Isoscalar $E0$ strength between 6 and 11 MeV in ^{40}Ca

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The region from $6<E_x<11$ MeV in ^{40}Ca has been studied with inelastic scattering of 240 MeV α particles at small angles including 0°. Strength corresponding to 3.2±1.0% of the isoscalar $E0$ sum rule was identified with a centroid of 8.7±0.30 MeV.

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The location of the isoscalar giant monopole resonance is important because its energy can be directly related to the nuclear compressibility and from this the compressibility of nuclear matter ($K_{\rm NM}$) can be obtained. In a previous paper [1] strength corresponding to 97±11% of the $E0$ energy-weighted sum rule was identified between $11<E_x<55$ MeV in ^{40}Ca using inelastic scattering of 240 MeV α particles. Kamerdzhiev, Speth, and Tertychny have carried out microscopic calculations in continuum random-phase approximation including $1p1h$ coupled to two-phonon configurations [2] showing significant $E0$ strength from $6<E_x<35$ MeV. The data of Ref. [1] are in quite good agreement with these calculations above the E_x=11 MeV limit of the data.

In another (earlier) measurement [3], data were obtained for the same reaction with a different detector over the range $2<E_x<30$ MeV, and $E0$ strength was inferred from this data with a spectrum subtraction technique. This technique is particularly sensitive to experimental background, detector response functions, and the presence of other multipolarities. We report here analysis of the data in Ref. [3] covering $6<E_x<22$ MeV with a technique that unambiguously identifies multipole strength [1].

The experimental technique was described thoroughly in Ref. [3] and is summarized briefly below. A beam of 240-MeV α particles from the Texas A&M K500 superconducting cyclotron bombarded a self-supporting natural Ca foil 11.6 mg/cm^2 thick located in the target chamber of the multipole-dipole-multipole spectrometer. The horizontal acceptance of the spectrometer was 4° and ray tracing was used to reconstruct the scattering angle. The out-of-plane scattering angle was not measured. Sample spectra from Refs. [1,3] are shown in Fig. 1 and are generally in good agreement. Although the data from Ref. [1] extend down to about E_x =8 MeV, in the region between 8 and 10 MeV the solid angle was varying rapidly due to detector edge effects and reliable cross sections could not be obtained. With the experimental setup described in Ref. [3], the cross sections were reliable down to about 3.5 MeV. For the analysis described below, the spectra were each divided into a peak and a continuum. For each spectrum analyzed in this work, the continuum used was that obtained for a similar angle in the work described in Ref. [1]. This continuum is shown in the figure.

The multipole components of the giant resonance peak were obtained [1] by dividing the peak into multiple regions (bins) by excitation energy and then comparing the angular distributions obtained for each of these bins to distorted-wave Born approximation (DWBA) calculations to obtain the multipole components. The uncertainty from the multipole fits was determined for each multipole by incrementing (or decrementing) that strength, then adjusting the strengths of the other multipoles to minimize total χ^2. This continued until the new χ^2 was one unit larger than the total χ^2 obtained for the best fit.

The DWBA calculations were described in Ref. [3] and the same Gaussian Woods-Saxon folding potentials were

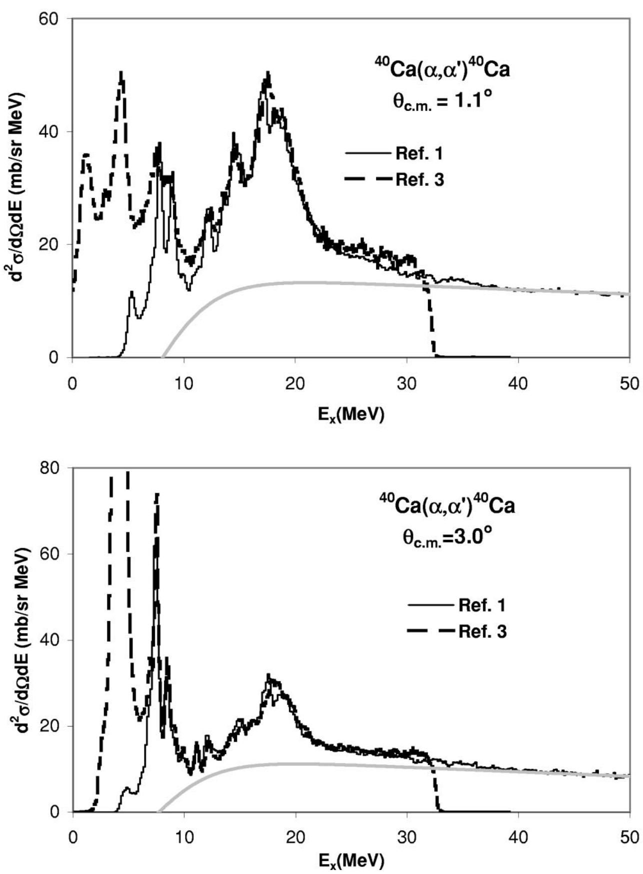

FIG. 1. Inelastic α spectra (reported in Refs. [1,3]) obtained with the spectrometer at average c.m. angles of 1.1° and 3.0°. The thick gray lines show the continuum used for the analysis.

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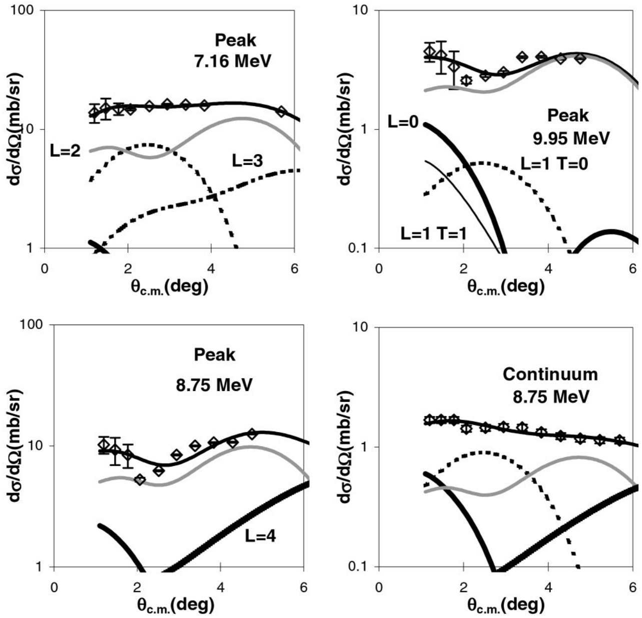

FIG. 2. Angular distributions obtained for inelastic α scattering for three excitation ranges of the GR peak and one range for the continuum in ^{40}Ca. The energy bins are approximately 450 keV wide. The medium black line shows the fits. Contributions of each multipole are shown. When not shown, errors are smaller than the data points.

used for the calculations in this work. A sample of the angular distributions obtained is shown in Fig. 2. Fits to the angular distributions were carried out with a sum of isoscalar $0^+, 1^-, 2^+, 3^-$, and 4^+ strengths. The isovector giant dipole resonance contributions are small, but were calculated from the known distribution [4] and held fixed in the fits. Sample fits obtained, along with the individual components of the fits, are shown superimposed on the data in Fig. 2. Although data were available for $4<E_x<6$ MeV, α particles scattered

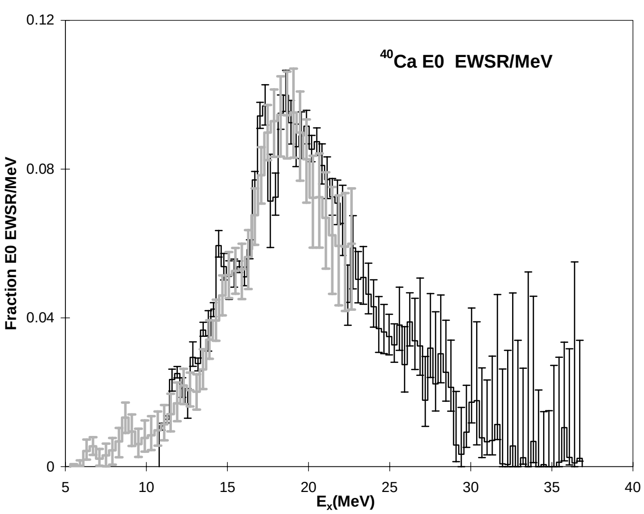

FIG. 3. The $E0$ strength distribution obtained is shown by the gray histogram. Error bars represent the uncertainty due to the fitting of the angular distributions as described in the text. The black line shows the $E0$ distribution reported in Ref. [1].

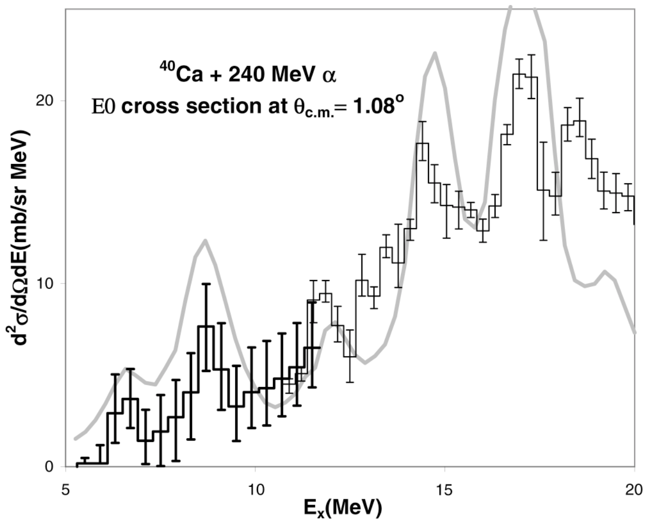

FIG. 4. The $E0$ cross section for 240 MeV α scattering at $\theta_{c.m.}=1.08°$ is shown by the histogram. The thick black line shows the cross section obtained in this work, while the thin line shows that from Ref. [1]. The calculation by Kamerdzhiev, Speth, and Tertychny [2] is shown by the wide gray line. The error bars represent the uncertainty in obtaining the $E0$ strength.

from hydrogen in the target were present in the crucial 3.5°–6° region, preventing a reliable extraction of multipole strengths in this energy region.

The (isoscalar) $E0$ multipole distribution obtained is shown in Fig. 3 superimposed on the distribution from Ref. [1].[1] They are in reasonable agreement over the $11<E_x<22$ MeV region where they overlap. The strength obtained in the $6<E_x<11$ MeV region in this analysis is in fair agreement with that reported from spectrum subtraction in Ref. [3]. The total $E0$ strength seen from 6 to 11 MeV is $3.2\pm1.0\%$ of the $E0$ EWSR and is centered at 8.7 ± 0.3 MeV. This compares with the spectrum subtraction result of 4.3% of the $E0$ EWSR and a centroid of 9.0 MeV.

The $E2$ strength obtained for $11<E_x<22$ MeV also agreed with that reported in Ref. [1]. Several 2^+ states are known [5] in the region $6<E_x<11$ MeV and approximately 10% of the $E2$ EWSR was identified in that region. Small amounts of $E1$, $E3$, and $E4$ strength were also seen.

Including the strength below $E_x=11$ MeV obtained from this analysis and the strength reported in Ref. [1], m_1/m_0 becomes $18.39+0.49-0.35$ MeV, $(m_1/m_{-1})^{1/2}=17.58\pm0.40$ MeV, $(m_3/m_1)^{1/2}=20.42+0.89-0.36$ MeV, and $100\pm13\%$ of the $E0$ EWSR in ^{40}Ca is accounted for.[2] This value of $(m_1/m_{-1})^{1/2}$ agrees within errors with those given in Refs. [1] and [3] and that used in Ref. [6] to obtain nuclear incompressibility by comparison with theoretical calculations [7].

[1]The vertical scale on the top graph in Fig. 3 of Ref. [1] is incorrect. The same data are shown in Fig. 3 with the correct vertical scale.

[2]The value $112\pm13\%$ reported on page 3 of Ref. [1] for the $E0$ strength including the spectrum subtraction results is misprinted. The correct value is $102\pm13\%$.

Kamerdzhiev, Speth, and Tertychny [2] have calculated expected $E0$ cross sections as a function of E_x for 240 MeV inelastic α particle scattering at 1.08°. We have used the strength distribution shown in Fig. 3 and calculated an equivalent 1.08° $E0$ cross section and that is compared to their calculation in Fig. 4. While the data are somewhat lower than the calculation over the region $6 < E_x < 11$ MeV, their calculation predicts both location and approximate relative strengths of the two peaks seen in the data.

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