The RMF theory based 3-Yukawas (R3Y) *vs.* the Michigan 3-Yukawas (M3Y) NN interactions for the cluster radioactive decay studies

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Introduction

Using the double folding model [1], the nucleon-nucleon (NN) interaction, say, the phenomenological M3Y effective NN interaction [1], can be used to obtain the nucleus-nucleus optical potential. We have recently [2] derived the microscopic NN interaction from the linear relativistic mean field (RMF) theory Lagrangian [3, 4], called R3Y, which compares exactly with one obtained in an another study [5] by starting from a non-relativistic bare potential and employing a G-matrix formalism, in the nuclear medium that depends on its density, and then established a connection between the RMF models and the, so obtained, bare NN interaction. In an earlier contribution [6], based on the work of Ref. [5], we compared the well known M3Y effective NN interaction and the one obtained from the RMF-based relevant fields with its fitted masses (ranges) and coupling constants (strength parameters). In this contribution, we use the double folding model to obtain the optical potentials for both the RMF-based R3Y [2] and M3Y interactions, and apply the same to study the exotic cluster radioactive decays in trans-lead region having doubly magic ^{208}Pb as daughters. Very recently, we have successfully applied the R3Y interaction to the study of α-decay as well as the fusion phenomena in heavy ion collisions [7], which further strengthens the scope of presently derived R3Y interaction from the RMF theory.

Methodology

From the linear RMF Lagrangian density for a nucleon-meson many-body system [3, 4], we obtain the effective NN interaction [2], in terms of three Yukawas (denoted R3Y), as

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

where, the values of coupling constants and masses of σ, ω, ρ mesons are listed in Table I for different parameter sets of RMF models [3, 4]. The contribution of ρ meson is ignored for W and L1 parameter sets.

The widely used M3Y effective interaction $v_{eff}(r)$ is given by [1]

$$v_{eff}(r) = 7999\frac{e^{-4r}}{4r} - 2134\frac{e^{-2.5r}}{2.5r}, \quad (2)$$

with ranges in fm and strengths in MeV.

Next, for calculating the cluster-daughter interaction potential $V(R)$ (=$V_n(R)+V_C(R)$, sum of nuclear and Coulomb potentials), first, the RMF model is used to calculate the nuclear matter densities for the (spherical) cluster (c) and daughter (d) nuclei, which when folded with the M3Y (or R3Y) interaction [plus-a zero-range pseudo-potential representing the single-nucleon exchange effects (EX), i.e., M3Y+EX or R3Y+EX], gives the nuclear interaction potential $V_n(R)$. Adding $V_C(R) = Z_dZ_ce^2/R)$, $V(R)$ is used in the following for calculating the WKB penetrability P.

The cluster decay constant λ or half-life time $T_{1/2}$ is defined, within the preformed cluster model (PCM) [8], as

$$\lambda_{PCM} = \frac{\ln 2}{T_{1/2}} = \nu_0 P P_0. \quad (3)$$

Comparing the calculated λ_{PCM} with experimental λ_{Expt}, an empirical estimate of the pre-formation factor P_0 can be obtained as ${P_0}^{emp} = \frac{\lambda_{Expt}}{\nu_0 P}$.

TABLE I: Coupling constants g_σ, g_ω, g_ρ and masses m_σ, m_ω, m_ρ (in MeV) for different RMF models.

Set	g_σ	g_ω	g_ρ	m_σ	m_ω	m_ρ	$\frac{g_\sigma^2}{\pi}$	$\frac{g_\omega^2}{\pi}$	$\frac{g_\rho^2}{\pi}$
HS [3]	10.47	13.80	08.08	520	783	770	6882.64	11956.94	4099.06
L1 [4]	10.30	12.60	–	550	783	–	6660.95	9967.88	–
W [4]	09.57	11.67	–	550	783	–	5750.24	8550.74	–
Z [4]	11.19	13.83	10.89	551.31	780	763	7861.80	12008.98	7445.91

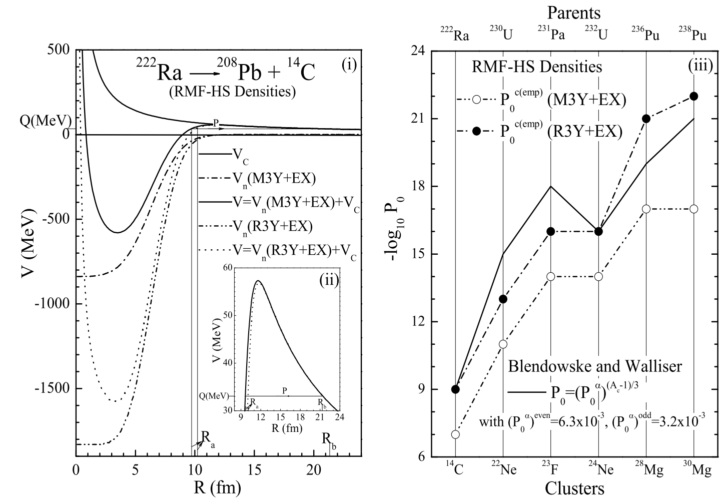

FIG. 1: (i) Optical potential $V(R)$ and the individual contributions $V_n(R)$ and $V_C(R)$, calculated for R3Y+EX and M3Y+EX interactions, using the HS parameter set. (ii) The inset shows the same on an enlarged scale. (iii) Calculated ${P_0}^{c(emp)}$ for cluster-decays from various parents, compared with the phenomenological formula of Blendowske-Walliser (BW) [9].

Calculations and Discussions

Fig. 1(i) shows the total interaction potential $V(R)$ for ^{14}C decay of ^{222}Ra, obtained for both the M3Y+EX and R3Y+EX NN interactions using RMF-HS densities. We notice that, compared to the M3Y case, the barrier is a bit lowered for the R3Y interaction (shown more clearly in the inset) and hence P increased by a few orders. Consequently, the deduced ${P_0}^{c(emp)}(R3Y+EX)$ are also affected. Interestingly, Fig. 1(iii) shows that the ${P_0}^{c(emp)}(R3Y+EX)$ are closer to the well accepted phenomenological formula of Blendowske-Walliser (BW) [9] whereas ${P_0}^{c(emp)}(M3Y+EX)$ are within two to three orders of magnitude of the BW result.

Concluding, R3Y, the effective NN interaction obtained from the RMF Lagrangian, is applicable within a satisfactory precision to the study of exotic cluster radioactive decays.

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