# Giant resonance strength in $^{28}$Si.

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We report here a reanalysis of the 240 MeV $^{28}$Si inelastic $\alpha$ scattering data reported in Ref. [1] up to an excitation energy of 42 MeV where the assumption is made that ALL of the cross section is due to multipole processes having $L \leq 4$(i.e. there has been no continuum or background subtraction). Alpha particles from the decay of the mass 5 ejectile created in the ($\alpha$,$^{5}$He) and ($\alpha$,$^{5}$Li) reactions will be a competing process above $E_x$=42 MeV($^{5}$Li) and 50 MeV($^{5}$He), so this "zero continuum" analysis would not be appropriate above $E_x$=42MeV.

The multipole components were obtained [1] by dividing the data 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 $\chi^2$. This continued until the new $\chi^2$ was 1 unit larger than the total $\chi^2$ obtained for the best fit.

The DWBA calculations were described in Ref. [1] and the same density dependent Woods-Saxon folding potentials were used for the calculations in this work. A sample of the angular distributions obtained are shown in Fig. 1. Fits to the angular distributions were carried out with a sum of isoscalar $0^+$, $1^-$, $2^+$, $3^-$, and $4^+$ strengths. The limited angular range of the data prevents distinguishing L=4 and higher contributions. The isovector giant dipole resonance (IVGDR) contributions are small, but were calculated from the known distribution [2] 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. 1.

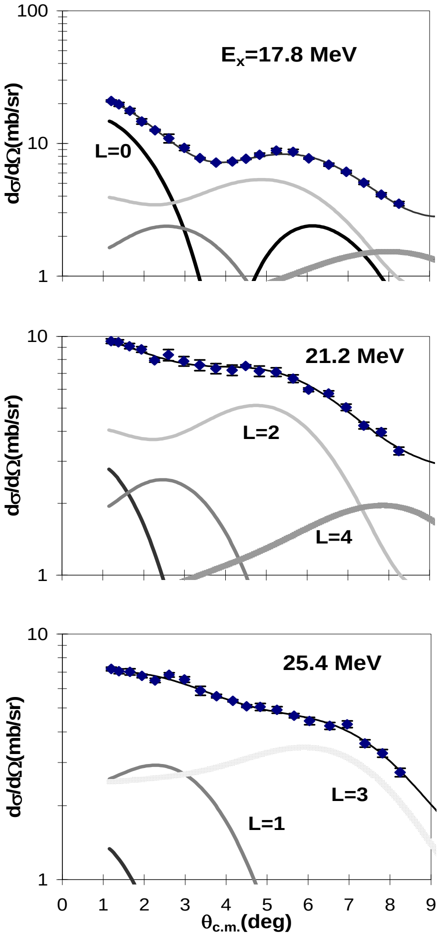

**Figure 1.** Angular distributions obtained for inelastic $\alpha$ scattering for three excitation ranges in $^{28}$Si. The energy bins are approximately 450 keV wide. The medium black line shows the fits. Contributions of each multipole are shown. When not shown, errors are smaller than the data points.

The strength distributions obtained for

isoscalar L = 0,1,2,3, and 4 are shown in Fig. 2. The E0 multipole distribution is superimposed on the distribution from Ref. [1]. They are in reasonable agreement over the entire energy region. The EWSR strength obtained, 74±7% of the E0 EWSR, the centroid energy (m1/m0) 20.89±0.38 MeV and RMS width 5.9±0.6 MeV all agree within the errors with those from Ref. [1] (81±10%, 21.25±0.38 MeV and 6.4±0.6 MeV respectively). This work and Ref. [1] used the same data, DWBA calculations, and fitting routines so that the small differences can be attributed entirely to the choice of continuum. This suggests that the extracted monopole strength is only weakly dependent on the assumptions made about the continuum, which we have seen in analyses of data for other nuclei. This is not true for other multipolarities.

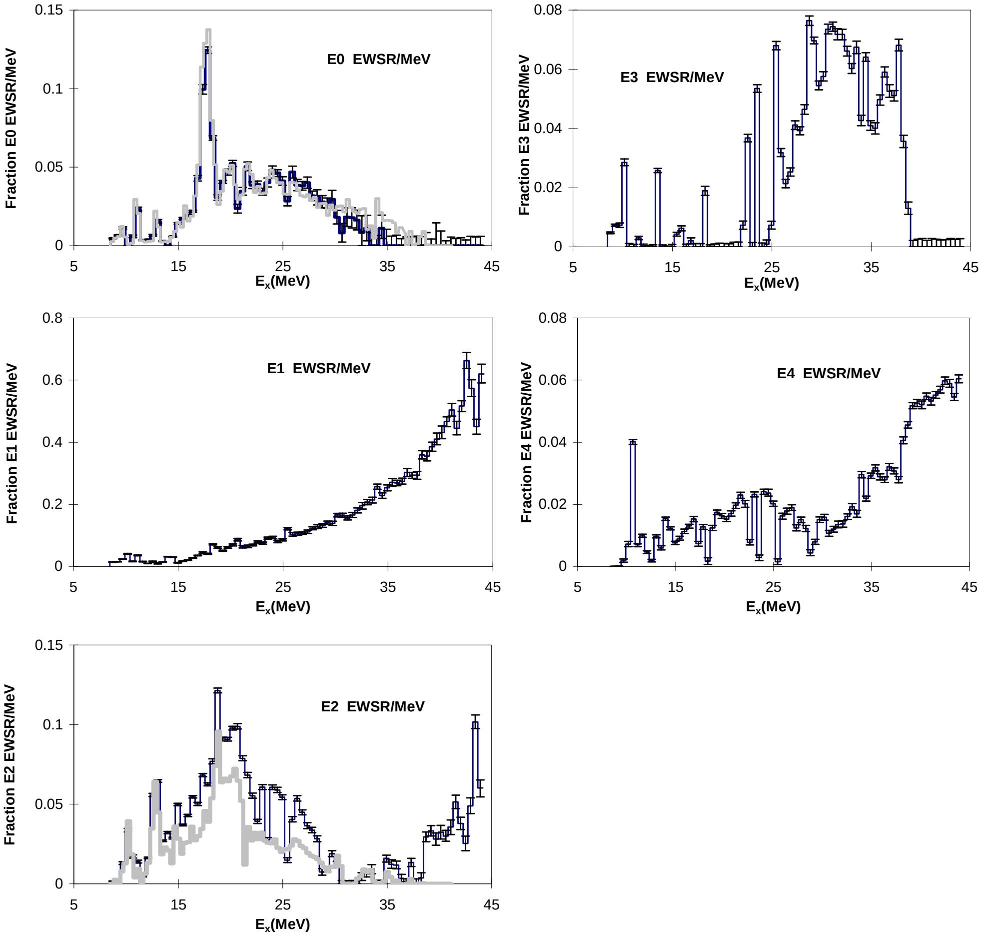

**Figure 2.** The E0, E1, E2, E3 and "E4" strength distributions obtained are shown by the gray histogram. Error bars represent the uncertainty due to the fitting of the angular distributions as described in the text. The grey lines shows the E0 and E2 distributions reported in Ref. [1].

In the region $E_x$=9–35 MeV E2 strength corresponding to 102±11% of the E2 EWSR was identified in a broad peak with a centroid of 18.77± 0.35 MeV and RMS width of 5.45±0.20 MeV. This contrasts sharply with the results of Ref. [1] (shown for comparison in Fig. 3) where after a continuum was subtracted, E2 strength was identified corresponding to 68±9% of the E2 EWSR. The centroid and RMS width of the E2 strength reported in Ref. [1] were 18.54±0.25 MeV and 4.7±0.6 MeV suggesting that the additional strength identified in this analysis lies predominantly in the higher energy region as might be expected since the continuum assumed in Ref. [1] was lower at lower excitation. The known $2^+$ strength in states below $E_x$~9.5 MeV corresponds to ~11.4% of the E2 EWSR [3], so that all of the expected isoscalar E2 strength in $^{28}$Si is accounted for below 35 MeV. Above $E_x$=35-38 MeV the E2 strength appears to increase up to the highest energy analyzed apparently containing another 27% of the E2 EWSR. This is likely due to unidentified continuum processes that have distributions similar to an L=2 multipole.

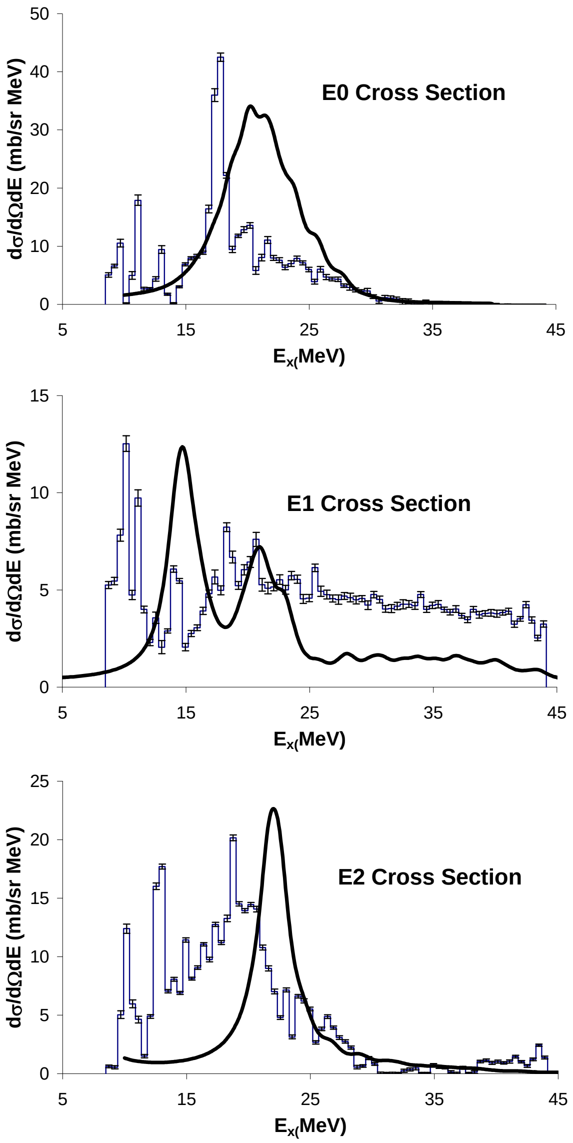

**Figure 3.** Cross sections (at the peak of the angular distributions) for E0, E1, and E2 excitation (obtained from the strength distributions shown in Fig. 3) are shown buy the histograms. The solid lines are calculations from Ref. [5].

As can be seen in Fig. 2, our analysis shows a small amount of E3 strength between 10 and 18 MeV (3% of the E3 EWSR) and a much larger amount (81±8% of the E3 EWSR) between 23 and 39 MeV centered at 32 MeV with an RMS width of 5.3±0.4 MeV. Only small amounts of E3 strength have been seen in other nuclei with A < 56. In heavier nuclei (A=90-208), approximately 75% of the E3 EWSR was identified at higher excitation [4] and $E_{HEOR}*A^{1/3}$ lies between 92 and 116 MeV. The observed HEOR strength in $^{28}$Si corresponds to $E_{HEOR}*A^{1/3}$=95 MeV, consistent with what is expected for the $3\hbar\omega$ component of the E3 strength.

The "E4" (L≥4) strength has a broad peak between 9 and 30 MeV followed by a dramatic increase above $E_x$=30 MeV. The total strength observed corresponds to ~ 80% of the E4 EWSR, but the relatively fast increase above 30 MeV is likely due to continuum processes having relatively flat angular distributions.

The "isoscalar E1 strength" obtained rises sort of smoothly from 9 MeV to 40 MeV and corresponds to 140% of the isoscalar E1 EWSR. In the analysis reported in Ref. [1] as well as analyses of the data for other nuclei [4], the isoscalar E1 strength extracted from a multipole analysis of the continuum rises almost monotonically up to the highest excitation energy studied and corresponds to significantly more than the sum rule strength. There are likely continuum processes which are responsible for much of this (apparent) E1 strength as discussed below.

In Fig. 3 the E0, E1, and E2 strength functions from Fig. 2 have been converted into cross section at the peak of the angular distribution. Also plotted are Hartree-Fock Random Phase Approximation calculations [5] for strength distributions converted to cross sections (at the peak of the angular distribution for each multipole) using double folding calculations where the transition densities for each multipole were obtained from the HF-RPA calculations. These calculations did not include specific nuclear structure effects and show no structure whereas in this light nucleus considerable structure is present in the data as expected. Of particular interest are the calculations for the E1 strength. Above $E_x$ ~ 25 MeV the E1 double differential cross section is about 50% of the observed cross section for all processes and is ~2.5 times the predicted cross section, suggesting that some (significant?) part of the data is not due to E1 excitation but other (unidentified) processes that somewhat mimic an E1 angular distribution.

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