THE INELASTIC SCATTERING OF PROTONS AND DEUTERONS FROM Mg^{24}

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We have studied the angular distributions of protons and deuterons scattered inelastically from the excited 2^+ state of Mg^{24} lying at 1.37 Mev. The energy of the protons was 6.8 Mev while that of the deuterons was 13.6 Mev; the range of angles covered was 2.5 – 140°. We observed some previously unknown details in the angular distribution at small angles. A comparison with theories of inelastic scattering leads to inferences about the relative importance of direct interactions.

INTRODUCTION

THE angular distributions observed in nuclear reactions and in inelastic scattering are an important source of information about the properties of nuclei and the mechanisms involved. Direct interactions become significant even at moderate energies. This is especially true of the deuteron, which has a small binding energy so that often only one nucleon takes part in the reaction.[1,2] Direct interactions can also occur in which the deuteron behaves like one unit.[3-6]

Inelastic scattering need not occur through direct interactions but can also be associated with the formation of a compound nucleus. This is important mostly for protons.[7]

Measurements have shown that in the interaction between protons and Mg^{24} in the energy range 7.3 – 18 Mev, inelastic scattering can occur both through a direct interaction and also through the formation of a compound nucleus (these results are generalized in references 8 and 9; see also reference 10).

On the other hand, from measurements on the inelastic scattering of deuterons at 7.5 Mev,[11] 8.9 Mev,[12] and 15 Mev,[13] it appears that the most important mechanism is a direct interaction. Haffner[13] has noted that at small angles the electric interaction between the deuteron and the nucleus is also significant.[6]

Although the angular distribution at small angles is very interesting, since it can give important information about the mechanism involved in inelastic scattering, most of the authors referred to above have not examined the small angle region in detail. It is for this reason that we have attempted to examine the angular distribution in detail, particularly at small angles.

EXPERIMENTAL METHOD

The measurements were made on the external beam of the cyclotron at the Physics Institute of the Academy of Sciences of the Ukrainian SSR. Our spectrometer was an ionization chamber with split electrodes which allowed us to detect particles selectively.[14]

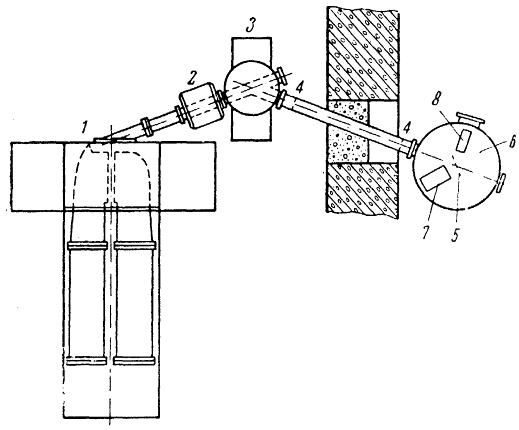

FIG. 1. Schematic diagram of the experimental setup.

The geometry of the experiment is shown in Fig. 1. The beam from the cyclotron, 1, is focused by quadrupole lenses, 2, bent by a deflecting magnet 3, collimated by diaphragms at 4, and is then incident on the target 5, which is at the center of the scattering chamber 6. The spectrometer 7 was placed at angles from 2.5° to 140° relative to the incident deuteron beam. Measurements were made at intervals of 2.5° at small angles and at intervals of 5° at larger angles. A scintillation counter at 8 served to monitor the beam and was place at 90° to it.

The statistical errors in the relative cross sections were about 15% at large angles and 25% at small ones. At angles less than 12.5° for deuterons and 15° for protons, the results are only qualitative because of the background arising from protons and deuterons which have first been inelastically scattered from the gas in the chamber and the 17 mg/cm^2 copper window, then elastically scattered in the target.

The target was a self-supporting magnesium foil which was 1.4 mg/cm^2 thick and was obtained by evaporation in a vacuum.

DISCUSSION OF THE RESULTS

Curve 1 in Fig. 2 shows the angular distribution we obtained for inelastically scattered deuterons, while curve 4 shows the result obtained in reference 13. In order to make the diagram clearer, the experimental results have not been normalized in the same way. Curve 2 shows the angular distribution calculated by Huby and Newns,[2] assuming a direct interaction, while curve 3 shows the calculations of Mullin and Guth.[6] According to the theory of Mamasakhlisov and Kopaleĭshvili,[3] the peak at 20° is related to collective behavior of Mg^{24}.

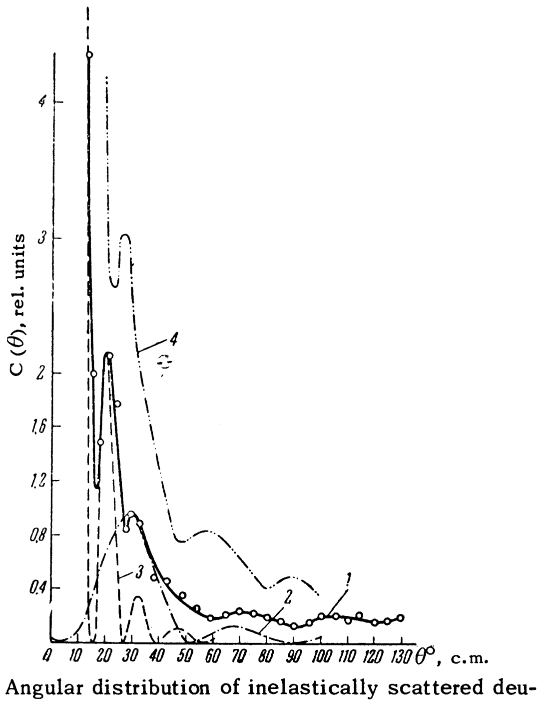

FIG. 2. Angular distribution of inelastically scattered deuterons Mg(dd′)Mg* (Q = −1.37 Mev); 1 – our data; 2 – theoretical curve for a nuclear interaction with $l = 2$ and $a = 6.3 \times 10^{-13}$ cm; 3 – theoretical curve for electrical interaction with $l = 2$, $a = 15.8 \times 10^{-13}$ cm; 4 – data from reference 13.

Best agreement between theory and experiment is obtained by taking an interaction radius $a = 6.3 \times 10^{-13}$ cm in the first case and $a = 15.8 \times 10^{-13}$ cm in the second case; at a radius of $a = 7 \times 10^{-13}$ cm, the peak in the theory of reference 2 occurs at 20°, as does the experimentally observed one. The angular momentum in both cases is 2; the experimental points for angles in the range 2.5 — 10° are not shown. At these angles the cross section rises with decreasing angle. Upon comparing the experimental results with the predictions of theory, one can conclude that direct interaction is the predominant mechanism in the inelastic scattering of deuterons at 13.6 Mev from the 1.37 Mev excited state of Mg^{24}. The electrical interaction is predominant at small angles.

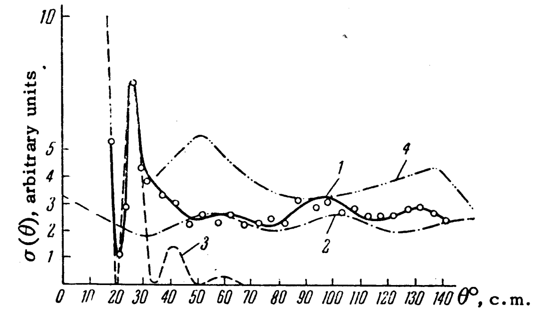

FIG. 3. Angular distribution of protons from the reaction Mg(pp′)Mg* (Q = −1.37 Mev). Curve 1 – our data; curve 2 – theoretical curve for direct interaction on the surface, $2.2\,P_0 + P_7$; 3 – theoretical curve for surface electrical interaction ($l = 2$, $a = 24.7 \times 10^{-13}$ cm); 4 – data from reference 8.

Figure 3 shows the angular distribution obtained for protons (curve 1). Curve 2 shows the results of calculations made by Yoshida[4] on the basis of a direct surface interaction.

The theoretical curve 2 is $2.2\,P_0 + P_7$, where the $P_n(\cos\theta)$ are Legendre polynomials; the term in P_7 must be included to get agreement with experiment. From this we may conclude that at middle and large angles most of the scattering occurs through the formation of a compound nucleus. At small angles some other mechanism must be important.

For small angles, the experimental results are difficult to reconcile with the theory of direct nuclear interaction proposed by Austern, Butler, and McManus:[15] the interaction radius R must be chosen anomalously large to give the right position for the minimum, and even then the function $j_2(KR)$ does not rise fast enough after passing through its minimum [$j_2(x)$ is the spherical Bessel function of order 2, $K = |\mathbf{K}_1 - \mathbf{K}_2|$ where $\mathbf{K}_1$ is the wave vector of the incident proton while $\mathbf{K}_2$ is the wave vector of the scattered one]. The agreement with the theory of electrical interaction[6] is somewhat better, as is indicated by curve 3 in Fig. 3, but here also an anomalously large interaction radius ($R = 24.7 \times 10^{-13}$ cm) is required if the function $[j_1(KR)/KR]^2$ is to fit the data at all well [$j_1(x)$ is the spherical Bessel function of order 1]. Such a large value of R can hardly be right.

Curve 4 in Fig. 3 represents the results of reference 8 for an energy 7.86 Mev.

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