Vacuum polarization effect in nuclear excitations

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It is well known that, if the Dirac sea filled by negative-energy nucleons is duly taken into account, the effective mass in the Walecka type model converges to an enhanced value naturally because the Lorentz scalar field is strongly suppressed due to the feedback effect from antinucleon states[1, 2]. Thus, the shell structure is significantly affected by the vacuum polarization effect. Because the isoscalar giant quadrupole resonance (ISGQR) is induced by the $2\hbar\omega$ particle-hole correlation in the harmonic oscillator model, the models with and without the vacuum polarization may yield the different results from each other in this mode.

The energy-wighted sum rule (EWSR) distribution of the Coulomb response of the ISGQR mode is shown in Fig. 1 for ^{208}Pb (left panel). The downward shift of the model with vacuum polarization (RHAT1) from the model without vacuum polarization (TM1 and NL3) is clearly observed in the ISGQR mode. Also, it is found that the RHAT1 result is in excellent agreement with the experimental data indicated by the arrow. The centroid energies calculated by the relativistic model with the parameter set NL3 and the relativistic point-coupling model were approximately 1-2 MeV above the experimental energies[3, 5]. These disagreements are drastically improved by the present model including the vacuum polarization. The centroid energies of the ISGQR as a function of the effective mass are plotted in Fig. 1 (right panel), where we see that the effective mass, as expected, has a substantial effect on the energy of the ISGQR. From this analysis, it is indicated that the effective mass $m_{eff}/m_N \sim 0.9$ is required experimentally. In the present model the large effective mass is theoretically caused by the vacuum effect. It is a quite interesting result that the inclusion of the vacuum polarization gives much better results for nuclear excitations through the effective mass effect.

Finally, it should be mentioned that in some relativistic models where the density-dependent coupling, the particle-vibration coupling and/or derivative nucleon-meson coupling are introduced, the effective mass could be made larger, and therefore, the ISGQR centroids might be able to be reproduced. In fact, it has been shown that choosing the parameters in the density-dependent couplings properly, the calculated ISGQR energy approaches to the experimental data[6]. Such QHD-like models are still highly phenomenological, and it is interesting to investigate whether the density-dependence can be related to many body theories of effective interactions such as Dirac-Brueckner-Hartree-Fock calculations.

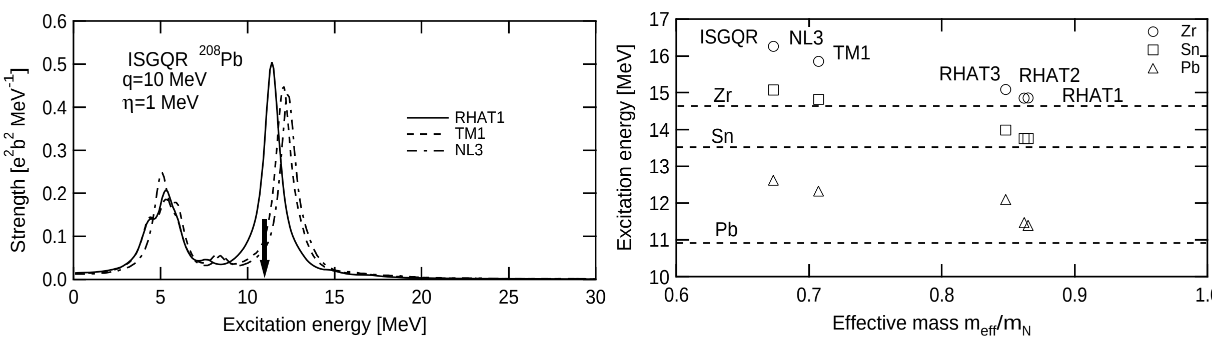

Figure 1: (Left panel) The isoscalar-quadrupole strength in ^{208}Pb. Arrow indicates experimental centroid energy[3, 4]. (Right panel) Excitation energy of the isoscalar-quadrupole resonance of ^{90}Zr, ^{116}Sn, and ^{208}Pb is plotted as a function of the effective mass m_{eff}/m_N obtained with the parameter sets RHAT1, RHAT2, RHAT3, TM1, and NL3. The corresponding data are displayed by the dashed lines[3, 4].

References

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