Isoscalar E0, E1, and E2 Strengths in ^{12}C

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Although the structure of ^{12}C has been studied with a number of probes, there have been few studies of high-lying isoscalar E0 and E2 strengths. There have been no reports of small-angle experiments looking for high-lying isoscalar E1 strength in ^{12}C. In an earlier work [1] we located 14.5±4% of the isoscalar E0 EWSR strength in ^{12}C. Considering that the isoscalar E0 strengths located in ^{16}O and ^{24}Mg are 48% and 72%, respectively, the above seems to be a small percentage. In Ref. [1] a spectrum subtraction technique was used to highlight the E0 strength, however, this technique is sensitive to experimental background and the presence of other multipolarities. Also the analysis was performed by deformed potential calculations using ^{28}Si parameters which may distort the strength distribution. Therefore, we obtained new elastic and inelastic scattering data with 240 MeV α-particles to states at 4.439 MeV 2^+, 7.655 MeV 0^+, and 9.641 MeV 3^- in ^{12}C from $\theta_{c.m.}$ = 3° to 48°, and folding potential parameters were determined. These parameters were used in a slice analysis [2] for determining the E0, E1 and E2 strength distributions. In order to further constrain the multipole slice-analysis, giant resonance data were obtained over a larger angular range than in Ref. [1]. The experiments were performed at the Texas A&M K500 superconducting cyclotron using the MDM spectrometer.

The experimental technique has been described thoroughly in [1] and [2]. Natural carbon foils of thicknesses 4 mg/cm^2 and 2 mg/cm^2 were used as targets. Elastic and inelastic scattering data were taken over the laboratory angular range from 2° to 37° with horizontal and vertical acceptance angles of 4° and 2°, respectively. The spectrometer central angle (θ_{spec}) was changed from 4° to 26° in steps of 2° and from 26° to 35° in steps of 3°. Thus nearly 50% overlap data could be taken. The excitation energy range covered was $-10 < E_x <$ 45 MeV.

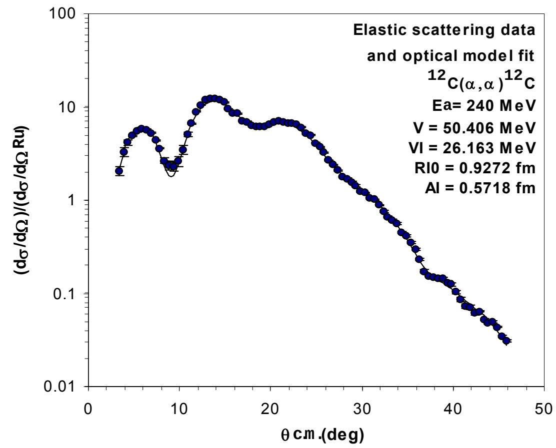

Figure 1: Angular distribution of the ratio of the experimental differential cross section for elastic scattering to Rutherford scattering for 240 MeV ∀ particles from ^{12}C plotted versus average center-of-mass angle. The solid line shows a DDWS calculation with parameters shown in the inset.

Giant resonance data were taken with θ_{spec} set at 0°, 3.5°, 4° and 6.5° covering a laboratory angular range from 0° to 8.5° with horizontal and vertical acceptance angle of 4°. A dipole field resulting in an excitation energy range $6 < E_x < 60$ MeV was used in the giant resonance measurements.

The angular distribution of the ratio of the experimental differential cross section for elastic scattering to Rutherford scattering is plotted versus average center-of-mass angle in Fig. 1. The data were fitted by optical model predictions using the code PTOLEMY using the DDWS procedure [3] and the solid line shows the best fit. The form of the real part of the optical potential was generated using a single folding model with a density dependent α-nucleon interaction. A two-parameter Fermi distribution was used for the ground state of ^{12}C, with a radius of 2.1545 fm and surface diffuseness of 0.425 fm [4]. The imaginary part was represented by a Woods-Saxon form. The optical model parameters obtained are shown in the inset of Fig. 1.

Angular distributions of the differential cross section for inelastic α scattering to states at 4.439 MeV 2^+, 7.655 MeV 0^+, and 9.641 MeV 3^- in ^{12}C are plotted versus average center-of-mass angle in Fig. 2. The lines show DWBA calculations for the transitions where the distorted waves were obtained from the above optical model parameters. For the 2^+ and 3^- transitions, the deformation parameters used were calculated using the reduced transition strengths reported in [5] and [6], respectively. For the 0^+ transition, the deformation parameter reported in [1] was used. The agreement for the first excited state (2^+) is very good. For the other states agreement is good at small angles.

In the slice analysis, the spectra obtained were divided into a peak and continuum, where the continuum was assumed to have the shape of a straight line at high excitation joining onto a Fermi shape at low excitation to model threshold effects [2]. The multipole components of the peak and continuum parts were obtained by dividing them into multiple bins by excitation energy and then comparing the angular distributions obtained for each energy bin to DWBA calculations. In this work two independent slice analyses were performed; one

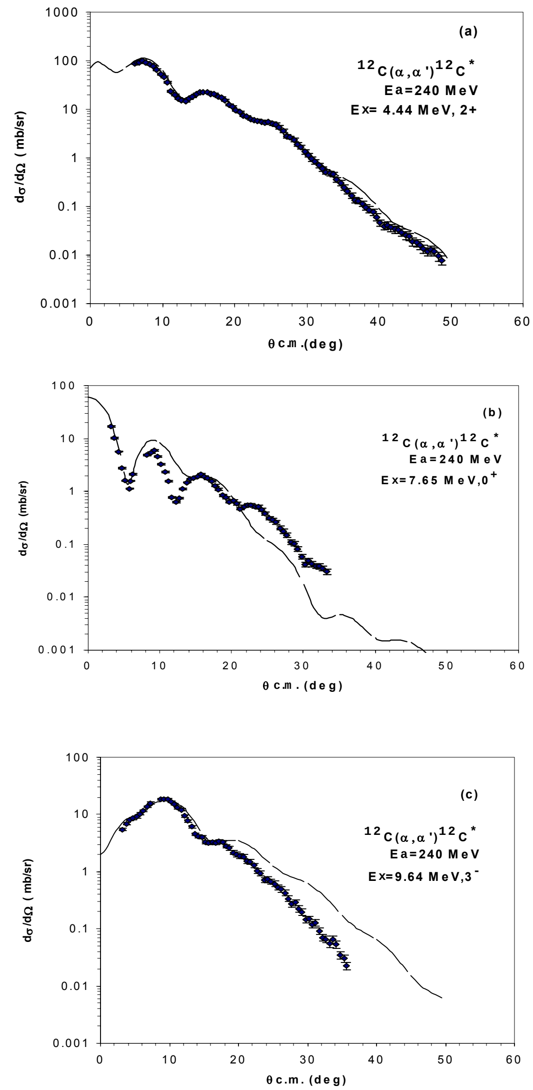

Figure 2: Angular distributions of the differential cross section for inelastic scattering to states at (a) 4.439 MeV 2^+, (b) 7.655 MeV 0^+, and (c) 9.641 MeV 3^- in ^{12}C are plotted versus average center-of-mass angle. The lines show the DWBA calculations for the transitions.

with a high threshold continuum (C1, similar to that found in an experimental study [7] of continuum scattering in ^{12}C) and the other with a low threshold continuum (C2, calculated using particle separation energy as described in [2]).

Fig. 3 shows sample giant resonance spectra taken on two occasions by setting θ_{spec}=0°. They have the same average angle $\theta_{c.m.}$ = 1.41°, but are from $\theta_{c.m}$ - bins left side and right side of 0°-direction. Their main

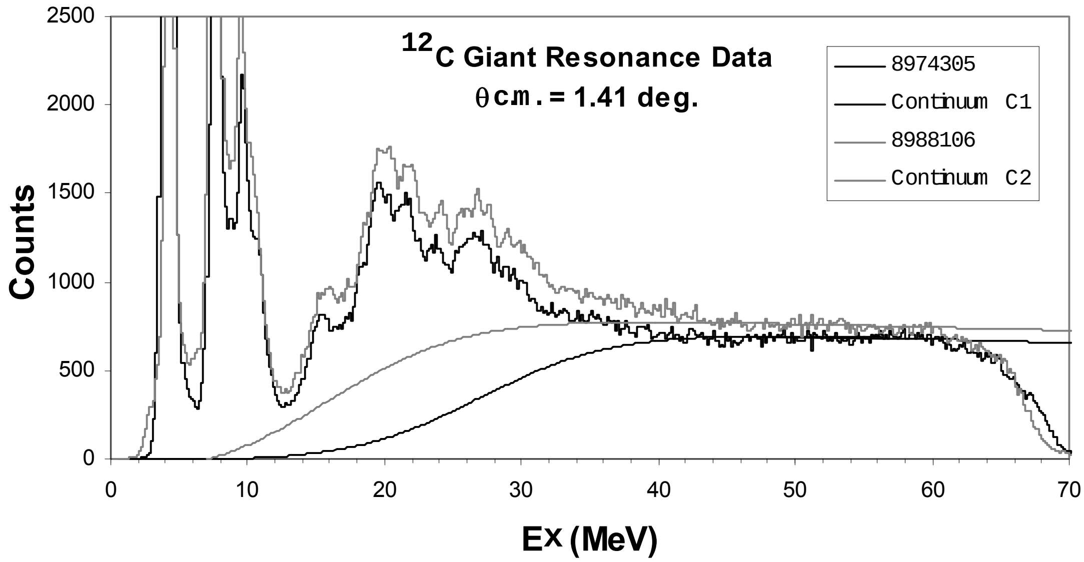

Figure 3: Inelastic ∀ spectra of ^{12}C obtained with the spectrometer at 0°. The histograms show the data and the lines the continua chosen. See text for details.

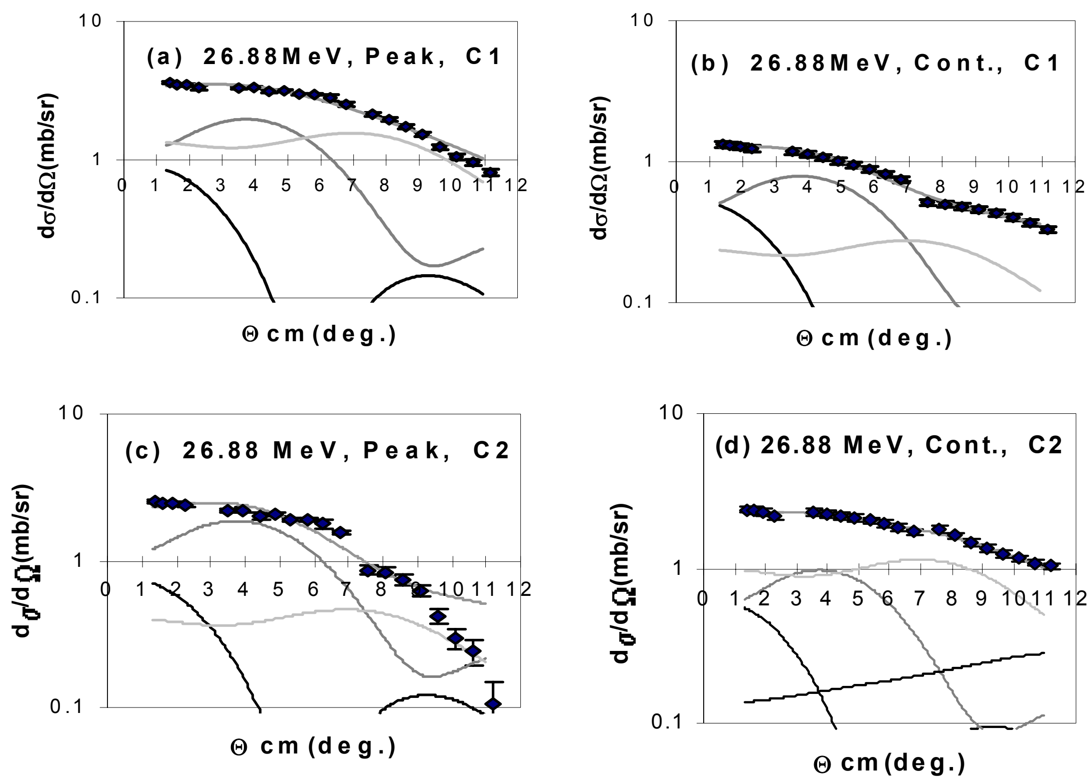

Figure 4: Experimental angular distributions for the peak (left panels) and continuum (right panels) for the energy bin Ex = 26.88 MeV are shown as points. Upper (a)-(b) and lower (c)-(d) panels correspond to continuum choice C1 and C2, respectively. The lines show the result of the multipole analysis of the angular distributions.

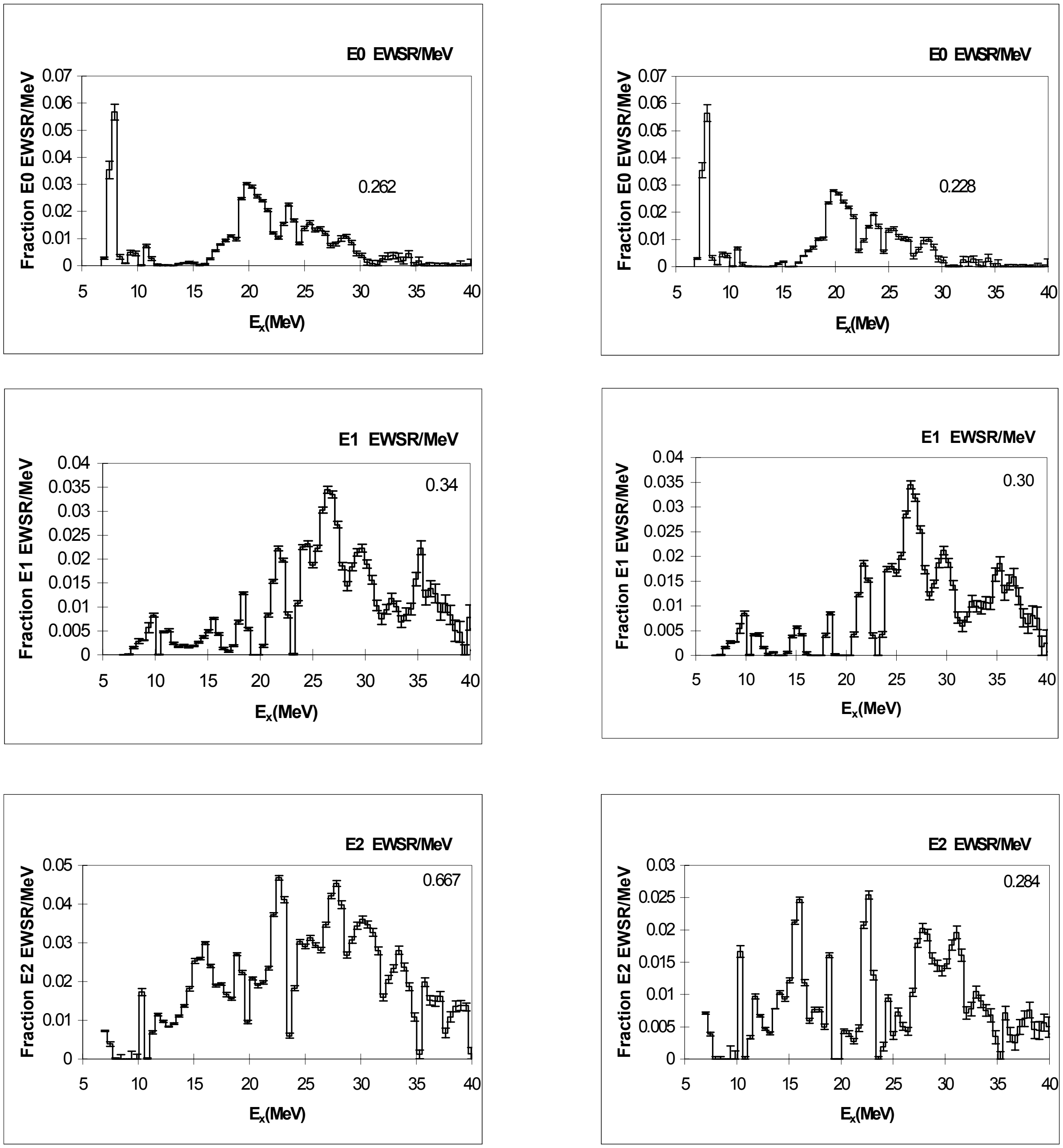

Figure 5: Isoscalar E0, E1 and E2 strength distributions obtained in the analysis of peak yields are shown by histograms. The histograms in the left panels are obtained in case of the high threshold continuum. C1 and those in the right panels are obtained in case of the low threshold continuum C2. Sum rule fractions obtained are shown in the inset.

features are identical. The continuum choices C1 and C2 are also shown in Fig. 3 as continuous lines.

Fig. 4 shows angular distributions obtained for the peak and continuum for the energy bin E_x = 26.88 MeV in the left and right panels, respectively. Upper and lower panels show the angular distributions in cases of continua C1 and C2, respectively. The lines show cross sections for the various multipoles and their sum found in the fits. Isovector E1 cross sections were assumed to be negligible.

The isoscalar E0, E1, and E2 multipole distributions obtained in the analysis of peak yields are shown in Fig. 5. Distributions in the left panels were obtained with the high threshold continuum C1 and those in the right were obtained with the low threshold continuum C2. For both continua the E0 EWSR distributions observed above 14 MeV have features similar to those reported in [1] except for a higher magnitude and lesser fluctuations. Significant isoscalar E1 and E2 strengths were also found in the energy region from 14 MeV to 40 MeV. Sum rule fractions are shown in the respective panels. The main difference in the two slice analyses is in the E2 strength distributions. E0 and E1 distributions are relatively unaffected by the continua choice.

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