been examined theoretically[3] as a means of determining nucleon momentum distributions inside nuclei. In experiments now in progress here, the pickup process is being studied with the improved resolution available with a proton beam—the external proton beam of the Harvard cyclotron has an energy of about 95 Mev, with an energy spread, in the work so far, of about 3 percent. Deuterons are identified by simultaneous measurement of range and specific ionization.

Some of the early results are shown in Figs. 1 and 2. Figure 1 shows the sharp energy peak obtained from carbon. Although there is some production of higher excited states of the residual nucleus, it is seen that, as was roughly indicated by the earlier work, quite predominantly only one type of neutron state in carbon enters into the pickup process. This may be regarded as rather strong evidence for an alpha-particle structure for carbon. One can readily estimate that if the six neutrons of carbon were distributed in a shell-type structure, with two in s states and four in p states, then the energy separation of these two types of levels should be of the order of 6 to 8 Mev, an easily observable separation.

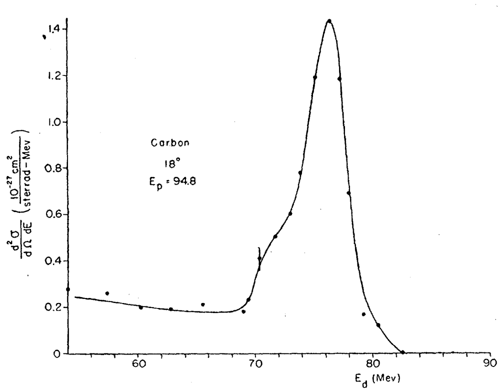

FIG. 1. Pickup-deuteron cross sections for carbon. The statistical accuracy of the points is indicated for a representative point.

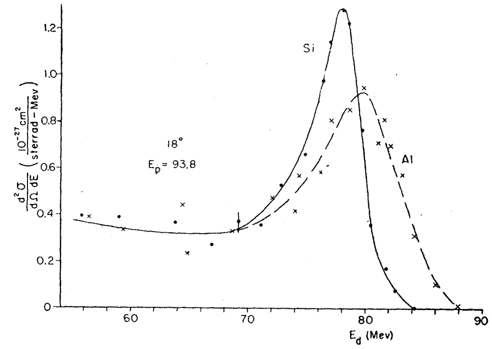

FIG. 2. Pickup-deuteron cross sections for aluminum and silicon. The accuracy of the points is indicated for a representative point.

The peak in carbon is still quite distinct at 60°, where the differential cross section is down by a factor of about 150 from its value in the forward direction. However, it is no longer so prominent relative to the continuum of deuterons (which presumably come from more complicated collisions), and so the separation of the "pickup" part of the cross section is uncertain to within a factor of perhaps two. Analysis of the angular distribution by the Born-approximation method of Chew and Goldberger[3] indicates a Gaussian momentum distribution for the picked up neutron.

In addition to carbon, other elements studied are beryllium, aluminum, silicon, copper, and lead; work is in process also on deuterium and helium. The heavier elements show less pronounced pickup peaks. All of the light elements show evidence of alpha-particle structure in "$4n$" nuclei. Beryllium shows the anticipated two peaks, one corresponding to a Q close to the $-16\frac{1}{2}$-Mev value found for carbon, the other to a Q near zero. Figure 2 shows the pickup deuterons from aluminum and silicon. Si^{28} (=89.6 percent of normal silicon) is expected to be a tightly bound structure on either the alpha-particle or the shell model. Al^{27} has the same number of neutrons as Si^{28}, and one proton less. Now to the extent to which the pickup process can be regarded as involving only the two nucleons concerned, with no interaction with the other nucleons in the target nucleus, the (p, d) pickup reaction samples the neutron distribution inside the target nucleus. On this basis, the results of Fig. 2 can be interpreted as showing that the neutron distribution present in the ground state of Si^{28} is considerably affected by the removal of one *proton*. This is a strong indication of alpha-particle structure in Si^{28}, particularly as compared to an individual-particle model having the neutron distribution relatively independent of the proton distribution.

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The Energy Levels of Be^{10}†

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THE proton spectrum from the reaction $Be^9(d, p)Be^{10}$ has been observed using a high-resolution magnetic spectrometer.[1] A thin (0.30 mb/cm^2) Be^9 foil was bombarded by a collimated beam of 14.5-Mev deuterons. After magnetic analysis the outgoing particles were detected by a scintillating crystal and identified both by their ranges in foils and by pulse-height analysis. Observations were made at ten laboratory angles.