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Reaction $^9Be(\gamma,\pi^+)^9Li$ (g.s.) at $\theta_\pi = 90°$

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Differential cross sections at $\theta_\pi = 90°$ (lab) for $^9Be(\gamma,\pi^+)^9Li$(g.s.) at $T_\pi = 17$, 29, and 42 MeV were measured. Results are compared to other data and to Helm model calculations.

[NUCLEAR REACTIONS $^9Be(\gamma,\pi^+)^9Li$(g.s.), $E_\gamma = 175$, 187, and 200 MeV; measured $\sigma(\theta_\pi = 90°)$, DWIA Helm model calculations.]

During the past few years, we have made measurements of charged pion photoproduction near threshold from several *lp*-shell nuclei[1-3] such as ^{10}B, ^{12}C, and ^{13}C. The agreement in such cases between experiment and theoretical calculations based on the distorted wave impulse approximation (DWIA) is somewhat mixed, though, in general, absolute cross section values agree to better than a factor of 2. Moreover, measured (γ,π) angular distribution shapes, which are multipole dependent, are in most cases well reproduced by theory.[4] We report here differential cross section measurements at $\theta_\pi = 90°$ (lab) for positive charged pion photoproduction on ^9Be leading to the ground state of ^9Li. We compare the data with Helm model calculations utilizing inelastic electron scattering data to the analog state in ^9Be.

In the experiment, an electron beam from the Bates Linac passed through a bremsstrahlung radiator which was located about 5 cm upstream from the target. The mixed photon-electron beam then irradiated the ^9Be target. Solid wafer-shaped ^9Be targets with intrinsic thickness about 140 and 240 mg/cm^2 were used. Pions emitted at 90° were momentum analyzed and detected using a quadrupole-dipole magnetic spectrometer with multiwire proportional counter in the focal plane, followed by an array of three scintillation counters and one Cerenkov counter to select pions from background electrons. The experimental details are described elsewhere.[5] The overall energy resolution of the system is about 600 keV. This is ample to clearly resolve the ground state transition from the transition to the first excited state of ^9Li at 2.69 MeV.

Pion spectra were obtained at pion energies of about 17, 29, and 42 MeV, corresponding to electron energies of about 175, 187, and 200 MeV, respectively. To check the relative channel-by-channel efficiency of the wire chamber, data were also taken for each pion energy with a higher electron beam energy (230, 280, and 245 MeV, respectively), where the pion spectrum was relatively smooth and flat. The wire chamber spectrum for the ground state transition was then divided by this flat spectrum to remove the effects of channel-by-channel efficiency variations. The (γ,π^+) cross section was extracted by fitting each normalized spectrum with an effective photon spectrum.[6] The effective photon spectrum included the bremsstrahlung photon spectrum from the radiator and target using a code of Matthews and Owens,[7] and a Dalitz and Yennie virtual photon spectrum[8] multiplied by an experimentally determined correction factor of 1.25.[9]

In obtaining the cross sections, pion decay was taken into account, but the small muon contamination of the pion spectra was neglected. Absolute cross sections were obtained by calibrating the apparatus with the known $^1H(\gamma,\pi^+)n$ cross section.[10] The differential cross sections for $^9Be(\gamma,\pi^+)^9Li$(g.s.) at $\theta_\pi = 90°$ for $T_\pi = 17$, 29, and 42 MeV are plotted in Fig. 1. The error bars shown are statistical only. Systematic uncertainties are estimated to be about 15%. The 90° point measured by Yamazaki *et al.*[11] at $T_\pi = 40$ MeV is also shown in Fig. 1. The agreement between their results and the present data is good.

We have made distorted wave impulse approximation (DWIA) calculations for this reaction, using the Helm model computer code of Nagl and Überall (NU). This code uses the nuclear form factor from Helm model fits[12] to the analog inelastic electron scattering data. In making these fits for magnetic transitions, it is assumed that the convection current contribution is small and can be neglected. In the (γ,π) calculation, the full elementary photoproduction amplitude of Berends *et al.*[13] is employed. A second order optical potential[14] is used to describe pion distortion effects. The sensitivity of the calcu-

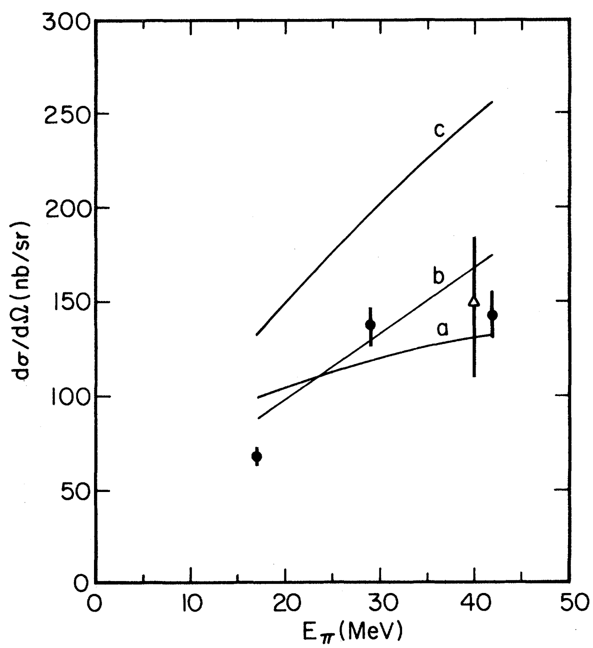

FIG. 1. Differential cross sections for ^{9}Be(γ, π^+) ^{9}Li(g.s.) at $\theta_\pi = 90°$ (lab). Data point denoted by (Δ) is from Ref. 11. Solid curves are Helm model calculations using a code of Nagl and Überall assuming: (a) pure $M1$; (b) $M1+E2$ admixture; (c) $M1+M3$ admixture.

lated (γ, π) cross section values to reasonable variations of the pion optical parameters should be at about the 20% level, according to several recent contributions.[4,15,16]

While the transition to the 14.39 MeV $J^\pi = \frac{3}{2}^-$ state in ^{9}Be (analog state to the ^{9}Li ground state) in the inelastic electron scattering could be an admixture of $M1$, $E2$, and $M3$ multipoles, Bergstrom *et al.*[17] found that a pure $M1$ transition gives a satisfactory description of their low q data ($q \leq 1.10$ fm^{-1}) in the Helm model fit. Recently, new electron scattering data from Bates, covering a higher q range, have been obtained.[18] However, it is still impossible to unravel the contributing multipolarities unambiguously. We have tried the following options to fit the (e,e') data with the Helm model: (1) pure $M1$ transition; (2) admixture of $M1$ and $E2$; (3) admixture of $M1$ and $M3$. These fits are shown in Fig. 2. All three options give about equally good fits. Other options such as pure $E2$ or $M3$ do not give good fits. We felt that it was not useful to try fitting an $M1+E2+M3$ admixture because of the many parameters involved.

The three sets of parameters corresponding to these Helm fits were then applied to the (γ, π) reaction using the NU code. The results are shown in Fig. 1.

While both pure $M1$ and $M1+E2$ give satisfactory fits to the present data, the $M1+M3$ calculation is too high by about a factor of 2. A pure $M1$ transi-

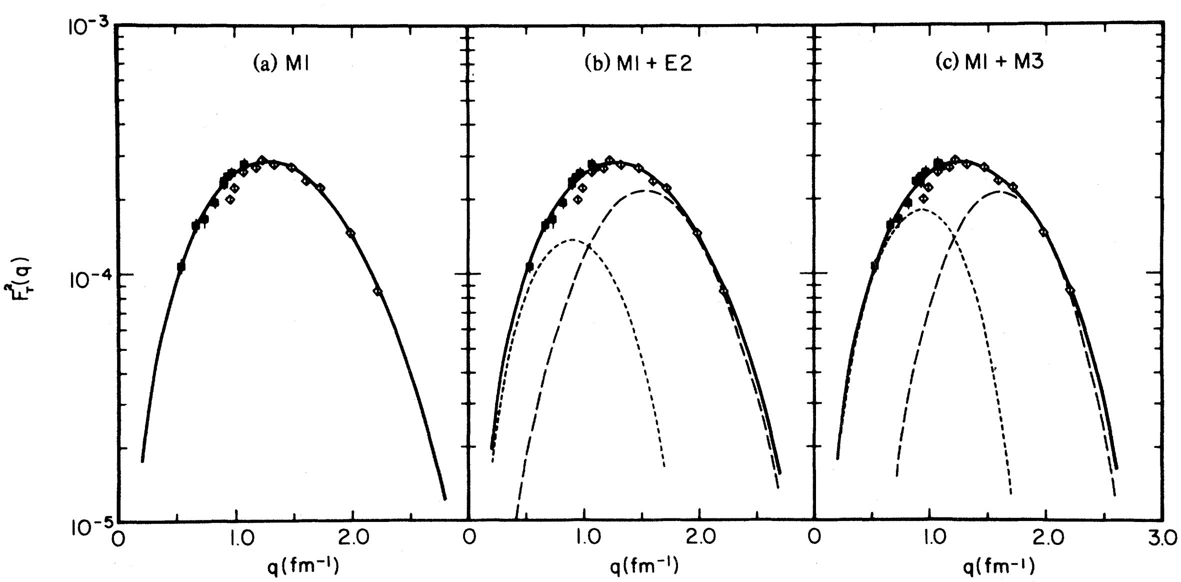

FIG. 2. Helm model fits of the transverse form factor for ^{9}Be (14.39 MeV) assuming: (a) pure $M1$; (b) $M1+E2$ admixture; (c) $M1+M3$ admixture. In (b), the dotted curve is the $M1$ component, the dashed curve is the $E2$ component, and the solid curve is the sum. In (c), the dotted curve is the $M1$ component, the dashed curve is the $M3$ component, and the solid curve is the sum. Data are from Refs. 17 and 18. The experimental results have been multiplied by $Z^2/4\pi$ to be consistent with the definition of the theoretical form factor as in Ref. 12.

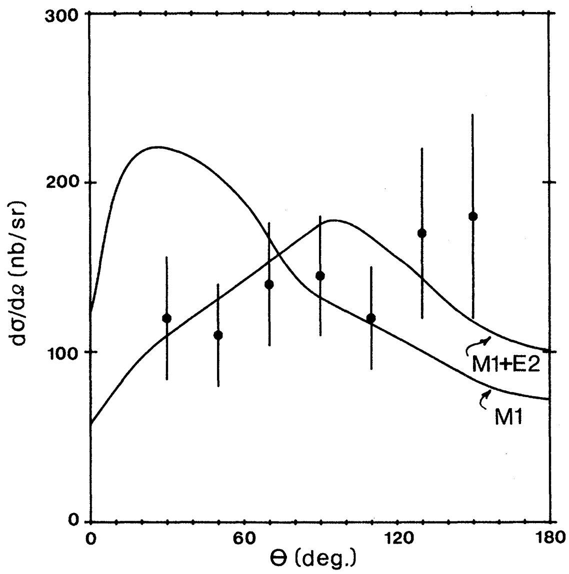

FIG. 3. Angular distribution data of Yamazaki *et al.* (Ref. 11) for the reaction ^{9}Be(γ, π^+) ^{9}Li(g.s.) at $E_\pi \sim 40$ MeV. The curves denoted $M1$ and $M1+E2$ are the result of the present Helm model fits.

tion is rather unlikely for two reasons: (1) The pure $M1$ Helm fit to the electron scattering data [Fig. 2(a)] requires a transition radius of $R \sim 1.5$ fm, which is much smaller than that found in typical $M1$ transitions for *lp*-shell nuclei. Examples are ^{12}C(15.11 MeV), ^{13}C(g.s.), ^{6}Li (3.56 MeV), and ^{10}B (7.48 MeV), which all require $R \sim 2.2$ fm. An exception is ^{14}N (2.31 MeV), which is an anomalously weak transition; (2) the resulting (γ, π^+) angular distribution based on the pure $M1$ Helm fit is somewhat forward peaked at pion $E_\pi \sim 40$ MeV. The angular distribution data of Yamazaki *et al.*,[11] shown in Fig. 3, which clearly resolves the ground state transition, is not forward peaked, but seems to favor the $M1+E2$ combination. Thus a pure $M1$ transition seems to be ruled out, and an $E2$ component appears to be present. We cannot rule out some additional $M3$ admixture on the basis of these fits, since we did not try full $M1+E2+M3$ admixtures.

The present data illustrate the sensitivity of the (γ, π) reaction to the multipole admixture of the transition. However, more data, especially precise angular distribution data, and more fundamental theoretical calculations, are needed.

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