Energy Dependence of $F^{19}+p$ Reactions*

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Excitation functions have been obtained for the $F^{19}(p,\alpha\pi)O^{16}$, $F^{19}(p,\alpha_0)O^{16}$, $F^{19}(p,\alpha\gamma)O^{16}$, and $F^{19}(p,p'\gamma)F^{19}$ reactions for proton energies of 1.2 to 5.4 Mev. The marked similarity of the pair and long-range alpha excitation functions is noted and in the proton energy interval 1.35 to 2.33 Mev the differences between the yields are explained by the penetration factors for alpha particles emitted from the excited states of Ne^{20}. The average reaction cross section has been obtained for the $F^{19}+p$ reactions by averaging the excitation functions over one-half Mev intervals. The result is compared to the cross section given by the continuum theory.

INTRODUCTION

THE excited states of Ne^{20} formed by proton bombardment of F^{19} show a high probability of decay by alpha emission to states of O^{16}. Alpha decay to the ground and first excited states of O^{16} is of particular interest in that, although these two states are widely separated in energy, they are identical in spin and parity (0^+) and hence a comparison of the total cross sections for these two processes should yield information concerning the energy dependence of the alpha decay transition probabilities for states in Ne^{20}.

Since the Q value of the $F^{19}(p,\alpha)O^{16}$ reaction is 8.124 Mev, the ground-state alpha transition can be detected with reasonable facility. The transition to the first excited state of O^{16} is followed by the decay of the state to the ground state through the emission of an electron-positron pair. The pair emission is an $l=0$ transition and hence should be isotropic in the center-of-mass system. In addition, the half-life of the pair-emitting state is sufficiently long, 5×10^{-11} second,[1] for the O^{16} nucleus to come to rest before the emission takes place. Thus, the number of pairs emitted at any angle with respect to the incident beam is a measure of the total cross section for the $F^{19}(p,\alpha\pi)O^{16}$ reaction.

Several previous investigations have been made of pair and long-range alpha emission for proton energies of 0.3 to 2.4 Mev. Streib, Fowler, and Lauritsen[2] made simultaneous measurements of pair and long-range alpha (α_0) yields, the latter at 90° to the proton beam, for proton energies from 0.3 to 1.5 Mev. Their results indicated that at the two common resonances for pair and α_0 emission which they observed, the pair yield was higher than the long-range alpha yield, a circumstance difficult to understand in the light of barrier-penetration considerations. More recent measurements of long-range alpha cross sections in this energy range have been made by Schardt and Fowler,[3] while Clarke and Paul[4] have made angular distribution measurements and give spin and parity assignments and total cross sections for several resonances between 1.3 and 2.60 Mev.

Pair-emission excitation functions have been obtained by several groups[1,5–8] covering a proton energy range of from 0.3 to 2.4 Mev. Because of the difficulty in obtaining accurate cross sections by pair detection, the magnetic spectrometer measurements of Chao *et al.*[6] on the α_π group itself have been used to normalize pair yields.

The general trend of the more recent measurements has been to show considerable similarity between the pair and α_0 excitation functions. In addition the cross sections now appear to be of the same order of magnitude. There are only two resonances, pair peaks at $E_p=1.236$ and 1.62 Mev, which have not been observed to be common to both transitions.

In the present work the pair and α_0 transitions are compared for proton energies from 1.3 to 5.5 Mev.

EXPERIMENTAL PROCEDURE

Detection of Pairs

The magnetic-lens intermediate-image pair spectrometer which was used to detect the O^{16} nuclear pairs has been described elsewhere.[9] For the present experiment the maximum transmission arrangement of the spectrometer was used. This arrangement gave 7.4% resolution, which was sufficient to exclude effectively any background from internal pairs from the 6.9- and 7.14-Mev states of O^{16}. There is a possibility of interference by internal pairs from the 6.14-Mev state and also by external pairs formed in the target backing

* Supported in part by the U. S. Atomic Energy Commission.
[1] Devons, Goldring, and Lindsey, Proc. Phys. Soc. (London) A67, 134 (1954).
[2] Streib, Fowler, and Lauritsen, Phys. Rev. 59, 253 (1941).
[3] A. L. Schardt and W. A. Fowler [private communication to F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. 27, 77 (1955)].
[4] R. L. Clarke and E. B. Paul, Can. J. Phys. 35, 155 (1957).
[5] Bennett, Bonner, Mandeville, and Watt, Phys. Rev. 70, 882 (1946).
[6] Chao, Tollestrup, Rowler, and Lauritsen, Phys. Rev. 79, 108 (1950).
[7] G. C. Phillips and N. P. Heydenburg, Phys. Rev. 83, 184 (1951).
[8] J. E. Perry and R. B. Day; work appears in "Charged Particle Cross Sections," Los Alamos Scientific Laboratory Report LA-2014, 1957 (unpublished).
[9] Bent, Bonner, and Sippel, Phys. Rev. 98, 1237 (1955); Ranken, Bonner, McCrary, and Rabson, Phys. Rev. 109, 917 (1958).

material by the 6.14-Mev γ rays. With the relatively thick target backing used, the detection of the nuclear pairs was still favored by a factor of 200 over the detection of the 6.14-Mev γ ray, assuming equal intensities of the two radiations.

Since no resonances of width less than 25 kev had been observed in the pair excitation curve for proton energies less than 2 Mev, there seemed little probability of finding narrower resonances at higher energies. Accordingly the fluorine target (in the form of CaF_2) was chosen to be 0.22 mg/cm^2 thick (24-kev to 2-Mev protons). The CaF_2 was deposited, by evaporation, on a 13-mg/cm^2 thick silver backing which was in turn mounted on a 130-mg/cm^2 silver foil to provide a target backing thick enough to stop 5.5-Mev protons and thus insure the proper functioning of the Faraday cup arrangement used to collect the beam.

Since the energy of the nuclear pairs is independent of the proton bombarding energy, it is necessary to adjust the magnetic field of the pair spectrometer for maximum counting rate (maximum 6.06-Mev pair transmission) at only one bombarding energy. The spectrometer field is then held constant while the proton beam energy is varied.

In order to compare the pair and α_0 cross sections to those for α-particle transitions to the 6.14-, 6.91-, and 7.12-Mev levels of O^{16}, and to compare the present results with previous work done in this energy range[10] measurements were made of the yield of high-energy γ rays *vs* proton energy. For this purpose a Geiger counter and sodium iodide scintillations counter were used, being placed at angles of 100° and 150°, respectively, with the incident proton beam. The scintillation counter was biased to detect only γ rays of energies greater than 3.5 Mev. There was an equivalent thickness of two or three inches of copper (the spectrometer field coils) between the target and the Geiger counter which served nicely to discriminate against low-energy γ rays from the target. Both counters were shielded from γ radiation originating from locations other than the target by at least 0.75 in. of lead.

Detection of Alpha Particles

Excitation functions for the long-range α particles were obtained at 90° and 160° in the laboratory coordinate system. Conventional target mounting and collimating arrangements were used which had acceptance apertures of 9.07×10^{-4} and 5.30×10^{-4} steradian, respectively, for the 90° and 160° α particles. After emerging from the target chamber through a 1.4-mg/cm^2 aluminum exit foil, the α particles were detected by means of a thin disk of CsI mounted on an RCA 6292 phototube. The detecting element was covered with a 1.4-mg/cm^2 thick aluminum foil and placed within 0.5 cm of the exit foil. Pulses generated by this arrangement and the associated electronic circuitry were fed into a 20-channel analyzer. Thus it was possible to follow continuously the increase of α energy with proton energy. For $E_p=2.0$ Mev the long-range α particles have an energy of about 8 Mev and hence a longer range than elastically scattered protons. However, for $E_p=2.3$ Mev the proton range becomes greater than the α range. When these observations are considered in conjunction with the fact that in CsI a proton produces a light pulse 50% larger than an α particle of equal energy, it is readily seen that the thickness of the CsI detecting element becomes critical for the higher bombarding energies, particularly for observations at 90° where the number of Rutherford scattered protons is much greater than the number of long-range α particles.

Two thicknesses of CsI were used, 1.7×10^{-3} and 3.7×10^{-3} in. The former was required for the 90° measurement in the region between $E_p=2.4$ and $E_p=3.7$ Mev where the proton range is just slightly greater than the α range and hence where the best arrangement is to have the CsI just thick enough to stop the α particle. For proton energies above 3.7 Mev the thicker crystal was used since at this proton energy the gain in the resolution of the detector achieved by completely stopping the alpha more than offset the increase in proton pulse height.

As with the pair experiment, the fact that resonances narrower than 25 kev were not expected dictated the choice of CaF_2 target thickness. However, to reduce the competition from scattered protons as much as possible, the CaF_2 was deposited on 0.20-mg/cm^2 thick aluminum electroscope foil. When the angles made by the targets with the incident beam were taken into account the target thicknesses used varied between 10 and 25 kev for 2.0-Mev protons. In addition, targets 11 kev thick for 1.4-Mev protons were used in the region between 1.4 and 2.0 Mev and for calibration purposes.

Results

The pair excitation function is given in Fig. 1. The cross-section scale has been obtained by normalization with the value given by Chao *et al.*[6] for the α_π resonance at 1.236 Mev as observed with a magnetic spectrometer at 138° to the proton beam.

The yield of high-energy γ radiation is also shown in Fig. 1. The cross-section scale for this curve has been obtained by normalization of the yield at 1372 kev to the value of 300 mb obtained by Chao *et al.*[6] Because of the target thickness the cross section as shown in Fig. 1 does not rise to its true value at 1.372 Mev. This is also true of the pair peak at 1.36 Mev. For the rest of the resonances observed, the target thickness correction to the cross-section scale is small.

In converting from the measured intensity at one angle to the total cross section the assumption is made that γ rays are approximately isotropic. The very

[10] Willard, Bair, Kington, Hahn, Snyder, and Green, Phys. Rev. **85**, 849 (1952).

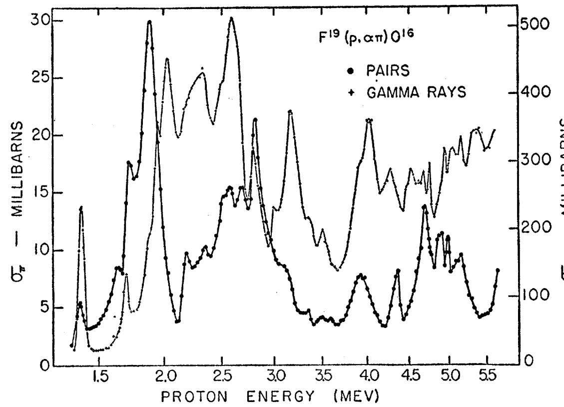

FIG. 1. Cross sections for the production of pairs and high-energy gamma rays from the reaction $F^{19}(p,\alpha)O^{16*}$.

similar behavior of the yield functions obtained with the Geiger counter at 100° and the scintillation detector at 140°, and also with the yield function obtained by Willard *et al.*[10] at 0°, is an indication that the assumption of approximate isotropy is reasonable, especially on the average.

Figure 2 is a presentation of the cross section per unit solid angle *vs* proton energy for the $F^{19}(p,\alpha_0)O^{16}$ reaction for laboratory angles of 90° and 160°. The acceptance solid angles have been calculated from geometrical considerations. Again there is some error in the cross-section scale resulting from target thickness. This amounts to about 2% at $E_p=1.347$ and 1.719 Mev and is less elsewhere.

TABLE I. Resonant energies and level widths for long-range α's and pairs from the reaction $F^{19}(p,\alpha)O^{16}$.

Long-range alpha particles α_0 (90°) E_p (Mev)	α_0 (160°) E_p (Mev)	Γ (kev)	Pairs E_p (Mev)	Γ (kev)	Best value of resonance (Mev)
	1.231	>30	1.236	58[7]	1.23
	1.347	48	1.36	40	1.35
	1.64	<115	1.62	60	1.63
1.72		110	1.72	95	1.72
1.91	1.85	140	1.89	170	1.88
2.15		100	2.19	95	2.17
2.39	2.33	110	2.35	~100	2.33
	(2.53)				(2.53)
	2.60	105	2.58	100	2.60
2.65	2.71	80	2.68	100	2.68
(2.82)	(2.84)		2.82	125	2.82
2.94	2.95				2.94
3.09	3.17	170	3.11	145	3.12
3.36	3.32	105	3.36	100	3.34
			(3.50)	(80)	(3.50)
			(3.59)	(115)	(3.59)
3.66	3.69	(100)			3.68
	3.89				3.88
3.98	3.98	135	3.93	200	3.96
4.11	4.13	100			4.13
4.36	4.36	100	4.37	95	4.36
4.46	4.46	95			4.46
4.67	4.68	65	4.71	<150	4.69
	4.90	90	4.90	115	4.90
4.97		40	5.00	40	4.99
			5.17	220	5.17

The energy scale for all four of these curves in Figs. 1 and 2 is based on the γ-ray resonance at $E_p=1.372$ kev.[11] The strength of the magnetic field required to bend this energy proton through the 90° analyzing magnet of the Rice Institute Van de Graaff accelerator was measured by a nuclear magnetic resonance magnetometer for the thinner targets previously described. Corrections to resonance energy values have been made for target thickness and for relativistic and analyzing-magnet saturation effects.[12]

The proton energies at which there is definite indication of a resonance in the α_0 or pair yield have been listed in Table I along with the widths of these resonances. In estimating the level widths the variation of proton and α-particle penetration factors across the resonance have been neglected. Interference between overlapping levels may introduce considerable errors in the estimates of the α_0 widths, but these estimates have been included in Table I for the purpose of comparison with widths obtained from the α_π total cross-section curve.

Angular distributions of the long-range alphas are known for the region between 1.3 and 2.6 Mev.[4] These distributions have been used to calculate the total cross sections for the individual resonances in this region. The results are compared with the measurements of Clarke and Paul[4] in Table II. Previous measurements of the cross section for the 1.35-Mev resonance[2,3] are not in agreement with the values listed in Table II.

The α_0 resonance at 1.64 Mev has not been reported previously. A comparison of the shape of the 90° and 160° curves (Fig. 2) between 1.6 and 1.7 Mev shows that the appearance of a peak at this energy might conceivably be explained as a result of interference between the 0^+ resonance at 1.72 Mev and the 1^- resonance at 1.86 Mev, except that for this to be true one must adopt an unreasonably large value for the width of the 1.86-Mev state.

The apparent success with which the level at 1.64 Mev was detected at 160° motivated a search for an α_0 resonance at 1.23 Mev. No resonance was observed

TABLE II. Comparison of present with previous results for the total cross section of the $F^{19}(p,\alpha_0)O^{16}$ reaction for resonances where the angular distribution is known.

E_p	σ (mb) Present results[a]	Clarke and Paul[b]
1.35	40±4	46±5
1.72	51±5	55±6
1.88	75±7	77±8
2.17	8±3	10±2
2.33	26±4	32±5

[a] Based on angular distributions of Clarke and Paul (reference 4).
[b] See reference 4.

[11] C. A. Barnes, Phys. Rev. 97, 1227 (1955).
[12] R. A. Chapman, Ph.D. thesis, Rice Institute, Houston, Texas, 1957 (unpublished).

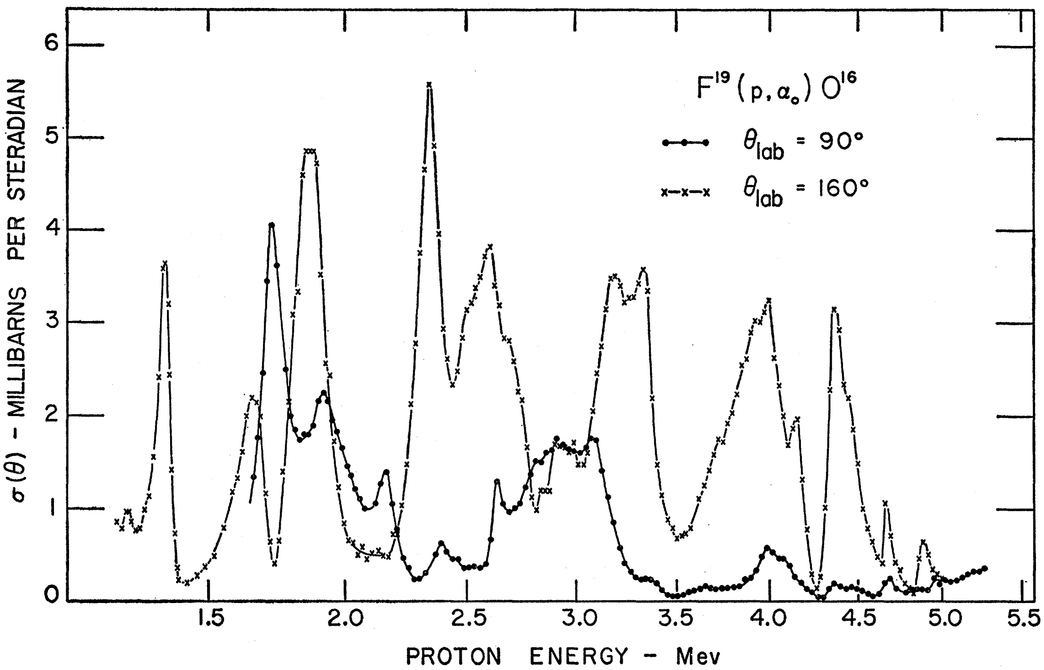

FIG. 2. Cross sections for the production of high-energy alpha particles from the reaction $F^{19}(p,\alpha_0)O^{16}$ taken at laboratory angles of 90° and 160°.

at this energy at 90°.[2] A definite resonance at 1.23 Mev was observed and is shown in Fig. 2. An isotropic angular distribution would result in a total cross section for this level of ≥ 3 mb, which is larger than the pair cross section of 2.5 mb.

DISCUSSION

The pair and α_0 excitation functions seem to bear little resemblance to one another. However, in the region where the total α_0 cross sections are known,[4] it seems apparent that the two functions are related. Further justification is lent to this observation if, for proton energies greater than 2.6 Mev, the values of $\sigma(\theta)$ at 90° and 160° are used to compute a rough estimate of the total cross section. (In following this procedure the approximation is made that the angular distributions are symmetric about 90°.) The total α_0 cross section obtained in this manner shows the same general shape as the pair cross-section curve and is equal in magnitude to the latter within a factor of 2 over most of the energy range studied. Further indication of the similarity of the pair and α_0 excitation functions is given by the fact that for every pair resonance, except for the doubtful peak at 3.50 Mev, there is indication of a resonance on either the 90° or the 160° curve or on both. There are only 6 of 23 α_0 resonances between $E_p=1.2$ and $E_p=5.1$ Mev for which a corresponding pair resonance is not clearly evident.

According to the single-level resonance formulation, the ratio of the cross sections for α_0 and α_π emission from a given state in Ne^{20} is just the ratio of partial widths for these reactions. These partial widths may be expressed in the form

$$\Gamma=2KRV_l\gamma^2,$$

where, in our case, K is the wave number of the emitted α particle, R is the radius at which the Coulomb field cuts off, V_l is the "penetration factor" for the Coulomb and angular-momentum barrier, and γ is the reduced width. The degree of similarity between the α_0 and pair excitation functions lends reason to the supposition that the reduced widths for these two processes are related by a constant factor. On the basis of this assumption, and with the constant factor taken to be one, the expected relative cross sections were calculated for several resonances between 1.3 and 2.4 Mev. The ratios calculated for a Coulomb cut-off radius of 6.5×10^{-13} cm are listed in Table III together with

TABLE III. Comparison of ratios of experimental α_0 and α_π cross sections with ratios calculated on a basis of the reduced width of states in Ne^{20} being the same for α-particle emission to ground and first excited states of O^{16}.

Proton energy at resonance (Mev)	Spin and parity[a]	$\sigma\alpha_0/\sigma\alpha_\pi$ (experimental)	$\sigma\alpha_0/\sigma\alpha_\pi$ (calculated)
1.35	2^+	6.2±0.5	6.5
1.72	0^+	3.3±0.3	3.2
1.88	1^-	3.0±0.3	3.3
2.17	4^+		13.2
		1.8±0.6	
	0^+		2.9
2.33	2^+	4.2±0.8	3.6

[a] See reference 4.

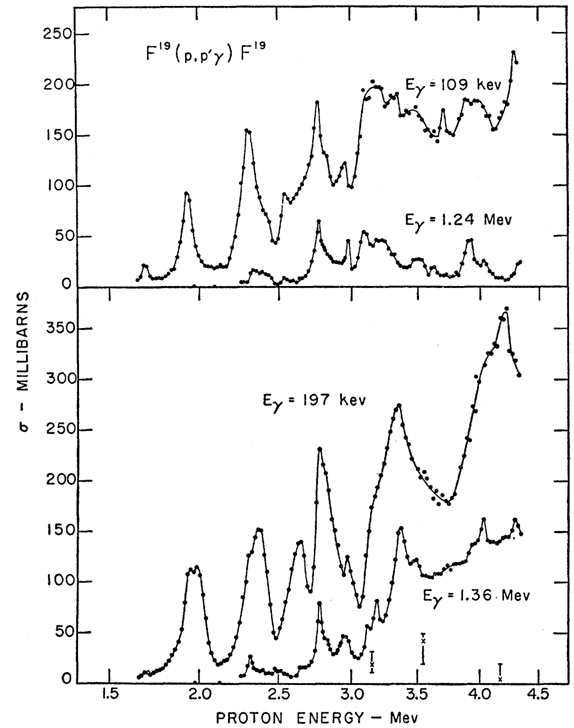

FIG. 3. Cross sections for the production of 0.109-, 0.197-, 1.24-, and 1.36-Mev γ rays from the reaction $F^{19}(p,p'\gamma)F^{19}$. The crosses at 3.2, 3.6, and 4.2 Mev give the yield of 1.35-Mev radiation contributed by the cascades from the 1.46-Mev level.

the experimental ratios. The agreement is fairly good except for the state at 2.17 Mev.

If the assignment of 4^+ is accepted this resonance shows a ratio factor of at least 6 smaller than would be expected on the simple picture described above. Clarke and Paul assigned the value of 4^+ to this state in order to explain the presence of a prominent p_4 term in the angular distribution of the 2^+ resonance at 2.31 Mev.[4] The present results show that the maximum in the α_0 yield at $E_p=2.60$ Mev, which was assumed to be one broad 0^+ level by the above authors, represents the contribution of two or more levels, one of which could quite possibly be a 4^+ level. If the spin of the level at 2.17 Mev is chosen to fit the experimental cross-section ratio then a 0^+ assignment would give the best fit although a 1^- value could not be ruled out. If a 0^+ assignment is correct, this level is probably of the same type as the 0^+ level at 0.843 Mev which is thought to have an isobaric spin of one.[11,13]

$F^{19}(p,p')F^{19*}$

The capture of a proton by F^{19} forms Ne^{20} in a highly excited region (greater than 13 Mev). The yield of high-energy γ's above $E_p=1.8$ Mev suggests that the levels are becoming broad enough and close enough together so that the average behavior might be approximated by the continuum theory of nuclear reactions.[14] When averaged over one-half Mev intervals, the total $F^{19}(p,\alpha)O^{16}$ cross section (which can be closely approximated by adding the contributions from α_0, pair, and the 6–7 Mev γ yields) has a pronounced minimum in the region of 2.8 to 3.8 Mev. The results of Barnes[11] indicate that the resonance cross sections for the $F^{19}(p,p')F^{19*}$ reactions are of the same order of magnitude as the cross sections for the high-energy γ's from the $F^{19}(p,\alpha)O^{16}$ reactions. For this reason it was thought that the (p,p') reactions might show strong resonances in the region of 2.8 to 3.8 Mev.

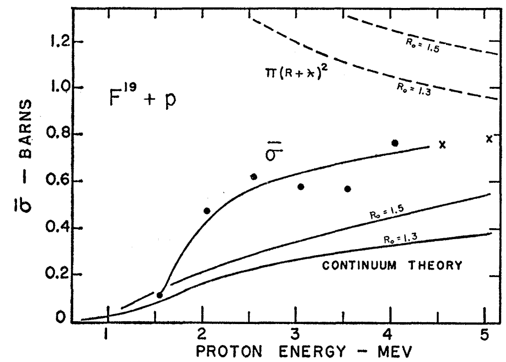

FIG. 4. Total cross section, averaged over 0.5-Mev intervals, for the $F^{19}(p,\alpha)O^{16*}$ and $F^{19}(p,p'\gamma)F^{19}$ reactions. The continuum theory cross section and $\pi(R+\lambda)^2$ are given for $R_0=1.3$ and 1.5×10^{-13} cm (where $R=R_0A^{\frac{1}{3}}$).

A 1-in.×1-in. NaI crystal, mounted on a DuMont 6292 photomultiplier tube, was used in conjunction with a 20-channel pulse-height analyzer to measure at an angle of 45° with the incident proton beam, the yield, as a function of proton energy, of the 109- and 197-kev γ radiation from the two low-lying states in F^{19}. The target was 0.130 mg/cm² of CaF_2 evaporated onto a 104-mg/cm² tungsten foil, which was mounted in turn on a $\frac{1}{8}$-in. thick aluminum plate.

The results of this experiment are shown in Fig. 3. The cross-sections scale is based on an extrapolation of curves obtained by Lazar *et al.*[15] for the total absorption peak efficiency *vs* γ-ray energy for NaI crystals. The transmission of tungsten and aluminum backing material was calculated from theoretical values of the total (Compton plus photoelectric) cross section for γ radiation.[16] The cross-section scale is expected to be accurate to within 10 or 15%, an error limit which includes the value obtained by Barnes[11] for the 109-kev γ ray at 1.70 Mev.

Excitation functions were also obtained for the 1.24-Mev radiation and the combined effects of the 1.35- and 1.36-Mev γ rays produced in the $F^{19}(p,p')F^{19*}$ reaction. For this puprose a 3-in.×3-in. NaI crystal,

[13] E. U. Baranger, Phys. Rev. 99, 145 (1955).

[14] J. M. Blatt and V. F. Weisskopf, *Theoretical Nuclear Physics* (John Wiley and Sons, Inc., New York, 1952), Chap. VIII.

[15] Lazar, Davis, and Bell, Nucleonics 14, No. 4, 52 (1956).

[16] C. M. Davisson, in *Beta- and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (Interscience Publishers, Inc., New York, 1955), Appendix I.

mounted on a DuMont 6363 photomultiplier tube, was used to measure the yield of the γ rays from a 0.032-mg/cm^2 CaF_2 target, again backed with 104 mg/cm^2 tungsten. These excitation functions are also given in Fig. 3. It is known that the 1.35-, 1.46-, and 1.56-Mev states in F^{19} decay primarily by cascade through the two low-lying states[17] and hence the yield of the 109- and 197-kev γ's is a good measure of the total inelastic scattering cross section for proton energies up to about 4.5 Mev. (The low yield of 1.24- and 1.36-Mev γ radiation below $E_p=2.8$ Mev gives weight to the argument that the 2.82-Mev state of F^{19} will not contribute much to the inelastic scattering below $E_p\approx 4.5$ Mev.)

The total cross section for the (p,α) and (p,p') reactions, averaged over one-half Mev intervals is presented in Fig. 4. The cross section rises much more rapidly than would be expected on the continuum theory model using a square-well potential and a radius of 3.6 or 4.1×10^{-13} cm. The large value of the cross section at 2 Mev can better be understood by using a Saxon potential in place of a square well. For a radius of 3.6×10^{-13} cm the height of the Coulomb potential barrier is reduced by a factor of two. This reduction in the height of the barrier and the effect of a smoother variation of potential with radius should increase the cross section at 2 Mev by a factor of over two. The shape of the curve above 4.0 Mev is based on the assumption that the average inelastic cross section is about constant between 4.3 and 5.3 Mev and includes the $F^{19}(p,n)Ne^{19}$ cross section[18] above the threshold for this reaction at 4.25 Mev. In Fig. 3 it may be seen that the yield of 1.36 γ radiation continues to rise for E_p greater than 3.0 Mev, while the yield of the 1.24-Mev radiation appears to be falling off. The behavior is consistent with the supposition that one or both of the states in F^{19} contributing to the 1.35-Mev radiation has a higher spin than the $J=\frac{3}{2}$, 1.36-Mev level, which is known to decay with at least 70% probability to the 109-kev state with the emission of a 1.24-Mev γ ray.[17] The 1.46-Mev level decays with 80% probability to the 109-kev state yielding a 1.35-Mev γ ray while the 1.56-Mev state decays to the 197-kev state, with the emission of a 1.36-Mev γ ray, with at least 90% probability.[17] Three points representing estimates of the amount of 1.35-Mev radiation contributed by the 1.46-Mev level are shown in Fig. 3 with the yield curve for the combined 1.35- and 1.36-Mev radiation. These estimates are taken from work done with a magnetic-lens photoelectric-conversion spectrometer.[19] The estimates represent average yields over an energy range of about 160 kev and agree, in essence, with estimates of the amount of radiation from the 1.46-Mev level obtained from the NaI counter pulse-height distribution. It is apparent that it is an increase in the excitation of the 1.56-Mev level which causes the increase in the yield of 1.36-Mev gamma radiation in the region of 3.3 to 4.3 Mev. If one accepts the present spin and parity assignment of $\frac{3}{2}+$ for the 1.56-Mev state, then it is apparent that the parity of the $J=\frac{3}{2}$, 1.36-Mev state is odd. However, the behavior of the 1.36- and 1.56-Mev level excitation functions would seem to be enough different to require more than a difference in parity as an explanation.

[17] Toppel, Wilkinson, and Alburger, Phys. Rev. **101**, 1485 (1956).

[18] Blaser, Boehm, Marmier, and Scherrer, Helv. Phys. Acta **24**, 465 (1951).

[19] Ranken, Bonner, McCrary, Rabson, Harlow, and Castillo (to be published).