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Brief Reports

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Electroexcitation of giant electric-dipole resonances in ^{42,44}Ca at low-momentum transfer

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The cross sections of the electroexcitation of the giant electric-dipole resonances in ^{42,44}Ca have been measured for low-momentum transfers $0.3 \leq q \leq 0.4$ fm^{-1}, where the quadrupole transition is as small as 10–20% of the total spectra. The dipole resonances were observed to be broadened with some structure in both nuclei, supporting the previous analysis for the measurement at high-momentum transfer.

[NUCLEAR REACTIONS ^{42}Ca(e, e′) and ^{44}Ca(e, e′), $E = 62.5$ and 75.0 MeV, $q = 0.3$–0.4 fm^{-1}, enriched targets, measured $\sigma(E', \theta)$ up to 30 MeV in excitation energy; deduced giant electric-dipole cross sections.]

A systematic experimental study of giant dipole resonance (GDR) in the calcium isotopes is quite important in order to understand the isospin dependence of the GDR as well as the influence of nuclear deformation on the GDR in f-shell nuclei.[1,2] An earlier inelastic electron scattering experiment performed using 150–250-MeV electrons has shown[1] the broadening and structure of the GDR's in ^{42}Ca and ^{44}Ca. However, the GDR's observed in this experiment are superimposed with quadrupole resonances, and the spectra were decomposed into multipole resonance in order to extract the cross sections of the GDR.

Inelastic electron scattering measurements at a low-momentum transfer (low q) and at forward angles is a powerful means of studying the GDR, where a longitudinal dipole excitation is dominant and the spectra are quite free from the effects of other multipole excitations. On the other hand, the measurements of the nuclear cross section at extremely forward angles with low-incident energy electrons are severely hampered by a huge radiation tail from the elastic scattering.

Inelastic electron scattering spectrum for the dipole excitation in the low-q and the forward-angle limit is related to the total photoabsorption cross section $\sigma_\gamma(\omega)$ by[3]

$$\frac{d^2\sigma}{d\Omega\, d\omega} = \sigma_M |W(q,\omega)|^2 \underset{q\to\omega}{\longrightarrow} \frac{\alpha}{4\pi^2}\frac{\sigma_\gamma(\omega)}{\omega}\frac{\epsilon_2}{\epsilon_1}\cot^2\frac{\theta}{2} ,$$

where σ_M is the Mott cross section for a charge Z nucleus, $W(q,\omega)$ is the differential form factor for the excitation energy ω and the momentum transfer q, θ is the scattering angle of the outgoing electron, and ϵ_1 and ϵ_2 are the initial and the scattered electron energies, respectively. With the intent to determine the cross sections of the GDR in the calcium isotopes more precisely, we have measured the inelastic electron scattering spectra at low q up to 0.30 fm^{-1} with a forward angle up to 55°. The present experiment is one of few measurements, if any, at the lowest q with relatively forward angles for the GDR region ever performed up to the present.

The experiment was performed using the electron beams from the Saskatchewan linear accelerator. Targets used were a 48.9-mg/cm^2-thick, isotopically 94.4%-enriched metallic ^{42}Ca and a 44.3-mg/cm^2-thick, 98.6%-enriched metallic ^{44}Ca. Data were taken at the incident energies and scattering angles of 62.5 MeV 86°, 97° and 75 MeV 55°. The scattered electrons were measured by a 45-channel array of plastic scintillators[4] located at the focal plane of a 127°, 50-cm radius double-focusing magnetic spectrometer. Two backup long plastic scintillators were also used for eliminating background. Spectra were measured up to 30 MeV in excitation energy with an overall resolution of 100 keV. Absolute normalization for the inelastic spectra was made by comparison with the yield of the elastic scattering, and the elastic scattering cross section was obtained by the phase-shift calculation using three-parameter Fermi densities for ^{42}Ca and ^{44}Ca.[5]

The measured spectra were unfolded for the radiative correction using the same iterative procedure used in the high-q measurement[1]; the radiation tail from the elastic scattering, which incorporates the radiation process and the ionization loss due to the finite-target thickness, was subtracted first and the radiation tail from inelastic scattering was subsequently subtracted bin by bin.

The radiatively unfolded spectra are shown in Figs. 1 and 2. Although the GDR is dominant at the momentum transfer presently studied, some contributions of the quadrupole resonance are still expected. In order to obtain the pure dipole cross sections, the quadrupole cross sections were subtracted from the spectra using the results of the high-q measurement,[1] assuming the q dependence of the Tassie model. It is estimated that the quadrupole transition amounts to approximately 10% of the radiatively corrected

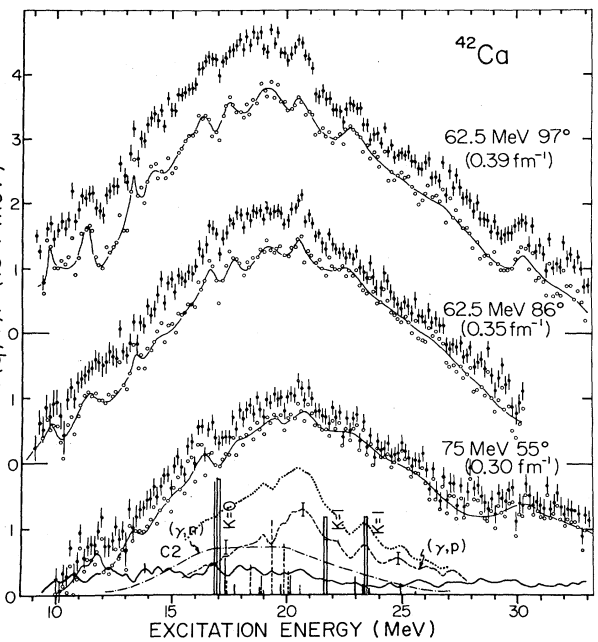

FIG. 1. The differential form factors of ^{42}Ca. The spectra were radiatively corrected. The open circles, with curves which are a guide for the eyes, show the dipole excitations. The quadrupole resonance (Ref. 1), the cross sections of the (γ, p) (Ref. 7), the (γ, n) (Ref. 8), and the sum of the (γ, p) and the (γ, n) are shown by solid, dash, dot-dashed, and dotted curves, respectively. The relative strengths of the $K=0$ and $K=1$ states predicted by the dynamic collective model are shown by histogram. The particle-hole model calculation (Ref. 12) is also shown by the solid and dashed lines for the $T=1$ and $T=2$ states, respectively. The largest $T_<$ strength at 16.9 MeV corresponds to 2.05 e^2fm^2.

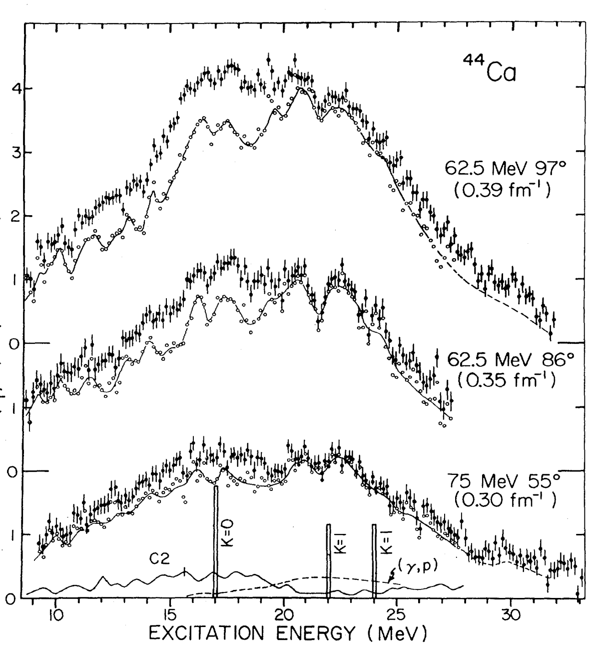

FIG. 2. The differential form factors of ^{44}Ca. See caption of Fig. 1. The (γ, p) cross section was taken from Ref. 9.

spectra at $q=0.30$ fm^{-1} and 20% at $q=0.39$ fm^{-1} in both nuclei.

The observed GDR's in both nuclei show a broad resonance with approximately 13 MeV at a full width at half maximum, which is in contrast to the observed width of 4.5 MeV of the GDR in ^{40}Ca.[6] In addition, different features were observed between the GDR's in ^{42}Ca and ^{44}Ca; the GDR in ^{42}Ca is almost a single-peaked resonance with several bumps superimposed, while that in ^{44}Ca has somewhat a flat-top shape resonance with at least four peaks at 16.2, 17.4, 20.7, and 22.4 MeV. The reduced transition probabilities $B(E1,\uparrow)$'s for the GDR region integrated between 10 and 30 MeV were obtained to be 18.8 ± 3.4 e^2fm^2 in ^{42}Ca and 15.8 ± 3.2 e^2fm^2 in ^{44}Ca. These strengths were determined by comparison of the observed strength with the $C1$ form factor of the Goldhaber-Teller model, which was computed in the distorted-wave Born approximation. The strengths of the GDR in both isotopes exhaust the energy-weighted sum rule values of 156 e^2fm^2 MeV for ^{42}Ca and 162 e^2fm^2 MeV for ^{44}Ca when integrated up to 22 MeV, and are twice the sum rule up to 30 MeV. The large strength may partly arise from the normalization procedure of the radiation tail from the elastic scattering, which was fitted to the observed spectra between 5 and 10 MeV. However, it is noted that the similar large strength for the GDR was also obtained by the high-q measurement[1] where the deduction of the strength is less influenced by the subtraction of the elastic radiation tail from the observed spectra.

In Figs. 1 and 2, the present results are compared with the available photoreaction cross sections of ^{42}Ca(γ, p),[7] ^{42}Ca(γ, n),[8] and ^{44}Ca(γ, p),[9] which were converted to the value $q=0.30$ fm^{-1}. The q dependence of the Goldhaber-Teller model was used for the conversion. The magnitudes of the converted cross sections were obtained through the $B(E1)$ value, which is related to $\sigma_\gamma(\omega)$ by

$$B(E1,\omega)\uparrow = \frac{1}{8\pi^3\alpha}\frac{9}{2}\frac{1}{\omega}\int_{\Delta\omega}\sigma_\gamma(\omega)d\omega \ .$$

Since a single proton and a neutron emission cross sections are major decay modes of the GDR in the medium-weight nuclei, the dipole spectrum in inelastic electron scattering is expected to be approximately the sum of the (γ, p) and the (γ, n) cross sections. As seen in Figs. 1 and 2, the shape of the inelastic electron scattering spectra for ^{42}Ca is similar in shape to the sum of the (γ, p) and the (γ, n) cross sections, although the strength obtained by the present result is much larger than the result of the photoreaction. As for ^{44}Ca, a comparison of the (γ, p) cross section with the present result indicates an existence of a large strength of the neutron decay cross section over a wide excitation energy.

As was discussed in the previous paper,[1] the trend of the increase of the neutron decay cross section with an increasing neutron number is understood in terms of isospin splitting, i.e., with the fact that the neutron and the proton decay channels roughly correspond to $T_<$ (T lower) $= T_z$ and $T_>$ (T upper) $= T_{z+1}$ states,[10] respectively. If the isospin splitting theory[11] is applied for the calcium isotopes, the $T_<$ resonance is predicted to account for 57% of the total isospin strength in ^{42}Ca and 75% in ^{44}Ca, with splitting energies of 2.9 MeV in ^{42}Ca and 4.1 MeV in ^{44}Ca,[11] respectively. The result of particle-hole calculation for ^{42}Ca,[12] as shown in Fig. 1, gives the similar features obtained by the isospin splitting theory, although both components are fragmented.

However, a further explanation is required for the observed broadening of the GDR's especially in ^{44}Ca, where a large part of the cross section is considered as $T_<$ state. The effect of nuclear deformation on the observed broadening was already discussed in the previous paper,[1] on the basis of the fact that the low-lying states exhibit the rotational structure in the calcium isotopes; if we take deformation parameters to be 0.241 for ^{42}Ca and 0.276 for ^{44}Ca, which were derived from the $B(E2)$ values for the first 2^+ states, it is expected that the GDR splits into $K=0$ and $K=1$ states by about 5–6 MeV, depending on whether the Suzuki-Rowe model[13] or the dynamic collective model[14] is adopted. The strength of the $K=1$ state is generally predicted to be 1.6–1.8 times larger than that of the $K=0$ state at $q=0.30$–0.40 fm^{-1} in the Suzuki-Rowe model, or 1.3 times larger at the photon point in the dynamic collective model.[1] As depicted in the figures, the splitting of the $K=1$ state ($S=\pm 1$) and even other small satellite states are furthermore predicted.[14] Although these splittings of the K states improve a fit of the theory to the data, it still seems to be far from a consistent explanation of the observed broadening and structure for the GDR's in the calcium isotopes. It would be extremely interesting to see a microscopic calculation for the GDR in the neutron-rich f-shell nuclei, which takes into account the effects of the nuclear deformation.

In summary, the cross sections of the giant dipole resonances in ^{42}Ca and ^{44}Ca measured at low-momentum transfer are presented. The present low-q measurement supports our previous result obtained by the method of multipole expansion at the high-q measurement. Both measurements may suggest other origins in addition to the isospin effect for the broadening of the giant dipole resonance in the calcium isotopes.

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