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# OVERTONES OF ISOSCALAR GIANT RESONANCES STUDIED IN DIRECT PARTICLE DECAY MEASUREMENTS*

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The isoscalar giant dipole resonance (ISGDR), which is the lowest-energy overtone mode of the isoscalar giant resonances, has been studied in some medium-heavy and heavy nuclei in coincidence measurements. The observation of the direct nucleon decay channels significantly helped to enhance giant resonance strengths with respect to the underlying background and continuum, which gave an indication for the existence of a new mode with $L$=2 character, assumingly the overtone of the ISGQR.

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The extension of experimental studies of the isoscalar giant resonances (GRs) toward the investigations of overtone modes was mainly motivated by the possibility of learning about the formation and damping mechanism of GRs over a wide excitation energy region. As the overtone modes are excited by the second-order term of the transition operators, they are weak responses to external fields, and this in combination with large oscillation frequencies and moderately fragmented doorway-state structures results in damped, broad strength distributions [1, 2]. The observation of such weak structures above an overwhelming background and continuum requires special technique with high selectivity for excitations of single-particle character, which effectively disentangles GR strengths from the continuum.

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The application of coincidence techniques offered a clean solution to obtain a better definition of GR strengths with respect to previous single-arm measurements [3] (and Refs. therein). On the other hand, a coincidence experiment, determining partial branching ratios of the direct-particle (neutron and proton) decay, is the only way to study the microscopic structure of GRs in medium-heavy and heavy nuclei.

The $3\hbar\omega$ isoscalar giant dipole resonance (ISGDR), being the lowest-energy isoscalar overtone mode, has been studied in coincidence experiments observing decay channels by neutron emission of $^{90}$Zr, $^{116}$Sn and $^{208}$Pb [4], and by proton emission of $^{208}$Pb [5]. The experiments were performed at the AGOR superconducting cyclotron facility of KVI using $(\alpha, \alpha')$ reaction at $E_\alpha$=200 MeV. The $\alpha'$ particles were momentum analyzed by the Big-Bite Spectrometer (BBS) in conjunction with the EuroSuperNova detector system. In the neutron decay experiment the kinetic energy of the neutrons was measured by the time-of-flight technique. In the proton decay experiment the protons were detected by an array of 5-mm thick Si(Li)-detectors. Further details of the experimental setup can be found in Refs. [5, 6].

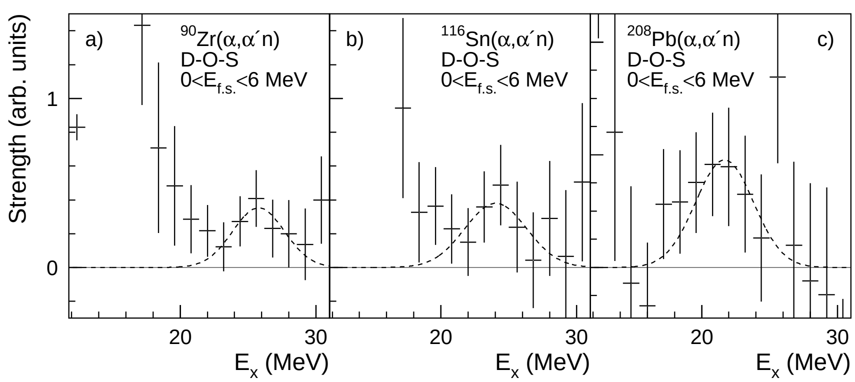


Fig. 1. $L$=1 strength distributions generated by the difference-of-spectra technique from the double-differential cross sections gated on the direct neutron decay of (a) $^{90}$Zr, (b) $^{116}$Sn and (c) $^{208}$Pb.

In order to disentangle the dipole strength from other multipolarities, angular distributions of the scattered $\alpha'$ particles were measured in angular intervals, which comprise both enhancement and suppression of the dipole strength, and allows the use of the difference-of-spectra technique. The gate on the direct decay channels, which was determined in the final-state energy spectra after taking into account the contribution of the statistical decay, strongly suppressed the underlying instrumental background and nuclear continuum. Although, in the neutron decay experiment the moderate energy resolution, the partial separation of the direct and statistical decays and the uncertainty of the random coincidence correction lead to difficulties in the definition of the ISGDR structures. In Fig. 1(a)–(c) a significant concentration of the dipole strength was observed. The parameters of the strength distributions at the expected ISGDR energies were determined by Gaussian fit and listed in Table I for comparison with the results of single-arm experiments of Refs. [7–9]. A satisfactory agreement was obtained for the excitation energies, but the deviations of the resonance widths are still remarkable and needs deeper analysis of the evaluation methods applied.

TABLE I

Comparison of parameters obtained for the ISGDR.

| | This work | | Single-arm experiments | |
|---|---|---|---|---|
| | $E_x$ | $\Gamma$ | $E_x$ | $\Gamma$ |
| Target | (MeV) | (MeV) | (MeV) | (MeV) |
| $^{90}$Zr | 25.8(0.8)$^{n}$ | 4.5(1.9)$^{n}$ | 26.7(0.5)$^{a}$ | 8.8(1.0)$^{a}$ |
| | | | 26.9(0.7)$^{b}$ | 12.0(1.5)$^{b}$ |
| $^{116}$Sn | 24.0(1.5)$^{n}$ | 5.3(1.7)$^{n}$ | 25.5(0.6)$^{c}$ | 12.0(0.6)$^{c}$ |
| | | | 25.4(0.5)$^{b}$ | 15.7(2.3)$^{b}$ |
| $^{208}$Pb | 20.9(1.0)$^{n}$ | 5.7(2.3)$^{n}$ | 22.2(0.3)$^{c}$ | 9.39(0.35)$^{c}$ |
| | 22.1(0.3)$^{p}$ | 3.8(0.8)$^{p}$ | 22.7(0.2)$^{b}$ | 11.9(0.4)$^{b}$ |

$^{n}$ $n$-decay exp., $^{p}$ $p$-decay exp.; $^{a}$ Ref. [7], $^{b}$ Ref. [8], $^{c}$ Ref. [9].

Most of the problems of the neutron decay experiment were not present in the case of the proton decay experiment, since the high Coulomb barrier hindered the statistical decay, and created especially clean conditions for the observation of GR strength. Fig. 2(a)–(b) shows the double-differential cross

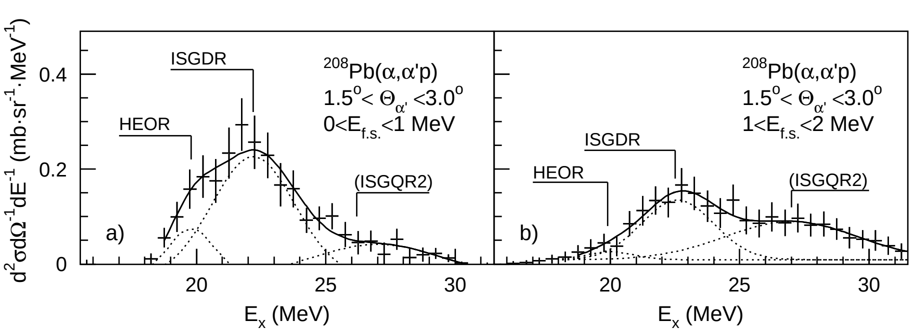


Fig. 2. Double-differential cross sections as a function of $E_x$ gated on the direct proton decay of $^{208}$Pb to $E_{\mathrm{f.s.}}$ regions in $^{207}$Tl indicated in the panels.

sections for two final-state energy regions, in which three GR components of the structure were recognized. While the ISGDR bump was easily identified based on the analysis of the angular distributions (see Fig. 3(a)), the bump at higher excitation energy most likely carried a quadrupole character (see Fig. 3(b)), but $L = 3$ and $L = 4$ multipolarities were not excluded. Recently performed continuum-RPA calculations on isoscalar overtone GRs predicted a broad quadrupole structure around $E_x = 30.5$ MeV corresponding to the $4\hbar\omega$ overtone mode of the ISGQR ($\rightarrow$ ISGQR2) [2].

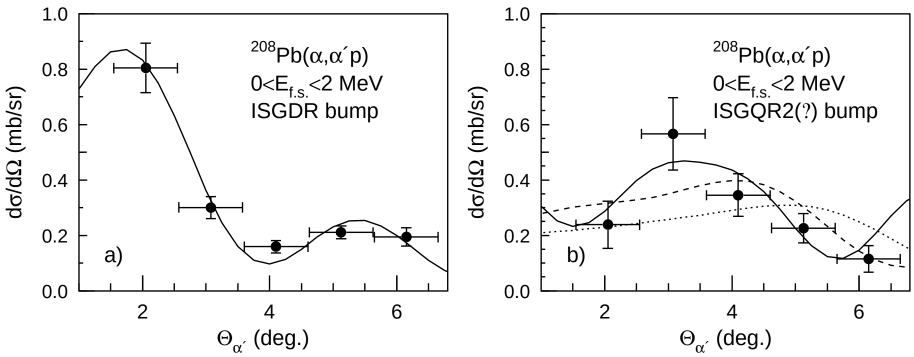


Fig. 3. Angular distributions of the (a) ISGDR and (b) ISGQR2(?). The theoretical curves were calculated by DWBA, and were scaled to fit the data points. In panel (a) $L$=1 curve (solid), in panel (b) $L$=2 curve (solid), $L = 3$ curve (dashed) and $L = 4$ curve (dotted) are shown.

In conclusion, we have performed the first coincidence experiments to investigate the direct neutron and proton decay channels of the ISGDR and possibly of other overtone resonances. The application of the direct particle decay measurements helped to find a better definition of GR strengths, which may also lead to the discovery of new GR modes, like the ISGQR2. Systematic decay studies of isoscalar GRs at high excitation energies would yield the ultimate evidence for overtone modes other than the ISGDR.

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