Can We Generalize the Giant Resonance Idea?*

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The term "the giant resonance" is usually considered a synonym for "the giant electric dipole resonance" (GDR) which has been the subject of many investigations over the past several years. But we might reconsider the fact that historically this nuclear synonym is the product of our empirical methods, not of theoretical speculation. Suppose we define a giant multipole resonance (GMR) as any nuclear state (or group of overlapping states) which exhausts at least 50% of the energy weighted sum rule (EWSR) strength allowed for that multipole and type (isoscalar or isovector) of excitation. The GDR, of course, conforms to this definition since the dipole strength is not absorbed by the low-lying or bound states of nuclei and therefore may be concentrated in a continuum resonance.

It is usually not realized, however, that the dipole states are not unique in this property. For example, in the table below are listed the results of recent measurements in which the bound states of ^{40}Ca ¹ and ^{208}Pb ² have been examined for their depletion of collective multipole sum rule strengths.

Table 1. Examples of isoscalar multipole strengths found in "bound" states of ^{40}Ca , ^{208}Pb

nucleus \ multipole	0	1	2	3	4	5	6	7	8
^{40}Ca	≈0%	≈0%	14%	38%	7.2%	11%	1.3%	0.2%	≈0%
^{208}Pb	≈0%	≈0%	16%	47%	14%	3.3%	3.1%	≈1.8%	≈1.3%

It is clear from the percentages of EWSR exhausted by the bound states in these nuclei that any multipole could exhibit a resonance in the nuclear continuum which would satisfy the above GMR definition.

The possibility of observing any GMR depends upon (a) the total (spreading) width of the resonance, and (b) experimental techniques which can excite, with multipole selectivity, the various collective states. The resonance width is determined by the dispersion of the collective (particle-hole) eigenstates and upon the mixing (damping) of these p-h states with background (2p-2h) states. There are empirical reasons³ to believe that the latter consideration is the most important and that $\Gamma \sim E^3$ where E is the excitation energy of the resonance. Following Mottelson's argument⁴ we might assume the harmonic oscillator approximation for the p-h states which characterize a vibration with angular momentum L. Then the selection rule follows that $E_L \leq \hbar\omega + \Delta E$, for $L \geq 1$, where $\hbar\omega \approx 41A^{-1/3}$. The effects of the residual interactions qualitatively decrease ($\Delta E_s < 0$) the isoscalar oscillation energy and increase ($\Delta E_v > 0$) the isovector energy. Consequently two difficulties ensue: (1) only the GMR with relatively low L will have small enough Γ to be distinctly observed, otherwise $\Gamma > \hbar\omega$ and extreme multipole selectivity is experimentally required, (2) isoscalar oscillations with multipole L will tend to overlap with isovector oscillations $L \sim 1$.

In the photoexcitation experiment this overlap of various GMR would be difficult to detect since only dipole states are strongly excited. In the inelastic scattering data, however, other collective multipole states are excited with intensities comparable to that for the dipole states and the overlap phenomena should be observable. The discovery of what appears to be a giant scalar quadrupole resonance overlapping the GDR region in the inelastic scattering (p,p')⁵, (e,e')⁶, and ($^3\text{He}, ^3\text{He}'$ and α, α')⁷ spectra has been the point of interest of several papers during the past year.

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Figure 1. Example of the decomposition of the gross resonance in $^{40}\text{Ca}(p,p')$, $E_p = 180$ MeV. A "background" continuum has been subtracted.

An example of the severe overlap problem is shown in figure 1 for the case of the $^{40}\text{Ca}(p,p')$ reaction at $E = 180$ MeV. In the giant resonance region we find a broad gross structure. The decomposition of the gross structure was attempted by first assuming that the giant dipole state was indeed excited and had a resonant energy $E = 20$ MeV and an intensity distribution consistent with that found in photonuclear experiments. Consequently, it was noticed that at least two additional collective multipoles were contributing to the angular dependence of the cross section of the gross structure, and the strongest of these (e.g., $E = 17$ MeV in ^{40}Ca) can most easily be explained as the excitation of the isoscalar quadrupole state(s) nearly exhausting the missing sum rule strength noted in Table 1. The weaker resonance at 13.5 MeV appears to be octupole in character, but is not a "giant" resonance according to the above definition.

Yet to be explored is the nature of the relatively unstructured continuum (not shown in figure 1) which underlies the resonance and extends

to extreme excitation energies. This continuum may be primarily composed of (a) collective states (possibly broad giant resonances) exhausting the sum rules for higher isoscalar and isovector multipoles, and (b) non-collective states weakly excited, but having such level density as to make their appearance dominant in the relatively low ($E \lesssim 50$ MeV) bombarding energy experiments. Estimates of contribution type-a are being carried out and show that at bombarding energies $E_p \approx 200$ MeV the enfolding of hypothetical giant resonances of larger ($L \geq 3$) multipolarities displays characteristics which might be mistaken for contribution type-b or of quasifree scattering.

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