Angular Distributions of Protons from the Reaction $F^{19}(d,p)F^{20}$†

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A Teflon (CF_2) target was bombarded with 3.6-Mev deuterons from the Rochester 26-inch cyclotron, and the angular distributions of the resulting proton groups were determined using an ionization chamber detector. The following table gives the angular momentum transfer (determined by comparison with the Butler curves) and the cross sections corresponding to the indicated levels in F^{20}:

Ground state:	$l_n=0$ and 2,	$\sigma=0.92\pm0.18$ mb/sterad (at 45°);
0.65-Mev level:	$l_n=2$,	$\sigma=7.15\pm1.4$ mb/sterad (at 45°);
2.05-Mev level:	$l_n=2$,	$\sigma<8$ mb/sterad (at 45°);
3.49- and 3.53(?)-Mev level:	$l_n=0$,	$\sigma=116\pm23$ mb/sterad (at 7°).

These F^{20} states were found to have even parity, and the ground-state spin was determined to be 1.

INTRODUCTION

A STUDY of the beta-decay of F^{20} has shown that only about 3.5 percent of the transitions are directly to the ground state,[1] indicating that this transition is forbidden. Until now, the spin of the F^{20} ground state had not been measured, and the shell models do not make a definite spin prediction.

A previous study of the $F^{19}(d,n)Ne^{20}$ ground state reaction[2] showed that the F^{19} ground state has even parity and spin $\frac{1}{2}$, in agreement with the known spin value[3] and with the shell model predictions. Consequently, a measurement of the angular distributions of the protons from the reaction $F^{19}(d,p)F^{20}$ makes possible the determination of the parities and possible spins of the F^{20} states which correspond to clearly resolved proton groups.

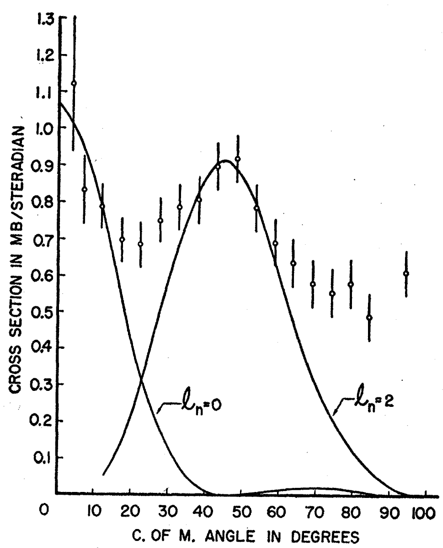

FIG. 1. Angular distribution of protons from the $F^{19}(d,p)F^{20}$ ground-state reaction.

EXPERIMENTAL METHOD

The Teflon (CF_2) target had an areal density of 1.43 mg/cm² and was prepared by slicing a thin film from a Teflon block with a microtome.

The experimental method has been described previously.[4] In brief, the target was mounted at the center of the scattering chamber and bombarded by a collimated beam of 3.6-Mev deuterons, and the protons were detected by a thin-window (0.003-inch Al) ionization chamber mounted on a rotatable arm inside the scattering chamber. At each angle the amplified output of the ionization chamber was analyzed by a 30-channel pulse-height discriminator. The energy scale was calibrated using polonium alpha-particles. Since the $C^{12}(d,p)C^{13}$ reaction has been studied here and elsewhere,[5] we were able to subtract out the corresponding proton group in the pulse height spectra.

The angular distributions obtained by analysis of the pulse-height spectra were transformed from the laboratory system to the center-of-mass system for comparison with the Butler theoretical curves.[6] These curves were calculated for $r_0=5.32\times10^{-13}$ cm and the appropriate Q.[7]

The cross sections were determined from the target areal density, the total deuteron charge measured by the beam integrator, and the geometry of the detector and scattering chamber. The absolute cross sections have an estimated accuracy of ±20 percent.

RESULTS

Watson[7] has reported the observation of eighteen excited levels in F^{20} with excitation energies less than 4.5 Mev. Our system resolution, although better than 0.22 Mev, was inadequate to separate most of these levels.

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[1] R. M. Littauer, Phil. Mag. **41**, 1214 (1950).
[2] D. A. Bromley, Phys. Rev. **88**, 565 (1952).
[3] H. G. Gale and G. S. Monk, Astrophys. J. **69**, 77 (1929); J. S. Campbell, Z. Physik **84**, 393 (1933).
[4] Fulbright, Bruner, Bromley, and Goldman, Phys. Rev. **88**, 700 (1952).
[5] D. A. Bromley and L. M. Goldman, Phys. Rev. **86**, 790 (1952), and J. Rotblat, Proceedings of the Chicago Conference, Sept. 17–22, 1951 (unpublished).
[6] S. T. Butler, Proc. Roy. Soc. (London) **A208**, 559 (1951).
[7] H. A. Watson, MIT Progress Report, May 31, 1952, p. 157 (unpublished).

The proton group corresponding to the F^{20} ground state was clearly resolved at all angles. The angular distribution of this group is shown in Fig. 1 with the appropriate theoretical curves.[6]

The group corresponding to the 0.65-Mev level was clearly resolved because of the relatively large energy separation between this group and that corresponding to the ground state, and because of the very low observed cross section ($\ll$1 mb/steradian) for the transition to the 0.83-Mev level. The angular distribution of this group with the corresponding theoretical curve is shown in Fig. 2.

On the basis of Watson's observed relative cross

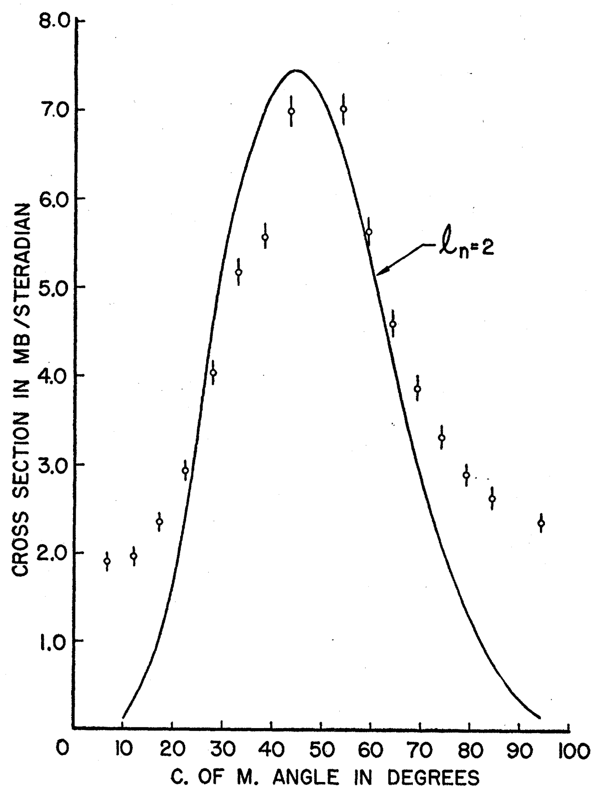

FIG. 2. Angular distribution of protons from the $F^{19}(d,p)F^{20*}$ (0.65-Mev level) reaction.

sections it is probable that the high intensity proton group, which is characterized by the $l_n=0$ angular distribution shown in Fig. 3, corresponds to transitions to the 3.49-Mev level. We cannot, however, exclude the possibility that the transition to the 3.53-Mev level is also characterized by $l_n=0$, in which case the observed distribution is the sum of the two $l_n=0$ distributions.

Our resolution was inadequate to separate the proton groups corresponding to transitions to the 1.95-, 2.05-, and 2.20-Mev levels. The angular distribution shown in Fig. 4 is, therefore, the sum of these three individual distributions. In view of the observed relative intensities[7] of 0.25, 2.0, and 0.85, respectively, it seems prob-

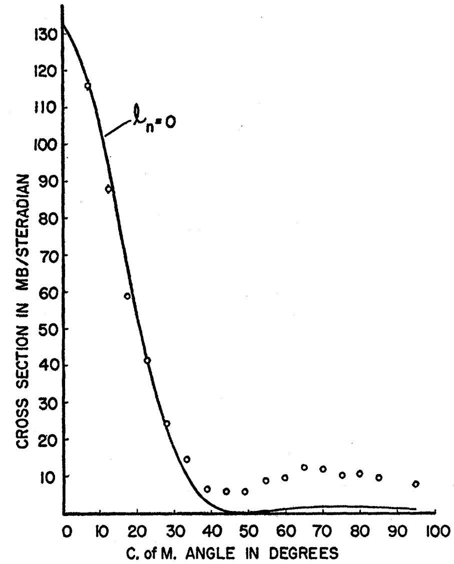

FIG. 3. Angular distribution of protons from the $F^{19}(d,p)F^{20*}$ (3.49-Mev level) reaction.

able that at least the transition to the 2.05-Mev level is characterized by $l_n=2$.

DISCUSSION

The angular distribution of the F^{20} ground-state group indicates a mixture of $l_n=0$ and $l_n=2$ transitions. Consequently, since the F^{19} ground state has spin $\frac{1}{2}$, conservation of angular momentum requires that the F^{20} ground state have spin 1. Furthermore, the F^{19} ground state parity is even, and the F^{20} ground-state parity must therefore be even, also.

With this knowledge and from the F^{20} beta-decay

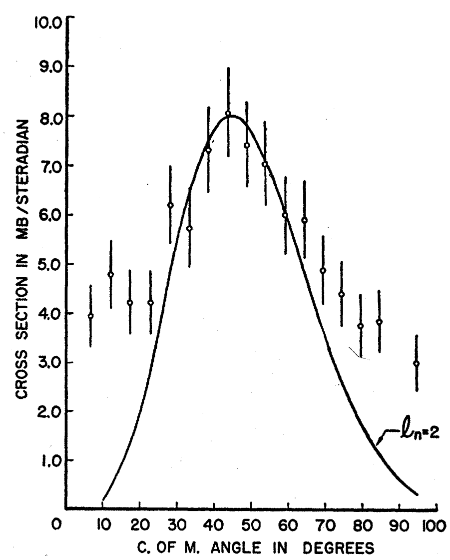

FIG. 4. Angular distribution of protons from the $F^{19}(d,p)F^{20*}$ (2.05-Mev level) reaction.

data, we deduce that the most probable shell model configuration of the F^{20} ground state is $O^{16}+s_{\frac{1}{2}}\,^{1}(p)+D_{\frac{3}{2}}(n)$ (see reference 8) with a small admixture of $O^{16}+s_{\frac{1}{2}}\,^{1}(p)+d_{\frac{5}{2}}\,^{2}(n)+s_{\frac{1}{2}}\,^{1}(n)$ corresponding to $l_n=0$) neutron capture. This admixture cannot constitute the major part of the F^{20} ground state, since it is experimentally observed that the proton intensities corresponding to the $l_n=0$ and 2 transitions are comparable. On the basis of the Butler theory this indicates that the probability of the $l_n=2$ transition is greater by a factor of about 10. Furthermore, this latter configuration would result in a "doubly l-forbidden" F^{20} beta-decay to the Ne^{20} ground state. The configuration cannot be $O^{16}+d_{\frac{5}{2}}\,^{1}(p)+d_{\frac{5}{2}}\,^{2}(n)+s_{\frac{1}{2}}\,^{1}(n)$, because this does not yield spin 1. Finally, the configuration $O^{16}+d_{\frac{5}{2}}\,^{1}(p)+D_{\frac{3}{2}}(3n)$ would lead to an allowed ($\Delta I=1$, no, $\Delta l=0$) beta-transition to the Ne^{20} ground state (contrary to experimental evidence[1]), since the Ne^{20} ground-state configuration is almost certainly $O^{16}+d_{\frac{5}{2}}\,^{2}(p)+d_{\frac{5}{2}}\,^{2}(n)$. We conclude, therefore, that a single-particle model is inadequate to account for the present observations on the F^{20} ground state.[9]

The $F^{20}\rightarrow Ne^{20}$ (ground state) beta-decay is thus characterized by $\Delta=1$, no, and by a change of 2 units of orbital angular momentum of the proton not participating in the beta-decay. The assigned configuration would thus explain the relatively large ft value of the allowed transition ($\log ft=6.9$).

Since the most intense group of beta particles in the F^{20} decay is in coincidence with a 1.63-Mev gamma-ray,[1] a study of the $F^{19}(d,n)Ne^{20}$ reaction, to determine the parity and possible spins of this final state, would be of interest.

We are indebted to Dr. M. Watson for cutting the Teflon film, and to Mr. W. Skillman for the calculation of the Butler curves.

[8] There is an analogous situation involving the 11 protons in the Na^{23} ground state. See M. G. Mayer *et al.*, Revs. Modern Phys. **23**, 315 (1951).

[9] See, for example, L. W. Nordheim, Revs. Modern Phys. **23**, 322 (1951).

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Thermal Treatment of Silicon Rectifiers

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The effect of thermal treatment on silicon point contact rectifiers over the temperature range between 900°C and 1400°C, both in high vacuum and in an oxygen atmosphere below about 0.1 mm Hg, has been investigated by means of heating a silicon specimen directly. During the treatment above 1250°C in vacuum, the rectification is changed remarkably and is finally lost. It is recovered by successive heat treatment in oxygen. Both the creation of thermal donors or acceptors and the absorbed oxygen may be regarded as causes of these phenomena. The contact area calculated from the ohmic resistance at the non-rectifying contact is the order of 10^{-6} cm^2.

In the course of studying the thermal treatment of point contact rectifiers,[1] it has been found that the rectification of both p- and n-type silicon disappears, when the specimen is heated above 1250°C in high vacuum, and it reappears through heating at 1000°C in oxygen from 10^{-1} to 10^{-3} mm Hg.

In the experiment, several silicon specimens were prepared from ingots of p-type or n-type of specific resistivity from 0.05 to 0.135 ohm-cm containing aluminium or phosphorus as impurity. The specimen and tungsten whisker were sealed in a tube, which was evacuated to a pressure below 10^{-6} mm Hg. If necessary, oxygen was admitted after sufficient evacuation. The specimen was heated to high temperature by passing current directly through it, and dc rectification characteristics were measured after quenching the specimen to room temperature. Such successive thermal treatments in high vacuum and in oxygen, as listed in Table I, made the rectification change remarkably, as illustrated in Figs. 1 and 2. In almost all cases the

TABLE I. Conditions for thermal treatment.

Number in Fig. 1	Conditions for treating	Number in Fig. 2	Conditions for treating
I		I	
	930°C, 20 min		1400°C, 1 sec.
	950°C, 20 min	II	
II			1400°C, 1 sec
	1100°C, 120 min	III	
III			1400°C, 5 sec
	1250°C, 30 min	IV	
IV			1100°C, 60 min
	1000°C, 20 min in oxygen at 0.03 mm Hg		1300°C, 10 min
		V	
			1300°C, 30 min
V		VI	
			1000°C, 10 min in oxygen at 0.12 mm Hg
		VII	
			1000°C, 10 min in oxygen at 0.006 mm Hg

[1] A comprehensive survey of crystal rectifiers has been given by H. C. Torrey and C. A. Whitmer, *Crystal Rectifiers* (McGraw-Hill Book Company, Inc., New York, 1948).