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Short-Range, High-Momentum Effects in the Reaction $^{16}O(\gamma, p_0)$ for E_γ=100–300 MeV

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The $^{16}O(\gamma,p_0)$ cross section has been measured for a series of photon energies between 100 and 300 MeV at proton angles of 45°, 90°, and 135°. Above 250 MeV, the results exceed simple shell-model predictions by several orders of magnitude. The data are compared with a calculation which involves Δ excitation in an intermediate state.

The (γ,p) reaction at energies well above the giant dipole resonance has long been recognized as a potential source of information about short-range effects in nuclei, on account of its sensitivity to high-momentum components in nucleon wave functions. If the experimental (γ,p) cross section is found to exceed that predicted by a shell-model calculation assuming a single-step knock-out mechanism, this could be taken as evidence that short-range effects are operating to increase the high-momentum amplitudes above those of the simple shell-model wave functions. Precise (γ,p) measurements[1,2] on several nuclei are now available for photon energies up to 100 MeV. The comparison of recent theoretical calculations with these data does not in fact yield any conclusive evidence that short-range effects are important. A consistent explanation of a wide range of data has been achieved[3] by a model which introduces a residual interaction with the range of the one-pion exchange force, thus increasing the cross section predicted by the single-step proton knock-out mechanism. However, the need for this medium-range residual interaction can be largely removed by an alternative and perhaps more reasonable choice[2] of the potential-well parameters which determine the single-nucleon wave functions. The inadequacy of the single-step mechanism may nonetheless become evident at higher photon energies, which sample higher initial proton momenta. Accordingly, the earlier investigation of the reaction $^{16}O(\gamma,p_0)$ has been extended to 300 MeV. The results are reported below.

The experimental technique employed in the present work is similar to that used previously,[2] in which the spectrum of protons emitted from a beryllium oxide target bombarded by a bremsstrahlung beam is measured. Because of the relatively high excitation energies ($\approx$ 5 MeV) of the lowest excited states of the residual nucleus ^{15}N, the cross section for the (γ,p) reaction leaving ^{15}N in its ground state can be obtained directly from the highest 5 MeV of the bremsstrahlung-produced proton spectrum.[4]

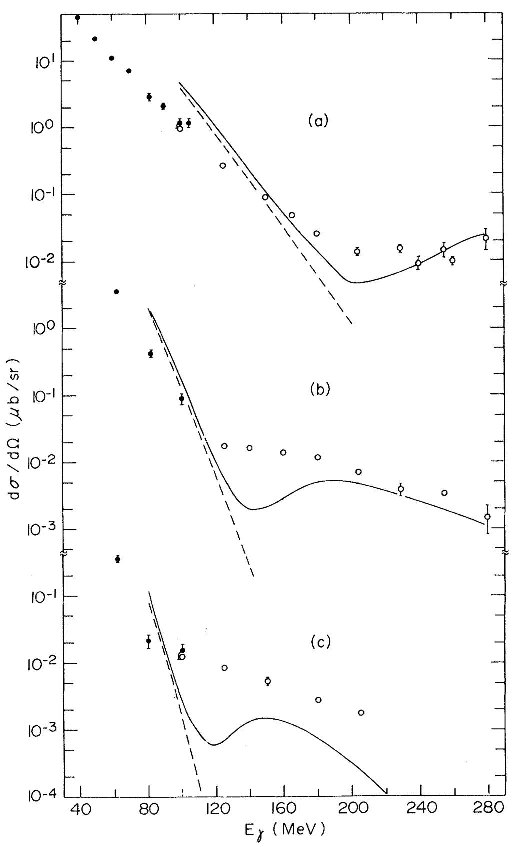

FIG. 1. Differential cross section in the laboratory system for the reaction $^{16}O(\gamma,p_0)^{15}N$ as a function of photon energy at proton angles (a) 45°, (b) 90°, and (c) 135°. Solid circles are used for the data of Ref. 2, open circles for the present results. Only statistical errors are shown. The curves represent the theoretical predictions of Ref. 5, as discussed in the text: dashed curve, single-step process only; solid curve, one-step plus two-step process (see Fig. 2).

The 400-MeV electron linear accelerator and the 900-MeV/c magnetic spectrometer at the Massachusetts Institute of Technology Bates Laboratory were used to make these measurements. A multiwire drift chamber determined the position in the spectrometer focal plane and thus the momentum of the protons, and a backup counter telescope consisting of three NE110 plastic scintillators served for particle identification and background reduction. The data were analyzed by calculating the photoproton spectrum shape assuming a theoretical bremsstrahlung spectrum and taking into account the energy loss and straggling of the protons in the beryllium oxide target. The calculated shape was then fitted to the measured spectrum to determine the cross section. A complete description of the experimental system will be published separately.

The present results for the $^{16}O(\gamma,p_0)$ reaction cross section populating the ground state of the residual ^{15}N nucleus are presented in Fig. 1, together with the earlier data[2] below 100 MeV and theoretical calculations by Nixon, Londergan, and Walker.[5] This single-step (shell-model) prediction, calculated by evaluating the diagram shown in Fig. 2(a), is not claimed to be very accurate since, for simplicity, harmonic-oscillator wave functions are used and the distortion of the outgoing proton wave by the final-state potential is ignored. However, its general trend, viz. a very rapid fall of the cross section with increasing photon energy, is a common feature of all calculations which include only single-step photoejection from a simple shell-model orbit. It is immediately clear from Fig. 1 that the ex-

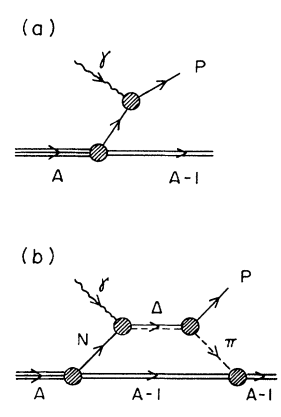

FIG. 2. The (γ,p) processes considered in the calculation of Ref. 5: (a) one-step, (b) two-step process.

perimental data deviate strongly from this trend in the 100–200-MeV region. Above 250 MeV the measured cross sections are seen to exceed the single-step predictions by several orders of magnitude. This discrepancy is far beyond the range of theoretical uncertainty in the single-step cross section ensuing from reasonable variations in the potential well parameters. It provides strong evidence for the involvement of more than one nucleon in the photon absorption mechanism and, hence, the possibility of discovering the details of the interaction processes which provide the necessary additional high-momentum components.

Two such processes have already been investigated theoretically in a qualitative way and are shown to be capable of enhancing the (γ,p) cross section above 100 MeV, viz. short-range correlations[6] due to the repulsive core of the internucleon force and a two-step mechanism[5] in which the $\Delta(1232)$ nucleon isobar is excited in an intermediate state [see Fig. 2(b)]. The preliminary results of this latter calculation are shown in Fig. 1. It is evident that the Δ excitation mechanism can make a major contribution in the 100–300-MeV photon energy region.

Experimental data of reasonable accuracy and extent are now available over the kinematic range in which one might hope to observe short-range effects in the (γ,p) reaction. Because of the apparent importance of virtual Δ excitation, however, a more careful theoretical treatment of this and other processes[3,5,6] is necessary before additional constraints on the internucleon force at small distances may be obtained.

We wish to thank Dr. Londergan for sending us his calculations prior to publication.

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Nuclear Sp(3,R) Model

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A microscopic model is presented which provides a practical means for selecting the states necessary for the development of nuclear collective rotational and quadrupole vibrational motions in a shell-model calculation. The model is based on the noncompact Sp(3,$\mathbb{R}$) algebra and is a natural generalization of Elliott's SU(3) model to include many major shells.

In spite of the enormous successes of the nuclear rotational model, a microscopic theory of rotational states has proved extraordinarily elusive. One of the problems is to learn how to recognize rotational states. In a recent paper[1] we proposed a criterion for designating a state rotational based on the concept of a *well-defined intrinsic shape,* measurable with *shape observables.*

The essential idea follows a suggestion of Baranger.[2] One observes that each set of nucleon coordinates defines a traceless quadrupole mass tensor Q and hence a set of principal axes and principal values. Thus the nuclear density $|\psi(\vec{r}_1, \ldots, \vec{r}_A)|^2$ defines a probability distribution $P(\lambda_1, \lambda_2, \lambda_3)$ for the principal values of the quadrupole mass tensor. The criterion for a state to be rotational is then that the width of the distribution in λ_k should be small compared to its mean value It was shown that $\hat{\lambda}_k$ can be expressed as a func-