Pion photoproduction on ^{6}Li near threshold*

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We present the results of an improved calculation of pion photoproduction on ^{6}Li near threshold and compare with the recent data of Deutsch *et al.* The theoretical cross sections are found to be about 60% higher than the experimental values.

[NUCLEAR REACTIONS ^{6}Li$(\gamma, \pi)^6$He, calculated $\sigma(E)$ near threshold.]

In the light of recent experimental data for the reaction $^6\text{Li}(\gamma, \pi^+)^6\text{He}$ near threshold[1] we have reexamined our previous theoretical predictions for this process[2] and present the improved results in the present note. The total cross section may be written[2]

$$\sigma = \frac{1}{4\pi}\left(\frac{q^C}{k^C}\right)\left(1+\frac{\epsilon^C}{E'^C}\right)^{-1}\left(1+\frac{k^C}{E^C}\right)^{-1}|M|^2, \qquad (1)$$

where k^C is the photon energy, q^C is the pion momentum, $\epsilon^C = m_\pi + (q^C)^2/2m_\pi$ is the pion energy, and $E^C = [M_i^2 + (k^C)^2]^{1/2}$ is the energy of the target whose mass is M_i, where all quantities are in the c.m. system (C). Conservation of energy requires that the final nucleus of mass $M_f = M_i + \omega_{\text{ex}}$, where ω_{ex} is the nuclear excitation energy, have energy

$$E'^C = k^C + E^C - \epsilon^C. \qquad (2)$$

In the lab system (L) the photon energy is

$$k^L = k^C(k^C + E^C)/M_i. \qquad (3)$$

The nuclear matrix element may be written[2]

$$|M|^2 = \frac{1}{m_\pi^2} C_{\gamma\pi} \frac{4\pi}{2J_i+1} \sum_{J\ge 1} \{ |\langle J_f \| T_J^{\text{mag}5}\tau_\pm \| J_i\rangle|^2 + |\langle J_f \| T_J^{\text{el}5}\tau_\pm \| J_i\rangle|^2 \}, \qquad (4)$$

where J_i, J_f are the initial and final nuclear angular momenta and $T_J^{\text{mag}5}$ and $T_J^{\text{el}5}$ are defined in Refs. 2–4. The coupling constant $C_{\gamma\pi}$ in the present work is adjusted so that when the target is a proton ($M_i = M_p$ = proton mass; $M_f = M_n$ = neutron mass) the single-nucleon cross section near threshold has the form

$$\sigma_p = \left(\frac{q^C}{k^C}\right) a_p, \qquad (5)$$

where the experimental value[5] $a_p = 193.5 \pm 6.7$ μb is used to determine $C_{\gamma\pi}$. This yields a value of $C_{\gamma\pi} = 0.080 \pm 0.003$, compared to the result obtained from soft-pion theorems[6,7]

$$C_{\gamma\pi} = (4\pi)^2 \alpha f^2 (1 + m_\pi/M_N)^{-1}, \qquad (6)$$

where α is the fine-structure constant, M_N is the nucleon mass, and this value of $C_{\gamma\pi}$ requires $f^2 = 0.079 \pm 0.003$.

The improvement here over our previous results[2] is in the treatment of the single-nucleon cross section. Our procedure in Ref. 2 was to approximate the single-nucleon amplitude[8] by using the Kroll-Ruderman theorem in its simplest form. We then extended this to the nuclear many-body system and computed the ^{6}Li cross section. Here we use Eq. (1), with the appropriate kinematic fac-

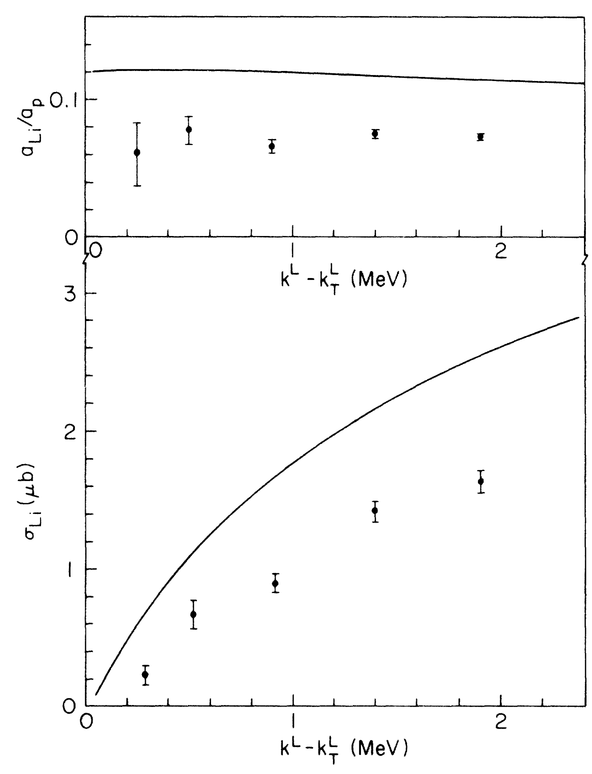

FIG. 1. The ratio a_{Li}/a_p and the total pion-photoproduction cross section σ_{Li} are shown as functions of the laboratory photon energy k^L measured from its threshold value k_T^L. The experimental data are from Ref. 1.

tors, and *directly determine* the constant $C_{\gamma\pi}$ which is required to reproduce the single-nucleon (γ, π^+) cross section. The basic assumption in this work is that the interaction Hamiltonian density is of the form

$$\mathcal{H} \sim \sum_{j=1}^{A} \tau_{\pm}(j)\vec{\sigma}(j)\cdot\vec{\epsilon}(k^C, \lambda)\delta(\vec{x}-\vec{x}_j), \qquad (7)$$

where $\vec{\epsilon}(k^C, \lambda)$ is the polarization vector of the incident photon with polarization λ. We treat the outgoing pion as in Ref. 2 by using an optical-model potential (including the Coulomb potential of the extended nuclear charge distribution) and solving for the s-wave part of the pion wave function. The nuclear wave functions are also the same as in Ref. 2, namely, those obtained by studying semileptonic weak and electromagnetic interactions in mass 6 in a unified manner.[9]

The results are presented in Fig. 1 along with the recent experimental data of Deutsch *et al.*[1] Here we show the ^{6}Li cross section $\sigma_{\rm Li}$ and the ratio $a_{\rm Li}/a_p$ where a_p is defined in Eq. (5) and $a_{\rm Li}$ is deduced from the representation of the cross section used in Ref. 1:

$$\sigma_{\rm Li} = a_{\rm Li}\left(\frac{q^C}{k^C}\right)\frac{2\pi\eta}{e^{2\pi\eta}-1}, \qquad (8)$$

where $\eta = Z\alpha\bar{m}/q^C$ with Z the charge of the final state (2) and $\bar{m}$ the reduced mass in the final state. Our calculated results are about 60% higher than the experimental values, although the cross sections are seen to have the same energy dependence.[10] This represents a 13% reduction from the calculated results given in Ref. 2.

The origin of this disagreement appears to be uncertain at present. Since the nuclear wave functions were determined[9] by studying weak and electromagnetic processes in mass 6 (particularly inelastic electron scattering and muon capture, which occur at medium to high values of momentum transfer as are appropriate here), we believe that they provide only a small degree of uncertainty. Less certain is the assumed form of the interaction Hamiltonian [Eq. (7)], although, if more complicated terms enter in the πN interaction [e.g., contributions from the (3, 3) resonance], then it is unclear whether the energy dependence of the cross section will be the same. We reemphasize that the over-all coupling constant $C_{\gamma\pi}$ has been directly fitted using the experimental single-nucleon cross section. Perhaps most uncertain is the optical-model potential used. The Coulomb distortion of the pion wave function in particular is appreciable[2] and the strong interaction potential is not too well determined for a nucleus as light as mass 6. All these questions are presently being studied and, whatever the outcome, the resolution of the disagreement between theory and experiment should yield new information on the process of pion-photoproduction.

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[8]Note that in Ref. (2) we used $f^2 = 0.088$.

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[10]Note that in Ref. (1) the last footnote containing a private communication from us on a preliminary version of this work is overly optimistic: once the single-nucleon amplitude was considered in detail we found that the calculated and measured results for ^{6}Li still differ, but not by as much as indicated in Ref. (1).