$^{18}O(\gamma,pn+np)$ cross section

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Measurement has been made of the $^{18}O(\gamma,pn+np)$ cross section. The cross section rises to a maximum of 1.2 mb at 27.5 MeV, approximately one-tenth of the total (γ,n) cross section there. The integrated cross section is correspondingly small (11.8 MeV mb to 43 MeV). As a result, the assignments of isospin distribution in the giant dipole resonance made by Woodworth *et al.* [Phys. Rev. C **19**, 1667 (1979)] are unaffected by neglect of this reaction channel.

INTRODUCTION

In an earlier experiment[1] on ^{18}O the photoneutron and photoproton cross sections were measured simultaneously. Specifically, cross sections were meaured for reactions in which one neutron was instantaneously emitted after photon excitation [(γ,n) plus $(\gamma,pn+np)$] for those in which two neutrons were emitted [$(\gamma,2n)$] and for reactions in which one proton was emitted [(γ,p)].

In discussing these results, interferences were drawn concerning the distribution within the dipole resonance of the isospin components $T_<$ $(T=1)$ and $T_>$ $(T=2)$. These inferences were based largely on the relative proportions of neutron to proton emissions from excited states of ^{18}O, as such proportions are in part dependent on isospin.[2] However, the data of Ref. 1 do not unambiguously provide the relative strengths to photoneutron and photoproton emissions.

To determine the (γ,p) cross section, the authors of Ref. 1 counted the delayed neutrons from the production from ^{18}O of ^{17}N. They therefore did not include in the (γ,p) cross section transitions in which proton emission was immediately followed by neutron emission [the (γ,pn) reaction]. However, the $(\gamma,1n)$ cross section of Ref. 1, that of transitions leading to the (immediate) emission of one neutron, includes (γ,pn) reactions as well as (γ,np). The magnitude of the $(\gamma,pn+np)$ cross section is then of importance. If the cross section is large, it would make the measured value of the relative proportions of neutron to proton emissions from ^{18}O erroneously high and could then affect the correctness of conclusions of Ref. 1 regarding the isospin assignments in the giant dipole resonance of ^{18}O. The $(\gamma,pn+np)$ cross section had not been measured at the time of the work of Ref. 1.

To help clarify this situation and to obtain a more complete picture of the photodisintegration of ^{18}O, the cross section of the reaction in which ^{16}N results from the photodisintegration of ^{18}O has been measured using quasimonoenergetic photons in the energy range 19–43 MeV. The reaction channel includes, but does not separate, the (γ,pn) and the (γ,np) reactions (threshold energy 21.8 MeV) and the (γ,d) reaction (threshold energy 19.6 MeV). This experimental reaction channel does not include that in which ^{16}N is momentarily left in an excited state above 2.49 MeV, as all such excited states are neutron unstable; these reaction channels are included in the $(\gamma,2n)$ cross section of Ref. 1.

METHOD

A detailed account of the procedures for obtaining quasimonoenergetic photons has been given previously.[1] A beam of positrons from the Lawrence Livermore National Laboratory electron-positron linear accelerator was incident on a 0.76-mm-thick beryllium annihilation target to produce bremsstrahlung and annihilation photons which passed through an ionization-chamber beam monitor before striking the photonuclear sample, which consisted of 96.6 g of $H_2{}^{18}O$. Details of the experiment are given in the report of the measurement of the $^{17}O(\gamma,p)$ cross section,[3] which was done concurrently.

The positron-beam energy was varied from below the threshold for the (γ,d) reaction, from 19 to 43 MeV. Data were subsequently taken using a negative-electron beam over the same energy range to measure the bremsstrahlung contribution. Subtraction of the normalized negative-electron data gave the photonuclear yield from the monoenergetic gamma rays.

The $^{18}O(\gamma,pn+np)$ reaction leads to the formation of ^{16}N, which is radioactive with a half-life of 7.2 sec. 68% of the decays of ^{16}N lead to the 6.13-MeV state of ^{16}O, which gamma decays directly to the ground state. These 6.13-MeV gamma rays were detected by two NaI crystals, one 20.3 cm in diameter by 20.3 cm thick, and the other 28 cm in diameter by 14 cm thick. The outputs of these detectors were gated off during the linac beam burst and the recorded spectra were subsequently analyzed to provide a measure of the number of 6.13-MeV gamma rays. Because the $H_2{}^{18}O$ water sample included a small contaminant of $H_2{}^{17}O$, some of these 6.13 MeV gammas rays were the result of the $^{17}O(\gamma,p)^{16}N$ reaction. In order to allow for this contribution, additional data were acquired alternately with the $H_2{}^{18}O$ sample and with samples of $H_2{}^{17}O$ and $H_2{}^{16}O$. Data from the $H_2{}^{16}O$ sample provided background information. Subtraction after proper normalization gave the gamma-ray yield from the ^{18}O target itself.

A further correction to the data was necessary because the $^{18}O(\gamma,p)$ reaction leads to ^{17}N, which β decays (half-life of 4 sec) to neutron unstable levels of ^{17}O. These delayed neutrons may be captured by the NaI crystals during the "gate-on" period, resulting in 6.9-MeV capture gamma rays, which are not resolved from the 6.13-MeV gamma ray produced by the $^{18}O(\gamma,np)$ reaction. As the threshold of the $^{18}O(\gamma,p)$ reaction is 15.9 MeV, there was quantitative evidence of this effect well below the $^{18}O(\gamma,pn+np)$ threshold. Moreover, the raw gamma-ray spectra contains peaks which correspond to known peaks in the $^{18}O(\gamma,p)$ cross section.[1] Based on these features and the known $^{18}O(\gamma,p)$ cross section, Zubanov[4] calculated the correction to be applied for this (γ,p) effect.

RESULTS

The measured $^{18}O(\gamma,pn+np)$ cross section is shown in Fig. 1. Integrated cross sections to 30 and 43 MeV, and their moments, are given in Table I.

The most significant feature of the $^{18}O(\gamma,pn+np)$ cross section is a broad peak with a maximum at 27.5 MeV. The cross section at this energy is 1.2 mb, approximately one-tenth of the total photoneutron cross section.[1] There is no evidence of any significant peak at 23.7 MeV, where both the $^{18}O(\gamma,p)$ and $^{18}O(\gamma,n_{total})$ have their greatest strengths; in this region the present data give a cross section of about 0.25 mb, to be compared with a total cross section of 18 mb.[1] Several small peaks appear superposed on the major resonance peak at 22.2, 24.6 and, possibly, at 29 MeV; none of these coincides with any of the peaks seen in Ref. 1.

The integrated cross section for the $^{18}O(\gamma,np+pn)$ reaction from threshold to 30 MeV, of 5.6 MeV mb, is to be compared with 170 MeV mb for the sum of the integrated cross sections for the (γ,p) (γ,n), and $(\gamma,2n)$ reactions up to 30 MeV (the individual values are 30, 90, and 50 MeV mb, respectively) (see Fig. 4 in Ref. 1).

DISCUSSION

This work has shown that the cross section for the $^{18}O(\gamma,pn+np)$ reactions is small. This observation is unaffected if one takes into consideration the (γ,d) channel, which also contributes to the present data. Subtracting it can only reduce the net $(\gamma,pn+np)$ cross section; the data of Bangert *et al.*[5] indicate that the integrated cross section for the (γ,d) reaction to 30 MeV is approximately 2 MeV mb.

There is no experimental evidence available on the relative proportions of the (γ,np) and (γ,pn) reactions. Assuming as one extreme that (γ,np) is zero, at 27.5 MeV the cross section of (γ,pn) will be 1.2 mb. Adding this to the (γ,p) cross section at this energy and subtracting it from the (γ,n) cross section, the $\sigma(\gamma,sp)/\sigma(\gamma,sn)$ ratio changes from the value given in Ref. 1, namely, 0.33, to 0.54. This change is not large enough to affect substantially the isospin assignments of Woodworth *et al.*[1] in this energy region.

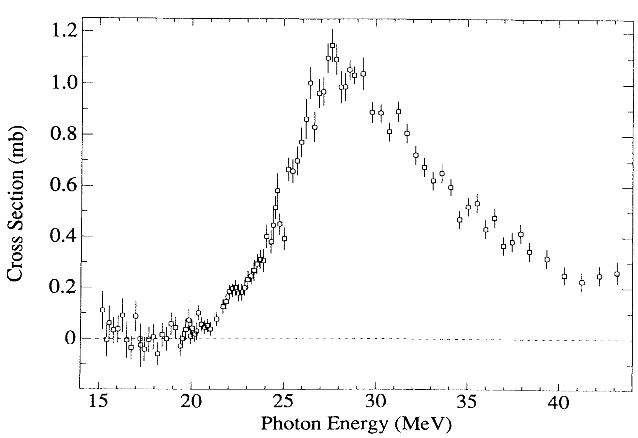

FIG. 1. Cross section for the reactions $^{18}O(\gamma,pn+np)$.

TABLE I. Integrated cross sections from threshold.

	to 30 MeV	to 43 MeV
$^{18}O(\gamma,pn+np)$		
$\int \sigma\, dE$	5.6±0.2 MeV mb	11.8±0.4 MeV mb
$\int (\sigma/E) dE$	0.21±0.01 mb	0.39±0.02 mb
$\int (\sigma/E^2) dE$	0.009 mb MeV^{-1}	0.014 mb MeV^{-1}
	to 30 MeV	to 41.8 MeV
$^{18}O(\gamma,\text{total})$[a]		
$\int \sigma\, dE$	170 MeV mb	243 MeV mb
$\int (\sigma/E) dE$	8.7 mb	10.7 mb
$\int (\sigma/E^2) dE$		0.55 mb MeV^{-1}

[a]from Table IV and Fig. 4 of Ref. 1.

At 23.7 MeV, where there is a prominent peak in the (γ,p) cross section, the (γ,pn) cross section would contribute only 10% or less to the (γ,sp) cross section, and its effect would be even less significant in the isospin determination. Assuming as the other extreme that (γ,pn) is zero, the values of the (γ,p) and (γ,sn) cross sections given in Ref. 1 are completely unaffected.

Therefore, we are able to confirm that the implicit assumption made in Ref. 1 in assigning the isospin distribution, that the $^{18}O(\gamma,pn+np)$ cross section is small, is correct.

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