ANGULAR DISTRIBUTIONS IN THE REACTIONS Ne^{22} *(d, p)* Ne^{23} *AND* A^{36} *(d, p)* A^{37}

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Thick nuclear emulsions were used to study the angular distributions of protons from (d, p) stripping reactions initiated by 4-Mev deuterons in gaseous targets enriched with Ne^{22} and A^{36}. It was established that the orbital angular momenta of the neutron captured into the ground and first (0.98 Mev) excited states of Ne^{23} are 2 and 0 (shell model configurations $(1d_{5/2})^{-1}$ and $(2s_{1/2})^{-1}$), while in A^{37} the orbital angular momentum of the neutron in the ground state is 2 [corresponding to a configuration $(1d_{3/2})^{-1}$].

INTRODUCTION

PARITIES and probable values for spins of the final nuclei in stripping reactions can be determined from studies of the angular distributions.[1,2] As is well known, the Coulomb and nuclear interactions are not taken into account in the Butler theory. These factors have little effect on the positions of the peak in the angular distribution, although the Coulomb interaction does move the peak a little toward bigger angles while the nuclear interaction has the opposite effect. Up to $Z \approx 20$ and for deuteron energies the same order of magnitude as the Coulomb barrier in the target nucleus, the orbital angular momentum l_n of the captured particle can usually be inferred from the position of the peak in the angular distribution. However, the Coulomb, and to a lesser extent the nuclear, interactions have a big influence on the cross section.

The Coulomb interaction is hard to take into account exactly[3] because the calculations are complicated. Taking the Coulomb and nuclear interactions into account, the reduced widths Θ_l^2 of single particle states in the final nucleus should be little less than one, if measured in units of Wigner's sum rule limit, while $\Theta_l^2 \ll 1$ for states with a complicated structure, formed by many-particle excitation. Hence the value of Θ_l^2 obtained from such experiments without taking into account corrections has, essentially, only qualitative significance. However, if two-lying states of the final nucleus have approximately equal values of Θ_l^2, then, considering the corrections due to Coulomb and nuclear forces to be of the same order of magnitude, that is evidence that the two states have similar types of excitation.

In the work being reported upon here, the angular distributions in (d, p) stripping reactions occurring in gaseous targets enriched with the isotopes Ne^{22} (enriched by 90%) and A^{36} (enriched by 11%). The angular distribution associated with the reaction Ne^{22} (d, p) Ne^{23} has been studied by several authors (for example, reference 4); in the case of the reaction A^{36} (d,p) A^{37}, the angular distribution is reported for the first time.

DESCRIPTION OF THE EXPERIMENT

Experimentally, it is harder to study the angular distributions from gaseous targets than it is from solid ones, especially when nuclear emulsions are used as detectors, since in this case it is necessary to define the directions of the outgoing particles simultaneously for many angles. The best way of doing this is to use the target construction described by Chadwick, Burrows, and others,[5,6] where the ring-shaped space between two concentric cylinders forms a common window for all angles. A drawback of this construction is that a large volume of gas is needed, filling the whole chamber with target and emulsions. We had only a small amount of enriched gas available, so the construction was modified somewhat.

A diagram of the experiment is shown in Fig. 1. Accelerated to approximately 4 Mev by the cyclotron of the Institute of Nuclear Physics, Moscow

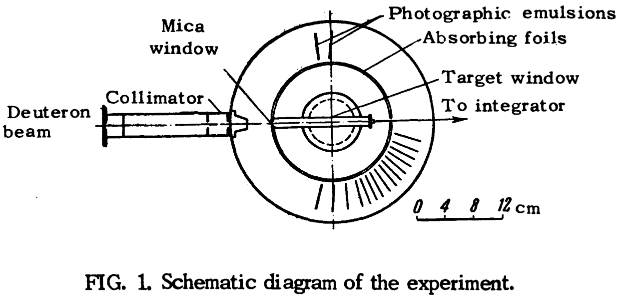

FIG. 1. Schematic diagram of the experiment.

State University, the deuterons passed through a set of collimating slits and were focused on a thin mica window (1.4 mg/cm^2) which limited the volume of gas serving as the target. The particles produced in the reaction passed through two windows (4mm × 4mm) in the sides of the target volume, the windows being covered with thin organic films of thickness 50 $\mu g/cm^2$. The total volume of gas required was then the sum of the target volume, the volume of the filling system, and of the pressure gauge. This sum was about 20 cm^3. Under the gas pressure, the film bulged out into the vacuum in the shape of an irregular hemisphere. The products of the reaction passed through the film at approximately right angles for all angles which were counted, so the effect of multiple scattering in the film was held to a minimum. The gas pressures used were about 6.0 cm Hg. Aluminum foils were placed in front of the nuclear emulsions to absorb particles of energies less than those of interest.

The variations in deuteron energy due to different path length in the gas target for various emission angles θ were small and could be neglected (for neon and θ in the range 17 to 60°, $\Delta E_d \approx 0.15$ Mev). The deuteron energy was determined from the range of the most penetrating group of protons and from the known Q of the reaction. In the target gas, multiple scattering did not spread the deuteron beam by more than 30′.

The tracks were scanned with a MBI-2 microscope having a magnification 1.5 × 90 × 5. The errors shown on the angular distributions below (see, for example, Figs. 3, 5) are statistical; the dotted horizontal line shows the isotropic part of the angular distribution. This is presumably connected with formation of the compound nucleus.

EXPERIMENTAL RESULTS AND DISCUSSION

1. Ne^{22} (d, p) Ne^{23}. Figure 2 shows the energy spectra of protons emitted at an angle $\theta_{lab} = 58°\ 30'$ in (d, p) reactions on Ne^{22} and Ne^{20}. The resolution is not good enough to distinguish between the groups $Ne^{23}(0)$, $Ne^{21}(2)$ and $Ne^{23}(1)$, $Ne^{21}(3)$. However, the groups from reactions on Ne^{20} must be small in view of how rich the sample was in Ne^{22}. Hence the intensities of the proton groups $Ne^{23}(0)$ and $Ne^{23}(1)$, corresponding to transitions to the ground and first excited states of Ne^{23}, were obtained from the normal distribution of track lengths in the histograms. Figure 3 shows the experimental angular distributions, together with theoretical curves calculated using Butler's formulae. The calculations were made with values $R = 6.1 \times 10^{-13}$ cm and $R = 6.5 \times 10^{-13}$ cm for the radii of the ground and first excited states respectively. The angular distribution of the proton group $Ne^{23}(0)$ corresponds to capture of a neutron with orbital angular momentum $l_n = 2$, while that of $Ne^{23}(1)$ corresponds to $l_n = 0$. These results agree with those given in reference 4, the latter having been obtained by magnetic analysis at deuteron energies $E_d \sim 8$ Mev; our values of R were taken from this paper.

The possible values for the spin and parity of the ground state of Ne^{23} are therefore 5/2+ or 3/2+, while the corresponding quantities for the first excited state are 1/2+. The value 5/2+ for the ground state is predicted by the shell model and was used in calculating the reduced width. At the maxima of the angular distribution (and neglecting the isotropic part), the differential cross sections for transitions to the ground and first

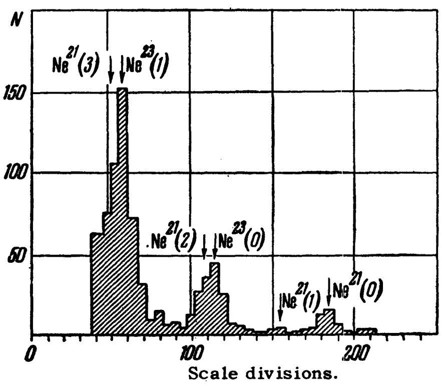

FIG. 2. Proton spectrum from the reactions $Ne^{20,22}$(d, p) $Ne^{21,23}$ at an angle $\theta_{lab} = 58°30'$. One scale division = 1.25 μ; thickness of the aluminum absorber: 39 mg/cm^2.

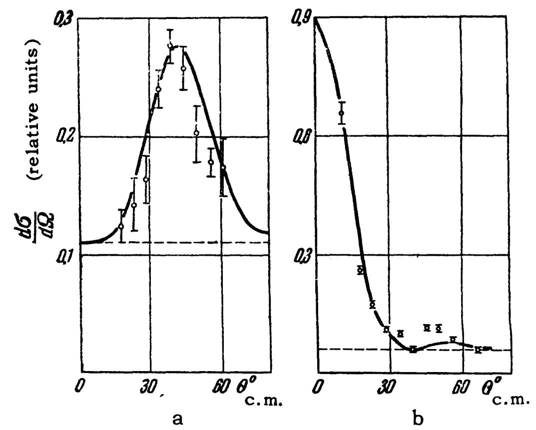

FIG. 3. Angular distributions of protons from the reaction Ne^{22}(d, p)Ne^{23}; a – ground state, $l_n = 2$, b – first excited state $l_n = 0$. $d\sigma/d\Omega$ in units of 12 mbn/sterad.

excited states are 1.87 (38°) and 11.1 (0°) mbn/steradian respectively, while the corresponding values of Θ_l^2 are 0.22×10^{-2} and 0.16×10^{-2}. According to the shell model, the ground state of Ne^{23} with T = 3/2 has the configuration $(1d_{5/2})^{-1}$, corresponding to a "hole" in the filled neutron sub-shell $1d_{5/2}$, while the first excited state (0.98 Mev) is $(2s_{1/2})^{-1}$.

2. A^{36} (d, p) A^{37}. The proton spectra from reactions on the isotopes A^{36}, C^{13} and N^{14} at and angle θ_{lab} = 32° 30′ are shown in Fig. 4. The last two isotopes were present in the target gas as impurities. The statistics are unsatisfactory because there was relatively little A^{36} present, and in addition air as a contaminant; the emulsions were overloaded with grains from the γ-background and tracks from (d, n) reactions on light nuclei (C^{12}, O^{16}). The angular distribution corresponding to transitions to the ground state of A^{37} is shown in Fig. 5. The theoretical curve is calculated from Butler's formulae with R = 6.7 $\times 10^{-13}$ cm. The absolute value of the cross section could not be calculated because the amount of air in the gas was unknown. The results show that a neutron is captured into the ground state of A^{37} with orbital angular momentum l_n = 2. Hence the possible values of spin and parity for this state are 3/2+ and 5/2+. The nucleus A^{37} has two proton and one neutron "holes" in the filled $1d_{3/2}$ shell, which according to the shell model implies a configuration $(1d_{3/2})^{-1}$ for the ground state. This conclusion is supported by

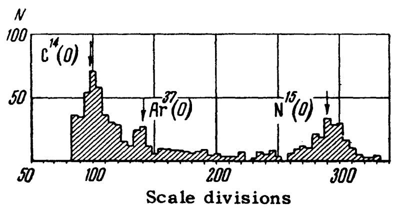

FIG. 4. Proton spectrum from (d, p) reactions on A^{36}, C^{13} and N^{14} at an angle $\theta_{lab.}$ = 32° 30′. One scale division = 1.25μ; thickness of the aluminum absorber: 120 mg/cm².

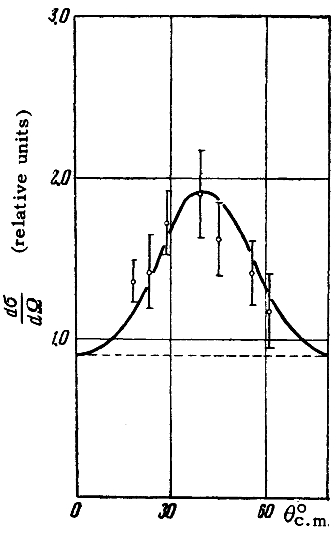

FIG. 5. Angular distribution of protons from the reaction A^{36},(d, p) A^{37} on the ground state, l_n = 2.

analysis of the allowed β decay $A^{37} \rightarrow Cl^{37}$ (reference 7).

In conclusion, I should like to express my gratitude to S. S. Vasil'ev for his constant interest in this work. I should also like to thank the cyclotron crew and their director, engineer G. V. Koshelyaev.

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