Workshop On Nuclear Matter Incompressibility Coefficient

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The main goal of the Workshop, which took place in RIKEN, Wako, Japan, was to focus on recent experimental and theoretical development in the study of the nuclear matter incompressibility coefficient, K_{nm}, defined by,

$$K_{nm} = k_f^2 \frac{d^2(E/A)}{dk_f^2}\Big|_{k_{f0}} = 9\rho_0^2 \frac{d^2(E/A)}{d\rho^2}\Big|_{\rho_0}. \quad (1)$$

Here E/A is the binding energy per particle of the nuclear matter, and k_{f0} and ρ_0 are the Fermi momentum and the matter density at saturation. The participation of quite a few of the leading workers in the field led to very stimulating discussion on the results of new theoretical works and experimental techniques. In particular, we examine during the workshop the most sensitive method which is based on experimental data on the strength function distribution of the isoscalar giant monopole and dipole resonances, which are compression modes of nuclei.

The current status of theory and experiment concerning the the strength distributions of ISGMR and ISGDR and their relations to K_{nm} has been discussed in the presentations given in the Workshop. Experimental results were presented by Lui (TAMU), Clark (TAMU), Yosoi (Kyoto) and Bacelar (KVI) and theoretical works were described by Danisov (INR, Kiev), Morawetz (Rostock), Sharma (Kuwait), Colo (Milan) Satpathy (Bhubaneswar) and Shlomo (TAMU). We also mention the talks given at the Symposium by Youngblood (TAMU) and Garg (Notre Dame), on recent accurate data for the ISGMR and ISGDR, respectively, and by Blaizot (Saclay), Van Giai (Orsay), Toki (RCNP) and Vretenar (Zagreb), on theoretical results.

Drs. Youngblood, Garg, Lui and Clark, reported on highly accurate new data on the ISGMR and the ISGDR strength distributions for a wide range of nuclei, from ^{12}C to ^{208}Pb, obtained by inelastic scattering 240 MeV $\alpha-$particles carried out at the Cyclotron Institute at Texas A&M University. Excellent peak-to-continuum ratios were obtained and the presence of high lying structure for the ISGMR was found for each nucleus. Moreover, ISGDR strength was identified for each nucleus. Dr. Yosoi reported on a new program at RCNP (Osaka) to measured the strength distribution of giant resonances by inelastic scattering of 400 MeV protons and $\alpha-$particles. Preliminary results showed that about 60% of the EWSR was identified in ^{58}Ni. Dr. Bacelar described the program at KVI to measure the dilepton decay of giant resonances. Preliminary investigations showed that a more sensitive detector should be constructed.

Although the experimental analysis of the Texas A&M University new data, for some nuclei, is only preliminary, one observed the following: (i) An increase in the centroid energy of the ISGMR when compared to previous data. In particular, an increase from 16.2 MeV to 17.8 MeV was found for the centroid of the ISGMR in ^{90}Zr. With the new results, the A dependence of the ISGMR energy is now in agreement with those calculated by the HF-RPA method with effective interactions having a value of 230 MeV for K_{nm}. (ii) However, preliminary analysis of the experimental data show that the centroids for the ISGDR are significantly smaller (by 3-5 MeV) than those obtained by the HF-RPA calculations with effective interactions which reproduced the ISGMR data. If this preliminary data for the ISGDR is confirmed, it will pose a serious problem to current theories of giant resonances.

The theoretical works were concerned with certain aspects of collective motion in nuclei. Dr. Denisov presented a nonlinear hydrodynamic model to study the frequency shift of an N-phonon excitation due to nonlinearity. It was found that the effect of nonlinearity is important for the isoscalar resonances. Dr. Morawetz considered collective modes in asymmetric nuclear matter and surface effects, using a kinetic equation with a two-body collision term. He obtained good agreement with experimental data for the ISGDR using a Gamow-Teller like transition density. However, no results were presented for the ISGMR. Dr. Sharma, described a set of Skyrme type interactions having different values for K_{nm} and demonstrated the sensitivity of the two-neutron separation energies to the value of K_{nm}. Dr. Satpathy, presented a method for deducing K_{nm} from nuclear masses and obtained a value close to 300 MeV for K_{nm}. It is worthwhile to mention that during the Symposium, Dr. Van Giai showed that by taking into account the effect of the Dirac Sea, the value obtained for K_{nm} in the relativistic RPA calculations is about 250-270 MeV and it is in agreement with the value obtained by the time-dependent relativistic-mean-field calculations.

Dr. Colo presented results of HF-RPA calculations of the ISGMR and ISGDR strength distributions of various nuclei with commonly adopted effective interactions. It was found that the experimental data for the ISGMR is reproduced with interactions having a value of 230 MeV for K_{nm}. However, the theoretical values for the centroid energy of the ISGDR are significantly higher than the experimental results. Dr. Colo also found that the coupling to the 2p-2h states may affect the centroid of giant resonances by less than 1 MeV. We considered the problem of the analysis of hadron excitation of giant resonances and the comparison between theory and experiment. Using the folding model Distorted Wave Born Approximation and microscopic transition densities obtained from the self-consistent Skyrme-Hartree-Fock (HF)-Random-Phase-Approximation (RPA) calculations, we evaluated the inelastic cross sections of 240 MeV $\alpha-$particles for the isoscalar giant monopole resonance (ISGMR) excitation of ^{28}Si, ^{40}Ca, ^{58}Ni, and ^{116}Sn nuclei. Similar calculations of the cross sections were done using the collective model transition densities obtained from the Hartree-Fock ground state densities. Our results show that the approximation of the ISGMR transition density by the collective model form (which is widely done in experimental studies) may lead to up to 20% overestimation of the ISGMR strength extracted from the cross section analysis. Such an overestimation may further result in a shift of the ISGMR centroid energy. This shift, however, did not exceed 2% of the ISGMR centroid energy for the considered nuclei.

It is clear that more experimental work is needed to establish the strength distribution of:

(i) The ISGDR over a wide range of nuclei.

(ii) The ISGMR for medium, light nuclei and neutron rich nuclei.

(iii) Other isoscalar resonances (L = 2, 3) over a wide range of nuclei.

On the theoretical side, the new experimental data pose a challenge to theory to understand the conflicting results for K_{nm} deduced from the data on the ISGMR and the data on the ISGDR. Further theoretical investigations are needed to:

(i) Carry out analysis of the experimental data on the nuclear response functions, using ground state density and transition densities obtained from microscopic, self-consistent HF-RPA calculations.

(ii) Investigate the interplay between surface and volume vibrations for the ISGMR and the ISGDR, by exploring various types of effective interactions, and carrying out systematic microscopic HF-RPA calculations of the strength functions over a wide range of nuclei.

(iii) Obtain good assessment of the effects of more-complicated configurations, such as $2p-2h$, on the nuclear response function.

(iv) Carry out calculations of the ISGMR (and ISGDR) for neutron rich nuclei and compare with experimental data in order to extract the isospin dependence of the incompressibility coefficient.