POSITIVE PARITY GIANT MULTIPOLE RESONANCES IN $^{16}$O

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Distributions of the $(J^n = 0^+ , 1^+, 2^+, 3^+, 4^+) \text{ isoscalar and isovector strength in } ^{16}\text{O have been calculated in the } n \text{ particle} - n \text{ hole (} n = 0, 1, 2 \text{) shell model. The isoscalar quadrupole giant resonance comes out fragmented over eight peaks which exhaust } 33\% \text{ of the EWSR between } E^* = 17 \text{ and } 25 \text{ MeV. This result agrees nicely with the recent } ^3\text{He and alpha inelastic scattering experiments. Giant monopole isoscalar (isovector) resonance appears to exhaust more than } 50\% \text{ of the EWSR near } E^* = 30 \text{ MeV (} E^* = 40 \text{ MeV). Several collective states of other multipolarities are predicted either near to } 30 \text{ MeV or between } 50 \text{ and } 60 \text{ MeV. The ground state correlations of the } 2p2h \text{ type give rise to a considerable strength redistributions as compared with the case of the closed shell ground state.}

1. INTRODUCTION

It is perhaps the most surprising feature of the particle-hole (ph) model of the closed shell nuclei that it gives rise to collective states with specific and rich structure as a result of mixing very simple configurations. Experimentally such collective states may be excited by a large variety of low- and intermediate-energy projectiles such as photons, $e^-$, p, $^3\text{He}$, ... and e.g. in the capture processes like $\mu^-$- and radiative $\pi^-$-capture from the mesoatomic orbitals.

However different the particular properties of the above reactions may be, their physical universality manifests itself in a uniform response of the nuclear system, namely in the creation of the collective states frequently exhausting a considerable fraction of the respective sum rule (giant multipole resonances). Formally this universality may be traced to the fact that only a few elementary operators

$$Y_{LM} \tau_T, \ [Y_{L'} \cdot \sigma]_{LM} \tau_T,$$

where $\tau_0 = 1$ and $\tau_1 = \tau$ are supposed to mediate such transitions. A possible momentum dependence will be introduced later; $\sigma$ and $\tau$ are the nucleon spin and isospin matrices, the angular momentum coupling is indicated by the square brackets. Though the spherical functions $Y_{LM}$ arise from an infinite expansion of the wave function...
describing motion of the incoming (outgoing) particle of momentum $k$,

\[ e^{-ikr} = 4\pi \sum_{L=0}^{\infty} \sum_{M=-L}^{L} (-i)^L j_L(kr) Y_{LM}^*(\Omega_k) Y_{LM}(\Omega_r), \]

the usual classification into monopole, dipole, quadrupole, \ldots transitions is actually extremely useful, since only a few values of $L$ are allowed when the operators (1) are to describe the excitation of the nuclear states with sharp total spin $J$.

The aim of the present paper is a theoretical search for the collective positive parity excitations in the $^{16}\text{O}$ nucleus as induced by the spin-, isospin-, and momentum-dependent transition operators. We examine in this respect a straightforward extension of the $\text{ph}$ shell model, namely we diagonalize the nuclear residual force within the complete subspaces of the $2\hbar\omega$ configurations. Our interest in the problem was strongly stimulated by the experimental observation of the giant (isoscalar) quadrupole resonance. We devote major attention to this mode. Nevertheless, a possible collectivization of the positive parity $T=1$ states seems also to be of importance in several experimental situations. Such levels are expected to lie at higher energies than the isoscalar ones and the possible candidates in $^{16}\text{O}$ were e.g. observed in electron scattering [1] (structures at 44.5 and 49 MeV) and in the radiative $\pi$-capture where the spin- quadrupole operator $[Y_2, \sigma]_{1+, 2+, 3+}$ should be responsible for the whole upper half of the experimentally observed spectrum [2]. Indeed, this last example involves such high transferred momenta that they cannot be studied quantitatively within the long-wavelength limit. At the same time our approach is appropriate [3] for investigation of the giant magnetic (and spin-flip electric) resonances in backward $e^-$ scattering. Similarly the model may be useful for the separation of isovector and isoscalar modes of the giant quadrupole resonance.

The idea of the possible existence of the spin-, isospin- and spin-isospin-resonances goes back to the early sixties [4]. In $^{16}\text{O}$ such states were sought within the Tamm-Dancoff and random-phase approximation (1p 1h) by ELLIS and OSNES [5]. Most recently LIU and BROWN [6] considered collective excitations in several closed shell nuclei including $^{16}\text{O}$ in an RPA-like model based on a specific choice of the nuclear interaction. The Skyrme potential, which is in fact a delta-shaped potential, has allowed them to include a large configuration space (1p−1h) via the response function technique.

Our approach is rather to keep a general nuclear interaction to avoid the inaccuracies in this sector. Simultaneously we are interested in the spreading of the collective states by coupling of the 1p1h and 2p2h configurations. In this respect and for the $E2$ excitations, our work is parallel to that by KNÜPFER and HUBER [7], and HOSHINO and ARIMA [8]. Unlike them, however, we consider a wide class of isoscalar and isovector transition modes. The results change critically with the inclusion of the ground state correlations omitted in the mentioned papers and exhibit an unexpectedly [7] strong dependence on several single particle energy parameters. Also, we argue that phenomenological interactions used in refs. [7] and [8] may prove to be