Reaction $F^{19}(d,p)F^{20}$ and the Spin of F^{20}†

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New measurements of the angular distribution of the protons from the reaction $F^{19}(d,p)F^{20}$ made with deuterons in the range $3.5 \leq E_d \leq 4.1$ Mev show that the reaction proceeds mainly by compound-nucleus formation, and that stripping makes at most a small contribution. It follows that the interpretation of the results of an earlier experiment in terms of stripping is unjustified, hence that the spin of F^{20} is not necessarily 1. At all energies the angular distribution of protons leaving F^{20} in its first excited state shows a clear stripping curve corresponding to $l_n=2$.

THE angular distributions of proton groups from the reaction $F^{19}(d,p)F^{20}$ have previously been measured by a number of investigators using deuterons of different energies. The distribution of the ground-state group is the most interesting because of its possible use to shed light upon the question of the spin of the ground state of F^{20}. Bromley, Bruner, and Fulbright[1] investigated the distribution in the angular range $5° \leq \theta \leq 95°$, using deuterons of energy approximately 3.6 Mev. Their results for the ground-state group showed a maximum at small angles and another at about 50° in the center-of-mass system. They attributed the two small peaks to a mixture of $l_n=0$ and $l_n=2$ stripping. This interpretation implies that the spin of the ground state of F^{20} is 1. Takemoto *et al.*,[2] working with deuterons of only 1.45 Mev, found little evidence for stripping in the ground-state distribution. El Bedewi,[3] using 8.9-Mev deuterons and magnetic analysis of the proton groups, found stripping curves for 21 excited states of F^{20}, but did not quote a result for the ground state because of low intensity. Additional information relative to the spin of F^{20} comes from the beta decay, which goes almost entirely to the first excited state of Ne^{20} (1.63 Mev, 2+). Less than 1% goes to the ground state (0+).[4,5] This would be consistent with a spin of 2 or 3 for F^{20}. It would not exclude spin 1, but in that case an explanation of the weakness of the ground-state transition would be required.

Because of the importance of the result, and because the earlier experimental evidence was not completely convincing (no points for $\theta > 95°$, cross section rather low for stripping reaction, and statistics not very good, especially at small angles) the measurements in the vicinity of 4 Mev have recently been repeated. The deuteron source was the variable-energy cyclotron at the University of Rochester,[6] which is equipped with a magnetic-beam analyzer having a measured energy resolution of 0.2% and an energy calibration accurate to within ±0.7% or better. Results are quoted below for $E_d=4.13$, 3.82, and 3.53 Mev. The target was a Teflon (CF_2) foil, 1.4 mg/cm² thick, set at an angle of of ±60° with respect to the direction of the beam. The protons were detected by means of an argon-filled ionization chamber. The spectra of pulses were analyzed by use of a 30-channel pulse-height discriminator. The beam current was monitored by means of a Faraday cup arrangement. In addition, the yield of protons at $\theta=35°$ was monitored by use of a CsI(Tl) scintillation counter covered with sufficient aluminum to stop scattered deuterons, and protons from $C^{12}(d,p)C^{13}$. Counts from this monitor were used for the internal normalizing of data of angular-distribution measurements made at each energy.

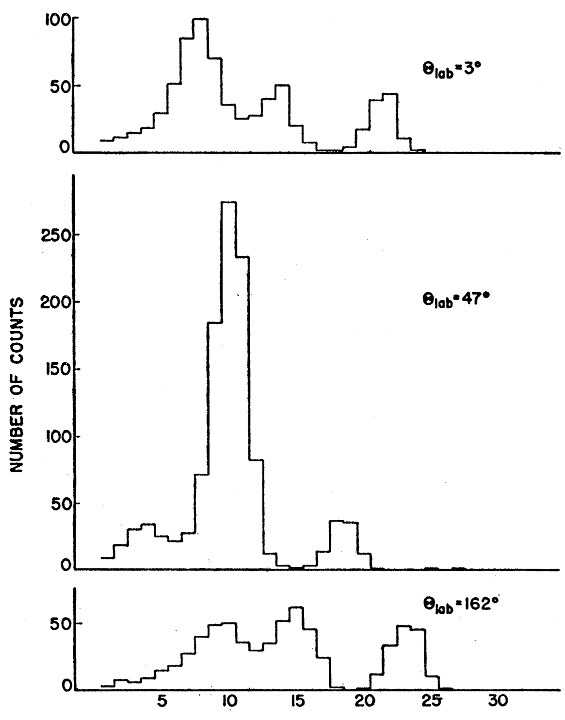

FIG. 1. Pulse-height spectra for $E_d=3.82$ Mev. The ground-state group is well resolved at all angles.

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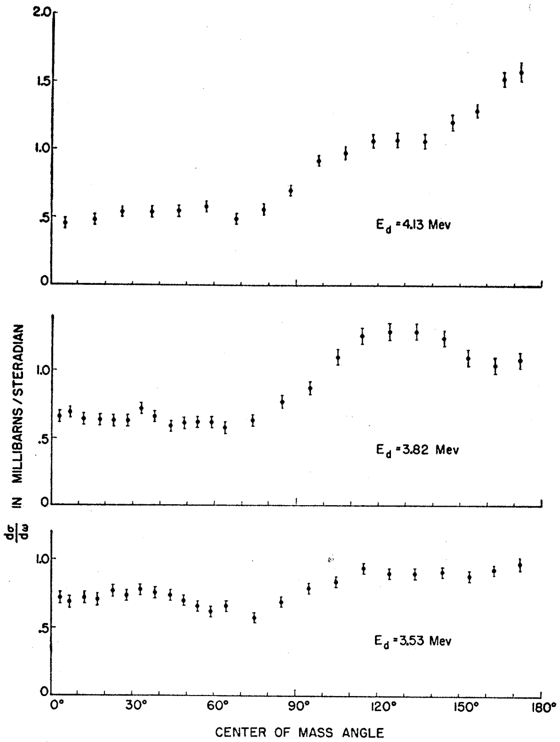

FIG. 2. Angular distributions of protons leaving F^{20} in its ground state from $F^{19}(d,p)F^{20}$.

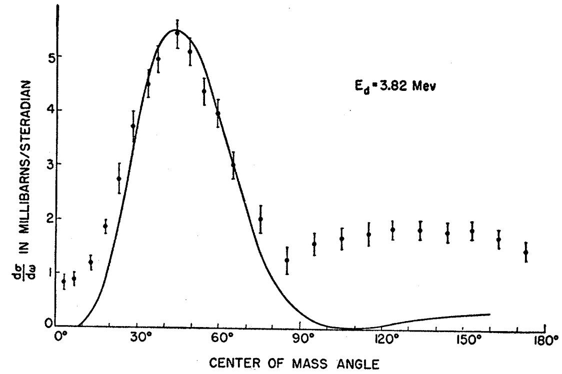

FIG. 3. Angular distribution of protons leaving F^{20} in its first excited state from $F^{19}(d,p)F^{20}$. The solid curve was calculated from Butler's theory using $l_n=2$ and $r_0=5.5\times10^{-13}$ cm.

In preliminary runs an aluminum window sufficiently thick to stop 4-Mev deuterons (it was about 70 mg/cm^2 thick) was used in the ionization chamber, but difficulty was encountered at small angles, where the number of deuterons striking the window after being scattered by the target foil was so great that pulses due to the reaction $Al^{27}(d,p)Al^{28}$ occurring in the window were observed. Since such pulses would have interfered somewhat with the experiment, it was considered best to remove the aluminum window. The Mylar $[C_6(H_2O)_5]$ window which was substituted proved very satisfactory. Protons generated in (d,p) reactions occurring in the window were too low in energy to interfere with the experiment. The window was always sufficiently thick to stop both the scattered deuterons and the protons from the $C^{12}(d,p)C^{13}$ reaction in the target.

Figure 1 shows pulse-height spectra obtained at three different angles using deuterons of energy 3.82 Mev. In every case the ground-state group was clearly resolved. Two other peaks are evident, the higher-energy one being due to the formation of F^{20} in its first excited state at 0.65 Mev, the lower-energy one being due to a mixture of two proton groups corresponding to the third and fourth excited states at 0.99 and 1.06 Mev. No peak due to the second excited state at 0.83 Mev is observed. This is consistent with the low intensity (about 10% of the intensity of the first excited-state group) reported by others[3,7] for the second excited state.

Angular distributions for the ground-state group are shown in Fig. 2. Statistical-error bars are shown for each point. The absolute cross section values have accuracy limits estimated at $\pm20\%$. The three curves bear no resemblance to the usual stripping curves. Furthermore their shape is strongly dependent upon the energy. One can therefore conclude that the predominant mechanism by which the reaction proceeds is compound-nucleus formation, and that stripping plays at best a minor role. It follows that the interpretation of the earlier experiment, mentioned above, in terms of stripping cannot be justified, hence that the spin of F^{20} is not necessarily 1.

A broad backward maximum in the ground-state angular distribution similar to ours has been observed by Ôno *et al.* using 2.03-Mev deuterons.[8]

In conclusion it should be mentioned that the protons corresponding to the first excited state of F^{20} showed typical stripping distributions at all energies. See Fig. 3. The Butler-theory curve shown for comparison was computed for $r_0=5.5\times10^{-13}$ cm. The reduced width, $(2J_f+1)\theta^2$, was found to be 0.10. θ^2 is the fraction of the first sum-rule limit.

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[8] K. Ôno (private communication).