Gamma-Neutron Reactions in Fluorine

R. J. HORSLEY, R. N. H. HASLAM, AND H. E. JOHNS
Department of Physics, University of Saskatchewan, Saskatoon, Saskatchewan, Canada
(Received May 26, 1952)

The cross-sectional curves for the reactions $F^{19}(\gamma, n)F^{18}$ and $F^{19}(\gamma, 2n)F^{17}$ have been determined by measurement of the induced positron activities. The (γ, n) cross-sectional curve rises almost vertically from the threshold to a value of about 2 mb, remains constant for about 3 Mev, and then increases again to a maximum value of 3.48 mb at 20 Mev. The $(\gamma, 2n)$ cross-sectional curve has a peak value of 0.66 mb at about 26 Mev. The integrated cross sections for the (γ, n) and $(\gamma, 2n)$ reactions are 0.039 and 0.0024 Mev-barns, respectivcly. However, the $(\gamma, 2n)$ reaction is evaluated only up to its peak position at 26 Mev. A new value of 60 ± 1 seconds is reported for the F^{17} activity.

INTRODUCTION

As part of a general program of measuring the photonuclear reactions in elements of low atomic number, the cross sections for the two reactions $F^{19}(\gamma, n)F^{18}$ and $F^{19}(\gamma, 2n)F^{17}$ have been measured as functions of photon energy by detecting the residual position activities in F^{18} and F^{17}. This latter reaction is the first $(\gamma, 2n)$ cross-sectional curve determined in this laboratory using the photon difference method.[1]

EXPERIMENTAL PROCEDURE

For the reaction $F^{19}(\gamma, n)F^{18}$, the experimental procedure was similar to that previously reported.[2,3] One-gram samples of LiF powder were radiated in a small cadmium thimble which approximated in size the sensitive volume of a Victoreen 100 r chamber. The dose was monitored by a Victoreen 100 r chamber placed in the center of a 8-cm cube of Lucite. The cadmium thimble filled with LiF powder was radiated in this same position. The 112-minute F^{18} activity was then counted in a fixed geometry. A delay of about 15 minutes was allowed between the end of irradiation and the start of counting to allow the short-lived activities to die away. Although the LiF powder was reagent grade, a 2-minute activity was detected which was attributed to the presence of oxygen as an impurity.

For the reaction $F^{19}(\gamma, 2n)F^{17}$, the procedure was changed. The two-minute activity mentioned above made it impossible to use this same material to measure the shorter-lived F^{17} positron activity. Pure LiF crystals 2 cm×2 cm×2 mm were used in which no interfering activity was observed. The $F^{19}(\gamma, n)F^{18}$ activity was used to monitor the $F^{19}(\gamma, 2n)F^{17}$ reaction similar

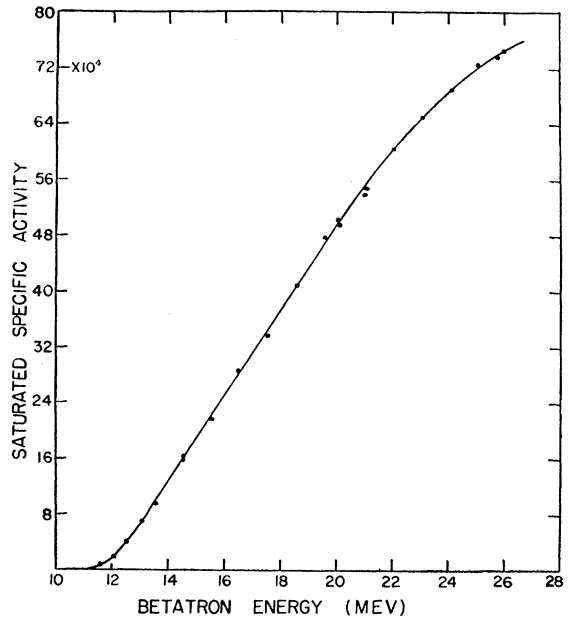

FIG. 1. Saturated specific activity in disintegrations per gram per 100 r as a function of maximum betatron energy for the reaction $F^{19}(\gamma, n)F^{18}$. Corrections for geometry, etc., have been applied.

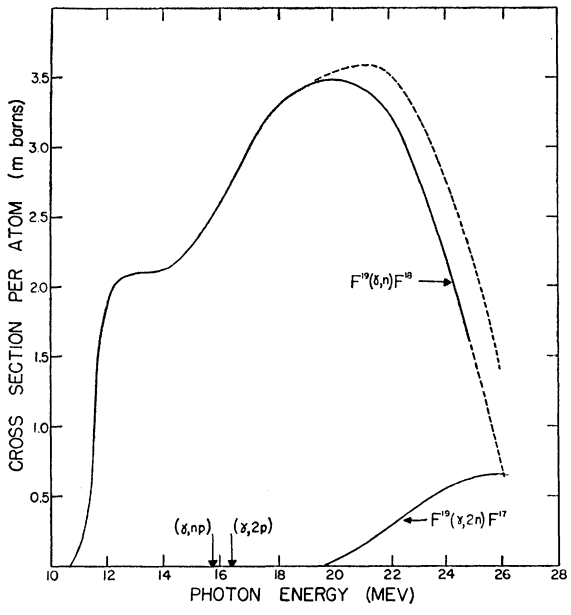

FIG. 2. Cross section *vs* energy curves for the reactions $F^{19}(\gamma, n)F^{18}$ and $F^{19}(\gamma, 2n)F^{17}$. The dotted line indicates the sum of the two reactions. The (γ, np) and $(\gamma, 2p)$ calculated thresholds are marked.

[1] L. Katz and A. G. W. Cameron, Can. J. Phys. **29**, 518 (1951).
[2] Johns, Horsley, Haslam, and Quinton, Phys. Rev. **84**, 856 (1951).
[3] Horsley, Haslam, and Johns, Can. J. Phys. **30**, 159 (1952).

to the method previously reported for the $Cu^{65}(\gamma, n)Cu^{64}$ reaction.[4] The counting equipment was placed close to the betatron in order that little time would be lost between the end of irradiation and the start of counting. With this arrangement it was possible to start counting 20 seconds after the end of the irradiation. Because of the 12-second neutron-induced F^{20} activity there was no advantage in starting to count sooner.

RESULTS

$F^{19}(\gamma, n)F^{18}$

Figure 1 shows the saturated specific activity curve for the $F^{19}(\gamma, n)F^{18}$ reaction per gram of parent isotope at a dosage rate of 100 r per minute. Corrections for self-absorption, back-scattering, and geometry have been applied. Normalization against the $Cu^{63}(\gamma, n)Cu^{62}$ reaction[4,5] was carried out at 23.5 Mev. The neutron yield at 22 Mev is 1.14×10^5 neutrons/mole/r as compared to the value 1.6×10^5 reported by Price and Kerst.[6]

The cross-sectional curve was determined by the photon difference method[1] and is shown in Fig. 2. This curve rises almost vertically from the calculated threshold at 10.7 Mev to a value of about 2 mb at 12 Mev, remains almost constant for about 3 Mev, and then increases again to a peak value of 3.48 mb at 20 Mev. The pertinent information obtained from this curve is shown in Table I.

TABLE I. Information obtained from the $F^{19}(\gamma, n)F^{18}$ and $F^{19}(\gamma, 2n)F^{17}$ cross-sectional curves.

Reaction	$F^{19}(\gamma, n)F^{18}$	$F^{19}(\gamma, 2n)F^{17}$
Peak position	20 Mev	26 Mev
Peak cross section	3.48 mb	0.66 mb
Width at half-maximum	12.9 Mev	—
Integrated cross section (to 26 Mev)	0.039 Mev-barns	0.0024 Mev-barns

The ratio of the $F^{19}(\gamma, n)F^{18}$ and $Cu^{63}(\gamma, n)Cu^{62}$ cross-sectional values has been determined by Wäffler and Hirzel,[7] with lithium gamma-radiation. Using the $Cu^{63}(\gamma, n)Cu^{62}$ cross-sectional results[4,5] previously determined in this laboratory and weighting our cross-sectional values according to the percentage of 17.6- and 14.5-Mev photons in lithium gamma-radiation, our value of 0.030 for this ratio is in satisfactory agreement with the value of 0.025 as reported by Wäffler and Hirzel.

$F^{19}(\gamma, 2n)F^{17}$

Many determinations were made of the F^{17} half-life using the LiF crystals. The average value obtained for this half-life is 60 ± 1 seconds, which is lower than the value of 66 seconds reported by Brown and Perez-Mendez.[8] A sample decay curve is reproduced in Fig. 3. In addition to the 112-minute F^{18} activity and the 60-second F^{17} activity, there is shown the 12-second F^{20} neutron-induced activity.

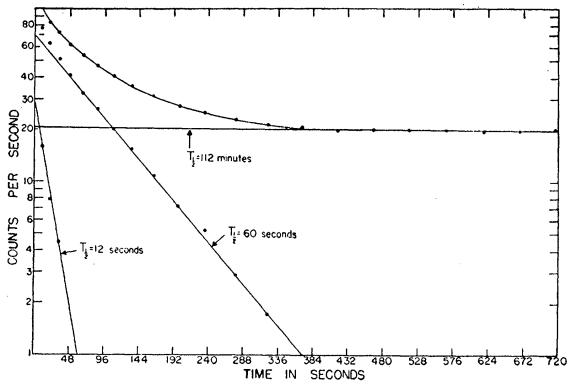

FIG. 3. A sample decay curve using pure LiF crystals, showing the F^{18} 112-minute activity, the F^{17} 60-second activity, and the neutron-induced 12-second F^{20} activity.

Figure 4 shows the saturated specific activity curve for the reaction $F^{19}(\gamma, 2n)F^{17}$. Normalization against the $Cu^{63}(\gamma, n)Cu^{62}$ reaction was carried out at 24.5 Mev. Because of the difficulty in procuring sufficiently thin LiF crystals to determine a self-absorption curve, the self-absorption correction was obtained indirectly. Recent work[9] done in this laboratory indicates that the self-absorption and self-scattering of samples of the same area but of different materials are the same to a first order of approximation, provided that the thicknesses of the samples, expressed in terms of the fraction of the range of their emitted β-particles, are equal. A sample of copper and one of fluorine of the same area were irradiated simultaneously and counted in the same

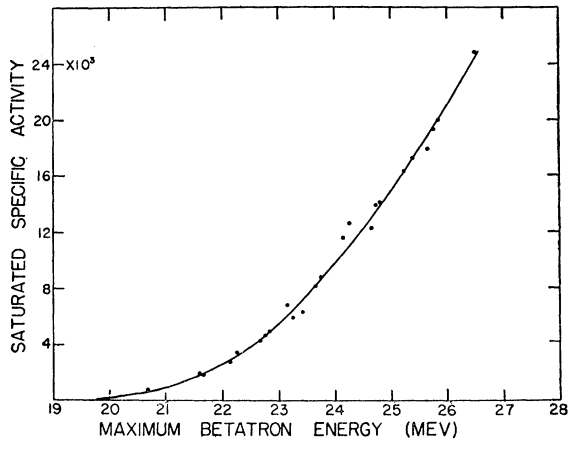

FIG. 4. Saturated specific activity in disintegrations per gram per 100 r as a function of maximum betatron energy for the reaction $F^{19}(\gamma, 2n)F^{17}$.

[4] Johns, Katz, Douglas, and Haslam, Phys. Rev. **80**, 1062 (1950).
[5] Haslam, Johns, and Horsley, Phys. Rev. **82**, 270 (1951).
[6] G. A. Price and D. W. Kerst, Phys. Rev. **77**, 806 (1950).
[7] H. Wäffler and O. Hirzel, Helv. Phys. Acta **21**, 200 (1948).
[8] H. Brown and V. Perez-Mendez, Phys. Rev. **75**, 1286 (1949).
[9] R. Baker, Master's thesis, University of Saskatchewan (1952).

geometry. Since the thickness of the copper (expressed in terms of the range of the 2.9 Mev β^+ particle) was made the same as the thickness of the LiF crystal (expressed in terms of the range of the 2.1 Mev β^+ particle), only corrections for saturation and isotopic abundances need be applied.

The cross-sectional curve for the $(\gamma, 2n)$ reaction in fluorine is shown in Fig. 2. It rises smoothly from a calculated threshold at 19.4 Mev to a peak value of 0.66 mb at 26 Mev. The integrated cross section up to 26 Mev is 0.0024 Mev-barns. Table I contains the information obtained from this curve.

A rough estimate of the total $(\gamma, 2n)$ integrated cross section can be obtained if we assume that the $(\gamma, 2n)$ cross-sectional curve is symmetrical about its peak position at 26 Mev. This assumption is questionable, since we have no information concerning the shape of the latter part of the curve and how far it may extend. The above assumption leads to a value of 0.0048 Mev-barns for the total integrated cross section, and the ratio of the (γ, n) to the $(\gamma, 2n)$ integrated cross section is then about 8 to 1. Perlman and Friedlander[10] report that the ratio of the (γ, n) and $(\gamma, 2n)$ yields at 50 and 100 Mev bremsstrahlung energies are 18.7 and 12.3, respectively. The large difference in their results can hardly be explained in terms of the variation in shape of the bremsstrahlung spectrum in the region of importance for the (γ, n) and $(\gamma, 2n)$ reactions for maximum betatron energies of 50 and 100 Mev.

DISCUSSION

The shape of the (γ, n) cross-sectional curve differs somewhat from the usual resonance type of curve obtained for photonuclear reactions. The small step in the first part of the curve cannot be explained satisfactorily in terms of competing reactions since the thresholds for any possible competing reactions lie at too high energies. A possible exception is the $F^{19}(\gamma, p)O^{18}$ reaction which has a calculated threshold of 7.8 Mev. Although the "effective" threshold for this reaction may be 2 or 3 Mev higher because of the barrier effect, it is doubtful if it would come in strongly enough at an energy of 12 or 13 Mev to account for the observed distortion of the curve. A somewhat similar behavior of the cross-sectional curves for the reactions $O^{16}(\gamma, n)O^{15}$ and $N^{14}(\gamma, n)N^{13}$ was tentatively explained in terms of the absorption mechanism.[2,3] It was suggested that the initial portion might be due in large part to electric quadrupole and magnetic dipole absorption, while the subsequent rapid rise might be attributed to increased electric dipole absorption. A similar explanation may hold in this case.

However, an alternative explanation may be provided by work in progress in this laboratory. It has been found that there are sharp breaks in the $O^{16}(\gamma, n)O^{15}$ and $C^{12}(\gamma, n)C^{11}$ activation curves which may be explained as being due to strong absorption levels in the initial nucleus.[11] A variation in the density and strength of F^{19} levels in the critical region may well account for the observed cross-sectional shape. A careful investigation of levels in F^{19} is planned.

The turning over of the (γ, n) cross-sectional curve above 20 Mev cannot be attributed to the competing $(\gamma, 2n)$ reaction since the sum of these two cross-sectional curves also turns over. This is shown by the dotted line in Fig. 2. The effect of the (γ, np) and $(\gamma, 2p)$ reactions are not known, but it seems probable that the magnitude of these cross sections would be insufficient to account to any appreciable extent for the rapid falling off of the sum of the (γ, n) and $(\gamma, 2n)$ cross-sectional curves. The decreased cross section is thus thought to be due to a falling off in the photon absorption cross section at energies above 22 Mev.

CONCLUSIONS

The shape of the $F^{19}(\gamma, n)F^{18}$ cross-sectional curve cannot be explained satisfactorily in terms of any competing processes including the measured $F^{19}(\gamma, 2n)F^{17}$ reaction. The anomalous shape of the first part of the curve as well as the turning over of the curve at 21 Mev must be explained in terms of the mechanism of gamma-ray absorption which at present is being investigated.

The authors appreciate the financial assistance of the National Research Council of Canada and the National Cancer Institute. One of the authors (R.J.H.) is indebted to the National Research Council for a studentship.

[10] M. L. Perlman and G. Friedlander, Phys. Rev. 74, 442 (1948).

[11] Haslam, Katz, Horsley, Cameron, and Montalbetti, Phys. Rev. 87, 196 (1952).