The nucleon-nucleon potential from relativistic mean field theory

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Nucleon-nucleon (NN) interaction arising from the exchange of pions is an active area of research since the discovery of the neutron. Though substantial progress has taken place to understand it in a number of theoretical (and experimental) attempts, it still remains an open problem. A large number of interactions have been constructed from NN scattering, but extensive modifications in the scattering behaviour due to the presence of many other nucleons inside the nucleus make it appropriate to use the phenomenological effective or averaged interactions instead, which typically depend on the local density of nuclear matter. The nucleus-nucleus optical potentials, obtained by using effective NN interactions, are used to study a number of observed nuclear phenomena and hence also provide a useful understanding of the NN interaction itself. For example, the effective NN interaction has been remarkably related to the nucleus-nucleus optical potential in the double folding model (DFM).

In this paper, rather than using a simple phenomenological prescription, we modified the derived linear microscopic NN interaction in our earlier work Ref. [1] from the linear relativistic mean field (RMF) theory Lagrangian [2]. It is worthy to mention that the modified NN interaction is based on the inclusion of non-linear terms (coupling constant) in the Walecka Lagrangian (NR3Y) for the first time. It is important to note that the RMF formalism is an successful and well established approach for the description of nuclear bulk properties like the binding energy, root-mean-square radii, deformation and clustering phenomenon over the entire region of nuclear chart, including the superheavy nuclei. This has also been applied successfully to infinite nuclear matter, like the equation of state (EOS) and neutron star. The NN interaction is derived in such a way that the obtained interaction is similar to that of M3Y form and has/may have crucial significance for its applicability in different field of Physics.

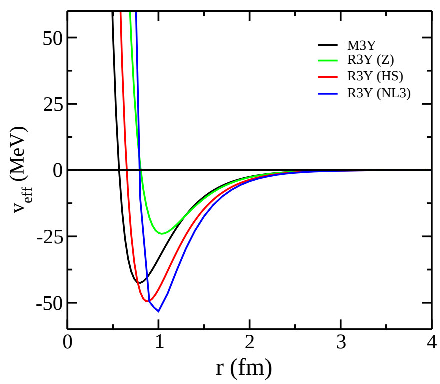

FIG. 1: The NN interaction pontetial obtained from RMF (NL3) compare with other relativistic force parameters and M3Y potential.

The resultant NN interaction, obtained from the Lagrangian is nothing but summation of induced effective potental from different mesons and the form of the NN potentail is given by

$$v_{eff}(r) = \frac{g_\omega^2}{4\pi}\frac{e^{-m_\omega r}}{r} + \frac{g_\rho^2}{4\pi}\frac{e^{-m_\rho r}}{r} - \frac{g_\sigma^2}{4\pi}\frac{e^{-m_\sigma r}}{r} - \frac{g_\delta^2}{4\pi}\frac{e^{-m_\delta r}}{r} + \frac{b^2}{4\pi}\frac{e^{-2m_\sigma r}}{r^2} + \frac{c^2}{4\pi}\frac{e^{-3m_\sigma r}}{r^3}. \quad (1)$$

It is to be noted that the contibution of δ meson is not taken in this present work. The results obtained from Eqn. (1) compare with

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TABLE I: The calculated half-lives of proton emitters are presented using M3Y+EX and NR3Y+EX NN interactions. The results of the present calculations have been compared with the experimental values and with the results of [4]. The experimental Q values, half-lives, and l values are taken from [5]. The asterisk symbol ($\star$) denotes the isomeric state.

Parent nuclei	Q (MeV)	L	$Expt.$ $log_{10}T(s)$	$(M3Y+EX)$ HS $log_{10}T(s)$	$(LR3Y+EX)$ HS $log_{10}T(s)$	$(M3Y+EX)$ $NL3$ $log_{10}T(s)$	$(NR3Y+EX)$ $NL3$ $log_{10}T(s)$	Ref. [4]	Ref. [5]
^{105}Sb	0.491	2	2.049	3.07	2.436	3.1	1.113	2.085	1.97
^{109}I	0.819	0	-3.987	-5.627	-5.897	-5.593	-6.941	–	–
		2				-5.522	-3.666	–	–
^{112}Cs	0.814	2	-3.301	-2.857	-3.555	-2.835	-4.705	–	–
^{113}Cs	0.973	2	-4.777	-5.236	-5.803	-5.204	-7.017	–	–
^{117}La	0.803	2	-1.628	-1.943	-2.504	-1.922	-3.878	–	–
^{117}La*	0.954	5	-2.0	2.794	1.203	–	-1.241	–	–
		4				-0.226	-3.266	–	–
^{131}Eu	0.940	2	-1.749	-2.097	-2.764	-2.085	-4.256	–	–
^{140}Ho	1.094	3	-2.221	-1.374	-2.132	-1.376	-4.007	–	–
^{141}Ho	1.177	3	-2.387	-2.487	-3.298	-2.468	-5.038	–	–
^{141}Ho*	1.256	0	-5.180	-6.374	-6.846	-6.366	-8.047	–	–
^{145}Tm	1.753	5	-5.409	-3.415	-4.698	-3.278	-6.962	-5.170	-5.14
^{146}Tm	1.127	5	-1.096	3.384	1.945	3.51	-0.547	–	–
^{146}Tm*	1.307	5	-0.698	0.919	-0.484	1.043	-2.870	–	–
^{147}Tm	1.071	5	0.591	4.191	2.775	4.369	0.315	1.095	0.98
^{147}Tm*	1.139	2	-3.444	-2.916	-3.546	-2.963	-5.036	-3.199	-3.39

M3Y interaction and the results of earlier predictions [1] are shown in Fig.1. From the figure, one can demonstrate the effect non-linear terms in NN potentail. Further, the work extended in the direction of cluster radioactivity because to shows the applicablity of the modified NN interaction. Calculations are made for a few exotic cluster radioactive (CR) decays in the intermediate regions of the nuclear chart, using the RMF (NL-HS and NL3) parameters based spherical densities. The detail derivation and procedure for the caluculation of cluster radioactivity are given in Ref. [1,3]. It is relevant to mention here that the mass and charge densities calculated by using the RMF theory, support the clustering effects in various heavy parents with observed cluster decays. The calculated half-lives of proton emitters for the above defined NN interaction (NR3Y) are compared with M3Y, Linear R3Y (LR3Y) and other prediction of Ref. [4,5] also listed in Table. I. In the conclusion, the results obtained with NR3Y are resonable well and also the applicability of this formalism to the other regions is in progress.

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