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Looking for the Isoscalar Giant Dipole Resonance in ^{208}Pb using Inelastic α Scattering at and near 0°

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ABSTRACT

The isoscalar giant dipole resonance (ISGDR) in ^{208}Pb has been investigated using inelastic scattering of 200 MeV α particles at and near 0° where the angular distribution of the ISGDR can be clearly differentiated from other modes. The "difference of spectra" technique was employed to separate the contribution from the high-energy octupole resonance (HEOR). Results from a preliminary analysis of the data are consistent with the expected positions of the ISGDR and HEOR, as well as their expected angular distributions near 0°.

The isoscalar giant dipole resonance (ISGDR) is best described as a "hydrodynamical density oscillation", in which the volume of the nucleus remains constant and the state can be visualized in the form of a compression wave oscillating back and forth through the nucleus (the "squeezing mode") [1]. This is a second-order effect (in the first order, of course, the isoscalar dipole mode

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corresponds merely to spurious center-of-mass motion) and in addition to being of substantial intrinsic interest as an exotic mode of collective oscillation, also has its importance in that it provides, like the monopole resonance (or "breathing mode"), a direct measurement of the nuclear incompressibility.

The excitation energy of the ISGDR, as given by the scaling model [2] is:

$$E_x = \sqrt{\frac{7}{3} \cdot \frac{K_A + \frac{27}{25}\varepsilon_F}{m \langle r^2 \rangle}}$$

where K_A is the incompressibility of the nucleus and ε_F is the Fermi energy. Indeed, the most common and well-known experimental determination of the nuclear incompressibility has been achieved via the excitation energies of the giant monopole resonance (GMR) the systematics of which are already quite well established [3]. There have been some concerns, however, about the extraction of the nuclear incompressibility for infinite nuclear matter from the available GMR data [4-6] and a detailed and systematic investigation of the ISGDR could provide additional information on the incompressibility of nuclei, leading, it is hoped, to a more precise determination of the incompressibility of nuclear matter.

The evidence for the ISGDR has been rather sparse so far. Indications for this resonance have been reported in inelastic scattering experiments at forward angles on ^{208}Pb and ^{144}Sm [7-9]. However, since it lies very close in energy to the high-energy octupole resonance (HEOR), an unambiguous identification of the ISGDR, based on the angular distributions, is possible only at angles near 0° because any appreciable differences in the angular distributions of the two resonances appear only in that angular region. The situation, thus, is quite similar to that of the GMR more than a decade ago: unambiguous evidence for GMR could be established only by measurements at the smallest angles where the GMR angular distribution differs substantially from that of the giant quadrupole resonance (GQR) which lies at an excitation energy close to the GMR.

Fig. 1 shows the expected inelastic α scattering angular distributions for the ISGDR and HEOR in ^{208}Pb over the angular range 0°–14° as calculated in DWBA by the program CHUCK3 [10]. The optical model parameters used in this calculation are: V = 155 MeV, r = 1.282 fm, a = 0.677 fm, W = 23.26 MeV, r_W = 1.478 fm, a_W = 0.733 fm and r_C = 1.3 fm and were adopted from Ref. [11]. For the HEOR,

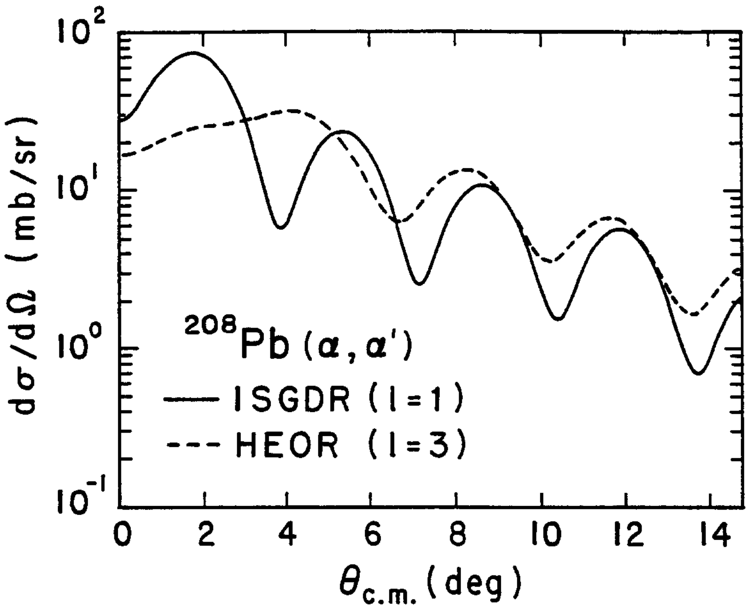

Figure 1. Angular distributions for the ISGDR (solid line) and the HEOR (dashed line) as obtained in a DWBA calculation using the program CHUCK3. For details of the calculation and the parameters used, see text.

the standard collective form factor [12] was used; for the ISGDR, the form factor was taken from Ref. [1]. Inelastic scattering of alpha particles near 0° has the advantage that, because of the isoscalar nature of this reaction, only these two giant resonances are expected to be predominantly excited at the excitation energies of interest. In addition, as indicated by the calculations presented in Fig. 1, the cross sections for these resonances are at or near their maximum at these angles.

We have undertaken a detailed investigation of the ISGDR in ^{208}Pb to obtain conclusive evidence for its existence via measurements at very small angles. The expected angular distributions make imperative the use of the "difference-of-spectra technique" which has been very effectively used in detailed investigations of the GMR [13]: the inelastic spectrum near 0° (0°→2° in our case) can be divided into two parts (0°→1° and 1°→2°, respectively); since the ISGDR cross section is rising rapidly in this region whereas the HEOR cross section remains nearly constant, the difference of these two spectra would show little contribution from the octupole resonance or from the background. In principle, this would yield a spectrum that is a lucid picture of the desired ISGDR.

We have performed (α, α') measurements at very small angles (including 0°) using a 200 MeV alpha-particle beam in conjunction with the K600 spectrometer at the Indiana University Cyclotron Facility. The K600 is a versatile, high resolution dipole spectrometer with an elaborate detector array in the focal plane [14]. In our experiment, the detector system consisted of two clusters of horizontal and vertical drift chambers--one vertical drift chamber to measure horizontal position *x*, and two horizontal drift chambers with staggered sense-wire positions to measure the vertical position *y*. The two clusters were spaced approximately 20 cm apart so that slope information for the particle track could be obtained in both the *x* and *y* directions. This information was essential to perform ray-tracing required for angle reconstruction. Particle identification was obtained using the ΔE signals provided by two plastic scintillators placed behind the clusters.

Data was obtained at (0±2)° (the maximum angular opening possible at 0° in the K600), as well as at 4°, 5°, 6°, 7°, 8° and 10°, with an energy resolution of approximately 100 keV; although the resolution achievable for this system is significantly better, no serious attempts were made to optimize the resolution for this work. The non-zero angle measurements were taken using a newly-commissioned septum magnet which allowed measurements below 7° for the first time at the K600. A 3.0 mg/cm^2 thick ^{208}Pb target was used for all non-zero degree angle measurements. For the 0° data, a horizontal strip target with a thickness of 9.0 mg/cm^2 was employed. The strip target was required to properly resolve the scattering angle along the y-axis because of a large magnification (~7) of the K600 spectrometer in this direction; the horizontal magnification of the K600 is about 0.5, so that the angle along the x-axis is resolved easily with the normal beam-spot size. Since the beam spot (typically 2 mm by 5 mm) was larger than the width of the strip target, a ΔE-E scintillator detector system, placed just outside the scattering chamber, was used to determine the amount of the alpha beam coming in contact with the strip target by comparing the yields generated by the strip target to those by a "full" target.

The measurements at small angles, as is well known, require a very careful tuning of the beam to minimize the contributions from the background due to beam halo and slit-scattering, etc. After considerable effort, it was possible to obtain a rather "clean" beam whereby, for 1 nA (electrical) of beam current, the blank target (empty target frame) runs yielded a count rate of 30 counts/second as compared to an event rate of 262 counts/second with the target in place. Further "cleaning" of spectra was achieved by employing a gate on the TOF from the scintillators.

An example of the quality of data obtained in our setup is presented in Fig. 2 which shows a ^{24}Mg calibration spectrum taken at 0° and compares it to similar data from KVI [15]. This comparison provided the energy calibration and also established that the excitation energy range was sufficient for the study of the ISGDR which lies at approximately 22 MeV in ^{208}Pb.

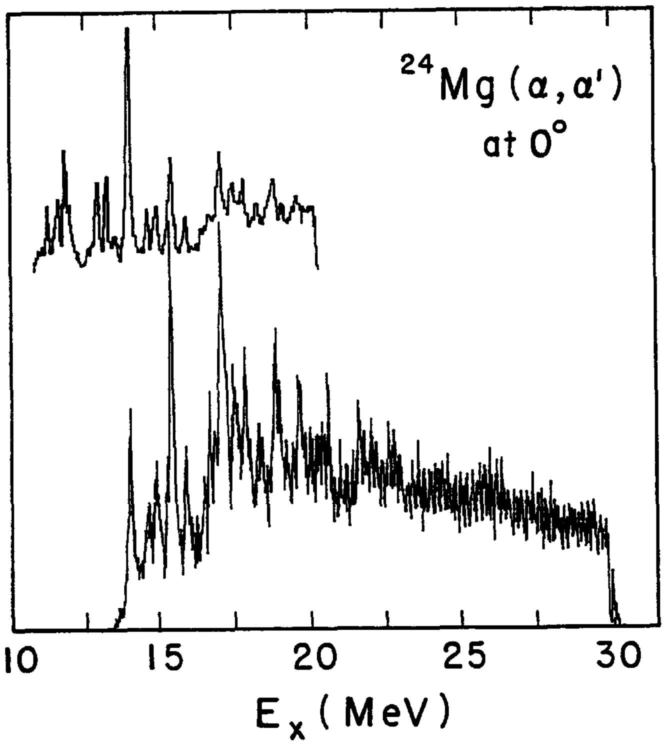

Figure 2. Inelastic α scattering spectrum for ^{24}Mg at (0±2)°. Spectrum from a similar experiment [Ref. 15] is shown in the upper part for a direct comparison and calibration.

Fig. 3(a) shows the 0°→2° spectrum for ^{208}Pb. A broad "bump", most likely

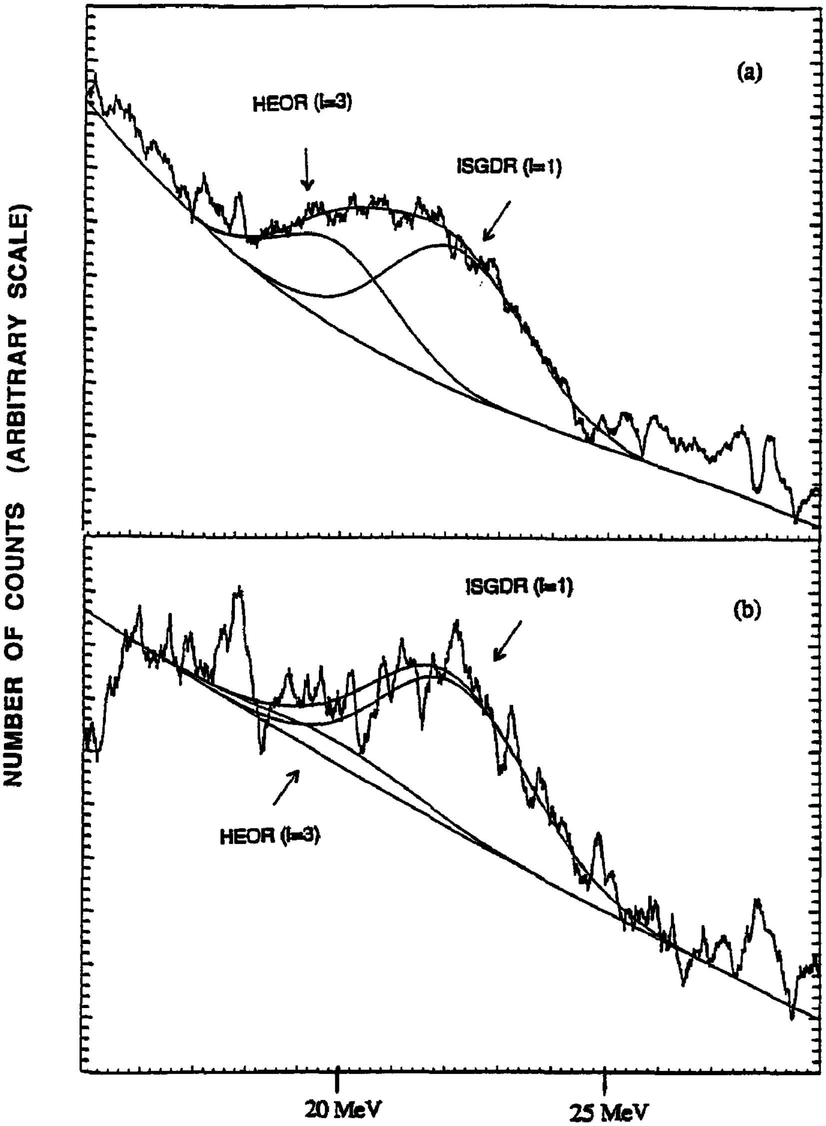

Figure 3. (a) Inelastic α scattering spectra for ^{208}Pb for (0±2)°. A two-peak + polynomial background fit to the data is shown superimposed with the peaks corresponding to the HEOR and the ISGDR indicated. (b) The "difference" spectrum, obtained as described in the text. Also shown is a fit using peak-parameters identical to those in (a).

comprised of the ISGDR and the HEOR, is clearly visible above background. The data has been fitted with a polynomial background and two Gaussian peaks; the results of the fit are shown superimposed (using a single, wider, peak always resulted in a significantly worse fit). The centroids of the two peaks (20.0±0.5 MeV and 22.1±0.5 MeV) are in agreement with the energies previously suggested [7-9] for the HEOR and ISGDR, respectively; the widths of the two peaks in these fits (3–4 MeV) are, however, somewhat smaller than those previously reported.

The "difference" spectrum, obtained by subtracting the 0°→1° cut from the 1°→2° cut, is shown in Fig. 3(b) along with a two-peak fit employing peak parameters identical to those used in the peak fits shown in Fig. 3(a). In this case, a "free" fit always preferred a single, slightly broader, peak; the fit as shown was obtained by requiring two-peaks in order to show the reduction in the strength of one of the components. As can be seen, the "HEOR component" of the bump is almost completely eliminated in this spectrum, leaving only the "ISGDR component", as expected. A similar conclusion can be drawn from a comparison of the centroids of the "bumps" in the two spectra: the centroid of the "difference" spectrum (22.1 MeV) is located at almost 1 MeV higher in excitation energy than that in the full spectrum (21.3 MeV), again consistent with a reduction in the HEOR strength as expected from the predicted angular distributions for the HEOR and the ISGDR. The "bump" in Fig. 3(b), thus, represents the ISGDR and can be subjected to detailed investigation to extract the properties of this resonance.

We wish to point out here that, due to a previously unnoticed focus in the y vs. focal-plane position plot occurring at the low energy end of the "bump", we were unable to set gates on the y-component of the scattering angle. Consequently, the cuts resulting in the "difference spectrum" shown in Fig. 3(b) could only be made in the x-direction and this spectrum does not incorporate the angular distribution effects in the y-direction. Nevertheless, the results obtained so far are quite promising and clearly indicate that the "difference of spectrum" technique can be successfully employed to investigate the ISGDR. The aforementioned y-focus problem can be corrected by adjusting the K600 entrance quadrupole appropriately and an experiment is planned in the near future to that end as also to achieve higher statistics. Once the efficacy of this technique has been established for the case of ^{208}Pb, further experiments will be carried out to study the systematics of the ISGDR.

To summarize, we have measured inelastic α-scattering spectra at and near 0° with a view to obtaining conclusive evidence for the ISGDR in ^{208}Pb. Our data are consistent with the presence of the ISGDR adjacent to the HEOR in ^{208}Pb. The excitation energies of the two resonances, as extracted from our data, are in agreement with those previously suggested for ISGDR and HEOR; the widths are somewhat smaller, however. Further, inasmuch as the two resonances appear to exhibit different angular distributions near 0°, the efficacy of the "difference of spectra" technique in identifying the ISGDR has been affirmed.

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