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Anomalously low cross section in $^{13}C(\gamma,\pi^-)^{13}N_{g.s.}$

John J. LeRose,* K. Min, D. Rowley,† B. O. Sapp, P. Stoler, E. J. Winhold, and P. F. Yergin
Department of Physics, Rennsselaer Polytechnic Institute, Troy, New York 12181

A. M. Bernstein, K. I. Blomqvist, S. Dytman, G. Franklin,‡ and M. Pauli§
Physics Department and Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

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Differential cross sections for the reaction $^{13}C(\gamma,\pi^-)^{13}N_{g.s.}$ were measured at 90° (lab) for three pion energies: 17, 29, and 42 MeV. The experimental cross sections are anomalously low compared with distorted wave impulse approximation calculations and contrary to the predicted enhancement due to pion condensation precursor effect.

[NUCLEAR REACTIONS $^{13}C(\gamma,\pi^-)^{13}N_{g.s.}$; $E_\pi = 17$, 29, and 42 MeV; measured $\sigma(E_\pi, \theta=90°)$; compared with DWIA calculations.]

In this Communication we report on an anomalously small cross section we observed in the photoproduction of negative pions in the reaction $^{13}C(\gamma,\pi^-)^{13}N$ (ground state). We also point out the implication of this result to the pion precursor effect. Our experimental cross sections at 90° (lab) and three different pion energies (17, 29, and 42 MeV) are as much as an order of magnitude lower than those predicted by standard distorted wave impulse approximation (DWIA) calculations. Previously published work[1] includes about 20 measurements of either total or differential $(\gamma,\pi^\pm)$ cross sections to several final nuclear states in nuclei with $A \leq 16$. In general there is reasonable agreement between experiment and theory with factor-of-2 discrepancies occurring in a few cases. This makes $^{13}C(\gamma,\pi^-)^{13}N_{g.s.}$ the only case on record of such a major discrepancy between theory and experiment.

Most theoretical calculations[1] of photopion cross sections are based on DWIA, use one of several versions of production amplitude for the elementary process $\gamma + N \rightarrow N + \pi^\pm$, and describe the pion distortion effect by optical potentials constrained to fit pion-nucleus scattering and pionic atom data. The nuclear structure inputs to the calculations are usually tested against or derived from inelastic electron scattering data for the analogous $\Delta T_z = 0$ transitions, either using shell-model wave functions or Helm model parameters.

The reaction $^{13}C(\gamma,\pi^-)^{13}N_{g.s.}$ involves a mirror transition between $(J^\pi,T) = (\frac{1}{2}^-,\frac{1}{2})$ nuclear states and the relevant nuclear structure information should be reasonably well in hand. Experimentally this reaction is a favorable case to study because the nuclear final state in question, namely, the ground state of ^{13}N, can be clearly separated from the first excited state at 2.37 MeV.

The electron beam from the Bates linac passed through flux and position monitors and traversed a tungsten bremsstrahlung radiator. The mixed electron-photon beam impinged on a ^{13}C target (pressed powder disk of intrinsic thickness of about 150 mg/cm^2, isotopically enriched to 99%). The pions emitted at 90° were momentum analyzed by a quadrupole-dipole magnetic spectrometer system.[2] Data were taken for three pion energy groups around 17, 29, and 42 MeV. As an example, the pion spectra near 42 MeV are shown in Fig. 1. Cross sections were extracted by fitting the pion yield curve with the photon spectrum and a flat background as indicated by the solid line. The photon spectrum reflects the shapes of the real bremsstrahlung[3] from radiator and target as well as a virtual spectrum[4] for electroproduction with an experimentally determined correction factor.[5] Electron and pion energy losses as well as the system energy resolution were accounted for in the photon spectrum. After correcting for the pion decay the absolute cross sections were determined relative to that of the $p(\gamma,\pi^+)n$ reaction as tabulated by Genzel *et al.*[6] The arrows in Fig. 1 indicate the threshold energies for the excitation of the ground state and levels at 2.37, 3.5, and 7.4 MeV, respectively, in the residual nucleus ^{13}N. The energy scale was carefully determined by observing the pion spectra from two other reactions in the same run, $^{10}B(\gamma,\pi^+)^{10}Be_{g.s.}$ and $^{11}B(\gamma,\pi^-)^{11}C_{g.s.}$, both of which have threshold energies very close to the $^{13}C(\gamma,\pi^-)^{13}N_{g.s.}$ threshold.

The most noteworthy feature of our result is the anomalously small pion yield leading to the ground state and the first excited state at 2.37 MeV in ^{13}N. The lack of pions to these two states is in conspicuous contrast to the strong excitation of the 3.5 MeV state.

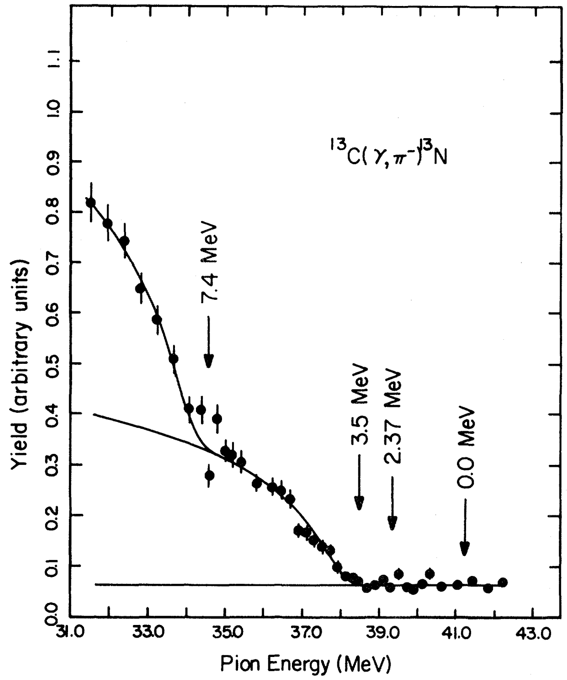

FIG. 1. Pion yield as a function of pion energy in $^{13}C(\gamma,\pi^-)^{13}N$. The threshold energies for exciting the residual nuclear levels are indicated by arrows. The solid line is the least-squares fitted yield curve, using flat background plus calculated photon spectrum (see text), from which the cross section of Fig. 2 is obtained.

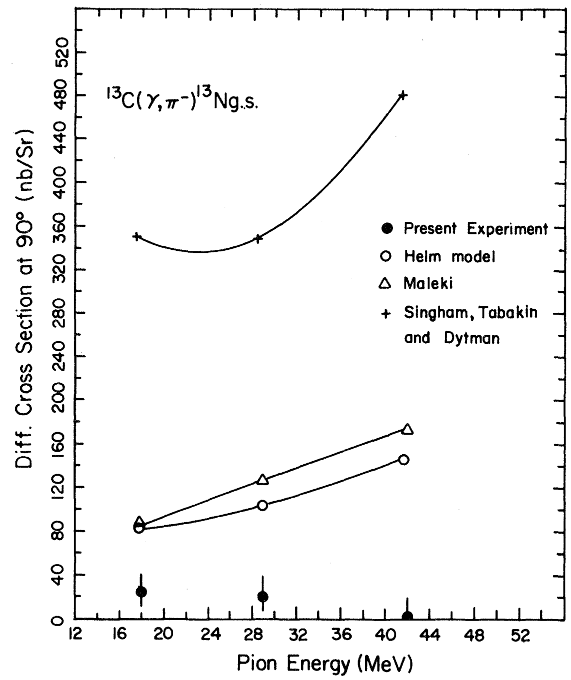

FIG. 2. Comparison of experimental cross sections with theoretical calculations. (●) experiment, (○) Helm model, (△) Maleki, and (+) Singham, Tabakin, and Dytman. See text.

In Fig. 2, the measured ground state cross sections are compared with three independent DWIA calculations. The dominant contribution to the errors indicated arises from the uncertainty of determining the background level. The calculations of Singham, Tabakin, and Dytman[7] (STD) use Blomqvist-Laget amplitudes,[8] Cohen-Kurath wave functions,[9] and the optical potential of Stricker, McManus, and Carr.[10] Maleki's calculations[11] use the elementary amplitude of Chew, Goldberger, Low, and Nambu,[12] Cohen-Kurath wave functions, and a local Laplacian optical potential as given by Lee and McManus.[13] In the Helm model calculations we used the computer code of Nagl and Überall[14] with the parameters obtained by fitting to the $M1$ elastic electron scattering data.[15] The source of discrepancy among the different theoretical calculations in Fig. 2 is not clearly understood at present. However, our experimental cross section at 42 MeV is lower by almost an order of magnitude than even the lowest theoretical estimate.

A recent theoretical study by Reynaud and Tabakin[16] on the (π,γ) process reports an interesting destructive interference which occurs specifically for this and other mirror transition involving p-shell nuclei. The destructive interference occurs between the pion-pole term and the usually dominant $\vec{\sigma}\cdot\vec{\epsilon}$ term in the elementary amplitude. This interference minimum is not significantly affected by the remaining Born terms in the amplitude, which make a small contribution to the cross section for the present experimental conditions. However, the Δ resonance term plays an important role. It fills in the interference minimum to give the STD theoretical results shown in Fig. 2.

At present there are no available theoretical calculations of the $^{13}C(\gamma,\pi^-)$ cross sections to the 2.37 MeV state. However, it is to be noted that for electron scattering to the ground and 3.09 MeV states in ^{13}C (the latter is the analog to the 2.37 MeV state in ^{13}N), the shell model analysis[17] indicates that spin magnetization [which is usually the major factor in (γ,π) reactions] contributes about equally to the transverse form factors for the two transitions.

We point out that the large suppression of the cross sections observed in the present experiment is in the opposite direction from the enhancement predicted[18] on the basis of the pion condensation precursor effect. Recent measurements on $^{12}C(p,p')$ reaction[19] also fail to observe the enhancement of cross sections due to pion condensation precursors.

The plane wave calculations by Delorme[18] of the reaction $^{13}C(\pi^+,\gamma)^{13}N_{g.s.}$ ($T_\pi=70$ MeV) show that the precursor effect enhances the cross section at $\theta\sim70-90°$ by a factor of about 5 at the momentum transfer $q \sim 1.2\ \mathrm{fm}^{-1}$. The present work on the inverse photopion reaction at 90° at a comparable $q \sim 1.1\ \mathrm{fm}^{-1}$, however, yields an experimental cross section which is an order of magnitude smaller than the conventional DWIA calculations without the inclusion of any precursor effect.

In conclusion the anomalously small cross section we observe here is hard to reconcile with the known predictive power of the present DWIA theory of photopion reactions. Whether this anomaly is particular to the kinematic conditions of the present experiment or whether it would persist under other dynamical conditions remains a question for further investigation. The preliminary results[20] of an on-going experiment on in-flight pion capture appear to be qualitatively consistent with the present results.

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*Currently at Department of Physics, Louisiana State University, Baton Rouge, La. 70803. This paper is taken in part from a Ph.D. thesis submitted to the Department of Physics at Rensselaer Polytechnic Institute.

†Currently at Lawrence Livermore National Laboratory, P. O. Box 808, Livermore, Cal. 94550.

‡Currently at Department of Physics, Carnegie-Mellon University, Pittsburgh, Pa. 15213.

§Currently at General Research Corportation, 7655 Old Springhouse Rd., Westgate Research Park, McLean, Va. 22102.

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