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Nuclear photoabsorption by quasi-deuterons and an updated evaluation of Levinger's constant

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Abstract. Levinger's quasi-deuteron model of nuclear photoabsorption has been used together with modern root-mean-square radius data to obtain Levinger's constant L of nuclei throughout the Periodic Table. It is found that $L = 6.8 - 11.2A^{-2/3} + 5.7A^{-4/3}$, which gives L values in good agreement with those obtained from measured total nuclear photoabsorption cross sections.

The present work originated in a study to obtain an estimate of the total nuclear photoabsorption cross section for incident photons of energies between 200 and 1000 MeV. As is generally accepted, above ~ 150 MeV the interaction of photons with a nucleus of mass number A and atomic number Z has been described by two competing mechanisms, namely the photomesonic (pm) and quasi-deuteron (qd) ones, with the total nuclear photoabsorption cross section given by

$$\sigma_{\gamma A}^T(E_\gamma, A) = \sigma_{\text{pm}}^t(E_\gamma, A) + \sigma_{\text{qd}}^t(E_\gamma, A). \quad (1)$$

In the course of this study we faced the problem of estimating the contribution due to the quasi-deuteron mechanism of interaction to the total cross section as given by (1). The quasi-deuteron model proposed by Levinger [1] represents the total nuclear photoabsorption cross section as

$$\sigma_{\text{qd}}^t(E_\gamma, A) = L \frac{NZ}{A} \sigma_d^t(E_\gamma) \quad (2)$$

where $N = A - Z$, σ_d^t is the total cross section of the deuteron photodisintegration [2] and L is a constant (the so-called Levinger's constant) which can be thought of as a factor which measures the relative probability of two nucleons being near each other in a complex nucleus compared with that in a free deuteron. The aforementioned problem of estimating $\sigma_{\gamma A}^T(E_\gamma, A)$ would be thus solved provided that the values assumed by L for different target nuclei throughout the Periodic Table could be evaluated.

In order to evaluate L values it is believed best to use the original formalism introduced by Levinger [1] in the framework of a model for nuclear photoabsorption

via n - p pairs, which is valid for incident photons of energies larger than 150 MeV interacting with nuclear 'quasi-deuteron' structures. According to Levinger, the cross section of the quasi-deuteron is the cross section for the deuteron multiplied by the square of the ratio of the wavefunction of the quasi-deuteron (considered to be in a triplet state) to the wavefunction of the deuteron ground state, i.e.

$$\sigma_{qd}(E_\gamma) = (\psi_k/\psi_d)^2 \sigma_d^t(E_\gamma). \quad (3)$$

From the theory of the effective range of nuclear forces [3, 4], and taking into account the number of choices for protons (Z) and for neutrons (N), it follows that the total nuclear photoabsorption cross section via n - p pairs is given by

$$\sigma_{qd}^t(E_\gamma, A) = \frac{2\pi}{\alpha^2 + k^2} \frac{1 - \alpha r_0}{\alpha} \frac{A}{v} \frac{NZ}{A} \sigma_d^t(E_\gamma). \quad (4)$$

Here, v is the nuclear volume, α^{-1} is the scattering length, r_0 is the effective range of the n - p force in the ground state free deuteron, and k is the wavenumber for the relative motion of proton and neutron. Levinger's constant L is thus identified as

$$L = 2\pi\xi \frac{1 - \alpha r_0}{\alpha} \frac{A}{v} \quad (5)$$

where ξ is the average value of the quantity $(\alpha^2 + k^2)^{-1}$. This last quantity was calculated formerly by Levinger by assuming Fermi distributions up to the same wavenumber k_m for both protons and neutrons and an isotropic distribution for the angle between \mathbf{k}_p and \mathbf{k}_n , where $k = \frac{1}{2} |\mathbf{k}_p - \mathbf{k}_n|$. With these assumptions it was found that

$$\xi = \left(\frac{1}{\alpha^2 + k^2} \right)_{av} = \frac{9}{k_m^2} - \frac{24\alpha}{k_m^3} \tan^{-1} \left(\frac{k_m}{\alpha} \right) - \frac{6\alpha^2}{k_m^4} + \left(\frac{18\alpha^2}{k_m^4} + \frac{6\alpha^4}{k_m^6} \right) \ln \left[1 + \left(\frac{k_m}{\alpha} \right)^2 \right]. \quad (6)$$

In this way a constant value $L = 6.4$ was found [1] by taking $\alpha = 0.23 \text{ fm}^{-1}$, $k_m = 1.0 \text{ fm}^{-1}$ and $v = \frac{4}{3}\pi A(1.4)^3 \text{ fm}^3$, whereas the value $L = 8$ was calculated for a nuclear radius parameter of 1.2 fm [5].

Later, Levinger's constant was considered a purely phenomenological parameter, and was varied by different authors to fit photonuclear data obtained from experiments carried out in a rather wide range of both photon energy and target mass number. In a previous work [6] we noted, however, a dependence of L on the nuclear radius parameter, and deduced the expression $L \approx 0.67 A^{2.28}/NZ$. Afterwards, this expression was changed to $L = 2.1 \ln(1.3A)$ to take into account the condition $L = 2$ for a deuterium target. Also, from an analysis of the total nuclear photoabsorption data taken at $E_\gamma \leq 150 \text{ MeV}$ by the Saclay and Mainz groups [7, 8] it was found that $L = A^{2.147}/NZ$, to be used in the context of Levinger's modified quasi-deuteron model (see [9, 10]).

It seems evident from (5) that the dependence of L on A is eventually connected with the trend of the A/v ratio. In recent years, new experiments have provided nuclear radius data over an extended range of mass number. It was therefore felt worthwhile to undertake an updated evaluation of Levinger's constant as given by equation (5) taking advantage, as far as the physical quantities which appear in (5) are concerned, of the new nuclear radius data available.

The analysis has been performed over 63 nuclei lying along the beta-stability valley, from Be up to U. The nuclear volume v was calculated from the 'equivalent

root-mean-square radius' of the nucleus, Q , which is given by [11]

$$Q = (\frac{5}{3})^{1/2} \langle r^2 \rangle^{1/2} \quad (7)$$

where $\langle r^2 \rangle^{1/2}$ is the root-mean-square radius of the nuclear charge distribution, the quantity measured directly by the experiments. To calculate ξ from (6), first we obtained the values of k_m from the corresponding average maximum Fermi momentum p_A^F of the A nucleons, i.e.

$$k_m = p_A^F / \hbar = (\frac{3}{2} \pi^2)^{1/3} (A/v)^{1/3} = 1.18 A^{1/3} / \langle r^2 \rangle^{1/2}. \quad (8)$$

Inspection of (8) shows that if the value of the ratio $A^{1/3} / \langle r^2 \rangle^{1/2}$ was constant for all nuclei then one would have constant values for both k_m and ξ , and, therefore, (5) would give a unique value for L whatever the mass number of the target nucleus. The ratio $A^{1/3} / \langle r^2 \rangle^{1/2}$ is instead found to increase, even if slightly, throughout the Periodic Table, e.g. from 0.826 fm^{-1} for ^9Be up to 1.061 fm^{-1} for ^{238}U . As a consequence L values are expected to vary with mass number. Values of $\langle r^2 \rangle^{1/2}$ used in the present calculation have been taken from the recently published compilations of Brown *et al* [12] and Wesolowski [13] which report available experimental data of $\langle r^2 \rangle^{1/2}$ of nuclei ranging between ^4He and ^{238}U . By taking $\alpha = 0.23 \text{ fm}^{-1}$ as reported in [1], and $r_0 = 1.79 \text{ fm}$ as results from an average of different r_0 values reported in the literature, L values have been obtained by making use of (5).

Results are reported in figure 1, where calculated L values (dots) have been plotted against mass number. A regular trend of L increasing with A is clearly observed (an increase of $\sim 45\%$ from lighter to heavier nuclei). The full curve is the result of a least-squares treatment of the L values obtained by the method described above. By imposing the condition $L = 2$ for $A = 2$, it has been found that

$$L = 6.8 - 11.2A^{-2/3} + 5.7A^{-4/3}. \quad (9)$$

The present analysis disregarded only the value of L calculated for ^4He , due to the strong shell effect manifested by such a nucleus.

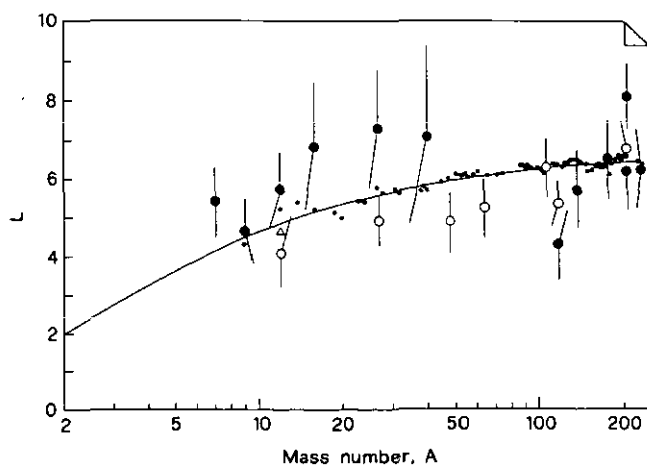


Figure 1. Levinger's constant L plotted against mass number A . The dots represent L values calculated according to Levinger's model as explained in the text. The line is the trend obtained by least-squares fitting of the calculated L values (equation (9)). Full circles represent L values obtained from total nuclear photoabsorption cross section data [14]. Open symbols represent L values deduced from: \circ , data by Stibunov [16]; \triangle , data by Homma *et al* [17, 18].

In order to see the reliability of the present evaluation of L values we report in figure 1 the L data obtained recently by Terranova *et al* [14] (points) from a semi-empirical analysis of total nuclear photoabsorption cross section data [7, 8, 15] as well as data deduced from measurements of a number of effective quasi-deuteron clusters in nuclei [16–18]. Good agreement is indeed found between L values evaluated in the present work and those obtained from a phenomenological fit [14]. Notice that the present evaluation of Levinger's constant represents, to our knowledge, the first attempt to obtain L values of nuclei throughout the Periodic Table directly from the formerly proposed model of nuclear photoabsorption by n - p pairs [1], and not in a phenomenological way.

References

- [1] Levinger J S 1951 *Phys. Rev.* **84** 43
- [2] Rossi P, De Sanctis E, Levi Sandri P, Bianchi N, Guaraldo C, Lucherini V, Muccifora V, Polli E, Reolon A R and Urciuoli G M 1989 *Phys. Rev. C* **40** 2412
- [3] Bethe H A 1949 *Phys. Rev.* **76** 38
- [4] Bethe H A and Longmire C 1950 *Phys. Rev.* **77** 647
- [5] Levinger J S 1960 *Nuclear Photo-Disintegration* (Oxford: Oxford University Press)
- [6] Di Napoli V, Salvetti F, Terranova M L, De Carvalho H G, Martins J B and Tavares O A P 1975 *Gazz. Chim. Ital.* **105** 317
- [7] Leprêtre A, Beil H, Bergère R, Carlos P, Fagot J, Veyssi  re A, Ahrens J, Axel P and Kneissl U 1978 *Phys. Lett.* **79B** 43
- [8] Ahrens J, Borchert H, Czock K H, Eppler H B, Gimm H, Gundrum H, Kr  ning M, Riehn P, Sita Ram G, Ziegler A and Ziegler B 1975 *Nucl. Phys. A* **251** 479
- [9] Tavares O A P, Pinheiro Filho J D, Di Napoli V, Martins J B and Terranova M L 1980 *Lett. Nuovo Cimento* **27** 358
- [10] Levinger J S 1979 *Phys. Lett.* **82B** 181
- [11] Myers W D 1973 *Nucl. Phys. A* **204** 465
- [12] Brown B A, Bronk C R and Hodgson P E 1984 *J. Phys. G: Nucl. Phys.* **10** 1683
- [13] Wesolowski E 1984 *J. Phys. G: Nucl. Phys.* **10** 321
- [14] Terranova M L, De Lima D A and Pinheiro Filho J D 1989 *Europhys. Lett.* **9** 523
- [15] Lepr  tre A, Beil H, Berg  re R, Carlos P, Fagot J, De Mini  c A and Veyssi  re A 1981 *Nucl. Phys. A* **367** 237
- [16] Stibunov V N 1984 *Sov. J. Nucl. Phys.* **40** 1
- [17] Homma S, Kanazawa M, Maruyama K, Murata Y, Okuno H, Sasaki A and Taniguchi T 1980 *Phys. Rev. Lett.* **45** 706
- [18] Homma S, Kanazawa M, Maruyama K, Murata Y, Okuno H, Sasaki A and Taniguchi T 1983 *Phys. Rev. C* **27** 31