

The nature of the low energy isovector dipole excitations in neutron rich nuclei

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We investigate the properties of the Isovector Giant Dipole Resonance (IVGDR) in neutron-rich nuclei, in particular the nature of its low-energy components. Studies of properties of the IVGDR in neutron-rich nuclei are important for the understanding of processes occurring in neutron stars and heavy-ion collisions. It is common in the literature to carry out discretized Hartree-Fock (HF)-based random phase approximation (RPA) calculations of the strength function of giant resonances by putting the nucleus in a box [1]. In this case, all single-particle states are bound and have no width. Therefore, all p-h excitations appear as bound excited states. In particular, discretized HF-RPA calculations for the strength function of the IVGDR have been carried out in the past with violations of self-consistency and employing a large smearing parameter. Because of this, small peaks in the RPA response function may have been incorrectly interpreted as low-energy resonances. It is thus important to establish whether these excitations are indeed resonances or are due to threshold effects.

The main way to establish if the small peaks seen in the IVGDR response function obtained in some discretized HF based RPA calculations represent bona-fide resonances is to perform the HF-based Continuum RPA (CRPA) calculations. The Continuum HF-RPA properly accounts for the decay of particles excited beyond the threshold energy [2], whereas the discretized version deals only with bound single particle states. Comparing the results obtained with the continuum calculations with those from the discretized calculations should indicate if these peaks are truly resonance states or not [3].

For the effective nucleon-nucleon interaction we use a simplified Skyrme-type nucleon-nucleon interaction given by

$$V_{ij} = t_0 \delta(\mathbf{r}_i - \mathbf{r}_j) + \frac{1}{6} t_3 \rho^\alpha \left(\frac{\mathbf{r}_i + \mathbf{r}_j}{2} \right) \delta(\mathbf{r}_i - \mathbf{r}_j), \quad (1)$$

where $t_0=1600 \text{ MeV}\cdot\text{fm}^3$, $t_3=12500 \text{ MeV}\cdot\text{fm}^4$ and $\alpha=1/3$. In our RPA calculations we use a Green's Function formalism. The RPA Green's Function is given by [2]

$$G^{RPA} = G^{(0)} (1 + V_{ph} G^{(0)})^{-1}, \quad (2)$$

where V_{ph} stands for the particle-hole (p-h) interaction and $G^{(0)}$ is the bare p-h Green's Function. The nuclear response associated with the scattering operator F is given by

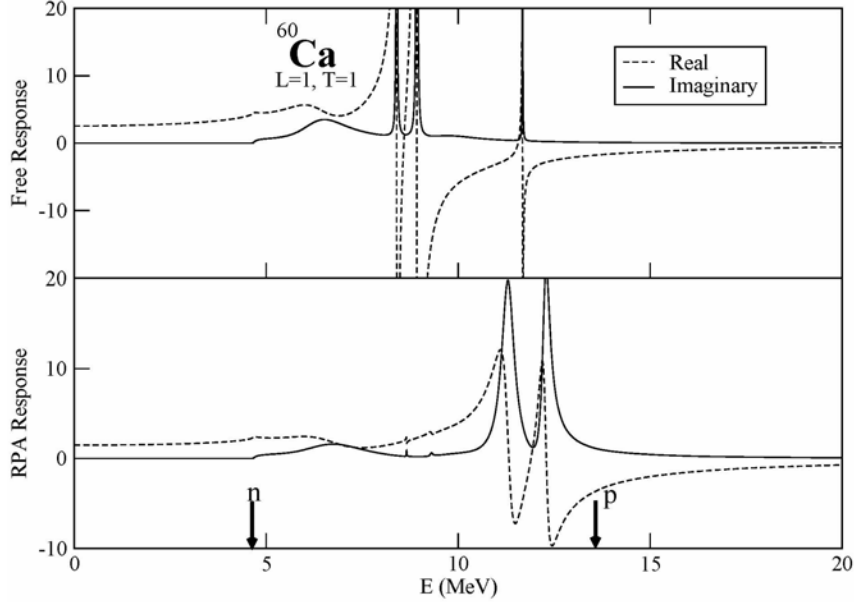
$$S(E) = \sum_n |\langle 0 | F | n \rangle|^2 \delta(E - E_n), \quad (3)$$

where $|0\rangle$ and $|n\rangle$ denote the ground and excited states, respectively. In the Green's Function formalism,

$$S(E) = \frac{1}{\pi} \text{Im}[Tr(fGf)] \quad (4)$$

For a resonance $\text{Im}\langle fGf \rangle$ has a peak at a resonance energy $E=E_R$, and $\text{Re}\langle fGf \rangle$ decreases with E , going through zero at E_R .

The Figure shows the results for $\text{Im}\langle fGf \rangle$ (solid line) and $\text{Re}\langle fGf \rangle$ (dashed line) of the free (top) and CRPA (bottom) response functions for ^{60}Ca . We note that: (i) The neutron and proton separation (threshold) energies are; $S_n=4.674$ MeV, $S_p=13.591$ MeV. (ii) The sharp peaks at 8.398, 8.917 and 11.676 MeV are due to proton bound to bound particle-hole excitations $\pi 0d \rightarrow \pi 0f$, $\pi 1s \rightarrow \pi 1p$ and $\pi 0d \rightarrow \pi 1p$, respectively. (iii) The neutron particle-hole excitations are all to the continuum. The threshold effects of enhancement in $\text{Im}\langle fGf \rangle$ above 4.674 MeV and at around 6 MeV are clearly seen in the figure. (iv) In the RPA excitation strength ($\text{Im}\langle fGf \rangle$) we observe the collective IVGDR above 11 MeV with threshold enhancement at low excitation energies.



[1] N. Paar, D. Vretenar, E. Khan, and G. Colo, Rep. Prog. Phys. **70**, 691 (2007).

[2] S. Shlomo and G. F. Bertsch, Nucl. Phys. **A243**, 507 (1975).

[3] E. Nica, D. C. Fuls, and S. Shlomo (to be published).