Investigation of the Giant Monopole Resonance in the Sn, Cd, and Pb Isotopes: Testing the MEM Effect

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ABSTRACT

The giant monopole resonance (GMR) has been investigated in the Pb isotopes ^{204,206,208}Pb with the aim of testing the Mutual Enhancement Magicity (MEM) effect in nuclear incompressibilities. The MEM effect was advanced as a possible explanation of the puzzling "softness" of the Sn and Cd nuclei, as indicated by their low GMR energies. Our results rule out this possibility.

In recent investigations of the giant monopole resonance (GMR) in the Sn (A=112–124) and Cd (A=106–116) isotopes [1–4], it was discovered that the experimentally observed GMR energies in these nuclei are significantly lower (by almost 1 MeV in the case of the higher-A isotopes) than the values predicted by recent theoretical calculations that reproduce the GMR energies in the "standard" nuclei, ^{90}Zr and ^{208}Pb, very well. This disagreement has posed a big challenge for theory and the question of why Sn isotopes are so "soft" [5] has engendered a lot of activity and debate in the field about the possible theoretical interpretation and implications [6–10]; indeed, this has been identified as one of the "open" problems in nuclear structure theory in a recent major compilation [11]. The effects of pairing (superfluidity) in these open-shell nuclei account for only a small part of the difference between the experiment and theory [6, 9].

A most intriguing suggestion has been made in this connection that this might be analogous to the so-called Mutual-Enhancement-Magicity (MEM) effect observed in predictions of masses with different energy-density functionals. It has been noted that the ability of these models to predict masses of doubly-closed shell nuclei is significantly poorer than that for nuclei over the rest of the nuclear chart [12, 13]. The implication, then, is that the nuclear incompressibility value obtained from the GMR in the doubly-closed nucleus, ^{208}Pb, would necessarily overestimate the GMR energies in the open-shell nuclei [9, 14], accounting for the observed behavior of the GMR in the Sn and Cd isotopes. An essential prediction of this conjecture was that the GMR energy in the doubly-magic nucleus, ^{208}Pb, would be significantly, and measurably, larger than that in the neighboring Pb isotopes: ^{204,206,210,212}Pb [14].

In order to test this conjecture, we have measured the GMR in the Pb isotopes, ^{204,206,208}Pb, using inelastic scattering of 400-MeV α particles at extremely forward angles, including 0°. The measurements were performed at the Research Center for Nuclear Physics (RCNP) at Osaka University, Japan, using the Grand Raiden spectrometer. The experimental techniques and data analysis procedures were identical to those in the measurements described previously for the Sn isotopes [1, 2]. Data with high statistics was obtained for all the three nuclei in the same experiment—this way, it was possible to maintain as ''constant" experimental conditions as possible so that the systematic errors, if any, are the same for all nuclei. Elastic scattering was also measured for the ^{204,206}Pb targets to obtain the optical model (OM) parameters to be used in DWBA calculations employed in multipole-decomposition-analysis (MDA) of the inelastic scattering data, to extract the various multipole strengths [1, 2]; the OM parameters for ^{208}Pb have been known from our previous measurements on the isoscalar giant dipole resonance (ISGDR) [15].

Fig. 1 shows the "0°" inelastic α-scattering spectra for the three Pb isotopes investigated in this work; the GMR cross sections are maximal at 0°. It is clear, even from a cursory look, that the three spectra are virtually identical, contrary to the expectation from the application of MEM effect to GMR's.

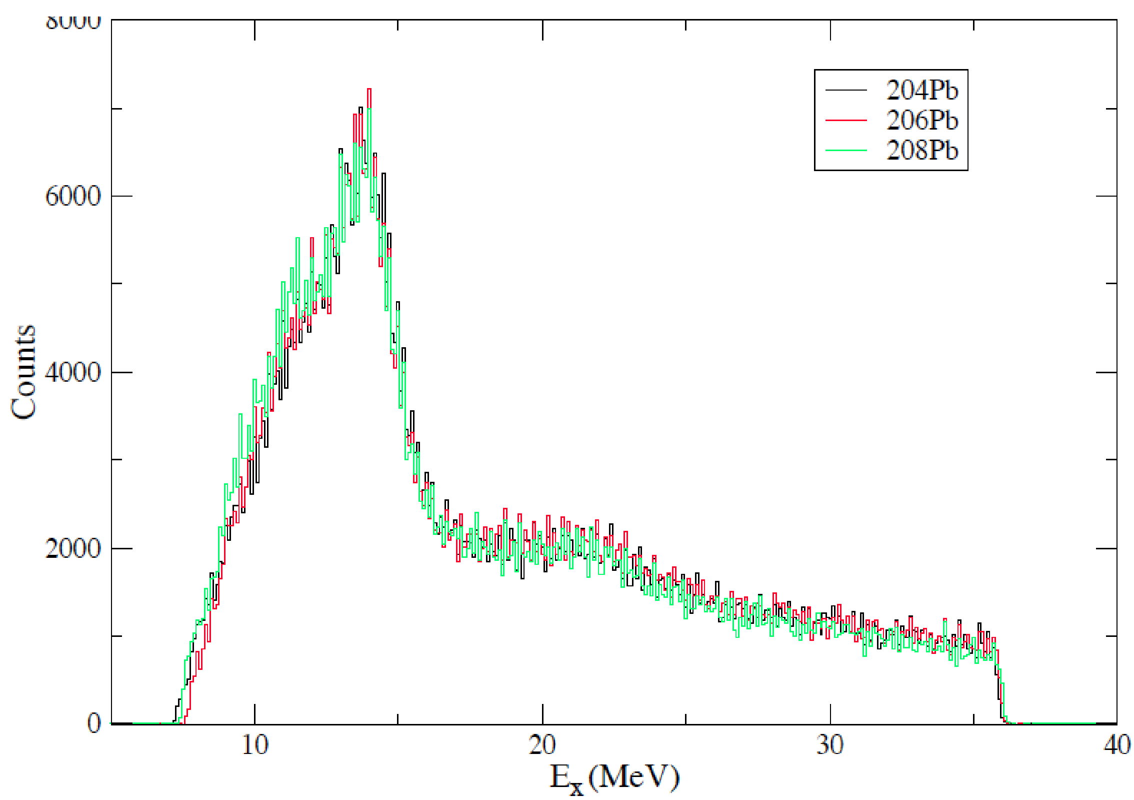

Fig. 1. Inelastic α scattering spectra at "0°" for ^{204}Pb (black), ^{206}Pb (red), and ^{208}Pb (green).

We have, further, extracted the $\Delta L = 0$ strength in all three Pb isotopes using the MDA technique again described in Refs. [1, 2]; as shown therein, and in many previous examples, this procedure allows determination of strength distributions associated with various multipoles with very good accuracy. Preliminary results from MDA for the ΔL=0 strength distributions for the three Pb isotopes are shown in Fig. 2; also shown are Lorentzian fits to the extracted strength distributions. The centroids for the Lorentzians

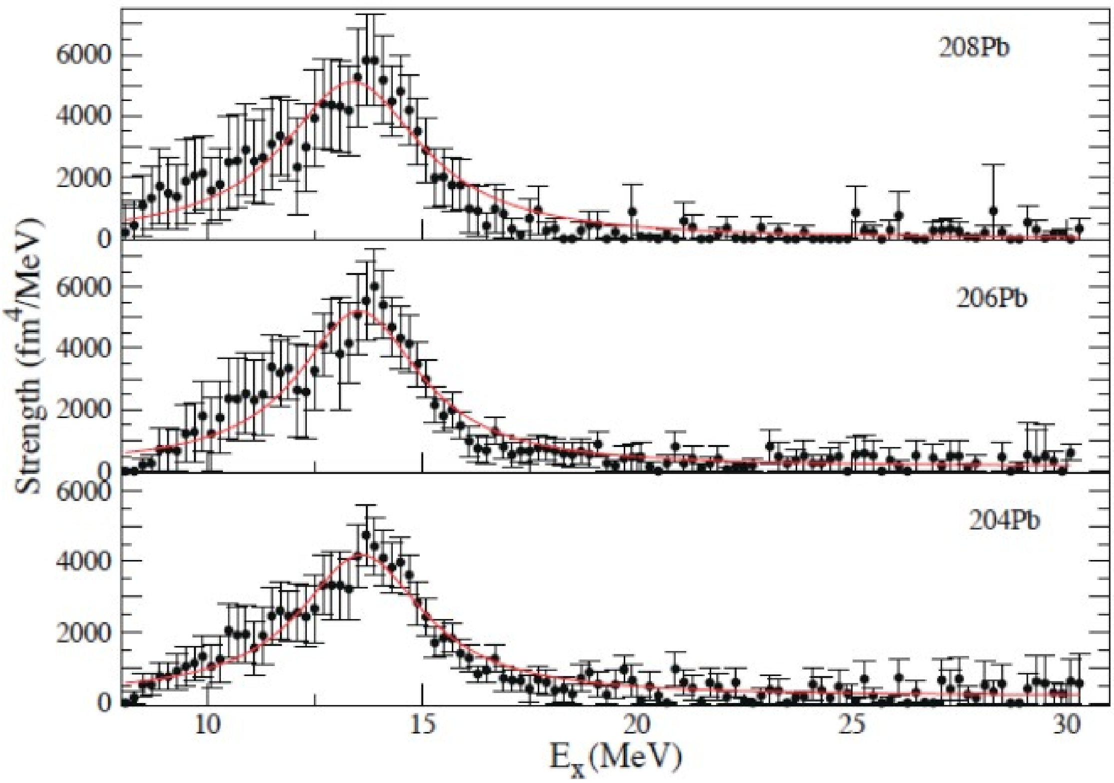

Fig. 2. Preliminary $\Delta L = 0$ strength distributions for ^{204}Pb (bottom panel), ^{206}Pb (middle panel), and ^{208}Pb (top panel) as extracted from Multipole Decomposition Analysis (MDA) of 400 MeV inelastic α-scattering spectra. Lorentzian fits to the distributions are also shown (solid red lines).

are at 14.1 MeV, 13.9 MeV, and 13.7 MeV, respectively, for ^{204}Pb, ^{206}Pb, and ^{208}Pb. While these numbers are very preliminary, it is clear, again, from the GMR strength distributions that, quite contrary to the expectation that the energy of the GMR would be largest in ^{208}Pb, the GMR energies in the three cases are nearly identical. Indeed, the variation in GMR energy corresponds to what one would normally expect from the standard $A^{-1/3}$ dependence for all giant resonances.

These results would imply, then, that the MEM effect does not hold for the Pb isotopes and, consequently, does not provide a good explanation for the observed "softness" of the Sn and Cd nuclei, as indicated by their GMR energies. As such, this remains an open problem, a challenge to theorists.

It is profound gratitude that I acknowledge my collaborators in the investigations of GMR in the Sn, Cd, and Pb isotopes: D. Patel, G.P.A. Berg, T. Li, Y. Liu, A. Long, R. Marks, J.T. Matta, B.K. Nayak, P.V. Madhusudhana Rao, K. Sault, and R. Talwar (University of Notre Dame); M. Fujiwara, H. Hashimoto, K. Kawase, K. Nakanishi, S. Okumura, and M. Yosoi (RCNP, Osaka); M. Ichikawa, M. Itoh, and R. Matsuo (Tohuku University); M. Uchida (Tokyo Institute of Technology); Y. Iwao, T. Kawabata, T. Murakami, H. Sakaguchi, S. Terashima, Y. Yasuda, and J. Zenihiro (Kyoto University); H. Akimune, C. Iwamoto, A. Okamoto (Konan University); and, T. Adachi and M.N. Harakeh (KVI, Groningen). Financial support from the ExtreMe Matter Institute (EMMI) at GSI, where this manuscript was prepared, is also gratefully acknowledged. This work has been supported in part by the U.S. National Science Foundation (Grant Nos. PHY07-58100 and PHY-1068192).

REFERENCES

[1] T. Li *et al*., Phys. Rev. Lett. **79**, 162503 (2007).

[2] T. Li *et al*., Phys. Rev. C **81**, 034309 (2010).

[3] U. Garg *et al*., Nucl. Phys. A **788**, 36c (2007).

[4] D. Patel *et al*., *to be published*.

[5] J. Piekarewicz, Phys. Rev. C **76**, 031301 (2007).

[6] J. Li *et al*., Phys. Rev. C **78**, 064304 (2008).

[7] J. Piekarewicz and M. Centelles, Phys. Rev. C **79**, 054311 (2009).

[8] V. Tselyaev *et al*., Phys. Rev. C **79**, 034309 (2009).

[9] E. Khan, Phys. Rev. C **80**, 011307(R) (2009).

[10] D. Vretnar, *private communication*.

[11] J. Piekarewicz, J. Phys. G: Nucl. Part. Phys. **37**, 064308 (2010).

[12] N. Zeldes *et al*., Nucl. Phys. A **399**, 11 (1983).

[13] D. Lunney *et al*., Rev. Mod. Phys. **75**, 1021 (2003).

[14] E. Khan, Phys. Rev. C **80**, 057302 (2009).

[15] M. Uchida *et al*., Phys. Lett. B **557**, 12 (2003).