PROTON SPECTRA FROM D(n, p)2n REACTION AT 14.4 Mev

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It has been pointed out[1-3] that the breakup of the deuteron by nucleons could give information on nucleon-nucleon interactions where this cannot be obtained from nucleon-nucleon scattering. Several measurements on D(n, p)2n and D(p, n)2p reactions have been performed.[4-7] At incident proton energies above 6 Mev for the D(p, n)2p reaction, the neutron energy spectra at 0° show a peak at the maximum neutron energy. This peak has been attributed[8,9] to the final-state interaction of the two protons. The present experiment was undertaken to see whether an analogous peak existed in the D(n, p)2n reaction. Such a peak could provide information on the n-n interaction.

The proton spectra have been measured using a dE/dx - E counter telescope described by Kuo, Petravić, and Turko.[10] Briefly, it consists of a CsI(Tl) scintillation counter and two proportional counters in coincidence and another proportional counter in anticoincidence. The main problem in this experiment lies in distinguishing the breakup protons from the elastically scattered deuterons. Since at the high-energy end of the spectrum, the number of deuterons exceeds that of protons by a factor of about 100, the more conventional methods of displaying E and dE/dx on an oscilloscope or multiplying electronically dE/dx and E are not reliable. The problem was overcome [as suggested by one of us (M.P.)] by displaying directly the dE/dx spectra, for fixed energy intervals, on a two-dimensional ultrasonic memory 100-channel analyzer.[11] Five dE/dx spectra corresponding to five consecutive energy intervals determined by the scintillation (E) counter could be examined simultaneously. By changing the bias at the scintillation counter output, the complete E spectrum was scanned. Figure 1 shows a typical set of spectra. The protons and deuterons could be identified without ambiguity. This was facilitated by the close agreement of the Landau theory with the experimental ΔE distributions.[10]

A flux of 1.5×10^9 neutrons/sec in 4π was obtained from the reaction T(d, n)He^4 using the 200-kev Cockcroft-Walton accelerator of Institute Ruder Bošković.[12] The neutrons were monitored by counting the associated α particles with a CsI(Tl) crystal polished to 6 mg/cm^2. The deuteron target was in the form of deuterated paraffin, 1×1 cm^2 in area and 8.4 mg/cm^2 in thickness. The experiment was performed with the counter set at 0° and 10° with respect to the incident neutrons. In the first case, the scattering angle was $4°\pm4°$ ($\pm4°$ denoting the extreme scattering angles accepted by the E counter),

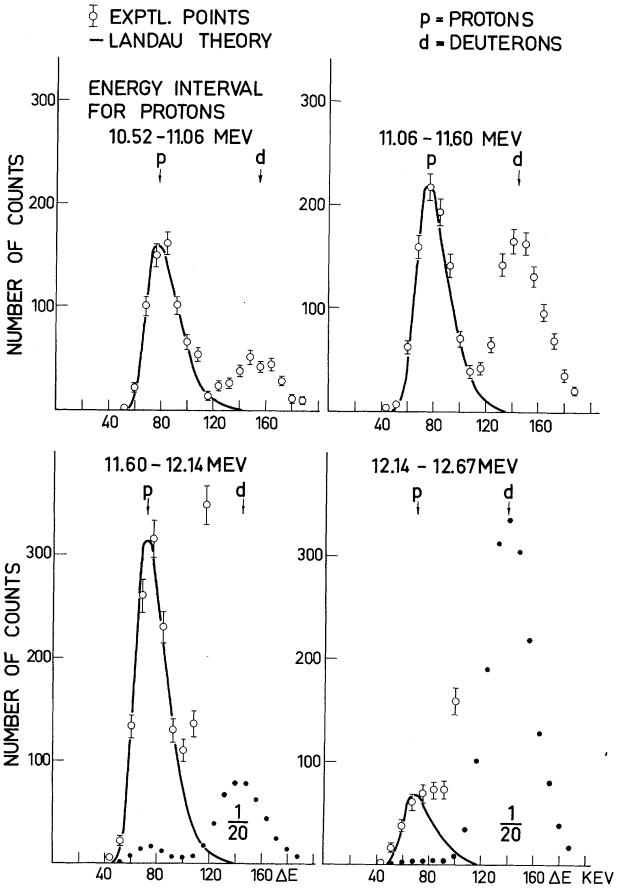

FIG. 1. Spectra of proton and deuteron energy losses (ΔE) in the dE/dx counter for fixed energy intervals in the E counter as measured by a two-dimensional ultrasonic memory 100-channel analyzer. The full curves are the predictions of the Landau-Symon theory calculated from B. B. Rossi, High-Energy Particles (Prentice-Hall Publications, Inc., New York, 1952). The errors shown are statistical errors.

and in the second case $10° \pm 8°$. Figure 2 shows the breakup proton spectra. The data have been corrected for the variation of energy interval arising from different energy losses at different energies. Neutrons degraded in energy or incident in other directions may cause a distortion in the energy spectra by two processes: firstly by n-p scattering on the hydrogen contamination present in the deuterated paraffin target, and secondly, by producing breakup protons. The hydrogen contamination in the target has been determined to be 2.8% by measuring the elastically scattered protons and deuterons at 4°. An estimate of the degraded neutron spectrum incident in the forward direction was obtained from the n-d elastic scattering spectrum. Corrections due to these neutrons have also been applied. These corrections were largest at the low-energy end where they amounted to 5%. Relative error in the spectrum, excluding statistical error, is about 4%. The absolute cross section was determined by normalization to n-p elastic scattering using a CH_2 target. The total error in absolute cross section is 8%.

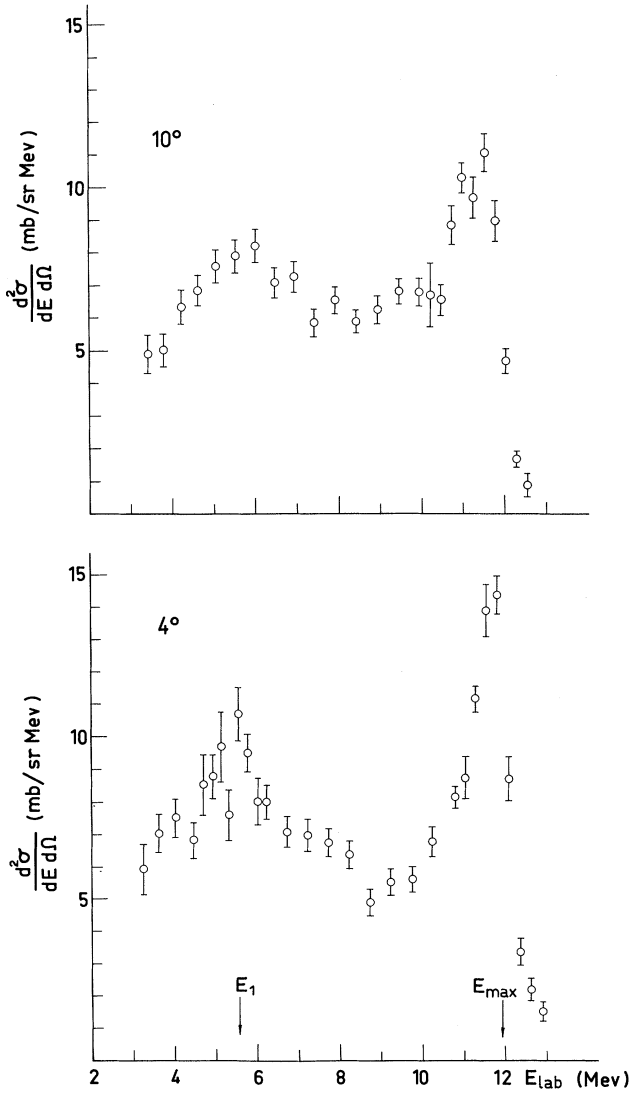

FIG. 2. Energy spectra of protons from deuteron breakup in the laboratory system. E_{max} indicates the maximum proton energy for $Q = -2.225$ Mev; this is in the case when the two neutrons are going together (unbound) backwards in the c.m. system. E_1 indicates the proton energy in the case where a neutron and the proton are going together (unbound) in the forward direction in the c.m. system. Each point represents an average over 0.54 Mev. The errors shown are statistical errors.

The proton spectrum obtained at 4° shows close similarity with the neutron spectra from the $D(p,n)2p$ reaction.[6] Although exact comparison cannot be made since the $D(p,n)2p$ data[6] are for a somewhat lower incident energy, it is possible to remark that the peak at the maximum proton energy is narrower and more pronounced in the present case. This is to be expected since Coulomb repulsion in the case of the final-state interaction of the two protons must broaden the peak.[8] Measurements at larger scattering angles which are in progress show that the peak becomes smaller as the angle increases and that at 30° (lab) it is hardly discernible. Komarov and Popova,[9] taking into account the final-state interaction between all pairs of nucleons, have obtained a very good fit to the $p+d$ data.[5,6] They point out that a similar calculation can be made for $n+d$ breakup where the low-energy part of the proton spectrum could be attributed to n-p interaction and the high-energy peak to n-n interaction. In fitting the high-energy peak, the n-n scattering length could be deduced.

Without a detailed theoretical analysis of the present data, one cannot draw a conclusion about the existence of a bound state of the di-neutron.

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RADII OF OPTICAL-MODEL POTENTIALS IN PROTON SCATTERING AT 183 Mev

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Previous analyses[1,2] of the elastic scattering of 150-300 Mev protons by nuclei using the optical model of the interaction have shown that it is able to give a good account of the existing experimental differential cross sections and polarizations. In most cases, however, the experimental data do not extend much beyond the first diffraction minimum, and so do not accurately determine the parameters of the optical-model potential.

Recently, Johansson and Svanberg[4] have made a series of accurate measurements of 183-Mev protons elastically scattered by a range of eight nuclei from lithium to gold. Particular care was taken to eliminate inelastically scattered protons, and the differential cross sections were obtained out to around 70°. Measurements of the reaction cross sections were also made and these, combined with the existing polarization data, make a more complete set of data for optical-model analysis than has hitherto been available. We have found that the elastic scattering and polarization can be simultaneously well described only if the imaginary part of the optical-model potential is given a significantly greater radius than the real part.

The optical-model potential was taken to have the usual form,

$$V(r) = V_{\mathrm{Coul}}(r) + Uf_1(r) + iW[\alpha f_2(r) + (1-\alpha)g(r)] + \left(\frac{\hbar}{m_\pi c}\right)^2 \left[U_s \frac{df_3(r)}{dr} + iW_s \frac{df_4(r)}{dr}\right] \frac{1}{r}\vec{l}\cdot\vec{\sigma},$$

where $f(r)$ and $g(r)$ are Saxon-Woods and Gaussian form factors, and the other symbols have their usual meanings.[4] All calculations were done on the Oxford University Mercury computer using methods described elsewhere.[5]

Preliminary attempts to fit the data were concentrated on aluminum, partly because it is a fairly light nucleus and partly because the difference between the experimental data and previous optical-model calculations at[2] 160 Mev is greatest for this nucleus.

The most striking feature of the experimental differential cross section [Fig. 1(a)] is the virtual absence of oscillatory structure, in sharp contrast to the considerable oscillations shown by the optical-model cross section with the potentials used previously. This effect is most marked beyond the first minimum and so has not been noticed previously. The absence of oscillations cannot be attributed to experimental smearing, as particular care was taken to achieve good angular (± 0.4°) and energy (± 0.5-Mev) resolution.

The first aim of the present work was to resolve this discrepancy. To facilitate comparison with previous work, as many parameters as possible were kept the same as before. The starting potentials were taken to be $U = -18$, $W = -12$, $U_S = 2.5$, $W_S = -1$ Mev, and all radii were fixed at $R = 1.25\,A^{1/3}$ f, with diffuseness parameters $a = 0.65$ f and $b = 1.0$ f for the Saxon-Woods and Gaussian form factors. With $\alpha = 1$, corresponding to a Saxon-Woods absorption potential, the parameters U, W, a_1, a_2, and $a_3 = a_4$ were varied to see if the oscillations could be removed, but without success. Further calculations were made with the Gaussian form for the absorbing part of the central potential, and with an equal mixture of Gaussian and Saxon-Woods forms ($\alpha = 0.5$). In each case the differ-