cles produced in a direct reaction and those which result from a hot spot produced in a sequential process. The out-of-plane spectra as well as a generalization of our model with respect to the initial conditions will be presented in a forthcoming paper.[8]

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nd Scattering at 180° for Neutron Energies from 200 to 800 MeV

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We have measured the cross section for neutron-deuteron elastic scattering over the incident energy range 200–800 MeV. Preliminary results for the extreme back angles ($\theta_n^* \geq 175°$) show a striking shoulder in the excitation function for neutron energies 300–600 MeV. Comparison is made with calculations using the Craigie-Wilkin triangle-diagram technique.

Near the end of the last decade, *pd* elastic scattering experiments demonstrated that the angular distributions were characterized by a strong backward peak in the neighborhood of 1 GeV.[1] Kerman and Kisslinger,[2] in an attempt to understand this behavior, found that simple one-nucleon exchange failed to fit the backward peak, the calculation being low by a factor of 2. They postulated the existence of isobars in the deuteron, finding that a 1% admixture of the $N^*(1688)$ sufficiently augmented the calculated cross section to bring it into agreement with the 1-GeV data of Bennett *et al.*[1] Since then, several experiments and calculations have been performed relating to backward *pd* elastic scattering at medium energy and isobars in nuclei.[3] Alternative explanations of the observed peaking were proposed. One was the calculation of Craigie and Wilkin[4] in which triangle diagrams were used to relate the cross sections for *pd* elastic and $pp \to d\pi^+$. Many authors have pursued this technique with success in fitting backward *pd* scattering. Another recent calculation[5] takes account of the fact that *np* angular distributions also are backward peaked and incorporates this into an extended Glauber multiple-scattering calculation plus one-nucleon exchange. With this approach, backward *pd* scattering is fitted over a wide range of energies above 660 MeV when a radically different form factor for the deuteron is postulated for the large momentum transfers encountered. Recent measurements[6] at the Stanford Linear Accelerator Center tend to verify the postulated shape of the deuteron form factor.

There are several plots in the literature of the extrapolated 180° cross section as a function of energy.[7] An interesting feature of these plots is the indication of a bump or shoulder in the extrapolated 180° excitation function centered at about 500 MeV. It has been noted that this behavior cannot be reproduced in calculations involving isobars in the deuteron, but does follow from the triangle-diagram calculations.[4] This shoulder is a manifestation of the (3,3) resonance which affects the pion-nucleon vertex in the triangle diagram as given by Craigie and Wilkin.[4]

Angular distributions for backward pd scattering have been obtained in several experiments[2,7-10] for center-of-mass (c.m.) angles less than 160°–170°. Extrapolation of these data was necessary in order to obtain the cross section at 180°, and as a result much ambiguity has existed. In addition, gross disagreement (a factor of 2) between the data sets[2,9,10] at 1000 MeV exists.

Recently, we measured the nd elastic-scattering angular distribution at 800 MeV.[11] The experimental difficulty associated with measurements at 180° c.m. for proton beams does not arise for neutron beams, and we have taken the angular distribution to 179° c.m. We found that the extrapolation to 180° is straightforward—a simple exponential function $A\exp[B(u-u_{180°})]$ fits the data at 800 MeV. In order to investigate the strucutre in the 180° excitation function in more detail than has been possible previously, we have performed an experiment to measure the energy dependence of backward nd elastic scattering. Data were taken for $130° \leq \theta_n^* \leq 180°$ and $170 \leq T_n \leq 800$ MeV. In this Letter we report preliminary results only for the extreme backward scattering angles (175°–180°).

The experiment consists of using a continuum neutron beam incident on a liquid-deuterium target and detecting the scattered deuterons in a multiwire proportional-chamber spectrometer.[12] The 800-MeV proton beam at LAMPF (Clinton P. Anderson Meson Physics Facility) strikes an aluminum target and is then deflected and buried some distance away. Neutrons emerging at 0° are collimated to form a neutron beam, which is then cleared of charged particles before encountering the liquid-deuterium target. Charged particles produced in the target are momentum analyzed in a multiwire-proportional-chamber spectrometer. Particle identification is achieved by a simultaneous measurement of their time of flight through the spectrometer. This allows a calculation of the particle mass from the relation $M=P/\beta\gamma$. Particle identification is unambiguous for more than 99% of the events. The elastic

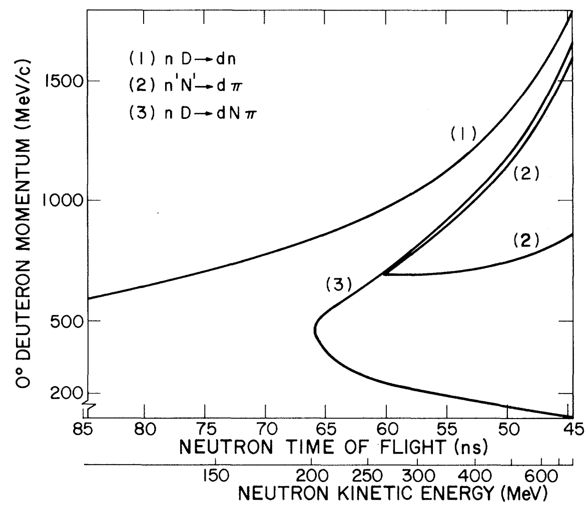

FIG. 1. Plot of the 0° deuteron momentum vs the incident-neutron time of flight for the three reactions which lead to deuterons in the final state: (1) nd elastic scattering, (2) quasifree deuteron production n"N" $\to d\pi$, and (3) "coherent" pion production, $nd \to dN\pi$. This illustrates that deuterons from the elastic process can be distinguished from those due to other reactions.

deuterons are not the only ones that are observed—they form a rather small fraction of the total. However, the elastic deuterons can be clearly separated from the others by measuring in addition the time of flight of the incident neutron. This is shown in Fig. 1 where the deuteron momentum is plotted versus the incident-neutron time of flight for both the elastic and those inelastic processes which lead to a deuteron in the final state. Therefore, in a manner analogous to identification of particle type by measurement of transit time through the spectrometer, we can determine the type of process which gave rise to the deuteron by measurement of the incident-neutron time of flight. Once we have identified the elastic deuterons, the measured deuteron momentum and angle uniquely specify the incident neutron energy to within the accuracy of the deutron momentum determination (about 1%).

The other requirement that must be met before the cross section can be determined is that the incident-neutron spectrum must be known absolutely. This was measured in a separate measurement, using the same apparatus and techniques, except that a liquid-hydrogen target instead of liquid deterium was used. The normalizing reaction is $np \to d\pi^0$, the cross section for which is known, using isospin invariance, from

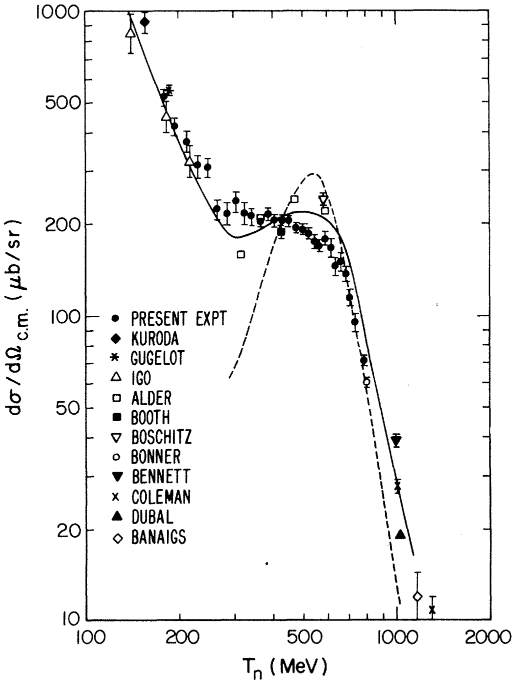

FIG. 2. Results of the present experiment on nd elastic scattering at $175 \leq \theta_n^* \leq 180°$ compared to the extrapolation of previous pd measurements plotted vs the nucleon kinetic energy. References to the pd measurements mentioned in the figure are, from the top, 14, 15, 18, 7, 16, 8, 11, 1, 9, 10, and 17. The dashed line is calculated using the triangle-diagram technique with the value of the parameter ξ determined at 800 MeV (Ref. 11). The solid line is taken from the calculation of Kolybasov and Smorodinskaya (Ref. 4) which uses the triangle diagram as well as one-nucleon exchange. The errors shown on all data points are due to statistics only and do not include any contribution from systematic or normalization errors.

the reaction $pp \to d\pi^+$.[13] Since the normalizing reaction $np \to d\pi^0$ is not available below about 300 MeV (800 MeV/c), another form of normalization is required. The method used for the data below was to extrapolate the np charge-exchange cross section from 300 MeV down to 180 MeV.

In Fig. 2 we show the results of the present experiment compared to previous pd measurements in the energy range from 150 to 1000 MeV. References to the previous experiments are given in the figure caption. Present results are indicated by the solid circles and were obtained for neutron c.m. scattering angles greater than 175°. It is apparent that the agreement with the lower-energy[14,15,18] measurements is quite good, but that the medium-energy data[7] differ considerably from the present results. Agreement is found with the 425-MeV point of Booth *et al.*[16]

We have performed a calculation based on the Craigie-Wilkin model, using the formula given by Barry[4] to relate the cross section for Nd scattering to the $pp \to d\pi^+$ cross section:

$$\frac{d\sigma^{nd\to dn}}{d\Omega_\theta} = \frac{\xi^2}{2}\,\frac{3\epsilon\alpha}{1-\alpha r_t}\,\frac{G^2}{4\pi}\,\frac{F^2(k_1^2)k_1^2}{(k_1^2+\mu^2)^2}\,\frac{s_{pp}}{s_{nd}}\left|\frac{p}{d}\right|\frac{3}{2}\,\frac{d\sigma^{pp\to d\pi^+}}{d\Omega_\varphi}.$$

The symbols used in this equation are defined by Barry.[4] The cross section for $pp \to d\pi^+$ was taken from Richard-Serre *et al.*[13] A value of $\xi = 3.97 \pm 0.03$ was obtained[11] at 800 MeV. In Fig. 2 we show the nd excitation function at 180° as calculated using the above formula. The calculation using the above value of ξ is about a factor of 2 too high at 500 MeV, and clearly fails to fit the lower-energy data. In addition, we show the results of a pd elastic backward scattering angle calculation by Kolybasov and Smorodinskaya,[4] which also utilizes the triangle diagram, but which in addition incorporates one-nucleon exchange as a background term. It is apparent that the trend of the data is fitted by the latter calculation, and it would thus appear that the use of such a model will be required to explain the energy dependence of the backward peaking in nd elastic scattering.

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Absolute Cross Sections for 2*s*-2*p* Excitation of C^{3+} by Electron Impact

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Absolute cross sections have been measured for excitation of the $2s\,^2S_{1/2}$-$2p\,^2P_{1/2,3/2}$ resonance doublet in Li-like C^{3+} by electron impact for energies ranging from below threshold (8.0 eV) to 530 eV. The measurements agree with recent unpublished Coulomb-Born and close-coupling calculations over the entire range of electron energies.

Electron-impact excitation processes for multiply charged ions are of considerable interest for the diagnostics and modeling of solar, astrophysical,[1] and high-temperature laboratory plasmas. In fusion reactors,[2-4] for example, the presence of multiply charged impurity ions can severely limit plasma heating, lead to instabilities, and cause significant energy losses in the form of line radiation. In all cases absolute cross sections or rate coefficients are needed to infer concentrations and radiation balance. Experimental measurements of cross sections for electron-impact excitation of ions have dealt primarily with singly charged ions. Experimental and theoretical results have been reviewed in recent articles by Dolder and Peart[5] and by Seaton.[1] Bradbury *et al.*[6] reported preliminary measurement for excitation of $N^{4+}(2s-2p)$ and found results averaging about 2.5 times higher than theory. Phaneuf, Taylor, and Dunn[7] measured cross sections for excitation of the 479.7-nm line of Hg^{2+}. However, results reported here are considered to be the first definitive results for a multiply charged ion.

Ions with lithiumlike structure are frequently observed in the plasmas mentioned. The 2*s*-2*p* transitions are strong and at relatively convenient wavelengths. Consequently, much of the excitation-rate–coefficient work has been for such ions.[8,9] Furthermore, since there are only three electrons in all, and only one valence electron, theoretical study and calculations of the cross sections are quite tractable.[1,10,11]

There remains the need for definitive experimental data on the cross sections for these ions. Measurements[12] on the first member of the sequence, Be^+, are uniformly displaced by about 18% from the most elaborate calculations[13] (five-state close coupling merged into CBX II at higher energies), and the source of the difficulty has not been identified. Known uncertainties in this case total to only about ±8%; so a discrepancy actually exists.

The less sophisticated theoretical predictions are expected to be more reliable for the higher-Z members of the Li sequence, since effects due to coupling to other excited levels should be of lesser importance as Z increases. The energy of the 2*p* level varies as $Z+1$, whereas the energies of higher-n levels vary roughly as $(Z+1)^{1.8}$. For