results, the narrowness of the peak and the slow variation of its energy with mass number. The neutron and proton would each be most easily "picked up" from the single-particle states in the major shell that is filling; the single-particle states in a given major shell are closely grouped in energy, and this energy depends only on the size of the "well" so that it varies slowly with mass number. This effect has been successfully used to explain a similar regular structure in (d, p) reactions.[8] There are several difficulties with this explanation, however. The energies expected from this model are somewhat closer to those of the ground-state transitions (in fact, ground-state transitions should be relatively prominent). The shift in energy with mass number should be in the opposite direction from that observed since the levels should sink deeper into the well as the radius of the well increases. There should be sharp discontinuities at closed shells, whereas none are observed between Zr and Nb, between Sn and Sb and between Pb and Bi. It is not even clear why the energy should not exhibit even-odd energy differences similar to those of the Q values.

Most of these difficulties could be avoided if one uses the cluster model and considers a deuteron to be picked up from a (deuteron) cluster state. The shift in energy with mass number is still in the opposite direction from that expected, but this could be explained by a variation in well depth with mass number. However, it must be recognized that the apparent reduction of difficulty obtained by using the cluster model is principally due to our almost complete ignorance of the parameters of the model.

It thus seems difficult to explain the observations with either a "knockout" or a "pickup" model. Further experiments to investigate these reactions are in progress.

*Work done at Sarah Mellon Scaife Radiation Laboratory and assisted by the National Science Foundation and the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

[1]C. B. Fulmer and B. L. Cohen, Phys. Rev. 112, 1672 (1958).

[2]H. W. Fulbright, N. O. Lassen, and N. O. R. Poulsen, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. 31, No. 10 (1959).

[3]R. Sherr and F. P. Brady, Proceedings of the University of Pittsburgh Conference on Nuclear Structure, 1957, edited by S. Meshkov (University of Pittsburgh and Office of Ordnance Research, U. S. Army, 1957), p. 376.

[4]L. R. B. Elton and L. C. Gomes, Phys. Rev. 105, 1027 (1957).

[5]B. L. Cohen, Phys. Rev. 114, 1143 (1959).

[6]J. B. Ball and C. D. Goodman, Phys. Rev. (to be published).

[7]M. El Nadi, Proc. Phys. Soc. (London) A70, 62 (1957).

[8]B. L. Cohen, J. B. Mead, R. E. Price, K. S. Quisenberry, and C. Martz, Phys. Rev. 118, 499 (1960).

MOMENTUM DISTRIBUTION OF PROTONS IN INDIVIDUAL NUCLEAR SHELLS

Peter Hillman,* H. Tyren,† and Th. A. J. Maris‡
Gustaf Werner Institute, Uppsala, Swedan
(Received July 5, 1960)

We have measured the angular correlation in quasi-free p-p scattering in Li^7, and interpret the results directly in terms of the momentum distributions of the $p_{3/2}$ and $s_{1/2}$ protons, respectively.

Light nuclei are appreciably transparent to protons above 50 Mev or so, and the wavelengths of such protons are comparable with internucleon distances. If the two emergent protons from a $(p, 2p)$ reaction are required to share most of the energy of the incident proton and are detected approximately 90° apart ("quasi-free" p-p scattering), collective effects should be relatively suppressed, and there should be a strong dependence of the angular and energy correlations between the emergent protons on the momentum distribution of the struck proton. That the refraction by the collective nuclear potential does not destroy this connection has been shown by Maris[1] for the case of Li^7 and a bombarding energy of 180 Mev.

For this nucleus and this energy, earlier experiments have shown that the spectrum of the sum of the energies of two protons emerging $\theta = 90°$ apart with equal energies and at equal angles exhibits two clear peaks, one near the incident energy minus the separation energy (10 Mev) and the other 16 Mev lower.[2] We ascribe the first peak to the $p_{3/2}$ proton and the second to the two $s_{1/2}$ protons in Li^7.

The variation in the areas of these peaks with the opening angle should depend on the component

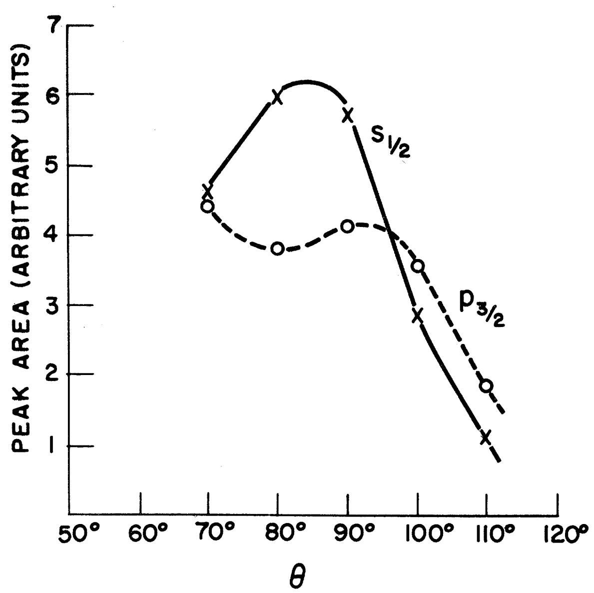

FIG. 1. The angular correlation of protons from the $(p, 2p)$ reaction on Li^7 bombarded with 180-Mev protons. The protons emerge at equal angles and with equal energies. The "$p_{3/2}$" curve corresponds to proton pairs the sum of whose energies is near 170 Mev, the bombarding energy minus the separation energy; the "$s_{1/2}$" curve to pairs with energies around 16 Mev lower. The summed-energy spectrum at each angle shows clear peaks near these energies, and the ordinate is the peak area. The abscissa is the angle between the two protons. The angular resolution is approximately a triangle with a 20° base.

of the momentum of the struck proton along the line of bombardment. In particular, since for free protons at rest $\theta = 90°$, the lithium s proton peak should be highest near 90°, because the most probable momentum of an s proton is zero. On the other hand, momenta near zero are improbable for p protons, and the corresponding peak should show a minimum near 90°. In both cases, the angle of the extremum should be reduced slightly by the effects of binding, and affected in a less obvious manner by refraction. The predictions of a simple model are shown in Fig. 1 of reference 1.

To test the model, a measurement has been made in the case described above. The conditions were identical with those of reference 2 except for the variation in θ. The results are shown in Fig. 1. The behavior of the curves clearly confirms the qualitative considerations given above. Further improved experiments are in progress with other nuclei and higher bombarding energies (450 Mev), where collective effects should be smaller, and a quantitative calculation of the momentum distributions of nucleons in individual nuclear shells may then be feasible.

*CERN Fellow. Now at Weizmann Institute, Rehovoth, Israel.

†Now visiting the Fermi Institute for Nuclear Studies, University of Chicago, Chicago, Illinois.

‡Now at Instituto de Fisica, Rio Grande du Sul.

[1]Th. A. J. Maris, Nuclear Phys. 9, 577 (1959).

[2]H. Tyren, P. Hillman, and Th. A. J. Maris, Nuclear Phys. 7, 10 (1958).

$T = 0$ K^+-NUCLEON PHASE SHIFTS BASED ON THE OPTICAL MODEL*

M. A. Melkanoff, D. J. Prowse, D. H. Stork, and H. K. Ticho
Physics Department, University of California, Los Angeles, California
(Received June 6, 1960)

Using first order multiple scattering theory in the high-energy limit, Lipperheide and Saxon[1] have recently shown that the forward scattering amplitude can be immediately related to the volume integral of the optical model potential. This result has two desirable consequences for experimental situations where an attempt is made to deduce the forward scattering amplitude of the elementary scattering process from interactions with complex nuclei: (a) it clarifies the somewhat ambiguous relation between the central potential and the "central nucleon density," and (b) volume integrals of the optical model potentials are less sensitive to the shape of the potential than the central potentials themselves.

Values of the central potential, $V_0 + iW_0$, of a Saxon well, obtained by an optical model calculation designed to fit the reaction cross sections and the angular distributions for elastic scattering of K^+ mesons in emulsion at 125 Mev and at