BRIEF REPORTS

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Experimental test of a newly proposed empirical relationship between the centroid and width of the giant quadrupole resonance and the neutron binding energy of the nucleus

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Via the inelastic scattering of 50 MeV/nucleon ^{14}N ions, the giant quadrupole resonance in ^{58}Ni and ^{64}Ni has been investigated to test experimentally a newly proposed relationship between the centroid and width of the giant quadrupole resonance and the neutron binding energy of the nucleus. Our results do not confirm the proposed relationship.

The giant quadrupole resonance (GQR) has been studied in detail over the past two decades and rich systematics have been obtained for the standard GQR parameters—the centroid (E_x), the full width at half-maximum (FWHM), and the strength as a percentage of the energy-weighted sum rule (EWSR)—using a variety of probes. The centroids of the GQR have been observed to follow closely a dependence on the mass of the nucleus, A, given by $E_x \sim 64.7\ A^{-1/3}$.[1] A less rigorous relationship between the FWHM and the mass number has also been widely accepted: $\Gamma \sim 85\ A^{-2/3}$.[1] Both these expressions can be derived from macroscopic calculations in a distorted Fermi-surface model wherein the isoscalar giant resonances are viewed as small-amplitude collective oscillations in which the neutrons and protons undergo in-phase, incompressible, irrotational flow with unit effective mass.[2]

Recently, a new empirical relationship has been proposed for the centroids and widths of the GQR by Loveman and Peterson (LP).[3] They note that the GQR parameters appear to be closely related to the neutron separation energy S_n of the nucleus and, but for very few exceptions, follow a rather simple empirical relationship given by

$$E_x - S_n = C_0 \times \Gamma ,$$

where C_0 is an empirical constant, the value of which they determine from fits to the GQR parameters in a large number of nuclei to be 0.91. Although no specific physical reason has been advanced for this particular relationship, it is reported that the quality of the fits to this new expression, as determined by the χ^2 values, is similar to that obtained for the previously accepted expression for the mass dependence of the excitation energy of the GQR.

An easy way to test the validity of this relationship is to compare the GQR parameters of two or more isotopes which differ significantly in their S_n values. The nuclei ^{58}Ni and ^{64}Ni provide excellent, and rather convenient, test cases—their neutron binding energies differ by 2.54 MeV (Ref. 4) and the GQR region is free from a strong excitation of the GMR,[5] making the extraction of the GQR parameters relatively uncomplicated. Recently, Oakley *et al.*[6] attempted to obtain GQR parameters in Ni isotopes by using 180-MeV π^+ and π^- beams but did not examine the LP relationship because of uncertainties in the widths which they attributed to possible broad features other than the GQR.

For the specific purpose of testing the validity of the LP expression, we have made inelastic scattering measurements on ^{58}Ni and ^{64}Ni sequentially, without any change whatsoever in the experimental setup and conditions between the runs. The targets consisted of isotopically enriched (to >98%) self-supporting foils of nearly equal thickness (approximately 2 mg/cm^2). A 700-MeV ^{14}N beam, obtained from the K500 cyclotron at the National Superconducting Cyclotron Laboratory, was employed to excite giant resonances in ^{58}Ni and ^{64}Ni. Inelastically scattered ^{14}N ions were detected in the focal

plane of the S320 spectrograph;[7] the detector system (details of which have been reported previously[8]) consisted of two single-wire proportional counters, two ionization chambers, and a scintillator. The position along the focal plane was determined by the charge division method and time-of-flight information was obtained by measuring the time interval between signals from the plastic scintillator and the cyclotron rf. The detector arrangement not only provided good charge and mass separation for the reaction products, but also, and perhaps equally important for this type of study, permitted ray tracing and angle reconstruction. This, combined with an active collimator system, ensured that the final spectra were virtually free of all contributions not associated with target scattering. The elastically scattered particles were stopped by a 1.5-cm-wide vertical post immediately before the focal plane. The angular bite of the spectrograph was about 1.3° and the angle-reconstruction technique allowed the data to be sorted into three angles each of 0.40° width and still fully avoid the edges of the slit. For the present investigation it was sufficient to obtain data for only one angular bite since complete angular distributions are not required. Energy calibration was obtained via ^{14}N elastic scattering off ^{208}Pb at several magnet settings; the ambiguity in absolute calibration is estimated to be better than 100 keV and the overall energy resolution was typically about 1-MeV FWHM.

Sample spectra for the two nuclei are shown in Fig. 1 and clearly show rather strong excitation of a GR "bump" in the excitation energy region of 10–20 MeV, where the GQR has been observed in previous measurements.[5] In the same energy region, however, some strength would also be expected from the Coulomb excitation of the giant dipole resonance (GDR). The excitation of GDR from hadronic probes has been discussed in detail in Ref. 9. To estimate the GDR strength in our spectrum, we have performed a coupled-channel calculation using the code ECIS.[10] The nuclear part of the transition potential was also taken into account but had a negligible effect on the final result. The optical-model (OM) parameters were taken from Ref. 11; the final results, however, were rather insensitive to the choice of OM parameters. For a 100% EWSR excitation of the GDR, the calculated cross section of the GDR at 4.9° is 1.6 mb/sr, compared with 17.8 mb/sr for the GQR (45% EWSR, as per Ref. 5). Therefore, GDR excitation does not play a significant role in our analysis and conclusions.

As is clear from Fig. 1 there is very little difference between the GR "bumps" in ^{58}Ni and ^{64}Ni; this holds true for data at all three angles measured in this work. Standard peak-fit analyses[5,12] of the data confirm that the centroid and width of the GQR differ at most by a few hundred keV, in accordance with the previously established relationship,[1] but in sharp contrast with the predictions of LP—according to the LP expression either the centroid of the GQR in ^{64}Ni should be lower by as much as 2.54 MeV when compared with that in ^{58}Ni, or the FWHM should be greater by 2.8 MeV (or some combination of the two effects). The values of C_0 we obtain from GQR parameters for ^{58}Ni ($E_x = 15.7 \pm 0.2$ MeV; $\Gamma = 4.2 \pm 0.2$ MeV) and ^{64}Ni ($E_x = 15.4 \pm 0.2$ MeV; $\Gamma = 4.2 \pm 0.2$ MeV) are 0.83 and 1.37, respectively, compared with the mean value of 0.91 obtained by LP. Thus, our results are in clear disagreement with the LP relationship.

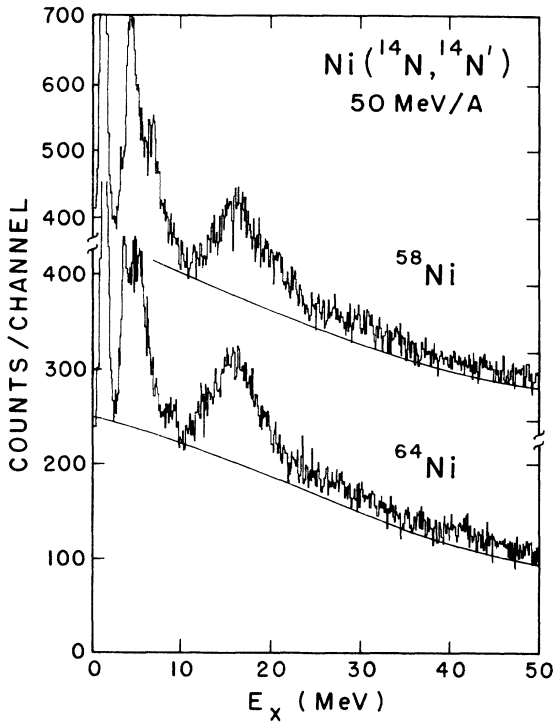

FIG. 1. Inelastic scattering spectra for ^{58}Ni and ^{64}Ni at 4.9°; the possible shapes for the continuum are indicated by solid lines. The main resonance "bump" primarily consists of the GQR with some contribution on its higher excitation energy side from the GDR (see text). The peaks at the extreme left are remnants of blocked elastic scattering. The ordinate scale may be converted from counts/channel to $\sigma(\Theta)_{c.m.}$ (mb/meV) by multiplying by factors of 0.028 47 and 0.032 43 for ^{58}Ni and ^{64}Ni, respectively.

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