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COHERENT AND INCOHERENT ELASTIC PHOTOPRODUCTION OF π^0 MESON ON LIGHT NUCLEI

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The paper presents calculations of the cross sections of the elastic photoproduction for π^0 meson on ^{6}Li, ^{7}Li *and* ^{9}Be *nuclei in terms of the impulse approximation using the intermediate coupling p-shell model. Measurements are performed in the excitation energy region of Δ(1232)3/2$^+$ resonance. The algorithm of the cross section selection is proposed for* $\gamma\ {}^7\text{Li} \to \pi^0\ {}^7\text{Li}$ *reaction. These calculation results are in good agreement with the experimental data on the elastic photoproduction cross sections for π^0 meson on* ^{7}Li *nucleus obtained by other authors [2].*

Keywords: nuclear shell model, photoproduction reaction, isobars

In our previous research [1] we presented the calculation of the cross sections for the elastic photoproduction for π^0 meson on light nuclei with the mass number $4 < A < 16$. These calculations we use here in the analysis of the differential cross sections for the reaction

$$\gamma + {}^7\text{Li} \to \pi^0 + {}^7\text{Li} \tag{1}$$

from its threshold to the incident-photon energy of $K_0 \approx 400$ MeV. However, in order to appropriately describe the differential cross sections for reaction (1), we refuse from the coherent photoproduction for π^0 meson on all nucleons and add the isobar absorption in the excitation energy region of Δ(1232)3/2$^+$ resonance. The cross sections measured for reaction (1) in [2] are compared with those calculated in our previous study at different photon energies as presented in Fig. 1.

The cross sections of the elastic photoproduction for π^0 meson on ^{7}Li nucleus are calculated as follows. The dotted line indicates the differential cross sections calculated by the approximation equation [1] with regard to the coherent π^0 meson photoproduction on all nucleons with the mass number A:

$$\frac{d\sigma}{d\Omega} \approx A^2 K \frac{1}{2}\sum_{\lambda}\left|H^{00}(\lambda)\right|^2 \left[\frac{4}{A}F_{00}(p) + \frac{A-4}{A}F_{01}(p)\right]^2 . \tag{2}$$

Here K is the kinematical factor which involves summation and averaging over the nuclear spin projection, respectively in the final- and initial-state nuclei; H^{00} is the independent isospin amplitude of π^0 meson photoproduction on nucleons which can take the form

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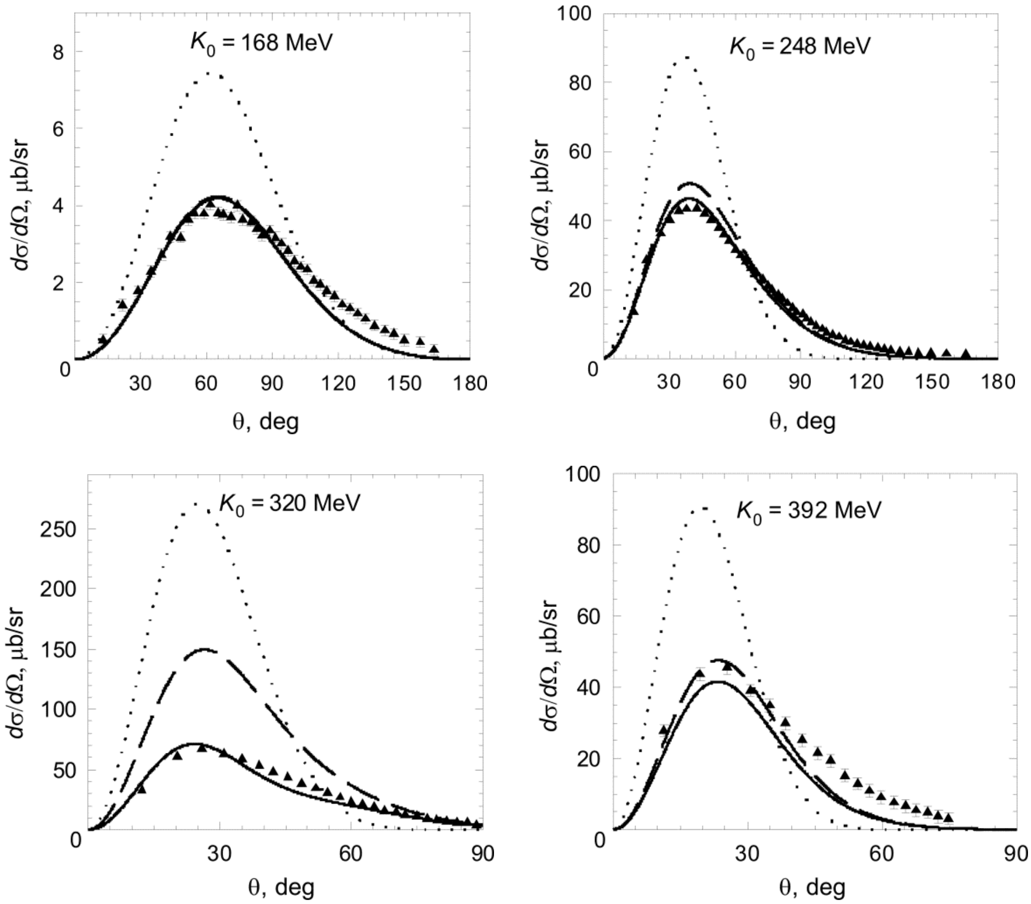

Fig. 1. Differential cross sections for the reaction $\gamma\ ^7\mathrm{Li} \to \pi^0\ ^7\mathrm{Li}$ in the center-of-mass system at the laboratory energies of incident γ-quanta calculated in the plane-wave impulse approximation with $\gamma N \to \pi N$ process amplitudes from [4]. Dotted, dashed and solid curves indicate calculations by various equations (see in the text). Experimental data are from [2].

$$H^{00} + H^{01}\tau + H^{10}\sigma + H^{11}\sigma\,\tau, \tag{3}$$

where σ and τ are respectively spin and isospin operators on nucleon [1, 3], λ is the polarization index of photon; F_{00}, F_{01} are form factors of *s*- and *p*-shell nuclei. Within the nuclear model based on a harmonic-oscillator potential, these form factors take the simplest form [3]:

$$F_{00} = \exp\left[-(A-1)/A\cdot p^2 r_0^2\right],\ F_{01} = \exp\left(1-1/6\cdot p^2 r_0^2\right)\exp\left[-(A-1)/A\cdot p^2 r_0^2\right], \tag{4}$$

where $p = |\boldsymbol{p}|$ is the three-momentum transfer to the target nucleus during π^0 meson photoproduction; r_0 is the nuclear harmonic-oscillator parameter. According to the mean-square radius of ^{7}Li nucleus (r_{ms} = 2.41 Fm), this parameter is selected to be 1.9 Fm. It is a fact that the calculated values of the differential cross section seriously exceed the experimental.

If we assume that the coherent elastic photoproduction of π^0 meson is absent on all nucleons, but present particularly on *s*- and *p*-shell nuclei, we obtain

$$\frac{d\sigma}{d\Omega} \approx A^2 K \sum \left\{ \frac{1}{2} \sum_{\lambda} \left| H^{00}(\lambda) \right|^2 \left[\frac{4}{A} F_{00}(p) \right]^2 + \frac{1}{2} \sum_{\lambda} \left| H^{00}(\lambda) \right|^2 \left[\frac{A-4}{A} F_{01}(p) \right]^2 \right\}. \quad (5)$$

The cross sections thus calculated for reaction (1) are indicated in Fig. 1 with dashed lines. In this case, the calculated values of the differential cross section slightly exceed the experimental in the excitation energy region of $\Delta(1232)3/2^+$ resonance (see dashed lines). It is possible to reduce the production cross section of π^0 meson at the Δ-isobar excitation, when π^0 meson production is suppressed at a stage of Δ-isobar photoexcitation. For this purpose, the absorption of excited Δ-isobar on the α-particle core of ^{7}Li nucleus was taken into account [1] rather than the absorption of produced π^0 mesons:

$$D = 1 - \beta \left(\frac{(\Gamma/2)^2}{(W - W_0)^2 + (\Gamma/2)^2} \right)^2. \quad (6)$$

Here W is the total energy of the photon-nucleon system at the incident-photon energy K_0; W_0 is the total energy of the photon-nucleon system at the incident-photon energy K^*_0 = 325 MeV; Γ = 120 MeV is the width of the unbound Δ-isobar. The adjustable parameter β is selected to be 0.69 for reaction (1). It can be changed depending on the considered target nucleus as described in [1]. As a result, we have

$$\frac{d\sigma}{d\Omega} \approx A^2 K \sum \left\{ \frac{1}{2} \sum_{\lambda} \left| H^{00}(\lambda) \right|^2 \left[\frac{4}{A} F_{00}(p) \right]^2 D + \frac{1}{2} \sum_{\lambda} \left| H^{00}(\lambda) \right|^2 \left[\frac{A-4}{A} F_{01}(p) \right]^2 \right\}. \quad (7)$$

In Fig. 1, solid lines indicate the isobar absorption by the α-particle core. We do not consider a satisfactory description of the cross section measurements [2] to be enigmatic. So let us validate the proposed calculation algorithm of the elastic photoproduction for the calculation of the cross sections for other reactions, such as

$$\gamma + {}^6\mathrm{Li} \rightarrow \pi^0 + {}^6\mathrm{Li}, \quad (8)$$

$$\gamma + {}^9\mathrm{Be} \rightarrow \pi^0 + {}^9\mathrm{Be}. \quad (9)$$

In order to measure the cross section for meson photoproduction we select the photon energies similar to those of reaction (1) [1]: K_0 = 168, 248, 320 and 392 MeV. It is worth noting that the experimental data on these reactions are not yet available, but if they will, this algorithmic validation is the best. There are solid grounds to expect that these experimental data will appear, because owing to the progress in the neutral meson production [5, 6] the reactions of the elastic photoproduction of π^0 mesons on nuclei have become possible, including even the excitation of stationary levels in the final-state nucleus [2].

The purpose of this work is to initiate the cross section measurements for π^0 meson elastic photoproduction on ^{6}Li and ^{9}Be nuclei having an open *p*-shell and compare them with the algorithmic calculations used in [1] for reaction (1). Next, a conclusion can be drawn relative to coherence or incoherence of the elastic π^0 meson photoproduction on the whole nucleus. The calculations of the cross sections of π^0 meson photoproduction on ^{6}Li and ^{9}Be nuclei are based on the same intermediate coupling shell model [7] and the same multipole analysis of π^0 meson photoproduction on nucleons [4]. The harmonic-oscillator potential for ^{6}Li and ^{9}Be nuclei is selected to be 2.03 and 1.8 Fm, respectively [3]. The results of calculations are presented in Figs 2 and 3.

It is obvious that within the considered range of photon energy, the cross sections of π^0 meson photoproduction calculated in the impulse approximation are much greater than that calculated with the proposed algorithm.

Another trait of cross sections measured by the proposed algorithm is their constant value within the incident-photon energy of 240–400 MeV, that is almost independent of the individual properties of nuclei. This is in good agreement with the experimental data [2, 8, 9].

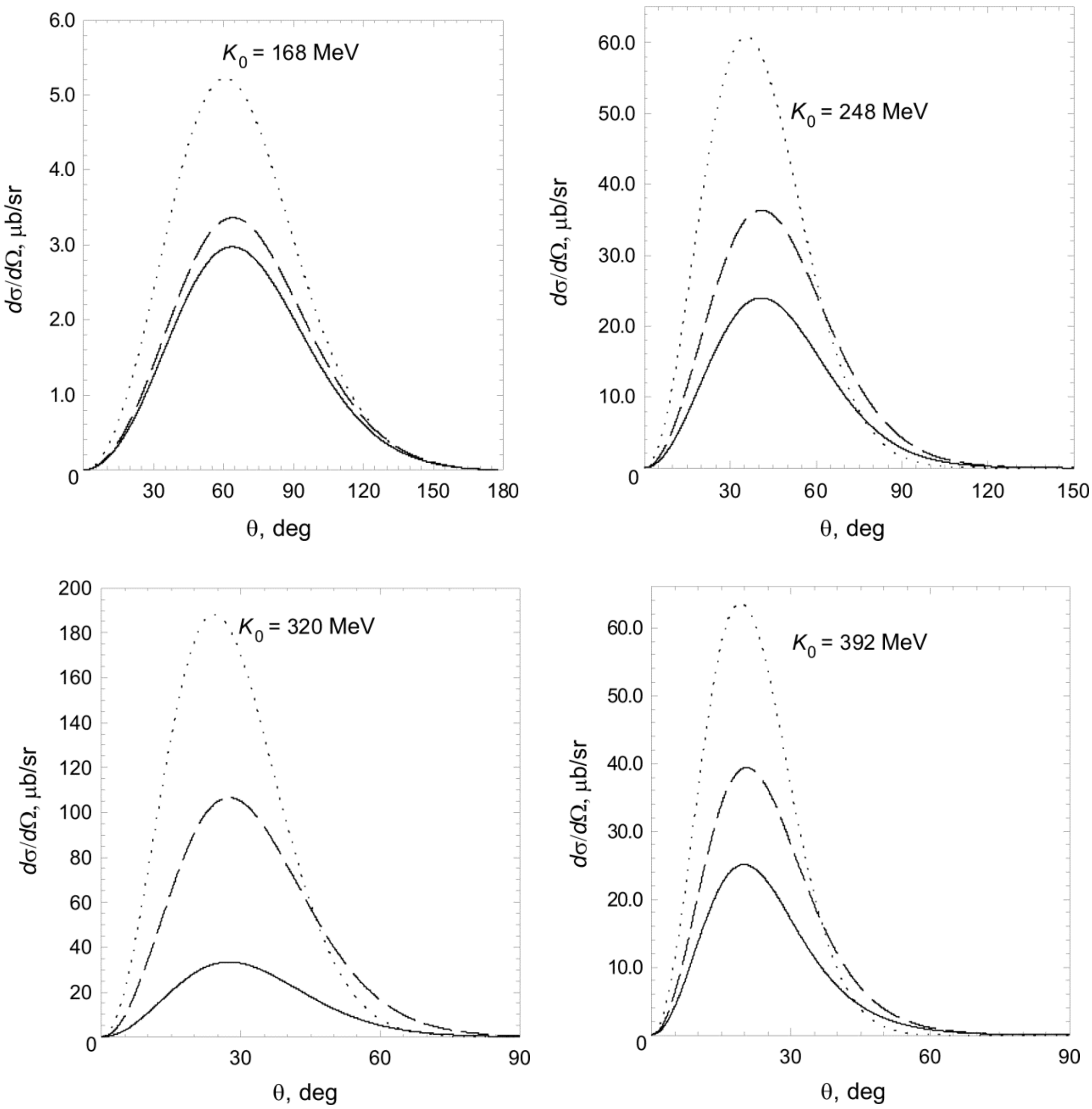

Fig. 2. Differential cross sections for γ^6Li $\rightarrow\pi^0\,{}^6$Li reaction in the center-of-mass system at the laboratory energies of incident γ-quanta calculated for $\gamma N \rightarrow \pi N$ process amplitudes from [4]. The oscillation parameter of ^{6}Li nucleus is 2.03 Fm. Dotted, dashed and solid curves indicate calculations by Eqs. (2), (5) and (7).

It is important, that the distorted-wave impulse approximation [10–12] cannot provide such a strong reduction in the cross sections of the elastic photoproduction for π^0 meson on nuclei calculated in the plane-wave impulse approximation. When the differential cross sections will be measured for (8), (9) and other reactions, their analysis can be used to obtain the dependences between D parameter in Eq. (6) and the nuclear mass, incident-photon energy and better definition of the physical sense of D parameter in Eqs. (6) and (7). Note that the use of another multipole analysis of $\gamma N \rightarrow \pi N$ process, for example, [13], will not affect our conclusions.

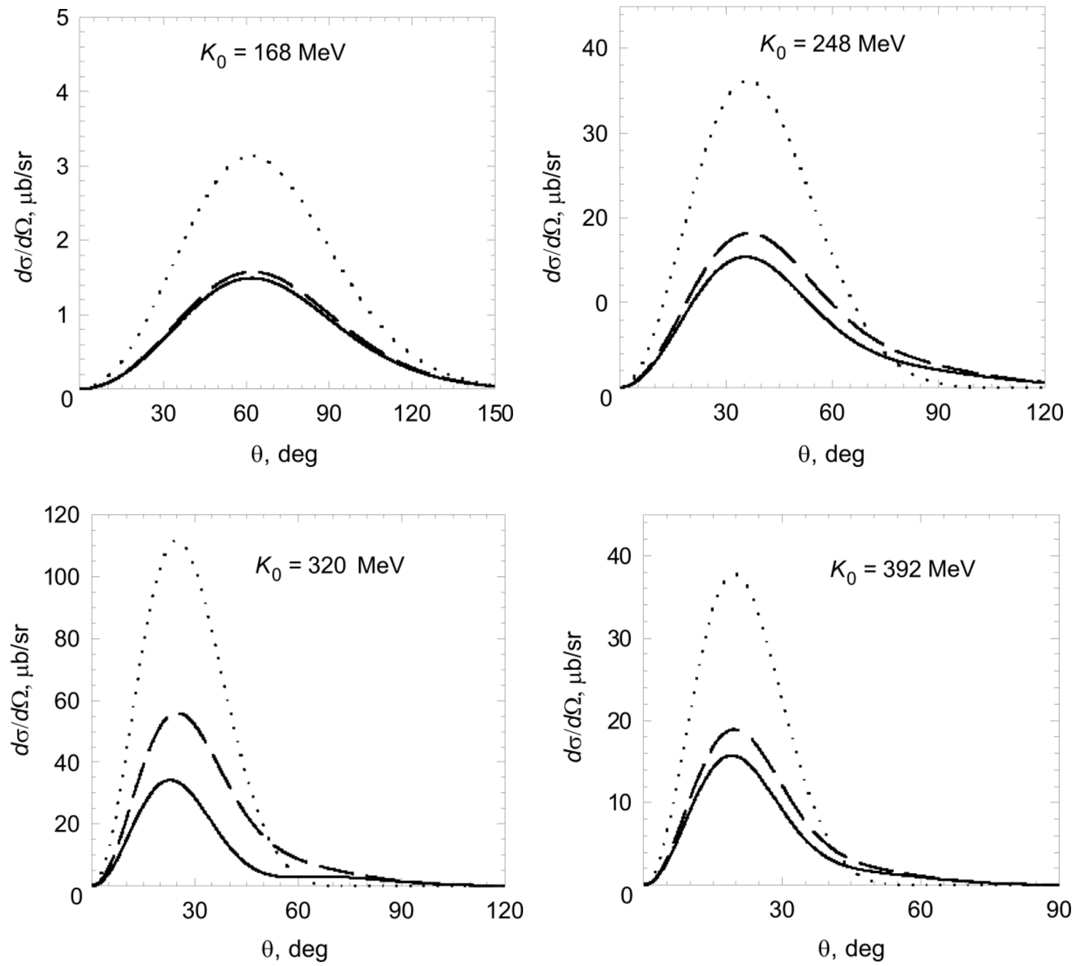

Fig. 3. Differential cross sections for $\gamma\,^9Be\to\pi^0\,^9Be$ reaction in the center-of-mass system at the laboratory energies of incident γ-quanta calculated for $\gamma N \to \pi N$ process amplitudes from [4]. The oscillation parameter of ^9Be nucleus is 1.8 Fm. Dotted, dashed and solid curves indicate calculations by Eqs. (2), (5) and (7).

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