tive range approximation. For a singlet range of 2.4×10^{-13} cm and a singlet scattering length of -23.7×10^{-13} cm, $\gamma_0=-40.9$ μb, $a=23.0$ μb, and $b=136.9$ μb. The above theories assume that only dipole transitions are involved and that noncentral forces are not important. We conclude that our experimental data are in satisfactory agreement with the theory. Because the calculated polarization is not sensitive to the effective-range parameters and the experimental errors are relatively large, we cannot derive improved values of the parameters. The experimental results do confirm the predictions of the current phenomenological theory of the neutron-proton system at low energy.

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Elastic Scattering of 11.8-Mev Deuterons from Several Elements

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The angular distributions of 11.8-Mev deuterons elastically scattered from C, Mg, Al, Ti, Fe, Ni, Cu, Zn, Zr, Nb, Rh, Pd, Ag, Cd, In, Sn, Ta, and Au have been measured. The detector is capable of electronically separating deuterons from other ions which may enter the detector. The data have been taken in 2-degree steps between 20° and 165°. The structure in the angular distribution observed with the light target elements is vanishing with increasing atomic weight. An exception is observed between $A=90$ and $A=120$.

INTRODUCTION

THE elastic scattering of deuterons at moderate energies has been studied by Alford and Slaus[1] at 4 Mev, by Rees and Sampson[2] at 11 Mev, by Cindro and Wall[3] at 13.5 and 15.5 Mev, by Gove[4] at 15 Mev, and by Yntema[5] at 21.6 Mev. Some of the data have been analyzed by Porter,[6] Melkanoff[7], Glassgold,[8] and Hodgson.[9] The angular distributions of elastically scattered deuterons are qualitatively similar to proton, neutron, and alpha-particle elastic scattering data. In particular, apsidal distance plots[10] of differential cross sections for heavy-element data, as in alpha-particle scattering, rise above the Rutherford differential cross section at some critical apsidal distance and then drop monotonically below at smaller apsidal distances. However, the critical apsidal distance for deuterons is larger than that for alpha particles, reflecting the loosely bound structure of the deuteron.[6] Optical model analysis of deuteron data indicates that the real potential is quite similar to that obtained for protons, and the imaginary part of the potential is probably larger for light elements than for heavy elements.[7] Melkanoff has interpreted this as due to the high probability for stripping at the surface of nuclei. Since light nuclei are mainly surface, they require a larger depth.

The present work at 11.8 Mev is extensive. The data have been taken in two-degree steps from about $\theta_{\mathrm{lab}}=20°$ to 165° for 18 targets constituted of elements spaced throughout the periodic table, with small statistical errors and good angular resolution. A dE/dx and E system[11] has been utilized to determine that only deuterons were counted.

EXPERIMENTAL PROCEDURE

A collimated beam of 11.8-Mev deuterons in excess of 1 μamp in intensity has been produced using a 100-cm cyclotron. The beam handling system and the scattering

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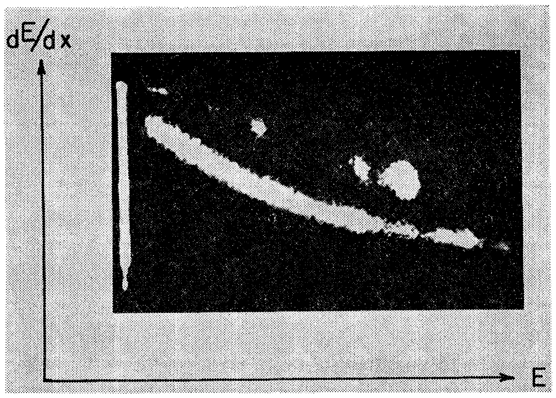

FIG. 1. Photograph of the oscilloscope display dE/dx versus E. This picture was taken with a Mg target at a detector angle $\theta=50°$. A large number of protons and two groups of inelastically scattered deuterons are well separated from the intense elastic deuteron group.

chamber have been described previously.[12–14] The final beam size is determined by a 5-mm diam collimating system. The beam impinges on a target of the element under study at the center of a 20-cm scattering chamber. Special care has been taken in the construction of the chamber to insure that the beam passes through the center of the scattering chamber, that the counter

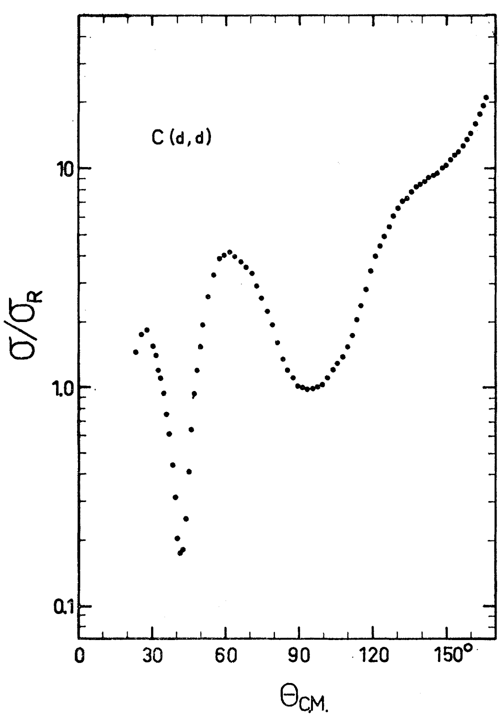

FIG. 2. The ratio of measured differential cross section to Rutherford cross section for C.

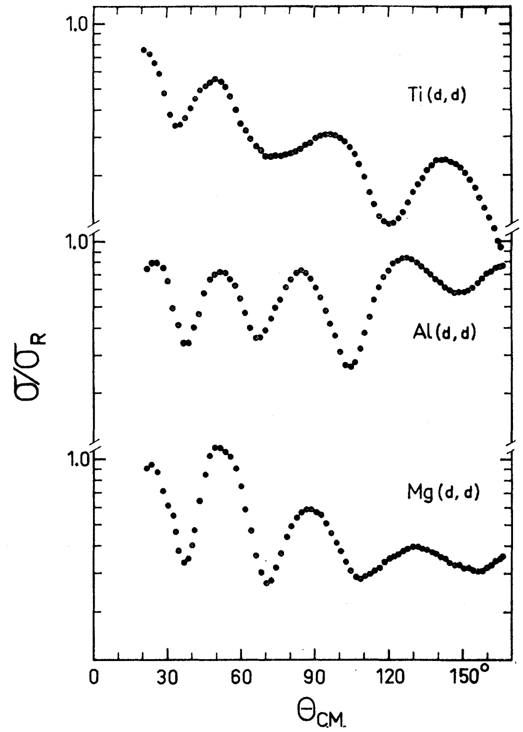

FIG. 3. The ratio of measured differential cross section to Rutherford cross section for Mg, Al, and Ti.

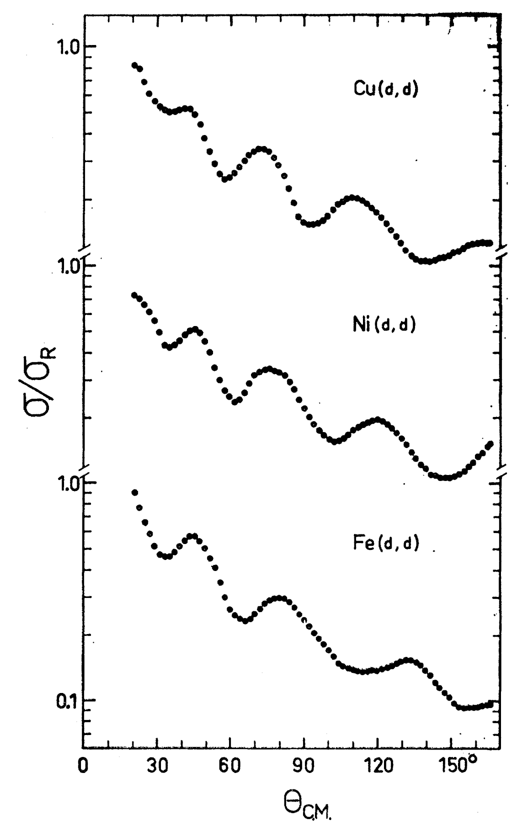

FIG. 4. The ratio of measured differential cross section to Rutherford cross section for Fe, Ni, and Cu.

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rotates about the center, and that the angle between the beam direction and the counter can be accurately determined. The scattered particles pass out of the scattering chamber through thin plastic windows and pass into a detector consisting of three proportional counters and a CsI(Tl) crystal. The "smallest pulse of three" technique described by Igo and Eisberg[11] has been used to obtain energy spectra of deuterons separated electronically from other particles.

The dE/dx and E pulses from the detectors are displayed on the plates of an oscilloscope. In Fig. 1 a photograph of the oscilloscope display at $\theta = 50°$ using a Mg target in the scattering chamber is shown. A large number of protons and two groups of inelastically scattered deuterons are shown well separated from the elastic deuterons. The spectra of the inelastically scattered deuterons have been measured extensively.[13–15] The influence of inelastic scattering on the elastic deuteron peak is negligible. The pulses are selected by a mask, and they are counted by a photomultiplier. At 11.8 Mev the full width at half maximum of the deuteron line is 4%. The collimating aperture of the detector system subtends usually an angle of 1.8°. For angular distributions with sharp minima (e.g., carbon) this angle was diminished by additional baffles. The intensity of the primary beam was measured by a Faraday cup with an integrating current meter sensitive to less than 10^{-10} amp. In addition a CsI(Tl) monitor counter was used. The Faraday cup intercepts over 99% of the beam passing through the target (except for Rh and Ta).

RESULTS

Plots of the measured differential cross section $\sigma(\theta)$ divided by the Rutherford cross section $\sigma_R(\theta)$ are shown in Figs. 2 through 8. Absolute differential cross sections have been measured at 50° and 130°. The error is $< \pm 5\%$, and is caused mostly by the inhomogeneity of the target foils. The error in the relative cross section is $< \pm 3\%$ between 30° and 120° and, mostly due to the statistical uncertainty in the number of counts, up to $\pm 5\%$ at backward angles. From 30° to 20° the error increases to $\pm 10\%$ due to the uncertainty in the measurement of the small currents involved.

The angular distributions of elastically scattered deuterons from light elements show marked diffraction structure (Figs. 2 through 5). The quantity $\sigma(\theta)/\sigma_R(\theta)$ for C increases to about 20 at $\theta = 160°$. The structure for adjacent elements is quite similar (compare Al with Mg, Fe, Ni, Cu, and Zn). The position of the maxima moves to smaller angles with increasing atomic number of the

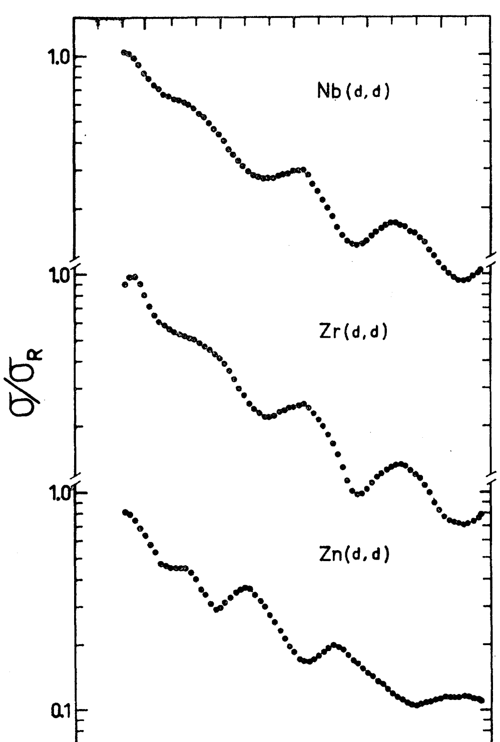

FIG. 5. The ratio of measured differential cross section to Rutherford cross section for Zn, Zr, and Nb.

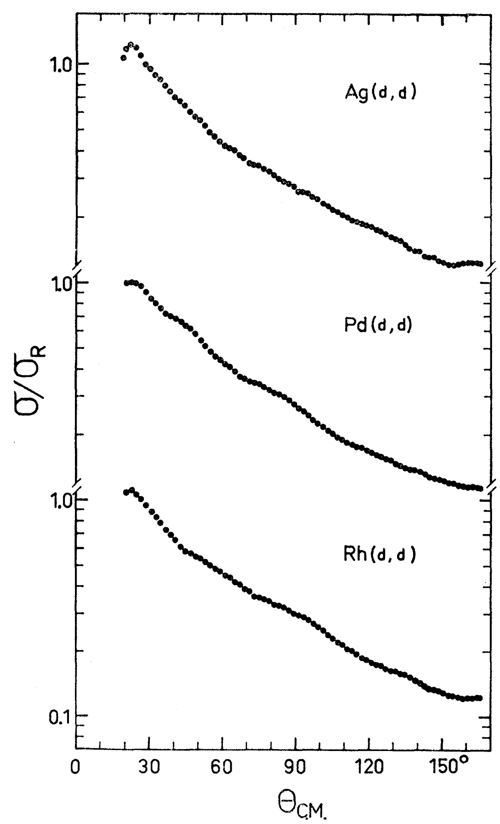

FIG. 6. The ratio of measured differential cross section to Rutherford cross section for Rh, Pd, and Ag.

[15] U. Schmidt-Rohr and O. Vater (to be published).

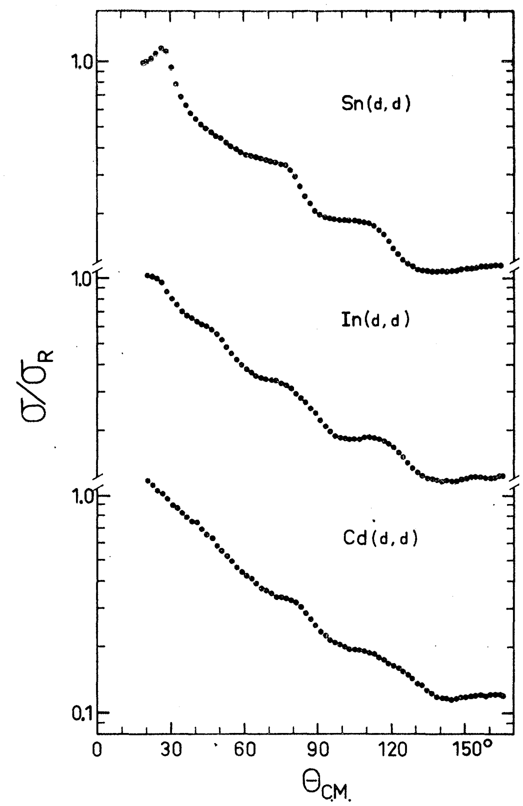

FIG. 7. The ratio of measured differential cross section to Rutherford cross section for Cd, In, and Sn.

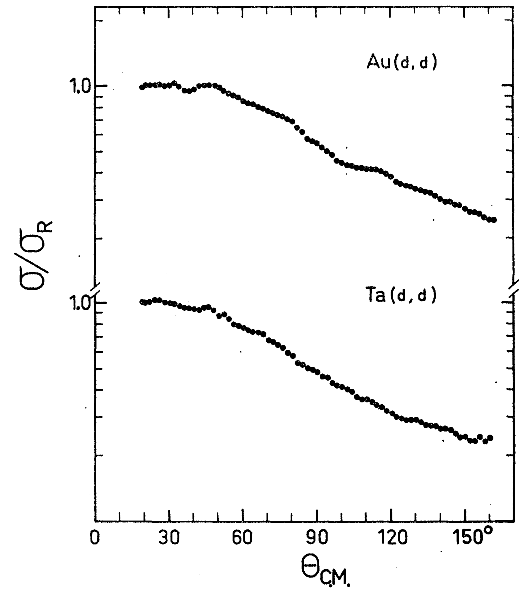

FIG. 8. The ratio of measured differential cross section to Rutherford cross section for Ta and Au.

target. Special attention has been paid to the elements between Zr and Sn. The sharp structure observed in the angular distribution of Zr and Nb vanishes between Rh and Ag, but returns between Cd and Sn. The heavy-element angular distributions like Ta and Au drop, as expected, monotonically beyond $\theta = 50°$. The Au angular distribution at small angles shows some oscillations reminiscent of heavy-ion elastic scattering data.[10]

The exact explanation of the fact that the general feature of decreasing diffraction amplitude in $\sigma(\theta)/\sigma_R(\theta)$ with increasing atomic charge is discontinuous at $A = 100$ has to wait for an optical model analysis. Lane *et al.*[16] referring to possible effects of nuclear shell closures on neutron strength functions have suggested that the shape and size of the imaginary potential W are changing if Z is near the magic number 50. This could explain the observed effect. An influence of the deformation of the nuclei around $A = 100$ on the sharpness of the diffraction structure is also possible.

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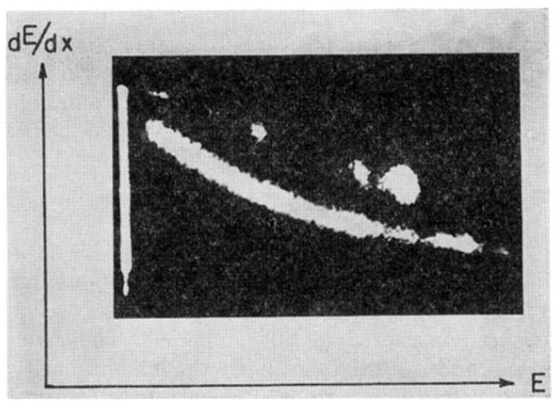

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