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CONFIGURATION MIXING EFFECTS IN ISOSCALAR GIANT DIPOLE RESONANCE* ** ***

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Based on an explicit verification of the coupling matrix elements between the 1p1h and 2p2h states we propose a new method of selecting the most important 2p2h states responsible for fragmentation effects. In this way the dimensionality of the problem is reduced, such that the computation becomes feasible and the spreading of the strength is realistic, as verified by some tests of convergence. Calculations in ^{208}Pb show that due to sizeable mixing effects only about 50% of the total isoscalar giant dipole resonance (ISGDR) $3\hbar\omega$ strength is located in the energy region between 20 and 25 MeV. This is the energy region which currently is available in experiment. Even above 30 MeV we find about 10% of the total strength. This indicates that the current experimental evaluations of the ISGDR centroid energy may significantly underestimate its value.

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In formal terms many interesting nuclear modes of excitation $|f\rangle$, as for instance the nuclear giant resonances, are generated by one-body operators of the type $\hat{f} = \sum_{\alpha\beta} f_{\alpha\beta} a^\dagger_\alpha a_\beta$ such that

$$|f\rangle = \hat{f}|0\rangle = \sum_n \langle n|\hat{f}|0\rangle |n\rangle, \tag{1}$$

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The symbol $|0\rangle$ represents the ground state and $|n\rangle$ the spectrum of eigenstates in a corresponding subspace. For such excitation modes certain global aspects of the strength function

$$S_f(E) = \sum_n S_f(n)\delta(E - E_n), \tag{2}$$

where

$$S_f(n) = |\langle n|\hat{f}|0\rangle|^2, \tag{3}$$

can thus be described in the subspace of one-particle – one-hole (1p1h) ($|1\rangle = a_p^\dagger a_h|0\rangle$) states generated by the nuclear mean field. In the 1p1h subspace we thus have $|n\rangle = \sum_1 c_1^n |1\rangle$. In general, however, such states no longer remain the exact eigenstates when more complex configurations of the npnh-type are taken into account. The 1p1h components of a much larger number of new eigenstates $|n\rangle$ are then spread over many more corresponding new eigenvalues. This is a mechanism of fragmentation. The nuclear interaction is predominantly two-body in nature and thus directly couples the 1p1h states to the 2p2h ones only. Therefore, in practical terms it is enough [1] to diagonalize the nuclear Hamiltonian

$$\hat{H} = \sum_i \varepsilon_i a_i^\dagger a_i + \frac{1}{4}\sum_{ij,kl} v_{ij,kl} a_i^\dagger a_j^\dagger a_l a_k, \tag{4}$$

in the combined space of 1p1h and 2p2h states. In this equation the first term denotes the mean field which in the present work is taken as a local Woods-Saxon potential including the Coulomb interaction. The second term is the residual interaction with antisymmetrized matrix elements $v_{ij,kl}$ and in the following discussion is represented by the density-dependent zero-range interaction of Ref. [2].

The Hamiltonian matrix then reveals the following structure:

$<1\vert\hat{H}\vert 1'>$	$<1\vert\hat{H}\vert 2>$
$<1\vert\hat{H}\vert 2>$	$<2\vert\hat{H}\vert 2'>$

Even after such a truncation the dimension of the above matrix is usually still much too large to be numerically diagonalized. This in particular holds true for the isoscalar giant dipole resonance (ISGDR) [3]. This $3\hbar\omega$ excitation is typically located in the energy region above 20 MeV and the number of relevant 2p2h states is of the order of 10^6. An interesting conclusion can however be drawn from Fig. 1 which shows the distribution of the coupling matrix elements $\langle 1|\hat{H}|2\rangle$ between the 1p1h and 2p2h states in the $J^\pi = 1^-$ sector of the ^{208}Pb nucleus. These states are here generated by the six mean field shells (three above and three below the Fermi surface). As it is clearly seen from Fig. 1 there is only a very small fraction of the coupling matrix elements which significantly differ from zero. This seems to offer an extra criterion for selecting the most important 2p2h states. Thus, by setting a finite positive threshold value $H_{\rm th}$ one can select the 2p2h states such that $|\langle 1|\hat{H}|2\rangle| \geq H_{\rm th}$ for those 1p1h states which carry the strength. Interestingly, an explicit numerical verification shows that even a relatively severe selection according to this prescription on average preserves a form of the distribution of 2p2h states. What in this connection is particularly important is that, as an example in Fig. 2 illustrates, even certain high energy 2p2h states survive selection and thus a possibility to move the strength to higher energies is retained.

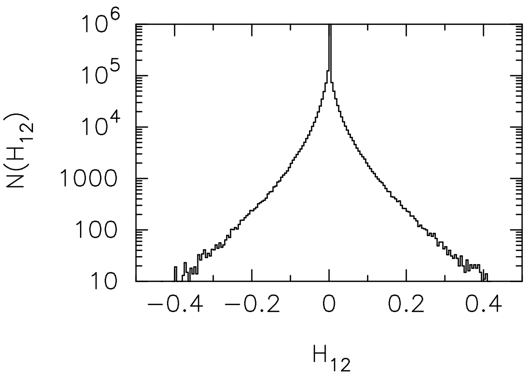

Fig. 1. Distribution of the coupling matrix elements between the 1p1h and 2p2h states for $J^\pi = 1^-$ sector in ^{208}Pb.

We now evaluate the ISGDR strength distribution using a prescription as described above. ISGDR is one of the most interesting nuclear excitation modes. This partly originates from the fact that its centroid energy can directly be related to the nuclear compression modulus [4]. The corresponding one-body isoscalar dipole operator reads:

$$f = r^3 Y_1 - \eta r Y_1, \tag{5}$$

where $\eta = 5\langle r^2\rangle/3$. The second term in this equation removes the spurious center of mass motion component from the operator r^3Y_1 [5]. The resulting $3\hbar\omega$ strength distribution in ^{208}Pb on the 1p1h level is shown in Fig. 3.

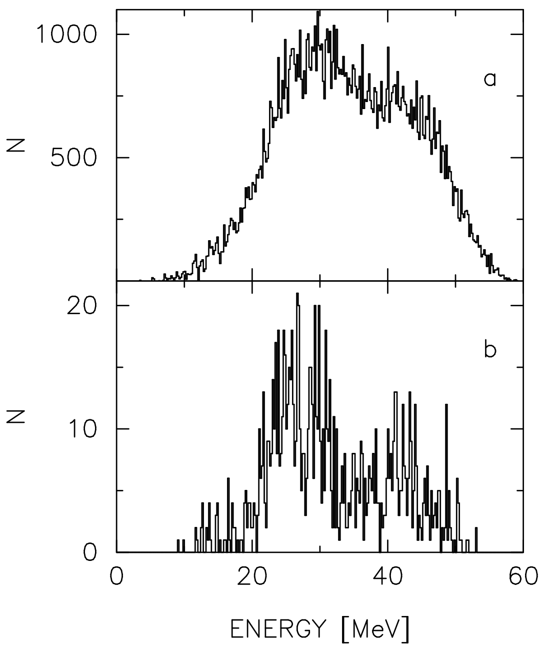

Fig. 2. Energy distribution of all the 2p2h states generated by the six major mean field shells (a). (b) corresponds to those 2p2h states (2) which fulfil the condition $|\langle 1|\hat{H}|2\rangle| \geq 0.3$ MeV. The symbol N denotes the number of states in the bin of energy equal to 0.2 MeV.

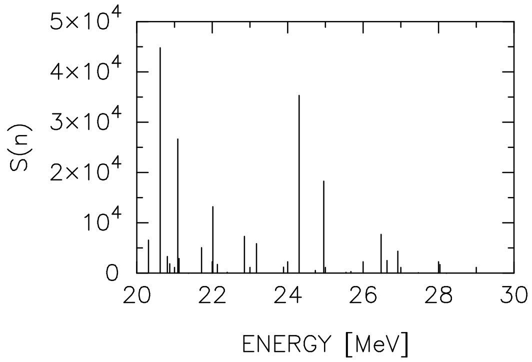

Fig. 3. Isoscalar $3\hbar\omega$ dipole strength distribution in ^{208}Pb calculated in the subspace of 1p1h states.

Almost all this strength is located between 20 and 25 MeV. This about corresponds to the energy region where the isoscalar dipole strength can be identified in the present day experiments on ^{208}Pb [6]. The picture changes however significantly when mixing due to the coupling to 2p2h states is al-

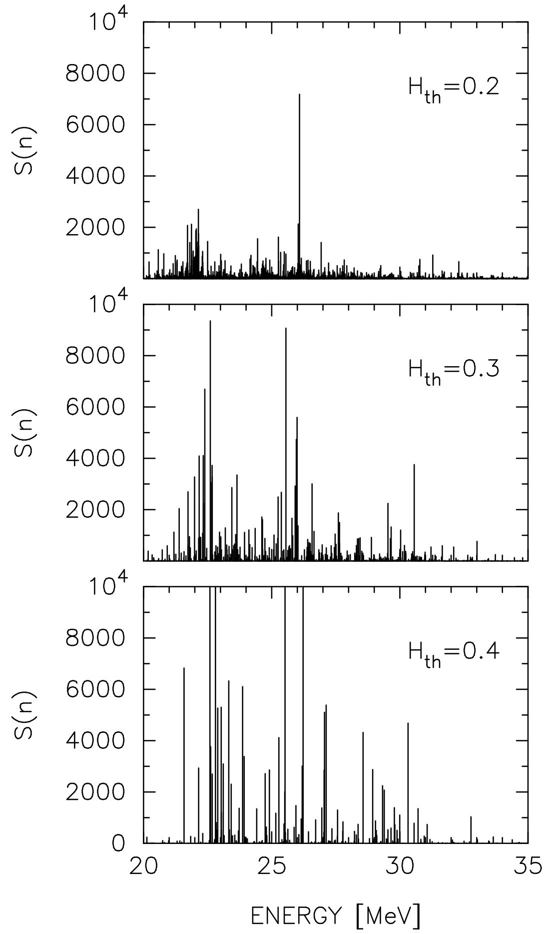

Fig. 4. Isoscalar $3\hbar\omega$ dipole strength distribution in ^{208}Pb calculated in the space of 1p1h and 2p2h states, for three different values of $H_{\rm th}$.

lowed. This is illustrated in Fig. 4 which on the three successive panels indicates a degree of fragmentation for $H_{\rm th}$ = 0.4, 0.3 and 0.2 MeV (from bottom to top). The number of the corresponding 2p2h states included equals 349, 1125 and 4374, respectively. Consistently with our previous investigations [7] a specific form of the resulting strength distribution strongly depends on many factors and thus also on $H_{\rm th}$. However, more global characteristics, like a percentage of the total strength in certain sufficiently large energy windows is much more stable as can be concluded from Table 1 which lists such quantities for energies above 25 and 30 MeV, respectively.

TABLE I

Percentage of the total isoscalar $3\hbar\omega$ dipole strength in ^{208}Pb calculated in the space of 1p1h and 1p1h states in the energy region above 25 MeV and above 30 MeV, respectively, for the three different values of $H_{\rm th}$. The numbers in parenthesis list the corresponding numbers of 2p2h states.

H_{th}=0.2 MeV (4374)		H_{th}=0.3 MeV (1125)		H_{th}=0.4 MeV (349)	
S(E > 25 MeV)	S(E > 30 MeV)	S(E > 25 MeV)	S(E > 30 MeV)	S(E > 25 MeV)	S(E > 30 MeV)
46.9 %	9.2 %	51.9 %	8.7 %	50.3 %	5.7 %

A reasonable convergence of those results, together with a realistic input of the present model, provides quite a convincing indication that one may expect about 50% of the total $J^{\pi} = 1^{-}$ isoscalar $3\hbar\omega$ strength in the higher energy region, above 25 MeV, *i.e.*, in the region which is dominated by many other multipoles and thus this portion of the strength escapes an experimental detection. Even above 30 MeV one finds almost 10% of the total strength. The present calculations thus suggest that a recent empirical estimation [6] of the nuclear incompressibility ($K_A = 126 \pm 6$ MeV) for ^{208}Pb may appear much to low.

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