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SUM RULE APPROACH TO THE STUDY OF STATISTICAL DECAY PROPERTIES OF NUCLEAR GIANT RESONANCES

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ABSTRACT

Corrections to the well-known statistical sum rule that relates the summed transmission coefficients on the one hand and $2\pi\Gamma_{\text{Comp.Nucl.}} \cdot \rho_{\text{Comp.Nucl.}}$ on the other, in the context of the statistical decay properties of nuclear giant resonances, are discussed. These corrections arise both from pre-equilibrium processes as well as from the giant resonance itself. It is shown that the C.N. average width is reduced as a result of these corrections.

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The theoretical description of the decay of nuclear giant multipole resonances (GR) has been so far done with one of two extreme models. These models either assume the dominance of the direct decay, exemplified by the GR escape width, $\Gamma\uparrow$, or the predominance of the statistical decay mode exemplified by the Hauser-Feshbach decay width $\Gamma_{H.F.}$ (the decay width of the statiscally equilibrated compound nucleus)[1]. Quite recently, however, attempts have been made to combine these two modes of decay into a mixed direct-compound model[2),3),4)].

Whereas in the work of Beene et al.[2)] and the closely related paper of Dias et al.[3)], the decay probability of the GR, P_{GR} is written simply as

$$P_{GR} = P_{GR}^{D} + P_{GR}^{C} \tag{1}$$

with P_{GR}^{D} and P_{GR}^{C}, the direct and compound probabilities, respectively, being completely independent of each other, the work of Dias, Hussein, and Adhikari (DHA)[4)] clearly identifies the physical inter-relation between P^D and P^C through a mixing parameter, μ, which measures the degree of fragmentation of the GR into the more complex compound-nucleus configurations. The full implementation of the theory developed in Ref. (4), however, requires first a qualitative assessment of the relative importance of P^D and P^C. In particular, P^C, which when treated completely independently of P^D, can be estimated using the statistical theory of nuclear reac..ions, has been given special attention in Refs. (2) and (3).

In the analysis of the decay of the giant quadrupole resonance in ^{208}Pb of Refs.(2) and (3), the quantity P^C was required. Of particular interest was the life time (or inverse average width) of the compound nucleus, assumed coupled to the GQR. This width, $\Gamma_{C.N.}$, was evaluated in Ref. (3) using the following relation

$$\Gamma_{C.N.} = \frac{1}{2\pi\,\rho_{C.N.}}\,Tr(T) \quad , \qquad (2)$$

where $\rho_{C.N.}$ is the density of states of the compound nucleus in the excitation energy region of the GR and T is the transmission coefficient (matrix), representing the optical coupling between the open channels and the C.N..

In principle the use of Eq. (2) should supply a reasonably precise value of $\Gamma_{C.N.}$. However the evaluation of $Tr\,T$, with T generated from optical model potential which fit elastic scattering, as was done in Ref. (3), may be inconsistent. The reason being that pre-equilibrium emission contribution, changes the sum rule, Eq. (2) in such a way as to establish equality between $\Gamma_{C.N.}$ and $(2\pi\rho_{C.N.})^{-1}\,Tr\,T$, with T now containing a pre-equilibrium piece.

The purpose of this short note is to discuss the above point and give an estimate of the error made in the

evaluation of $\Gamma_{C.N.}$ (as done in Ref. (3)), when pre-equilibrium emission is not taken into account in Eq. (2).

The correct sum rule which substitutes Eq. (2) was obtained several years ago by Hussein[5] and McVoy and Tang[6]. It reads the following

$$Tr\,T = \sum_n 2\pi\,\Gamma_n\,\rho_n \qquad (3)$$

where $\Gamma_n = \hbar/\tau_n$ with τ_n representing the life time of stage n in the equilibration sequence, ρ_n the corresponding density of states, and T is again the optical transmission coefficient. Thus, for example, the compound nucleus width in the case of just one pre-equilibrium emission stage (2p-2h) is related to $Tr\,T$ according to

$$\Gamma_{C.N.} = \frac{1}{2\pi\,\rho_{C.N.}}\left[Tr\,T - 2\pi\,\Gamma_{2p-2h}\,\rho_{2p-2h}\right] ,$$

or

$$\Gamma_{C.N.} = \frac{1}{2\pi\,\rho_{C.N.}}\,Tr\left[T\left(1 + \frac{\Gamma_{2p-2h}}{\Gamma_{C.N.}}\,\frac{\rho_{2p-2h}}{\rho_{C.N.}}\right)^{-1}\right] . \qquad (4)$$

The presence of the factor multiplying T should therefore reduce the value of the extracted $\Gamma_{C.N.}$. This reduction could be as large as 20% . Of course Eq. (4), as stands, is not so useful since $\Gamma_{C.N.}$ appears on both sides. However it can still be used, iteratively, to supply a more precise $\Gamma_{C.N.}$ than that extracted from Eq. (2).

A second correction to Eq. (2) arises from the contribution of the GR itself, namely since the GR is coupled to several final channels as well as to the entrance channel the optical transmission coefficients, e.g., for neutrons, γ, p, α, etc. should be affected. The contribution of the GR can be estimated through the use of a Lorentzian form of that piece of T connected with the GR. Upon averaging this Lorentzian one gets[4], again taking into account only the 2p-2h pre-equilibrium contribution

$$\Gamma_{C.N.} = \frac{1}{2\pi\rho_{C.N.}} \text{Tr}\, T \left[1 + \frac{\Gamma_{2p-2h}}{\Gamma_{C.N.}} \frac{\Gamma_{2p-2h}}{\rho_{C.N.}} + \frac{\Gamma^{\dagger}_{GR}}{\Gamma_{C.N.}} \frac{\rho_{G.R.}}{\rho_{C.N.}}\right]^{-1} \tag{5}$$

where $\Gamma^{\dagger}_{GR}$ is the escape width of the GR and $\rho_{G.R.}$ is about 1 MeV^{-1}. Thus, a further reduction in the value of $\Gamma_{C.N.}$ results when the GR is taken into account according to Eq. (5).

In conclusion, we have discussed in this paper several corrections to the well known statistical sum rule that relates the summed transmission coefficients on the one hand and $2\pi\Gamma_{C.N.}\rho_{C.N.}$ on the other, quite relevant in the study of the statistical decay of giant resonances in nuclei. These corrections arise both from pre-equilibrium channels as well as from the GR itself. The GR contributes, at most, to present effect in the sum rule. However, the pre-equilibrium correction may be as large as 20%. Thus care must be taken when applying the sum rule, Eq. (2), to the giant resonance decay studies.

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