Application of Mean Field Theory to Nuclear Equation of State and Drip-line Nuclei

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Introduction

In the thesis, we have clarified some important concepts like *Island of Inversion*, parity doublets in low lying states of finite nuclear system which are very exciting topics. A substantial progress has been done in drip-line region of nuclear landscape due to the advance facilities like Radioactive Ion Beams (RIB). We have analyzed the nuclear system starting from the microscopic origin of nucleon-nucleon potential to nuclear structure. The high density systems like nuclear matter or neutron star also taken into account in this thesis work. Recently, by using the Shapiro time delay technique, Demorest et al. measured the mass of neutron star (NS) with high accuracy which can help to constraint the equation of state and other nuclear matter properties, such as symmetry energy, slope and curvature of the symmetry energy at saturation density.

For analyzing the nuclear system, we have taken effective mean field models (SHF and RMF) and discussed the finite nuclei properties like binding energy, charge radius, nucleon density distribution, shapes (prolate, oblate and spherical), and evolution of single particle orbits. Apart from these, we have also discussed the microscopic origin of NN-potential [1] which is one of the most outstanding problem of past, current and future in nuclear physics. Our obtained NN-potential (NR3Y) is one of the good substitution for the widely used M3Y potential which has an empirical background and well established in literature. The main point of NR3Y (Non-linear three Yukawa) potential is that the constants are generated from the well established RMF parameters (HS, NL3). The NR3Y interaction is very useful in many body system at low energy.

We used the effective mean field models in low mass region and study the parity doublet in low lying Ω states [2]. Before going to study the parity doublets, we checked the applicability of mean field formalism in Ne-S region of the mass table comparing with the experimental data. We found that the considered models (SHF, RMF) are quite good to explain the drip-line nuclei ^{40}Mg and ^{42}Al which are predicted by various mass models beyond the drip-line. We analyzed the shape coexistence and deformation parameters of these considered nuclei and found that the low Ω orbits ($\Omega=\frac{1}{2}$) becomes more bound and nearly degenerate with the orbits of opposite parity, i.e. they show parity doublets structure.

In other works, we have calculated the binding energy (BE), rms charge (r_{ch}) and matter radii (r_{ch}), quadrupole deformation parameter (β_2) for the neutron drip-line nuclei having atomic number Z=17-23, 37-40 and 60-64 using RMF (NL3*) formalism. These regions are recently predicted to be "islands of inversion" due to their extra stability compared to the near by isotopes. Since the considered isotopes are experimentally unknown, we compared our results with the predictions of various mass formulas (FRDM and INM). We found large differences both in binding energy and deformation parameters indicating the special nature of these nuclei [3]. This type of special features can be resolved by experimental verification which may be possible in near future, because of advance experimental facilities all over the world. For more precise conclusion, one needs extra attention for these drip-line nuclei, which are presently very exciting. In our analysis, we got some inter-

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esting features just like jerk and deep at some places in charge radius which is different from our conventional distribution. The nuclei in region Z = 17 - 23, N = 42; Z = 37 - 40, N = 68; and Z= 60 - 64, N = 112 behave more stable compare to their neighboring isotpes. The true properties of these nuclei can be revealed after the experimental observations.

In second part of the thesis, major portion is focused on extension of the model [4–6]. This is done by incorporating some extra terms into the model Lagrangian. In this way, we have included cross coupling in the interaction which arises due the coupling between isovector-vector $\rho-$meson and isoscalar-vector $\omega-$meson. The important point for this term is that it does not affect the symmetry part of the system, but changes the neutron skin, giant dipole resonance and symmetry energy. It also makes the equation of state (EOS) softer and put the compressibility down which is one of the success of the modification. We have discussed its effects on finite and infinite nuclear systems in a very extensive manner and showed its applicability. We have added this coupling on top of the E-RMF parametrization (G2 parameter) which is very successful parameter available in literature. It plays a crucial role in softening the symmetry energy (E_{sym}) at large baryon density. The E_{sym} is found to be softer with the value $\Lambda_v \sim 0.15$ (cross coupling constant of $\rho - \omega$) and after that it overflows the experimental constraints. The results match with the experimental data as well as other theoretical predictions for E_{sym} and L_{sym} at saturation density for different values of Λ_v. The effects on composition of neutron star and mass radius trajectory also very important. With the help of this cross coupling, we can make the mass and radius of neutron star within current experimental observations, which are very good constraints on nuclear models. The predicted range of Λ_v helps us in making the new parameter sets.

With the same motivation, we include an extra meson degree of freedom in to the model, i.e. the $\delta-$meson, which arises due to the mass difference of neutron and proton. The effects of this extra coupling on finite and infinite nuclear systems are discussed and conclude that mass isospin is important only in the large asymmetric systems (drip-line nuclei). We have discussed the effects of $\delta-$meson coupling on BE, r_{ch} and energy levels of nucleons. From the analysis, we conclude that $\delta-$meson is more effective than the cross coupling on finite and infinite systems.

In the last portion of the thesis, we analyzed the behaviour of static and rotating neutron star [7]. We have used several (more than 20) relativistic and non-relativistic parameter sets and found the mass and radius for these force parameters. We have calculated the properties of rotating neutron star like gravitational wave strain amplitude, gravitational wave frequency, Keplerian frequency, quadrupole moment and ellipticity with various forces. Maximum mass and its corresponding radius are used to calculate these observables. We get almost consistent results in all considered forces, which show the model independent predictions of the observables. From the calculations, we approximate the range of the gravitational wave amplitude between 10^{-24} to 10^{-22} for rotating neutron star. The moment of inertia of the star comes around $\sim 10^{45}$ gcm^2 and the predicted range of the gravitational wave frequency is in between 400 to 1280 Hz. Our results will be helpful to the new generation of gravitational wave detectors.

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