Photopion cross sections and mass 14 structures

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Various wave functions that have been used to describe the ^{14}N system are examined. In particular it is shown that while the $^{14}\mathrm{N}(\gamma,\pi^+)^{14}\mathrm{C}_{\mathrm{g.s.}}$ reaction data at 173 and 200 MeV suggest that the Cohen and Kurath wave functions are inappropriate, the variations that these data imply can be explained in terms of core polarization effects.

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Recent studies of electromagnetic and hadronic transition data from ^{14}N have demonstrated the complementary nature of data taken with various probes in so far as they provide a test of the structure of the nucleus. Analyses of that data have been based upon one of two premises. The first premise is that the conventional $0p$-shell-model wave functions of Cohen and Kurath [1] are the appropriate structure functions from which to extract the basic one-body density matrix elements (OBDME's) required in calculations of transition matrix elements. To fit data those OBDME values must be varied and such variation is attributed to core polarization corrections. The second premise [2] is that the wave functions of ^{14}N are entirely described by a $0p$-shell structure and that the scattering data defines OBDME's to be interpreted solely within the $0p$ shell. As those OBDME's are few in number, they can be unfolded to give the specific state wave functions. Such wave functions are specified hereafter as fitted wave functions.

Of the two premises, the first is more soundly based and critiques of the second have been published [3]. Briefly, it is well known that core polarization corrections to the conventional, Cohen and Kurath (CK) $0p$-shell-model wave functions are important. Usually, measured gamma decay rates, electron scattering form factors, etc., can only be reproduced when the OBDME's are varied from the CK set. Such corrections, due in large measure (under premise 1) to components in the individual state vectors involving nucleons in the $1s$-$0d$ and other orbits, do not effect individual multipole OBDME's uniformly. Indeed data analyses based upon either premise proceed identically; to wit adjust the OBDME values to fit observation. It is the interpretation of the resulting values under premise 2 that draws criticism. The problem is that the fitted wave functions are eigenfunctions of a Hamiltonian that is unphysical. For ^{14}N it has been shown [3] that the Hamiltonian associated with the fitted wave functions of Huffman *et al.* [2] contain an excessively large symmetry violating component. Spectral properties of ^{14}N do not favor this.

Over several years now, low-energy pion photoproduction from p-shell nuclei has given constraints to be met by models of nuclear structure [4–8] additional to those of static properties of, and particle scattering from, such nuclei. Indeed, for the ground-state transition $^{14}\mathrm{N}(\gamma,\pi^+)^{14}\mathrm{C}$ in which we are particularly interested,

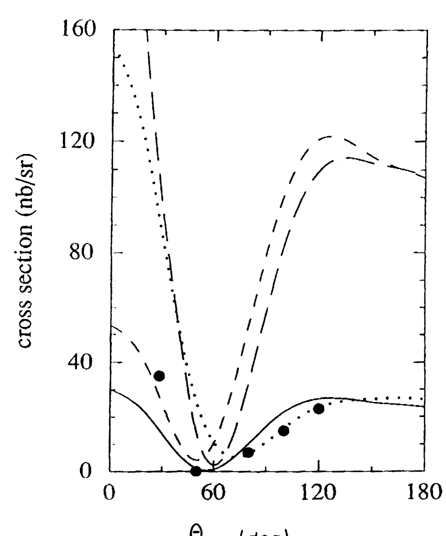

FIG. 1. Photopion differential cross section at a photon energy of 173 MeV. The theoretical curves are calculated, as described in the text with the (8-16)POT (long dashed lines); (8-16)2BME (short dashed lines); fitted (solid line) and corrected (dotted line) wave functions.

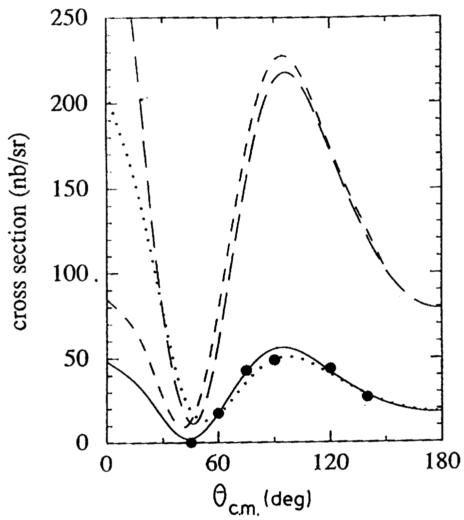

FIG. 2. As for Fig. 1, but with a photon energy of 200 MeV.

a low-energy study [9] was necessary to resolve uncertainties associated with analyses of higher-energy data. For this reaction the Kroll-Ruderman term is supressed whence data in the delta region are sensitive to details in the photoproduction operator such as its proper unitarization [10], and to the pion-nucleus final-state interaction [6, 7, 11]. The low-energy data [9] analysis revealed two significant aspects about the mass 14 sysytem. First the Gamow-Teller matrix element was small but finite in contrast to the suppressed ^{14}C β^- decay and second, the observations are quite at variance with the predictions based upon the CK wave functions. So also are the other data, including the β^- decay rate, electron scattering form factors, and (p,n) cross sections [2, 3]. The fitted wave functions do give good results however [2, 12]. But we show below that core polarization corrections to the CK wave functions ascertained previously [3] give equally good fits to the photopion cross sections.

Analyses have been made of the photopion cross section data taken with photon energies of 173 and 200 MeV, at which energies analyses based upon a nonrelativistic expansion of the pseudovector Born amplitudes of the elementary pion production operator are credible. Therein the Kroll-Ruderman term usually dominates. But for the transition of interest that term is suppressed and the data analysis must be made using a more complete description of the pion production operator. Such was done recently [5] within a distorted-wave impulse approximation. The same program has been used to obtain the results displayed in the two figures.

The 173 and 200 MeV photopion data [9] and calculations are displayed in Figs. 1 and 2, respectively. The continuous lines depict the results of calculations made using the fitted wave functions (designated H1 by Huffman *et al.* [2]) and the short dashed and long dashed lines, respectively, were obtained using the CK wave functions specified by the (8-16)2BME and (8-16)POT potential energy sets [1]. The fourth result, shown by the dotted curve in the figures, are those found using the previously defined [3], core polarization corrections to the CK wave functions; i.e., defined by fitting (p,p') and (p,n) cross-section data and (e,e') form factors. The spectroscopic amplitudes used for these calculations are given in Table I. Clearly the fitted and core polarization corrected wave functions give good fits to data beyond the minimum whereas the basic CK function results are much too large. Forward of the minimum the various results diverge markedly, with the sole data point a factor of two different from the fitted (larger) and core polarization (smaller) results. Intriguingly the (8-16)2BME wave functions give a good fit to this data point.

TABLE I. Spectroscopic amplitudes derived from the four sets of wave functions. In the notation of Ref. [4] these numbers must be multiplied by a factor of $\sqrt{3}$.

$(LS)I$	(01)1	(10)1	(11)1	(21)1
(8-16)2BME [1]	0.017	−0.0185	0.059	−0.483
(8-16)POT [1]	0.052	−0.200	0.037	−0.477
Fitted wave function [2]	0.019	−0.196	−0.023	−0.251
Corrected wave function [3]	0.052	−0.185	0.059	−0.242

It is instructive to consider the separate $(LS)I$ multipole contributions, to this transition. At the larger scattering angles, the (21)1 multipole OBDME's give the dominant contributions to calculated cross sections just as they did in calculations of large-angle (p,p') and (p,n) scattering cross sections. The marked reduction in these values previously defined [3] is confirmed by the photopion results. At forward angles, and again as is the case with (p,p') and (p,n) cross-section data, the (01)1 set of OBDME values are most important. These values are extremely sensitive to exact details of the nuclear structure model and previous analyses of β^- decay and forward angle (p,n) cross-section data have not resolved the question of whether a basic $0p$-shell model is sufficient to define the OBDME's [13]. In this regard photopion data at small scattering angles can be very useful as the current results show considerable diversity. Taken in conjunction with the constraints imposed by fits to (p,p') and (p,n) differential cross sections and the β^- decay rate, forward angle photopion data should allow us to delineate the (01)1 multipole set of OBDME's.

Clearly the core polarization corrections to the basic CK shell model calculations required to fit electron and proton scattering data also explain the photopion data. While fitted and core polarization corrected wave functions give similar $(LS)I$ component spectroscopic amplitude the assumption of purely p-shell wave functions appears to be too restrictive. There is no evidence that the fitted wave functions interpretation is unique. We have also observed a marked sensitivity in small-angle calculated results to structure input and hope that it is feasible to obtain further data.

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