Anomalous behavior of the giant monopole resonance

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The energy of the giant monopole resonance (GMR) in $^{48}$Ca is higher than in $^{40}$Ca, which is not reproducible with self-consistent mean field calculations[1], and the GMR’s in both $^{92}$Zr and $^{92}$Mo are much higher in energy than predicted with mean field calculations that reproduce the energies of the GMR in the other Zr and Mo isotopes.[2] Moreover the GMR’s in all Zr and Mo isotopes studied are split into two components separated by several MeV. In the past year we have studied the GMR in $^{44}$Ca and $^{94}$Mo to further explore these issues.

Fig. 1 shows a plot of the energy of the GMRs in $^{40,44,48}$Ca vs $A$, and the $^{44}$Ca energy falls between the $^{40}$Ca and $^{48}$Ca energies. Also plotted are calculations using the Leptodermous expansion.

The brown squares were calculated using values for $K_{NM}$ and $K_{\tau}$ obtained in a study of the Sn isotopes [3], and the $A$ dependence of the GMR energy is opposite that of the data, with the GMR in $^{40}$Ca well above that in $^{44}$Ca, and the GMR in $^{48}$Ca well below that in $^{44}$Ca. Varying $K_{NM}$ and $K_{\tau}$ to fit the data (orange triangles) results in $K_{NM}=188$ MeV and $K_{\tau}=+1200$ MeV. $K_{\tau}$ is generally accepted to be negative and roughly ~-500MeV, so the +1200MeV necessary to fit the $^{40,44,48}$Ca results is badly in disagreement. Fig. 2 shows a comparison of the Ca experimental results with three mean field calculations. The two calculations [4-5] that give an energy for $^{44}$Ca agree with the experimental results.
for $^{44}$Ca, and the Anders et al. calculation [4] shows the GMR energy in $^{48}$Ca above that for $^{44}$Ca in agreement with the data though it shows the $^{40}$Ca energy much higher than either $^{44}$Ca or $^{48}$Ca. The HF_QRPA calculation with pairing by Vesely et al. [5] shows the energy systematically decreasing as A increases, in contrast to the data. The RMF calculation by Sharma [6] shows the GMR in $^{48}$Ca below that in $^{40}$Ca.

We also studied $^{94}$Mo to complement our previous study [2] of $^{92,96,98,100}$Mo and $^{90,92,94}$Zr. The E0 strength distribution obtained (Fig. 3) is similar to those for $^{96,98,100}$Mo and $^{90,94}$Zr with a lower energy peak at $E_x \sim 16.9$MeV containing most of the strength and $\sim 20\%$ of the strength in a peak at $E_x \sim 24$MeV. The total E0 strength seen is 108\% of the E0 EWSR. The anomalous behavior of the centroid of the GMR is described in ref. [2], with those of both $^{92}$Mo and $^{92}$Zr well above values expected from mean field or Leptodermous expansion calculations. The GMR in $^{94}$Mo is well reproduced by the mean field calculations. In Figs. 4 & 5 we plot the energies of the low and high peaks separately vs A. The energies of the lower peaks have a smooth behavior for both Zr and Mo isotopes and those for Mo are well reproduced by a Leptodermous expansion calculation with $K_{NM}=210$MeV and $K_r=-750$MeV. The Zr data would require a slightly more negative $K_r$. The high energy peaks in the Mo isotopes are within errors at
the same energy whereas the high energy peak in $^{92}$Zr is over an MeV higher than in $^{94}$Zr and about 0.5 MeV higher than in $^{90}$Zr.

**FIG. 3.** E0 strength distribution for $^{94}$Mo plotted vs excitation energy.

**FIG. 4.** Plot of energy of the low energy E0 peaks in the Mo and Zr isotopes vs A. The uncertainties are indicated by the error bars. Also shown are Leptodermous calculations using the parameters indicated in the figure.
FIG. 5. Plot of energy of the high energy E0 peaks in the Mo and Zr isotopes vs A.