ENERGY SPECTRUM OF PHOTONEUTRONS FROM THE REACTION $O^{16}(\gamma,n)O^{15}$

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Measurements of the energy spectrum of photoneutrons from the reaction $O^{16}(\gamma,n)O^{15}$ have been made with a nanosecond time-of-flight system based on the Harwell Electron Linear Accelerator. The accelerator provides 400 pulses per second each of ≤ 10 nanoseconds duration, at a peak current of ~0.1 ampere and an energy of ~31 Mev. Bremsstrahlung produced in a thick (0.006 in.) tantalum foil irradiates a water target. The resulting photoneutrons are detected in a 5-in. diameter ×3-in. thick liquid scintillator at the end of a 20-meter flight tube, placed at 70° to the axis of the photon beam. Neutron flight times are measured with a time expander[1] and digital tape recording system[2] which provides 2000 channels, each of 1 nanosecond duration; a neutron energy resolution of 40 kev is obtained at 2 Mev.

The doubly magic nucleus O^{16} is of particular theoretical interest since it is amenable to shell-model calculations.[3,4] Moreover, it is well suited to this type of experiment; although a continuous bremsstrahlung spectrum is used, O^{16} absorbs photons only into discrete energy levels ~1 Mev apart. The interpretation of the data is further simplified by the fact that states in the daughter nucleus O^{15} are widely separated. The neutron energy spectrum may therefore be related to the photon excitation function without recourse to "photon difference" analysis.

Previous measurements of photoneutron spectra in the same energy region, but without relatively low resolution, have been reported by Milone and Rubbino,[5] who used emulsion techniques. A time-of-flight study by Bertozzi and Demos[6] was limited to an examination of the lowest neutron-emitting state at 17.3 Mev. Other measurements of relevance to the present work are the detailed study of the radiative capture of protons by N^{15},[7] and proton spectra from the reaction $O^{16}(e,e'p)N^{15}$.[6] "Breaks" in the photoneutron yield curve have also been interpreted[8,9] as energy levels in O^{16}.

The observed neutron spectrum from $O^{16}(\gamma,n)O^{15}$, in the range 2-13 Mev for $E_\gamma(\max) \sim 31$ Mev, is shown in Fig. 1. Neutron groups indicated by the solid line have been confirmed in an independent measurement. The energies of levels are converted to "excitation" in O^{16}, assuming that all neutrons are making transitions to the ground state

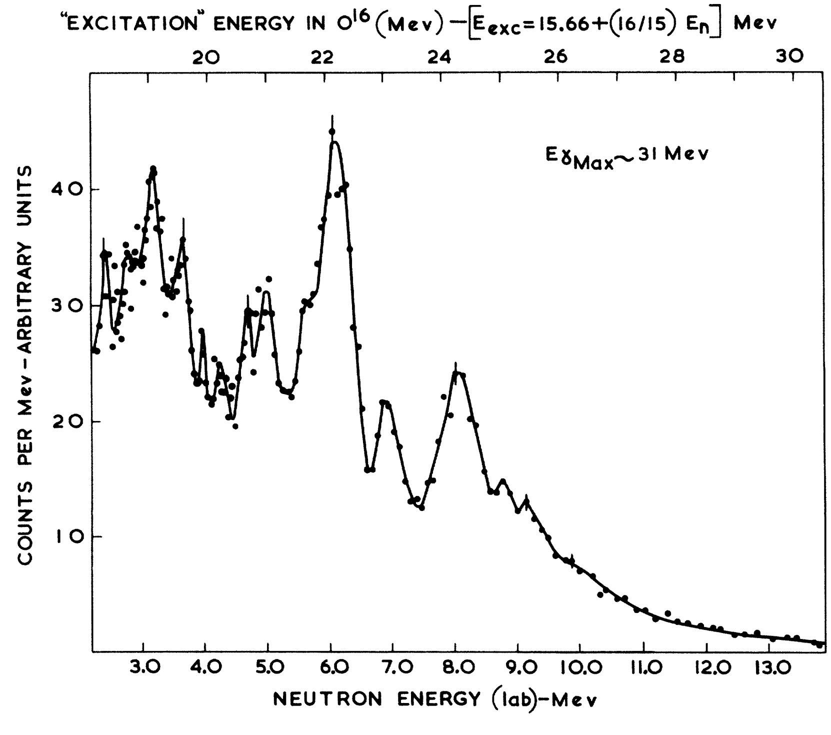

FIG. 1. The observed spectrum of photoneutrons from the reaction $O^{16}(\gamma,n)O^{15}$ when irradiated with bremsstrahlung of maximum energy 31 Mev.

Table I. Energy levels in O^{16}.[a]

E_n (Mev)	E_{exc} (Mev)	E_{exc}' (Mev)
1.54	17.3	17.3
2.43	18.25	
2.76	18.70	
3.23	19.1	19.1
3.70	19.6	19.6
3.96	19.9	
4.27	20.2	
4.7	20.7	21.0
5.0	21.0	
5.7	21.7	21.8(?)
6.1	22.2	22.2
6.9	23.0	23.1
8.1	24.3	24.3
8.8	25.0	25.2
9.1	25.4	

[a] E_n = observed neutron energy (Mev) from $O^{16}(\gamma,n)O^{15}$; E_{exc} = "excitation" in O^{16} (Mev) $[E_{exc} = 15.66 + (16/15)E_n]$; E_{exc}' = excitation in O^{16} (Mev) (reference 7) from $N^{15}(p,\gamma_0)O^{16}$.

of O^{15}; these are presented in Table I. The results[7] of ground-state γ-ray transitions from $N^{15}(p,\gamma_0)O^{16}$ are listed for comparison. Levels at excitations of 19.1, 19.6, 20.7, 21.0, 21.7, 22.2, 23.0, 24.3, 25.0, and ~25.4 Mev occur in both sets of data [and also in $O^{16}(e,e'p)N^{15}$][8] and are thereby definitely established as ground-state transitions. The remaining fine structure, observed at neutron energies of 2.43, 2.76, 3.96, and 4.27 Mev, may therefore be attributed to neutrons going to excited states of O^{15}.

The relative $O^{16}(\gamma,n)O^{15}$ cross section is presented in Fig. 2. This curve was obtained by correcting the data shown in Fig. 1 for the variation with energy of the photon yield from a thick target[10] and also for the variation of the detector efficiency with neutron energy. The curve departs from the true relative $O^{16}(\gamma,n)$ cross section for excitation energies $\lesssim 21$ Mev. This is due to the inclusion of both excited state transitions and an unknown, energy-dependent background from the water target.

The present measurements will be extended to cover a range of maximum bremsstrahlung energies, and to determine the angular distributions of the neutron groups. Detailed examination of backgrounds and of the multiple scattering of neutrons within the target will also be essential to a determination of the $O^{16}(\gamma,n)$ cross section as a function of energy.

We wish to acknowledge the invaluable assistance of Mr. J. K. Whittaker and Miss E. M. Bowey. The time expander was loaned to us by Dr. P. R. Orman and contributed greatly to the performance of the experiment. Finally, we are indebted to Dr. E. R. Rae for his continual encouragement and advice.

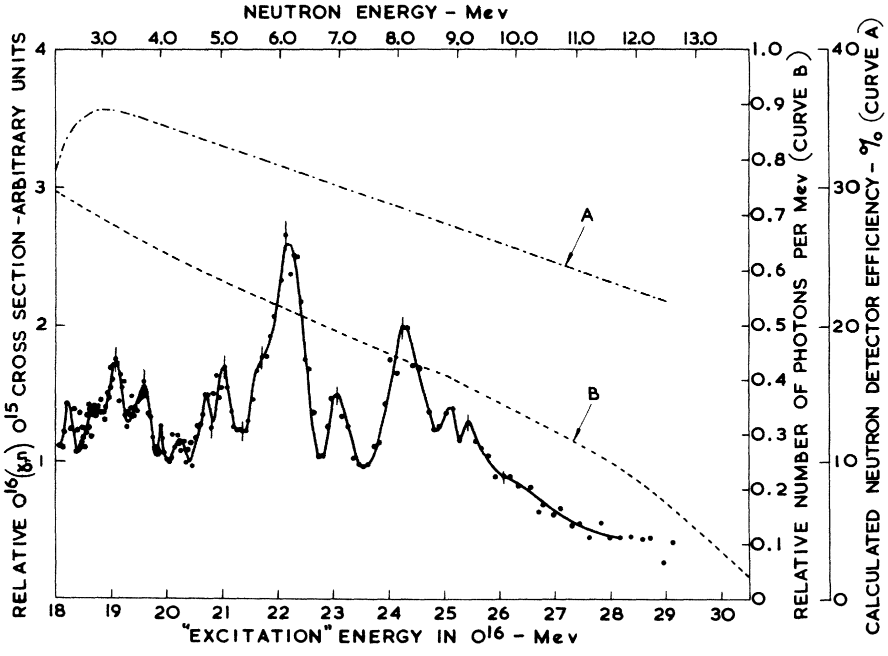

FIG. 2. The relative $O^{16}(\gamma,n)O^{15}$ cross section obtained from the data in Fig. 1. Corrections have been made for the calculation efficiency of the neutron detector (Curve A), and for the relative number of photons per Mev obtained from a thick-target calculation[10] (Curve B). The curve departs from the true relative (γ,n) cross section for excitation energies $\lesssim 21$ Mev. This is due to the inclusion of both excited-state transitions and an unknown, energy-dependent background from the water target.

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BINDING ENERGY OF THE TRITON*

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The first purpose of this Letter is to correct an erroneous result published last year,[1] and the second is to give new results for potentials of considerable interest from the meson-theoretical point of view.

In recoding the calculation of the binding energy of the triton, and of He^3, for the IBM 7090, we discovered a coding mistake in the IBM-704 code, which had evaded our previous checks. After correcting this mistake, we have rechecked the whole code in a number of ways, with satisfactory results. Nevertheless, we would greatly welcome a completely independent triton calculation by another group. As far as we know, this is the only way to be really sure that a code of this magnitude is free of mistakes.

This correction alters the results given in reference 1 for the Gammel-Brueckner (GB) potential.[2] The corrected result is $E(\mathrm{H}^3) \leq -5.7$ Mev, which is now higher than the known ground-state energy of the triton, $E(\mathrm{H}^3) = -8.492$ Mev. Since a better trial function than ours would lower the theoretical energy, there is no longer an immediate contradiction. We do not know whether the theoretical energy can be pushed down to -8.492 Mev, but rather doubt it (see later).

With the faster speed of the IBM 7090 it proved possible to test a number of different potentials so as to get a clearer over-all picture. In addition to the GB potential, we have calculated with the following:

(1) The three potentials used by Feshbach and Pease[3] (FP), but not their two interpolated potentials. The FP potentials have Yukawa well shape and zero core radius. They fit all low-energy data, but do not fit modern high-energy data.

(2) The first of the three "Yukawa" potentials listed in Table II, p. 141, of Hu and Massey[4] (HM). This potential is similar to the FP potentials, but fails to fit the triplet effective range, which is about 50% too high. The other two "Yukawa" potentials of HM have even longer ranges. However, this potential has been used in a triton calculation by Hu and Hsu[5] and thus provides a useful comparison.

(3) The latest potential of Hamada and Johnston[6] (HJ).

(4) The preliminary potential of the Yale group[7] (Yale). These last two potentials are very similar to each other, and of considerable theoretical interest, since they have the one-pion exchange tail, are in qualitative agreement with meson-theoretical predictions in the intermediate region of distances, and give reasonable fits to all the available data on the nuclear two-body systems.

Our results for all these potentials are given in Table I, which we shall now discuss:

For the FP potentials, our energies are system-