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Isospin in ^{17}O(γ,n_0) reactions

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This Brief Report presents a reanalysis of the energy scale of published measurements by Johnson *et al.* and Jury *et al.* of the ^{17}O(γ,n_0) cross section which brings the two sets into good agreement. This leads directly to new $(T_<)$ isospin assignments for levels previously reported by Ajzenberg-Selove at energies of 14.4, 15.2, and 15.6 MeV.

Effects of isospin are most likely to be observed in low-Z nuclei, those in which Coulomb effects are smallest and in which the overlapping of nuclear levels is low. It has been well established that for photonuclear reactions, those target nuclei with isospin $T=\frac{1}{2}$ exhibit the largest proportion of excitations to $T_>$ $(T=\frac{3}{2})$ states. Therefore, a nucleus such as ^{17}O, with $T=\frac{1}{2}$, is of great interest in the study isospin effects involving transitions to and from excited $T_>$ states.

Johnson *et al.*[1] measured the (γ,n_0) cross section of ^{17}O from excitation energies of 5 MeV (the threshold is 4.1 MeV) to 33 MeV. A time-of-flight method was used which incorporated a 50-m flight path and a digital timing clock of resolution 10 ns. This resulted in an energy resolution of about ±100 keV (for photons of 11 MeV). The angle of measurement of the ground-state photoneutrons was 98°. Much structure was revealed with a total of 45 peaks being measured. Many of these were of energies corresponding to levels identified in other reactions.[2]

Jury *et al.*[3] carried out a multiangle measurement of the same (γ,n_0) cross section and suggested that, to agree with their (lower-resolution) (γ,n_0) work, the energy calibration of Ref. 1 should be changed by an amount ranging up to 200 keV at 25 MeV. However, Fig. 6 of Ref. 3 indicates a shift of the data of Johnson *et al.*[1] by about 700 keV at 21 MeV. One of the authors (J.W.J.) now considers the 200-keV shift quoted in Ref. 3 to be a misprint. The authors of Ref. 3 felt that the necessary change in the energy scale of the work of Ref. 1 was due to uncertainties in the calibration of that experiment.

In the experiment of Ref. 3 carried out at the Lawrence Livermore National Laboratory, a digital timing clock of resolution 0.125 ns was employed and was calibrated by secondary time standards of high precision. The calibration of the work of Johnson *et al.*[1] was carried out using the energies of the well-known neutron absorption resonances in a ^{12}C (graphite) absorber placed in the neutron flight path. While this calibration technique is more than adequate for neutron energies of up to about 10 MeV (the highest reliable narrow resonance in ^{12}C is at 6.2 MeV), extrapolation to higher neutron energies may lead to systematic energy calibration errors. In the case of ^{17}O, excitation energies near 25 MeV yield ground-state neutrons of energies of about 20 MeV. The work at Livermore[3] with its more precise clock was much less prone to such a calibration error. A much more recent tabulation of energy levels in ^{17}O (Ref. 4) makes possible further comparison between photonuclear and other reactions if the discrepancies of the (γ,n_0) energies can be resolved. This resolution has therefore been done and is reported here. As discussed below, the isospins of states excited in ^{17}O above the (γ,p) threshold at 13.8 MeV are of particular interest.

In the fitting procedure, 15 points (peaks and valleys) in the (γ,n_0) cross sections of Refs. 1 and 3 were identified. Several of these were in turn identified with major levels listed in Ref. 4. The energy differences between the same points of identification given in Refs. 1 and 3 were measured. We have determined that these differences, when converted into neutron flight times, are well fitted by the linear relation in time:

$$t_c=1.032\,678t_0+51.4811\ \text{ns}\ ,$$

where t_c is the corrected neutron time of flight of Ref. 1 and t_0 is the original neutron time of flight of Ref. 1.

This observation supports the suggestion[3] that the time-of-flight calibration of the work of Ref. 1 requires correction above excitation energies of about 10 MeV. The corrected energies for the peaks observed by Johnson *et al.*[1] are presented in Table I. These values may be used for comparison with data from other measurements on the same or other nuclear reaction channels.

As is well known, $E1$ transitions from states of isospin T_0 may lead to excited states of T_0 or of T_0+1. Photoneutron reactions lead to a nucleus which in its ground state has isospin $T_0-\frac{1}{2}$. Thus the ground state of ^{17}O has $T=\frac{1}{2}$, while that of ^{16}O is $T=0$; the lowest $T=1$ state of ^{16}O is at 12.796 in ^{16}O, corresponding to an excitation energy of ^{17}O of 16.9 MeV. Isospin selection rules in photoneutron reactions, which will result in $\Delta T=\frac{1}{2}$ in the neutron emission phase of the reaction, "forbid" transitions from $T_>$ (T_0+1) states of the excited nucleus to $T_<$ $(T_0-\frac{1}{2})$ states of the daughter nucleus and thus for-

TABLE I. Energies of levels in ^{17}O.

Reference 1 Peak number	Reference 1 Energy (MeV)	Reference 1 Energy modified (MeV)	Reference 3 (MeV)	Reference 4 (MeV)	Reference 4 $J^{\pi};T$
19	8.98	8.9		8.9	
27	11.39	11.30	11.4	11.24	$\frac{5}{2};\frac{1}{2}$
28	11.89	11.75	11.7	11.75	
29	12.53	12.30		12.27	
30	12.83	12.66		12.67	
	13.06	12.87	12.9	12.81	
	13.30	13.10	13.1	13.08	
	13.69	13.47		13.48	
	14.65	14.38	14.4	14.3	$;\frac{3}{2}$
35	15.56	15.24	15.2	15.2	$\frac{3}{2};\frac{3}{2}$
	15.95	15.60	15.6	15.6	
	17.00	16.60	16.5	16.6	$(\frac{1}{2},\frac{3}{2});\frac{3}{2}$
	17.67	17.2	17.1		
	18.25	17.78		17.9	
40	19.0	18.5	18.4		
	19.7	19.1	19.2		
	21.2	20.5		20.4	$(\frac{5}{2},\frac{7}{2});$
	21.7	21.0	21.0	21.05	$\frac{3}{2};$
	25.7	24.7		24.4	
45	26.9	25.6			

bid transitions from $T_>$ states to the ground state of the daughter.

If the only alternative to a "forbidden" (γ,n) transition is gamma deexcitation of the excited state, neutron emission will, however, take place—a well-known example of this is the 15.1-MeV $J^{\pi}=\frac{3}{2}$, $T=\frac{3}{2}$ state in ^{13}C, from which neutron emission takes place to both the 0^+ ground state of ^{12}C and to the 1^- first excited state at 4.4 MeV (both of these states have $T=0$). This is generally ascribed to isospin mixing of the 15.1-MeV level. It should be noted that 15.1 MeV is below the threshold (17.5 MeV) for proton or any other particle emission, and so there is no other particle channel available. But above the (γ,p) threshold, photoneutron emission to the ground state should be not possible from $T_>$ states.

Table I also gives the levels listed in Ref. 4 which best fit the modified energies. In addition to the prominent peak at 8.9 MeV, there are 15 such fits in the energy region from 11.3 to 26 MeV. It may be noted that in this region there are 61 levels listed in Ref. 4 and 19 levels observed in the work of Ref. 1.

Of the 16 fits, 8 are below the (γ,p) threshold (and there is only one J^{π}, T assignment made in Ref. 4). Of the 8 fits above this threshold, only 3 have isospin assignments. But all of these are stated to be $T_>$ levels, which should not be able to decay to the ground state of ^{16}O and so should not be seen in the ^{17}O(γ,n_0) cross section.

However, a footnote to the relevant table in Ref. 4 states that "J^{π} assignments (were made) by comparison with ^{17}N states presumed to be analogs: then $T=\frac{3}{2}$ (Hi 81a)." The evidence that states at 14.4, 15.2, and 15.6 MeV decay to the ground state of ^{16}O leads to the conclusion that these states are in fact $T=\frac{1}{2}$.

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