Evaluation of Total Nuclear Photoabsorption Cross-Sections by the Modified Quasi-Deuteron Model

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Evaluation of Total Nuclear Photoabsorption Cross-Sections by the Modified Quasi-Deuteron Model.

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Abstract. – Levinger's modified quasi-deuteron model has been used to analyse available experimental data on total nuclear photoabsorption cross-section in the mass range $7 \leq A \leq 238$ and in the energy range $(35 \div 140)$ MeV. It is shown that the measured cross-sections are successfully reproduced by the formula $\sigma^T(E_\gamma) = LNZ/A\sigma_D(E_\gamma)\exp[-D/E]$ with $L = 6.1 \pm 2.2$ and $D = 0.72A^{0.81}$.

The recent years have seen a rise of interest in studying photonuclear reactions occurring in the energy region $(30 \div 140)$ MeV, *i.e.* above the giant-dipole resonance and below the pion photoproduction threshold, but data on total nuclear photoabsorption cross-section $\sigma^T(E_\gamma)$ are still very scanty. As a matter of fact, if one disregards data obtained before '70 by using continuous bremsstrahlung beams, which data can be considered only as a first approximation [1], total nuclear photoabsorption cross-section by monochromatic photons of $30\,\text{MeV} \leq E_\gamma \leq 140\,\text{MeV}$ are presently available for six light nuclei ($7 \leq A \leq 40$) [2] and for five heavy nuclei ($119 \leq A \leq 238$) [3, 4].

In the energy range considered the predominant mechanism of interaction of incident photons with nuclei seems to consist in the absorption of photons by correlated neutron-proton pairs inside the target nucleus, the so-called «quasi-deuteron» model proposed by Levinger in a first formulation [5-7], and more recently modified [8]. Within the framework of Levinger's «modified quasi-deuteron» model the total nuclear photoabsorption cross-section $\sigma^T(E_\gamma)$ is related to the total photodisintegration cross-section of a free deuteron

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$\sigma_D(E_\gamma)$ according to

$$\sigma^T(E_\gamma) = LNZ/A \exp[-D/E]\,\sigma_D(E_\gamma)\,, \tag{1}$$

where NZ is the possible number of n-p combinations in a nucleus of mass number A, and L and D are the so-called «Levinger's» and «damping» factors, respectively. As far as the physical meaning of L and D is concerned, the ratio LNZ/A may be thought of as the effective number of deuteronlike structures which take place in the photoabsorption mechanism, whereas D is a parameter accounting for some «quenching effect» on σ^T's at energies comparable to Fermi energy in the nucleus, *i.e.* a damping of the quasi-deuteron cross-section produced by Pauli blocking of the final states for the proton or neutron emitted directly by the absorbing quasi-deuteron.

In spite of the fact that a statistical treatment carried out [9] on what experimental $\sigma^T(E_\gamma)$ data was at that time available ($7 \leqslant A \leqslant 40$ [2], ^{nat}Pb [3]) led to rather good results in reproducing experimental σ^T's, no attempts were heretofore made to extend such a study to more recent measured cross-sections ($A \geqslant 100$ [4]). It is to be noted, moreover, that an experiment on deuteron photodisintegration induced by monochromatic photon beams energies up to 75 MeV has been recently carried out at the Frascati National Laboratories [10] and, therefore, a more reliable set of $\sigma_d(E_\gamma)$-values is presently available.

In the present work we analysed the cross-section data for ^{nat}Sn, ^{nat}Ce, ^{181}Ta, ^{nat}Pb and ^{nat}U measured at Saclay [3, 4] by using a continuously variable monochromatic photon beam ($25 \leqslant E_\gamma \leqslant 140$ MeV) obtained from annihilation in flight of monoenergetic positrons, as well as those for ^{7}Li, ^{9}Be, ^{12}C, ^{16}O, ^{27}Al and ^{40}Ca measured at Mainz [2] ($10 \leqslant E_\gamma \leqslant 200$ MeV) by means of attenuation experiments.

The present analysis was carried on at energies ranging between 35 MeV (where the contribution from the giant-resonance tail turns out to be negligible) and 140 MeV. The σ_D values used in the calculations have been taken from ref. [10] up to 75 MeV, and from ref. [5] in the energy range $(75 \div 140)$ MeV. Besides, the isotopic composition of the target nuclei was taken into account.

The D- and L-values for each nucleus under investigation were determined following the procedure adopted previously [9], and results have been plotted in fig. 1 as a function of mass number A. We obtained the following dependence of D on mass number A:

$$D = 0.72A^{0.81}\ \text{MeV}\,. \tag{2}$$

Values of D range from (3.5 ± 1.0) MeV for Li to (61 ± 7) MeV for U.

It is worthwhile to note that the value $D = (55 \pm 6)$ MeV found for Pb in the present work is in complete agreement with the value $D = 60$ MeV determined by Levinger [8] from the analysis of previous measurements carried out on Pb [3], and that the obtained trend of D increasing with A is consistent with the physical picture of a damping parameter related to the Fermi energies for protons and neutrons. Moreover, the exponent 0.81 in eq. (2) may be thought of as an indication that the quenching effect on neutrons and protons emission from a quasi-deuteron structure is effective in a large fraction of the whole nuclear volume. A discussion on this subject would imply an insight into nuclear transparencies, and it is beyond the purpose of the present work.

A constant value $L = 6.1 \pm 2.2$ (2σ) has been achieved in the whole considered mass region.

In fig. 1*b*) we report L-values deduced from the number of effective quasi-deuteron clusters in nuclei (N_{eff}) measured for various nuclei by Stibunov *et al.* [11], and for ^{12}C by Homma *et al.* [12, 13]. As one can see, a satisfactory agreement is found between our values

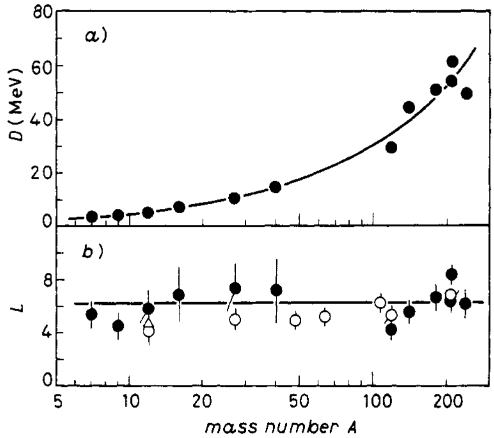

Fig. 1. – *a*) D-values obtained in the present work reported as a function of mass number A; the full line through the points in a least-squares fit which gives an A-dependence as $D = 0.72A^{0.81}$ MeV. *b*) L-values reported as a function of mass number A. Full circles: values obtained in the present work. The straight line represents the mean value $L = 6.1$. Open circles: experimental values from ref. [11] for ^{12}C, ^{27}Al, ^{38}T, ^{nat}Cu, ^{nat}Sn, ^{108}Ag and ^{207}Pb; open triangle: experimental value from ref. [12, 13] for ^{12}C.

and the experimental data published up to now and, therefore, the value obtained in the present work for the fit-parameter L seems to be rather grounded on a physical basis.

The overall accuracy of eq. (1) with the proposed L and D values in reproducing the measured cross-sections in the mass range $7 \leqslant A \leqslant 238$ has been tested by calculating more than 400 σ^e/σ^c ratios of experimental-to-calculated cross-sections. About 82% of the measured cross-sections are reproduced within a factor 1.4, and 98% within a factor 2.2. Even if the lack of experimental data in the intermediate mass region $40 \leqslant A \leqslant 100$ prevents one from inferring strictly conclusions about the mechanism involved in photon absorption at short wavelength, the very satisfactory degree of accuracy obtained in reproducing experimental data is an indication that the modified quasi-deuteron model may provide a proper description for absorption of photons by complex nuclei in the energy range $(30 \div 150)$ MeV, and that eq. (1) with parameter values for L and D as determined in the present work, is a useful tool in predicting any unmeasured total photonuclear reaction cross-section within an overall reasonable uncertainty.

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