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DIRECT vs STATISTICAL DECAY OF NUCLEAR GIANT MULTIPOLE RESONANCES*

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Abstract A theoretical framework for the description of the decay of giant multipole resonances is developed. Besides the direct decay, both the preequilibrium and statistical (compound) decays are taken into account in a consistent way. It is shown that the statistical decay of the GR is not necessarily correctly described by the Hauser-Feshbach theory owing to the presence of a mixing parameter, which measures the degree of fragmentation. Applications are made to several cases.

The study of the decay properties of giant multipole resonances (GR) is of paramount importance for the unraveling of their dynamical, microscopic structure. Since giant resonances are located at high excitation energies, they mainly decay by particle emission. Treated as isolated resonances, the GR are characterized by a total average width composed of two pieces: the "escape width", $\Gamma^{\uparrow}$, which represents the coupling of the GR to the continuum, and the spreading width, $\Gamma^{\downarrow}$, that measures the degree of fragmentation of the strengh due to coupling to complex intrinsic nuclear configurations (e.g. 2p-2h)[1,2]. Of course, whereas the first stage of the reaction, namely the giant resonance population, is a very coherent process, in which 1-particle 1-hole configurations act in phase, the other, more complicated stages, are complex enough to call for a statistical treatment.

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It has so far been a common practice to analyze the particle spectra originating from the decay of GR with one of two extreme models, which ignore completely the intermediate, pre-equilibrium stages[3,4]. These models either assume the dominance of $\Gamma^{\uparrow}$, namely the GR decays predominantly "directly", or the predominance of $\Gamma_{H.F.}$, which imlies necessarily that the fragmentation of the resonance into the complex background is complete. In this last case the Hauser-Feshbach theory is utilized in the analysis[4].

Recently a combination of both decay mechanisms has been suggested by Beene et al.[5] in their analysis of the gamma decay of the giant quadrupole resonance of ^{208}Pb. These authors write for the gamma branching ratio P, the following

$$P = P_d + P_c = \frac{\Gamma^{\gamma}_{GR}}{\Gamma^{\downarrow}} + \left\langle\frac{\Gamma^{\gamma}_{c}}{\Gamma_c}\right\rangle \tag{1}$$

The notation in Eq. (1) is obvious. After making the reasonable approximation $\langle\Gamma^{\gamma}_{c}/\Gamma_c\rangle \cong \langle\Gamma^{\gamma}_{c}\rangle/\langle\Gamma_c\rangle$, Beene et al. then proceed with the calculation of this term utilizing experimentally deduced neutron strength functions from resonance studies in the system n+^{207}Pb. Their aim was the estimation of the compound nucleus average width $\langle\Gamma_c\rangle$ since $\langle\Gamma^{\gamma}_{c}\rangle$ is basically known.

A more convenient approach was adopted by Dias et al.[6] throught the identification

$$2\pi \langle\Gamma_c\rangle \rho_c = \sum_{\alpha} T_{\alpha} \tag{2}$$

where T_{α} is the neutron transmission coefficients, and ρ_c is the compound nucleus density of states. The neutron channel is certainly the dominant one at the excitation energy considered, namely $E^* = 11$ MeV. The result of the calculation of Ref. 6 is that $\Gamma_c(E^*=11\ \mathrm{MeV},2^+) \simeq 8.5$ keV. This is about an order of magnitude larger than the value obtained by Beene et al.[5].

Irrespective to the different starting points of Beene et al.[5] and Dias et al.[6], their final conclusion comes out basically the same, namely that the compound nucleus contribution to P, namely $P_c \equiv \langle\Gamma_c^{\gamma}\rangle/\langle\Gamma_c\rangle$ is quite appreciable and corresponds roughly to about 40%. The above example is but one of several showing the necessity of considering both direct and compound decay mechanisms of the GR. In fact another case studied recently by our group[7], namely the fission decay probabilities of the giant quadrupole and monopole resonances in ^{236}U through the (γ,f) reaction, also exhibit this feature at E_γ above the fission threshold.

The above findings motivated us to develop a detailed theory of the decay of nuclear giant resonances. Such a theory[8] goes beyond the one underlying Eq. (1) in the sense that we take P_G and P_c as not completely independent due to the presence of a mixing parameter which measures the degrees of fragmentation of the GR into the complex compound nucleus background. Unitarity as well as some basic ideas borrowed from pre-equilibrium studies[9] have been used to obtain the major result of our theory namely the following expression for the energy averaged partial cross section.

$$\bar{\sigma}_{ab} = \bar{\sigma}^G_{ab} + \mu\tau^G_a \frac{\tau^C_b + \mu\tau^G_b}{\Sigma_c(\tau^C_c + \mu\tau^G_c)} \tag{3}$$

where the first term corresponds to the short-time-delay component of the process, usually called the "direct" contribution, and the second being the long-time-delay component, invariably called the "compound" contribution. This compound contribution is clearly different from the usual Hauser-Feshbach form, owing to the presence of the mixing parameter μ and two kinds of transmission coefficients; the GR one, τ^G, and the genuine compound one, τ^C. Dividing by τ^G_a, we obtain the equivalent to Eq. (1)

$$P = P_d + \mu\frac{\tau^C_b + \mu\tau^G_b}{\sum_c \tau^C_c + \mu\tau^G_c} \qquad (4)$$

Clearly the expression for P_c is more involved than the simple one used earlier for the analysis of the γ-decay of the in ^{208}Pb.

A careful analysis employing Eq.(4), could furnish important information about the mixing parameter μ. As an example we show in Fig. 1 an analysis performed on the neutron decay spectrum from the E0 giant resonance in ^{208}Pb[4].

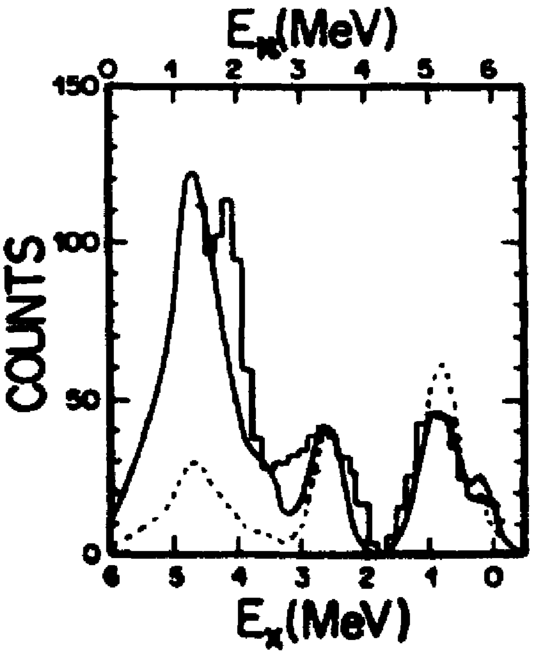

FIGURE 1. The histogram is the measured neutron decay spectrum from the ^{208}Pb (Ref. 4). The two curves shown by the full line (μ=1) and dashed line (μ=0.5) are the predicted spectrum using equation 6 taking into account the resolution of the experiment (500 keV). Each of the 141 neutron groups is represented by a gaussian with FWHM=500 keV (see Ref. 4 for more details). Both spectra (μ=1 and μ=0.5) are normalized to the number of neutrons in the interval between 3-4 MeV.

Two values of μ were considered, $\mu=1$ and $\mu=0.5$. The direct piece of the decay was estimated using the result of Kuchnir et al.[10] and de Haro et al.[11], whereas the statistical piece was calculated in accordance with Eq. (4) using for τ_b^C the Hauser-Feshbach model. Clearly for $\mu=1$ a renormalization of the calculation of Ref. 4 has to be made in order to account for the "indirect" CN decay exemplified by $(\mu-1)\tau_c^G$, whose value was taken to be $2\pi\,\Gamma_b^G\,\rho_G$ with $\rho_G \equiv \mathrm{MeV}^{-1}$. It is obvious from the figure that the GMR in ^{208}Pb does not accomodate appreciable direct decay piece since the more likely case is $\mu=1$, in complete agreement with the conclusions of Ref. 4. Analysis of cases which clearly contain both compound and direct contributions are being carried out by our group using Eq. (3).

Before ending, we dwell a little on a possible generalization of Eq. (3) to incorporate the contribution arising from pre-equilibrium emission (e.g. from the 2p-2h stage). This is easily accomplished using the nested doorway approach of Ref. 9. The important new features are that the cross section is now composed of three distinct pieces, and the mixing parameter μ is divided into three terms. Namely[9,12].

$$\bar{\sigma}_{ab}=\sigma_{ab}^{G}+(1-\mu_2)\mu_1\tau_a^G\,\frac{\tau_b^{Pr}+\mu_1\tau_b^G}{\sum_{c''}(\tau_{c''}^{P}+\mu_1\tau_{c''}^{D})}$$

$$+\;(\mu_1\mu_2+\mu')\tau_a^G\,\frac{\tau_c^C+\mu_2\tau_b^{Pr}+(\mu_1\mu_2+\mu')\tau_b^G}{\sum_c(\tau_c^C+\mu_2\tau_c^{Pr}+(\mu_1\mu_2+\mu')\tau_c^G)} \qquad (5)$$

with

$$\sigma^{G}_{ab} = (1-\mu_1-\mu')\tau^{G}_{a}\frac{\tau^{G}_{b}}{\sum_{c}\tau^{G}_{c}}$$

In the above μ_1 measures the mixing of GR with the 2p-2h states, which can be evaluated using the extended RPA approach, μ_2 refers to the mixing of the 2p-2h with the compound nuclear states and μ' refers to the mixing of the GR directly with the compound states, which may be set equal to zero for all practical purposes. The transmission coefficient related to the GR (1p-1h), the pre-equilibrium stage (2p-2h) and the compound stage are called τ^{G}, τ^{Pr} and τ^{C}, respectively. It is important to note here that unitarity is preserved both in Eqs. (3) and (5) in the sense that by summing over the final channels b, we obtain

$$\sum_{b}\bar{\sigma}_{ab} = \tau^{G}_{a} \qquad (6)$$

irrespective of the detailed nature of the decay.

Using our time-delay arguments again, we identify the third term in Eq. (5) with the "compound" contribution. The calculation of this term is certainly not possible wiht the Hauser-Feshbach model, as one has to differentiate among the three types of transmission coefficients. We are presently studying the feasibility of applying Eq. (5) for data analysis.

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