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KINETIC DESCRIPTION OF THE TOTAL PHOTOABSORPTION CROSS SECTION: CORRELATION EFFECTS

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KINETIC DESCRIPTION OF THE TOTAL PHOTOABSORPTION CROSS SECTION: CORRELATION EFFECTS

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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.

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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,

$$H = H_c + H_{int} + H' \qquad (1)$$

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' ($\rho = \rho_0 + \rho'$; $\dot{\rho}_0 = 0$)

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

with

$$K^{(t-t')}_{mn;ij} = \sum_{k\ell} \int_0^t dt' \Big[\langle C_m I_o | H' | C_k I_\ell \rangle \langle C_k I_\ell | H' | C_i I_o \rangle \delta_{nj} \cdot \exp\left[i(E_o - E_\ell - \epsilon_k + \epsilon_m)(t-t') \right]$$

$$+ \langle C_k I_\ell | H' | C_m I_o \rangle \langle C_j I_o | H' | C_k I_\ell \rangle \delta_{im} \exp\left[i(E_\ell - E_o + \epsilon_k - \epsilon_i)(t-t') \right]$$

$$- \langle C_j I_o | H' | I_\ell C_n \rangle \langle C_k I_\ell | H' | C_i I_o \rangle \delta_{km} \exp\left[i(E_o - E_\ell + \epsilon_j - \epsilon_n)(t-t') \right]$$

$$+ \langle C_m I_\ell | H' | I_o C_i \rangle \langle C_j I_o | H' | C_k I_\ell \rangle \delta_{km} \exp\left[i(E_\ell - E_o - \epsilon_i + \epsilon_n)(t-t') \right] \qquad (3)$$

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 $|c_0\rangle$ and $|c_1\rangle$ corresponding to the ground state and to an excited dipole state of energy $\hbar\omega_0$, 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 $$\Gamma(\epsilon) = 2\pi \sum_{\ell} |\langle c_0 I_\ell | H' | c_1 I_0 \rangle|^2 \, \delta(\epsilon - E_\ell + E_0) \qquad (5)$$

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

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

$$|\langle c_0 I_\ell | H' | c_1 I_0 \rangle|^2 = \omega_0 \, \Omega^{-1/2}(E_\ell) \, \Omega^{-1/2}(E_0) \cdot \exp\left\{ -\left[(E_\ell - \bar{E}_0 - \hbar\omega_0)^2 / 2\Delta^2 \right] \right\} \qquad (7)$$

In Eq. (7) ω_0 represents the coupling strength, the factors $\Omega^{-\frac{1}{2}}(E_\ell)\,\Omega^{-\frac{1}{2}}(E_0)$ 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

$$\Omega(\bar{E}) = \Omega_0 \exp(\beta \bar{E}) \qquad (8)$$

With these assumptions we get for the energy-dependent width

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

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	MeV
β	=	0.054	MeV^{-1}
Δ	=	84.12	MeV
ω_0	=	1.27	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 ($E \lesssim 20$ 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.

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FIGURE CAPTIONS

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.

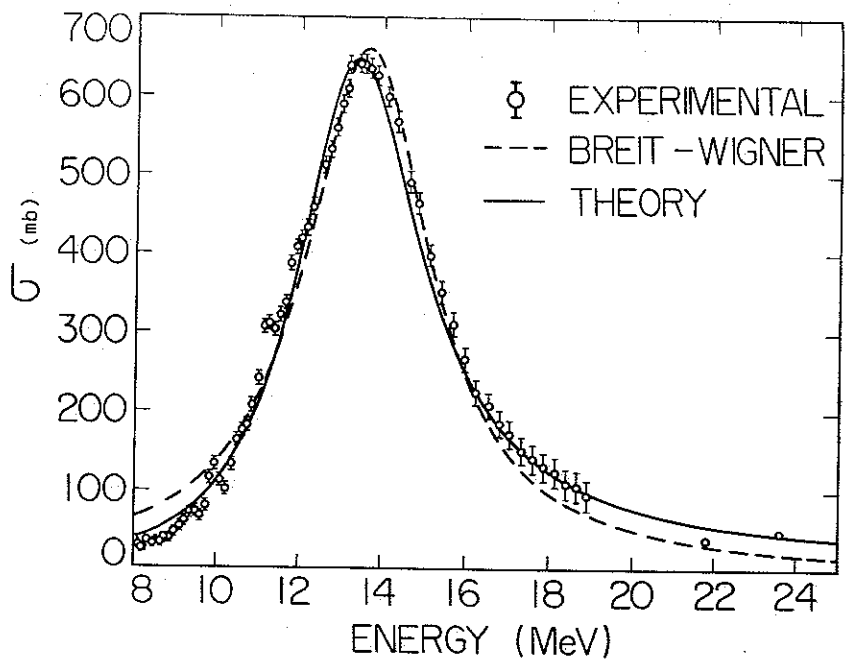

Fig 1a)

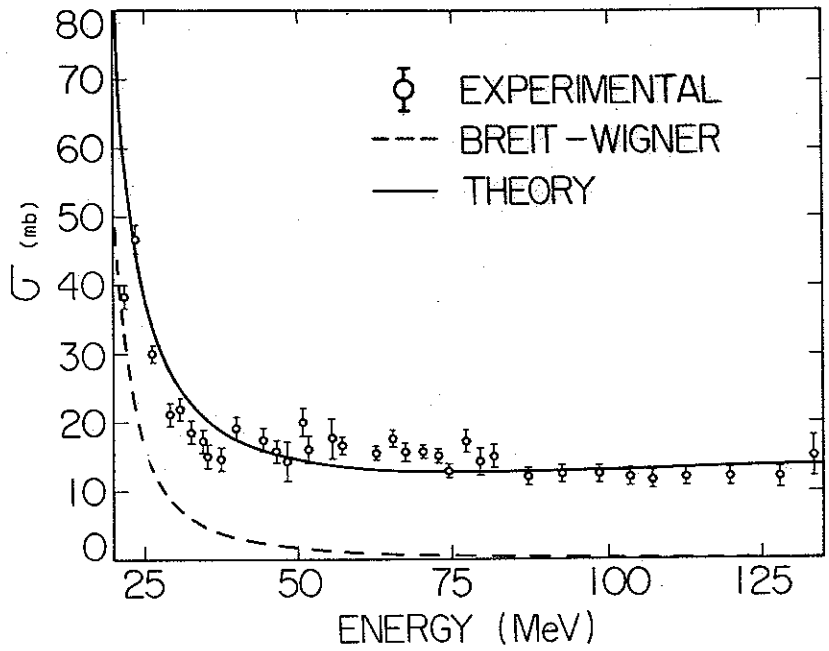

Fig 1b)