Isospin fragmentation of pairing vibrations

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The random-phase-approximation formalism with good isospin, developed previously for the particle-hole excitations, is extended to the two-particle and two-hole excitations. It is found that the effect of the isospin symmetry on the normal pairing vibrations is of minor importance. In contrast, the giant pairing vibrations are always split among the isospin components. As an illustration we discuss the experimental results for the ^{112}Sn(p,t) reaction.

The aim of this Brief Report is to call attention to the isospin structure of the pairing vibrations.

It has already been known for some time that the particle-hole and particle-particle excitations are formally related to each other.[1] However, only recently two very important features of the particle-hole vibrations have been extended to the particle-particle vibrations. These are: (i) the macroscopic description of the two-particle transfer reactions proposed by Dasso and Pollarolo[2] and (ii) the study of giant pairing resonances (GPR) performed by Herzog *et al.*[3] On the other hand, although the isospin structure of the particle-hole vibrations has been thoroughly discussed in the literature,[4–20] there is no similar discussion on the pairing vibrations available.

As a matter of fact it has been well established that the total isospin is a fairly good quantum number even for heavy nuclei, where the Coulomb interaction plays a relatively important role. One of the best examples, in nuclei with ground-state isospin $T_0=\frac{1}{2}(N-Z)>0$, is the fragmentation of the particle-hole excitations (e.g., giant electric-dipole and Gamow-Teller resonances) among multiplets with different total isospin T. It is also now well known that the subspace of one-particle–one-hole (1p-1h) states is not always characterized by a definite isospin and that it is necessary to include the 2p-2h and 3p-3h configurations in order to retrieve the isospin symmetry. Within this context a random-phase-approximation (RPA) formalism with good isospin, based on the method of the tensor equation of motion, has been developed.[12,13,19] In this formalism, it is not necessary to consider explicitly the higher-order particle-hole configurations, and the matrix elements with good isospin are related to the 1p-1h matrix elements with different M_T.

A quite similar situation occurs in the case of two-particle or two-hole excitations. It means that when $T_0>0$, these excitations do not possess in general a definite isospin and it is necessary to take into account more complicated configurations (such as 3p-1h, 4p-2h, etc.) in order to build up states with good isospin. At the same time, and as a consequence of the isospin symmetry, the pairing vibrations should also be fragmented into states with total isospin $T=T_0-1, T_0$, and T_0+1. Below we will show in which way the formalism developed in Ref. 19 can be straightforwardly applied to two-particle or two-hole excitations. That is, also in this case, the matrix elements with good isospin are obtained from the two-particle or two-hole matrix elements with different M_T, and it is not necessary to worry about more complicated configurations. As in Ref. 19 the single-particle states are divided into (a) the filled orbitals (f), completely filled for both neutrons and protons; (b) the valence orbitals (v), filled only for neutrons; and (c) the empty orbitals (e), containing neither neutrons nor protons.

The possible two-particle or two-hole configurations for different M_T values and the corresponding isospins are shown in Fig. 1. In the same figure are also displayed the analogous particle-hole excitations. Only the configurations totally aligned with respect to isospin, that is, those shown in the first, fourth and sixth lines, posses a well-defined isospin T. All the remaining excitations give rise to isospin fragmentation. It means that the two-proton-particle and two-neutron-hole excitations will be split among all three isospin components; the neutron-proton vibrations should exhibit a doublet with $T=T_0$ and $T=T_0+1$, while the two-neutron-particle and two-proton-hole excitations carry only the isospin $T=T_0+1$. The fragmentation of the unperturbed two-particle strengths is illustrated in Fig. 2. The analogous figure for a particle-hole system was presented in Ref. 17. Within the formalism developed in Ref. 19, the matrix elements with good isospin are obtained from the matrix elements of the configurations indicated by arrows. In order to apply the results presented in that work to the pairing vibrations, the following modifications are pertinent: (1) The particle-hole single-particle energy difference $\epsilon\equiv\epsilon_\nu(j_p)-\epsilon_\nu(j_h)$ should be replaced by $\epsilon_\pi(j_p)+\epsilon_\nu(j_p)$ and by $-\epsilon_\pi(j_h)-\epsilon_\nu(j_h)$, for the two-particle and two-hole excitations, respectively; (2) the particle-hole matrix element $F(j_1j_2,j_1'j_2';\lambda t)$ should be substituted by the corresponding particle-particle matrix element $G(j_1j_2,j_1'j_2';\lambda t)$; and (3) the transition multipole operator $M(\lambda m_t)$ should be replaced by the two-particle transfer operator $P(\lambda m_t)$. All the notation is the same as in Ref. 19.

The normal pairing vibrations are dominantly built up from configurations which lie close to the Fermi level, and therefore the fragmentation of the transfer strength

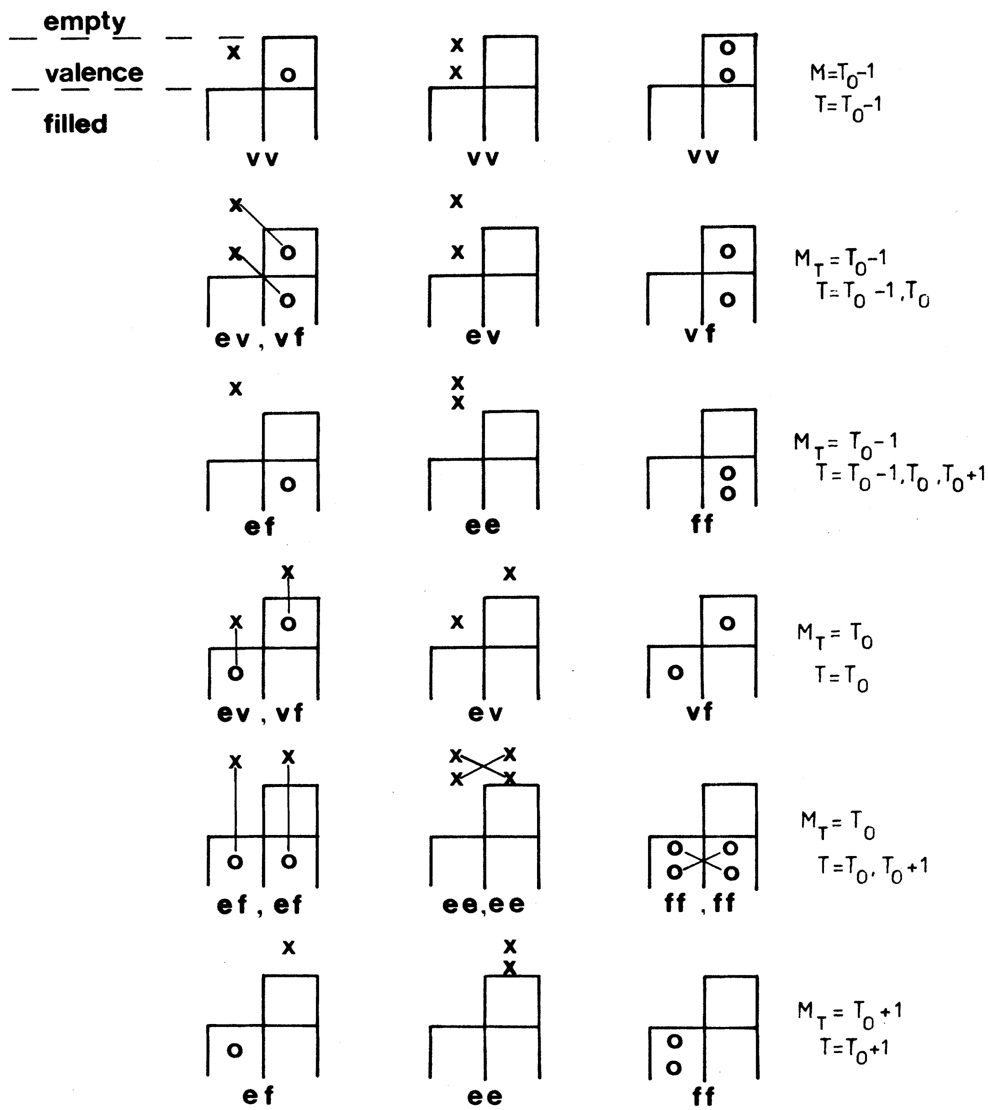

FIG. 1. Correspondence between particle-hole, particle-particle, and hole-hole excitations. Particles are represented by crosses (×) and holes by circles (o). The possible values of the total isospin T for each set of configurations are indicated below the corresponding M_T values.

among isospin components is of minor importance in this case. In contrast, the GPR arises from the clustering of high-lying single-proton-particle or deep-lying single-neutron-hole states, and its transfer strength will always be split among two or three isospin components.

Deep neutron-hole strengths have been studied in a variety of single transfer reactions from the Zr region to the Pb region.[21] The feature observed was a broad structure and sharp isobaric analog states ($T_>$ states) embedded into an underlying background. Broad bumps were also observed in a systematic study of the (p,t) reaction on even $^{112-124}$Sn isotopes.[22] In this work it is concluded that the bumps contain states with many different angular momenta J, and that it is not possible to definitively distinguish between the possibilities of both particles being picked up from deep holes or only one particle from a deep hole with one valence particle. These are two-neutron-hole configurations of the filled-filled (ff) and filled-valence (fv) types, respectively. Therefore, as indicated in Figs. 1 and 2, the transfer strength will be fragmented at least among two isospin components with $T=T_< \equiv T_0-1$ and $T=T_> \equiv T_0$. By increasing T_0, the energy splitting between the $T_<$ and $T_>$ states is also increased, but the $T_>$ component loses strength. More-

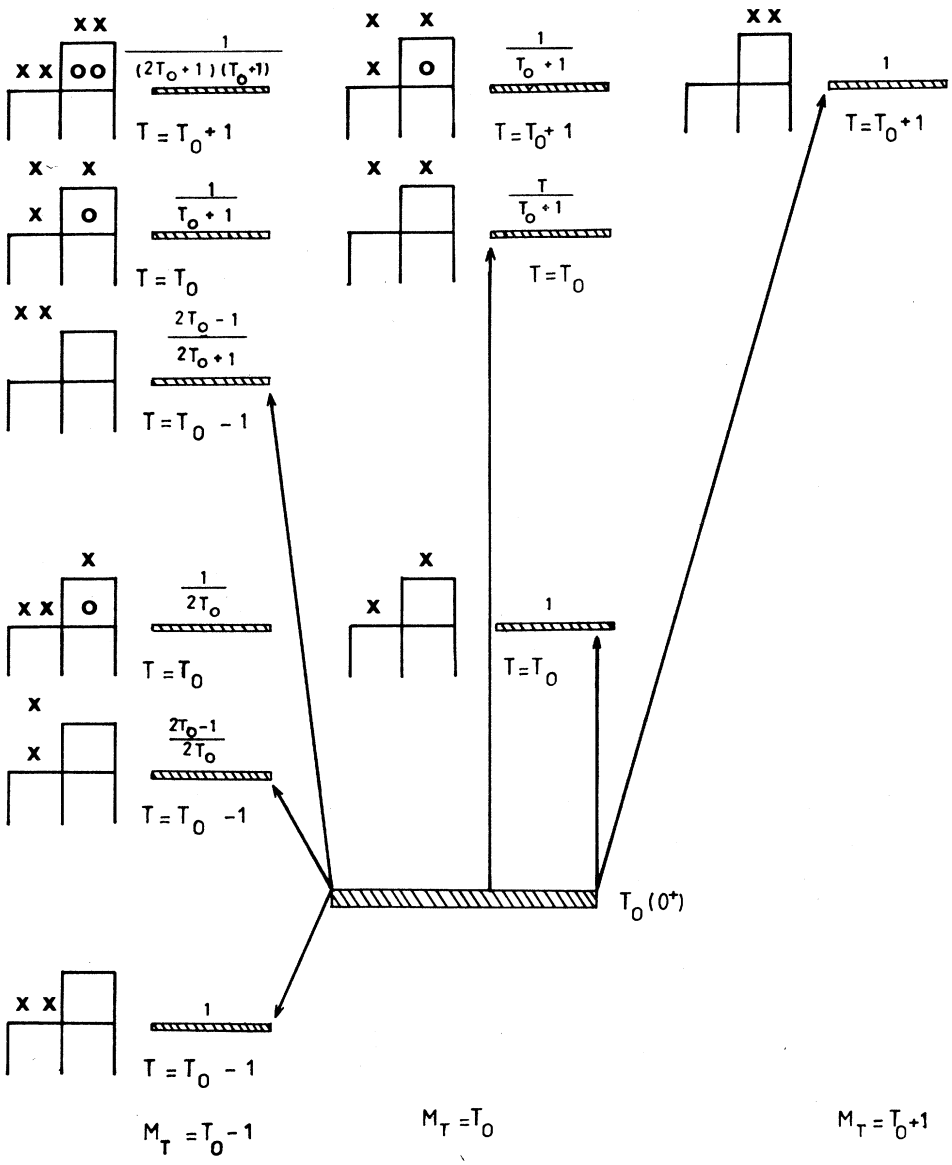

FIG. 2. Two-particle excitation scheme with good isospin. Only the isovector excitations are shown. States with the same T and different M_T are arranged at the same height. Below and above each state are depicted, respectively, the isospin and the fraction of the unperturbed transition strength. The main configuration for large T_0 is joined with the ground state T_0 (0^+) by an oriented line.

over, a rough estimate based on the calculations performed in Ref. 18 leads to the result that in the ^{110}Sn nucleus the energy separation between the $T_<$ and $T_>$ components should be of the order of 2 MeV, and that the $T_>$ states carries $\sim 10\%$ of the total transfer strength. This estimate is rater independent of the value of J. Thus the experimental results on the ^{112}Sn$(p,t)^{110}$Sn reaction may suggest that the second bump observed at $\simeq 9$ MeV is the $T_>$ isospin component of the first bump which lies at 7.15 MeV.

In conclusion, we have studied the fragmentation of the two-particle transfer strength due to the isospin symmetry. In addition, we advance an interpretation for structures observed in a ^{112}Sn(p,t) experiment. A systematic experimental search for the $T_>$ isospin component of the GPR in medium-weight nuclei will be highly welcome in order to test the ideas presented here, as well as to stimulate further theoretical studies.

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