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CROSS SECTION: CORRELATION EFFECTS

by

L. Gonzaga Ferreira Filho and M.C. Nemes
Instituto de Física, Universidade de São Paulo

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CROSS SECTION: CORRELATION EFFECTS

L. Gonzaga Ferreira Filho*

and

M.C. Nemes

Universidade de São Paulo

Instituto de Física

Departamento de Física Matemática

C.P. 20516, 01498 São Paulo, SP, Brasil

ABSTRACT

We show that the inclusion of correlation effects in describing the nuclear photoabsorption cross section leads to a Breit-Wigner type curve with energy dependent width. We also show that a very slow energy dependence is enough to reproduce the data up to ~139 MeV.

It has long been known that the total photoabsorption cross section can be well described by a Breit-Wigner type curve with constant width[1] for energies below 25 MeV. However, as the photon energy increases, the curve underpredicts the data, which remain approximately constant up to energies of the order of 140 MeV in lead. The difference between this theoretical curve and the experimental data has been attributed to a different photoabsorption process, i.e., the absorption by a correlated pair of nucleons (the "quasi-deuteron"[2]). The question we should like to address ourselves to is the following: How accurately are the "quasi-deuteron" cross sections extracted from the data in the way described above? The purpose of this letter is to show in a simple model that the line shape of the total photoabsorption cross section can be modified by the inclusion of correlation effects. We show that the leading correlation contribution yields for the cross section a Breit-Wigner type curve with energy dependent width. A fit to existing data for ^{208}Pb shows that even a very slow energy dependence can account for the total nuclear photoabsorption cross section.

We consider a phenomenological model which separates explicitly the collective degree of freedom and considers its interaction with intrinsic (as yet unspecified) degrees of freedom,

$$H = H_c + H_{int} + H'$$

(1)

The physical justification for such a model is based on the fact that giant resonances are highly collective excitations, and therefore it is plausible to consider the collective degree of

freedom as an independent entity. The exact effective dynamics
of a quantum subsystem has been derived elsewhere[3]. If we
linearize the equation corresponding to the effective dynamics
of the collective subsystem and restrict ourselves to the lowest
order in correlation corrections we get for the fluctuation
ρ' ($\rho = \rho_0 + \rho'$; $\delta_0 = 0$)

$$i\dot{\rho}'_{mn} = (\epsilon_m - \epsilon_n)\rho'_{mn} - i \sum_{ij} \int_0^t dt' \, K_{mn;ij}(t-t') \, \rho'_{ij}(t') \qquad (2)$$

with

$$K_{mn;ij}(t-t') = \sum_{k\ell} \int_0^t dt' \Big[\langle c_m I_o | H' | c_k I_\ell \rangle \langle c_k I_\ell | H' | c_i I_o \rangle \, \delta_{nj} \cdot$$

$$\times \exp\big[i(E_o - E_\ell - \epsilon_k + \epsilon_m)(t-t') \big]$$

$$+ \langle c_k I_\ell | H' | c_n I_o \rangle \langle c_j I_o | H' | c_k I_\ell \rangle \delta_{im} \, \exp\big[i(E_\ell - E_o + \epsilon_k - \epsilon_i)(t-t') \big]$$

$$- \langle c_j I_o | H' | I_\ell c_n \rangle \langle c_k I_\ell | H' | c_i I_o \rangle \, \delta_{km} \exp\big[i(E_o - E_\ell + \epsilon_j - \epsilon_n)(t-t') \big]$$

$$+ \langle c_m I_\ell | H' | I_o c_i \rangle \langle c_j I_o | H' | c_k I_\ell \rangle \delta_{kn} \exp\big[i(E_\ell - E_o - \epsilon_i + \epsilon_n)(t-t') \big]$$

$$(3)$$

where $\langle c_i I_j | H' | c_k I_\ell \rangle$ correspond to coupling matrix elements
between unperturbed collective (C_m) and intrinsic states (I_n).
The phases contain unperturbed energies of the collective (small
letters) and intrinsic states (capital letters).

It is a simple matter to verify that the diagonal
matrix elements obey a premaster equation. If we make the

markovian approximation and take the limit $t \to 0$, we obtain
the usual master equation. Now, we should like to calculate
the response function corresponding to an external excitation.
We shall assume for simplicity that the external field will
excite only the collective state. This can be extended to
include other types of excitation e.g., by allowing excitations
of the intrinsic system with the collective state remaining in
its ground state. This could simulate, for example, the
absorption of a photon by a neutron-proton pair as in the
"quasi-deuteron" effect. We shall neglect this in what follows,
assuming that it is small, in order to check how far we can get
with the excitation of the collective state only. The memory
integral in Eq. (3) represents an effect of quantum correlations.
If we make a Laplace transform of Eq. (2), this effect will
manifest itself as an energy dependence. In order to
calculate the photoabsorption cross section we use a simple
model: assume that there are only two possible states of the
collective variable which we call $|c_o\rangle$ and $|c_1\rangle$ corresponding to
the ground state and to an excited dipole state of energy $\hbar\omega_o$,
respectively. With this assumption and the consideration of
the leading contributions of Eq. (2), (3), i.e., transitions
involving matrix elements of the type

$$|\langle c_o I_\ell | H' | c_1 I_o \rangle|^2$$

we get

$$\sigma(\epsilon) = N \, \frac{\epsilon \, \Gamma(\epsilon)}{(\epsilon - \bar{\epsilon}_o)^2 + \Gamma^2(\epsilon)} \qquad (4)$$

where $\Gamma(\epsilon) = 2\pi \sum_{\ell} |\langle c_0 I_\ell | H' | c_1 I_0 \rangle|^2 \, \delta(\epsilon - E_\ell + E_0)$ (5)

$$\bar{E}_0 = \hbar\omega_0 + P \sum_\ell \frac{|\langle c_0 I_\ell | H' | c_1 I_0 \rangle|^2}{\epsilon - E_\ell}$$ (6)

and N is a normalization constant. If the energy dependence of $\Gamma(E)$ is replaced by the collective energy $\hbar\omega_0$, one obtains the usual Breit-Wigner curve, with constant width. This result is equivalent to the one obtained in a picket-fence model, i.e., assuming constant matrix elements and constant level density[4]. We shall adopt the ansatz proposed by M.E. Spina and H.A. Weidenmüller[4], which gives

$$|\langle c_0 I_\ell | H' | c_1 I_0 \rangle|^2 = \omega_0 \, \Omega^{-1/2}(E_\ell) \, \Omega^{-1/2}(E_0) \cdot$$

$$\cdot \exp\left\{-\left[(E_\ell - E_0 - \hbar\omega_0)^2 / 2\Delta^2\right]\right\}$$ (7)

In Eq. (7) ω_0 represents the coupling strength, the factors $\Omega^{-1/2}(E_\ell) \, \Omega^{-1/2}(E_0)$ are inversely proportional to the square root of the level densities and account for the fact that with increasing excitation energy the intrinsic states become more and more complex so that their overlap and therefore the coupling decreases. The gaussian function favours the coupling between states with about the collective energy, Δ being the correlation parameter. For the level density we use, for simplicity

$$\Omega(E) = \Omega_0 \, \exp(\beta E)$$ (8)

With these assumptions we get for the energy-dependent width

$$\Gamma(E) = \omega_0 \, \exp\left(\beta\frac{\bar{E}}{2}\right) \exp\left\{-(E - \hbar\omega_0)^2 / 2\Delta^2\right\}$$ (9)

We fit expression (4) with (9) to the lead data (see fig. 1) and get for the parameters the following values

$$N = 89.25$$

$$\bar{E}_0 = 13.237 \text{ MeV}$$

$$\beta = 0.054 \text{ MeV}^{-1}$$

$$\Delta = 84.12 \text{ MeV}$$

$$\omega_0 = 1.27 \text{ MeV}$$

The value for Δ is very large, which means that in the region of the peak the significant contribution comes from the product of the strength times the level density, as in the case of the picket fence model. This product varies very slowly with energy, as can be seen from the small value of β. In the region of the resonance (E $\leq$ 20 MeV), $\Gamma(E)$ is approximatelly constant, reproducing the usual picket fence model result, as it should. For higher energies $\Gamma(E)$ exhibits a slow energy dependence. The parameter values seem to us therefore reasonable and the quality of the fit indicates that the proper consideration of correlation effects can lead to assymetric curves for the total photoabsorption cross section turning the problem of extracting cross sections for other processes a rather delicate matter. Of course it is not

possible to make a quantitative assignment of the total collective
photoabsorption cross section in a phenomenological model of
this sort. The point we want to emphasize is the influence
correlation corrections can have on the line shape of this
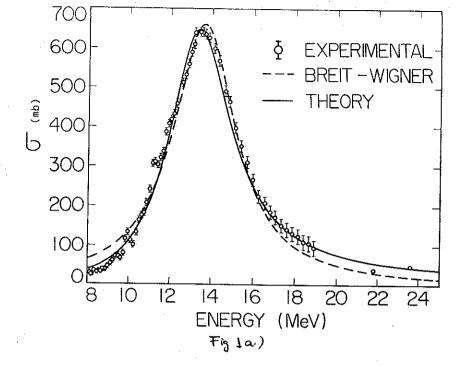cross section.

ACKNOWLEDGMENTS

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Fig. 1a - Total photoabsorption cross section of ^{208}Pb in the
energy range 8-24 MeV. The open circles with error
bars are experimental data from ref. 5. The dashed
line represents a Breit-Wigner with constant width,
the full line, the present theory.

Fig. 1b - Total photoabsorption cross section of Pb in the
energy range 25-130 MeV. The open circles with error
bars are experimental data from ref. 2. The dashed
line represents a Breit-Wigner with constant width,
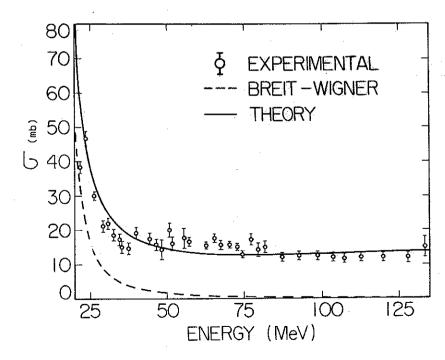the full line, the present theory.

Fig 1a)

Fig 1b)