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Folding model analysis of proton radioactivity of spherical proton emitters

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Half-lives of the decays of spherical nuclei away from the proton drip line by proton emissions are estimated theoretically. The quantum mechanical tunneling probability is calculated within the WKB approximation. Microscopic proton-nucleus interaction potentials are obtained by single folding the densities of the daughter nuclei with M3Y effective interaction supplemented by a zero-range pseudopotential for exchange along with the density dependence. Parameters of the density dependence are obtained from the nuclear matter calculations. Spherical charge distributions are used for Coulomb interaction potentials. These calculations provide reasonable estimates for the observed proton-radioactivity lifetimes of proton-rich nuclei for proton emissions from 26 ground and isomeric states of spherical proton emitters.

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The proton separation energies of nuclei lying in the domain beyond the proton drip line are negative. Consequently these proton-rich nuclei have positive Q values for proton emissions with a natural tendency to shed off excess protons and are spontaneous proton emitters. The phenomenon of proton emission from nuclear ground states limits the possibilities of the creation of more exotic proton rich nuclei that are usually produced by fusion-evaporation nuclear reactions. Apart from providing the limit to the proton dripline, the one proton radioactivity may be used as a tool to obtain spectroscopic information because the decaying proton is the unpaired proton not filling its orbit. These decay rates are sensitive to the Q values and the orbital angular momenta that in turn help to determine the orbital angular momenta of the emitted protons.

Because the observation of proton radioactivity is comparatively recent, only few theoretical attempts have been made to study this exotic process [1–4]. In the energy domain of radioactivity, proton can be considered as a point charge having highest probability of being present in the parent nucleus. It has the lowest Coulomb potential among all charged particles and mass being smallest it suffers the highest centrifugal barrier, enabling this process suitable to be dealt within WKB barrier penetration model. In the existing theoretical models [1,2] for proton radioactivity, Saxon-Woods-type potential has been used for the nuclear interaction. In another recent work [4], a unified fission model with proximity potential for nuclear force has been used. In the present work, quantum mechanical tunneling probability is calculated within the WKB approximation using microscopic proton-nucleus interaction potentials. These potentials have been obtained by single folding the densities of daughter nuclei with a realistic effective interaction supplemented by a zero-range pseudopotential for exchange along with density dependence. Calculations using such potentials provide excellent estimates for lifetimes of the exotic decay process of proton radioactivity.

A well-defined effective nucleon-nucleon (*NN*) interaction in the nuclear medium is important not only for different structure models but also for the microscopic calculation of the nucleon-nucleus and nucleus-nucleus potentials used in the analysis of the nucleon and heavy-ion scattering. Effective *NN* interaction can be best constructed from a sophisticated *G*-matrix calculation. This interaction has been derived by fitting its matrix elements in an oscillator basis to those elements of the *G* matrix obtained with the Reid-Elliott soft-core *NN* interaction [5]. The ranges of the M3Y forces were chosen to ensure a long-range tail of the one-pion exchange potential as well as a short-range repulsive part simulating the exchange of heavier mesons. Such an effective *NN* interaction has been shown to provide a more realistic shape of the scattering potentials of the nucleon or heavy-ion optical potentials obtained by folding in the density distribution functions of two interacting nuclei with the effective *NN* interaction [6].

The density-dependent M3Y (DDM3Y) effective *NN* interaction has been used to determine the incompressibility of infinite nuclear matter [7]. The equilibrium density of the nuclear matter has been determined by minimizing the energy per nucleon. The density-dependence parameters have been extracted by reproducing the saturation energy per nucleon and the saturation density of spin and isospin symmetric cold infinite nuclear matter. Results of such calculations also provide a reasonable value of nuclear incompressibility. In nuclear matter calculations, the calculation of potential energy per nucleon involves folding of interaction of one nucleon with the rest of the nuclear matter. It is therefore used in the single folding model description for nuclear matter calculations and thus density-dependence parameters obtained from nuclear matter calculations may be used as it is in describing nucleon-nucleus interaction potentials where single folding model comes into play. Such nucleon-nucleus interaction potentials have been used successfully to the analysis of elastic and inelastic scattering of protons [8].

In the present work we provide estimates for the proton radioactivity lifetimes of the spherical proton emitters from

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the ground and the isomeric states using the same nucleon-nucleus interaction potentials obtained microscopically by single folding the daughter nuclei density distributions with a realistic DDM3Y effective interaction whose density-dependence parameters have been extracted from the nuclear matter calculations.

Formalism. The microscopic nuclear potentials $V_N(R)$ have been obtained by single folding the density of the daughter nucleus with the finite range realistic DDM3Y effective interacion as

$$V_N(R) = \int \rho(\vec{r}) v[|\vec{r} - \vec{R}|] d^3r, \tag{1}$$

where $\vec{R}$ and $\vec{r}$ are, respectively, the coordinates of the emitted proton and a nucleon belonging to the residual daughter nucleus with respect to its center. The density distribution function ρ used for the daughter nucleus has been chosen to be of the spherically symmetric form given by the following:

$$\rho(r) = \rho_0/\{1 + \exp[(r - c)/a]\}, \tag{2}$$

where

$$c = r_\rho\left(1 - \pi^2 a^2/3r_\rho^2\right), \quad r_\rho = 1.13A_d^{1/3} \quad \text{and} \quad a = 0.54\,\text{fm} \tag{3}$$

and the value of ρ_0 is fixed by equating the volume integral of the density distribution function to the mass number A_d of the residual daughter nucleus. The distance s between a nucleon belonging to the residual daughter nucleus and the emitted proton is given by the following:

$$s = |\vec{r} - \vec{R}|, \tag{4}$$

whereas the interaction potential between any such two nucleons $v(s)$ appearing in Eq. (1) is given by the DDM3Y effective interaction. The total interaction energy $E(R)$ between the proton and the residual daughter nucleus is equal to the sum of the nuclear interaction energy, the Coulomb interaction energy, and the centrifugal barrier. Thus

$$E(R) = V_N(R) + V_C(R) + \hbar^2 l(l+1)/(2\mu R^2), \tag{5}$$

where $\mu = M_p M_d/M_A$ is the reduced mass, M_p, M_d, and M_A are the masses of the proton, the daughter nucleus, and the parent nucleus respectively, all measured in units of MeV/c^2. Assuming spherical charge distribution (SCD) for the residual daughter nucleus, the proton-nucleus Coulomb interaction potential $V_C(R)$ is given by the following:

$$\begin{aligned} V_C(R) &= Z_d e^2/R \quad \text{for} \quad R \geqslant R_c \\ &= (Z_d e^2/2R_c)[3 - (R/R_c)^2] \quad \text{for} \quad R \leqslant R_c, \end{aligned} \tag{6}$$

where Z_d is the atomic number of the daughter nucleus. The touching radial separation R_c between the proton and the daughter nucleus is given by $R_c = c_p + c_d$, where c_p and c_d have been obtained using Eq. (3). The energetics allow spontaneous emission of protons only if the released energy

$$Q = M_A - (M_p + M_d) \tag{7}$$

is a positive quantity, where M_A, M_p, and M_d are the atomic masses of the parent nucleus, the emitted proton, and the residual daughter nucleus, respectively, expressed in the units of energy.

In this work, the half-life of the parent nucleus decaying via proton emission is calculated using the WKB barrier penetration probability. The assault frequency ν is obtained from the zero point vibration energy $E_v = (1/2)\hbar\omega = (1/2)h\nu$. The decay half-life T of the parent nucleus (A, Z) into a proton and a daughter (A_d, Z_d) is given by the following:

$$T = [(h \ln 2)/(2E_v)][1 + \exp(K)], \tag{8}$$

where the action integral K within the WKB approximation is given by the following:

$$K = (2/\hbar)\int_{R_a}^{R_b} \{2\mu[E(R) - E_v - Q]\}^{1/2} dR, \tag{9}$$

where R_a and R_b are the two turning points of the WKB action integral determined from the following equation:

$$E(R_a) = Q + E_v = E(R_b). \tag{10}$$

From a fit to the experimental data on cluster emitters a law given by Eqn. (5) of Ref. [9], which relates E_v with Q, was found. For the present calculations same law extended to protons is used for the zero point vibration energies. The shell effects of proton radioactivity is implicitly contained in the zero point vibration energy because of its proportionality with the Q value.

Calculations. The M3Y interaction is based on a realistic G matrix. Because the G-matrix was constructed in an oscillator representation, it is effectively an average over a range of nuclear densities and therefore the M3Y has no explicit density dependence. For the same reason there is also an average over energy and the M3Y has no explicit energy dependence either. The only energy-dependent effect that arises from its use is a rather weak one contained in an approximate treatment of single-nucleon knock-on exchange. The success of the extensive analysis [6] indicates that these two averages are adequate for the real part of the optical potential for heavy ions at energies per nucleon of <20 MeV. However, it is important to consider the density and energy dependence explicitly for the analysis of α-particle scattering at higher energies (>100 MeV), where the effects of a nuclear rainbow are seen and hence the scattering becomes sensitive to the potential at small radii. Such cases were studied, introducing suitable and semirealistic explicit density dependence [10,11] into the M3Y interaction, which was then called the DDM3Y and was very successful for interpreting consistently the high-energy elastic α and heavy-ion scattering data. Present calculations have been performed using $v(s)$, inside the integral of Eq. (1) for the single folding procedure, as the DDM3Y effective [8] interaction given by the following:

$$v(s, \rho, E) = t^{\text{M3Y}}(s, E) g(\rho, E), \tag{11}$$

where t^{M3Y} is the same M3Y interaction supplemented by a zero-range pseudopotential is

$$t^{\text{M3Y}} = 7999\frac{e^{-4s}}{4s} - 2134\frac{e^{-2.5s}}{2.5s} + J_{00}(E)\delta(s), \tag{12}$$

TABLE I. Comparison between experimentally measured and theoretically calculated half-lives of spherical proton emitters. The asterisk symbol (*) denotes the isomeric state. The experimental Q values, half-lives, and l values are taken from Ref. [4]. The results of the present calculations have been compared with the experimental values and with the results of UFM estimates [4]. Experimental errors in Q [14] values and corresponding errors in calculated half-lives are given within parentheses.

Parent nuclei	Angular momentum	Released Energy	1st turning point (fm)	2nd turning point (fm)	3rd turning point (fm)	Expt.	Present calc.	UFM
	$l(\hbar)$	Q(MeV)	R_1	$R_2 = R_a$	$R_3 = R_b$	$\log_{10} T(\mathrm{s})$	$\log_{10} T(\mathrm{s})$	$\log_{10} T(\mathrm{s})$
^{105}Sb	2	0.491(15)	1.55	6.58	134.30	2.049	1.97(46)	2.085
^{145}Tm	5	1.753(10)	3.49	6.40	56.27	−5.409	−5.14(6)	−5.170
^{147}Tm	5	1.071(3)	3.51	6.40	88.65	0.591	0.98(4)	1.095
^{147}Tm*	2	1.139(5)	1.58	7.15	78.97	−3.444	−3.39(5)	−3.199
^{150}Lu	5	1.283(4)	3.50	6.44	78.23	−1.180	−0.58(4)	−0.859
^{150}Lu*	2	1.317(15)	1.59	7.20	71.79	−4.523	−4.38(15)	−4.556
^{151}Lu	5	1.255(3)	3.51	6.49	78.41	−0.896	−0.67(3)	−0.573
^{151}Lu*	2	1.332(10)	1.59	7.22	69.63	−4.796	−4.88(9)	−4.715
^{155}Ta	5	1.791(10)	3.51	6.55	57.83	−4.921	−4.65(6)	−4.637
^{156}Ta	2	1.028(5)	1.61	7.23	94.18	−0.620	−0.38(7)	−0.461
^{156}Ta*	5	1.130(8)	3.52	6.53	90.30	0.949	1.66(10)	1.446
^{157}Ta	0	0.947(7)	0.00	7.42	98.95	−0.523	−0.43(11)	−0.126
^{160}Re	2	1.284(6)	1.62	7.30	77.67	−3.046	−3.00(6)	−3.109
^{161}Re	0	1.214(6)	0.00	7.48	79.33	−3.432	−3.46(7)	−3.231
^{161}Re*	5	1.338(7)	3.52	6.63	77.47	−0.488	−0.60(7)	−0.458
^{164}Ir	5	1.844(9)	3.54	6.68	59.97	−3.959	−3.92(5)	−4.193
^{165}Ir*	5	1.733(7)	3.52	6.69	62.35	−3.469	−3.51(5)	−3.428
^{166}Ir	2	1.168(8)	1.61	7.35	87.51	−0.824	−1.11(10)	−1.160
^{166}Ir*	5	1.340(8)	3.56	6.70	80.67	−0.076	0.21(8)	0.021
^{167}Ir	0	1.086(6)	0.00	7.54	91.08	−0.959	−1.27(8)	−0.943
^{167}Ir*	5	1.261(7)	3.53	6.72	83.82	0.875	0.69(8)	0.890
^{171}Au	0	1.469(17)	0.00	7.60	69.09	−4.770	−5.02(15)	−4.794
^{171}Au*	5	1.718(6)	3.52	6.77	64.25	−2.654	−3.03(4)	−2.917
^{177}Tl	0	1.180(20)	0.00	7.62	88.25	−1.174	−1.36(25)	−0.993
^{177}Tl*	5	1.986(10)	3.53	6.89	57.43	−3.347	−4.49(6)	−4.379
^{185}Bi	0	1.624(16)	0.00	7.77	65.71	−4.229	−5.44(13)	−5.184

where the zero-range pseudopotential representing the single-nucleon exchange term is given by the following:

$$J_{00}(E) = -276(1 - 0.005E/A_p)\,(\mathrm{MeV\,fm^3}) \qquad (13)$$

where E and A_p are the laboratory energy and projectile mass number respectively. In the present case of proton radioactivity it can be shown that $E/A_p = Qm/\mu$, where m and μ are the nucleonic mass and reduced mass of the $p + A_d$ system, respectively, in units of MeV/c^2. The density-dependent part has been taken to be [11] the following:

$$g[\rho, E) = C(1 - \beta(E)\rho^{2/3}], \qquad (14)$$

which takes care of the higher order exchange effects and the Pauli blocking effects. Constants of this interaction C and β when used in single folding model descriptions, can be determined from the nuclear matter calculations [7] as 2.07 and 1.624 fm^2 respectively.

The two turning points of the action integral given by Eq. (9) have been obtained by solving Eq. (10) using the microscopic single folding potential given by Eq. (1) along with the Coulomb potential given by Eq. (6) and the centrifugal barrier described in Eq. (5). Then the WKB action integral between these two turning points has been evaluated numerically using Eqs. (1), (5), (6), (7), and (5) of Ref. [9]. Finally the half-lives have been obtained using Eq. (8).

Results and discussions. In this work, the same set of experimental data of Ref. [4] for the proton decay half-lives have been chosen for comparison with the present theoretical calculations. Experimentally measured values of the released energy Q [given by Eq.(7)], which is one of the crucial quantity for quantitative prediction of decay half-lives, have been used for the calculations. The proton emitters and the experimental values for their logarithmic half-lives have been presented in Table I. The corresponding results of the present calculations with microscopic potentials are also presented along with the results of the modified preformed cluster model (PCM) called the unified fission model (UFM) calculations [4]. The three turning points R_1, $R_2 = R_a$, and $R_3 = R_b$ obtained by solving Eq. (10) have been listed in the Table I.

Experimentally measured and theoretically calculated half-lives of spherical proton emitters have been provided in Table I. Positions of the turning points are very sensitive to the Coulomb barrier. Comparing the results for ground and isomeric states of same proton emitters it can be observed that the positions of the turning points are quite sensitive to the centrifugal barriers. Results of the present calculations with

TABLE II. Comparison between theoretically calculated half-lives of spherical proton emitters using the GOMP [15] and FMPL respectively. The asterisk symbol (*) denotes the isomeric state. Experimental Q values and l values used are taken from Ref. [4]. Errors in calculated half-lives arising out of experimental errors in Q [14] values are given within parentheses. The overall normalization constant C = 2.07 is not included in FMPL listed below at the turnings points and they should be multiplied by C to obtain their values used in the calculations or comparing them with the GOMP.

Parent nuclei	1st turning point (fm)	Nuclear GOMP at R_1	2nd turning point (fm)	Nuclear GOMP at R_2	3rd turning point (fm)	GOMP	1st turning point (fm)	Nuclear FMPL at R_1	2nd turning point (fm)	Nuclear FMPL at R_2	3rd turning point (fm)	FMPL
	R_1	MeV	$R_2 = R_a$	MeV	$R_3 = R_b$	$\log_{10} T(s)$	R_1	MeV	$R_2 = R_a$	MeV	$R_3 = R_b$	$\log_{10} T(s)$
^{105}Sb	1.72	−60.5	6.58	−13.2	134.30	1.97(45)	1.52	−36.1	6.61	−6.4	134.30	1.95(46)
^{145}Tm	3.89	−59.9	6.56	−27.4	56.27	−5.23(6)	3.43	−35.7	6.47	−13.5	56.27	−5.18(6)
^{147}Tm	3.90	−60.5	6.60	−27.7	88.65	0.86(3)	3.41	−36.1	6.46	−14.0	88.65	0.94(4)
^{147}Tm*	1.77	−61.6	7.25	−14.2	78.97	−3.44(5)	1.54	−36.5	7.19	−7.1	78.97	−3.41(5)
^{150}Lu	3.93	−60.4	6.64	−27.7	78.23	−0.70(4)	3.44	−35.9	6.51	−13.9	78.23	−0.63(4)
^{150}Lu*	1.78	−61.5	7.27	−14.7	71.79	−4.43(14)	1.55	−36.3	7.24	−7.0	71.79	−4.40(15)
^{151}Lu	3.91	−60.6	6.66	−27.7	78.41	−0.78(3)	3.44	−36.0	6.52	−13.9	78.41	−0.70(3)
^{151}Lu*	1.79	−61.6	7.29	−14.7	69.63	−4.93(9)	1.56	−36.5	7.25	−7.0	69.63	−4.90(9)
^{155}Ta	3.91	−60.5	6.75	−26.9	57.83	−4.77(6)	3.44	−36.0	6.62	−13.5	57.83	−4.70(6)
^{156}Ta	1.81	−61.9	7.33	−15.2	94.18	−0.44(7)	1.57	−36.7	7.27	−7.5	94.18	−0.41(7)
^{156}Ta*	3.92	−60.9	6.73	−27.9	90.30	1.53(10)	3.45	−36.2	6.60	−14.0	90.30	1.61(10)
^{157}Ta	0.00	−62.1	7.52	−12.5	98.95	−0.49(11)	0.00	−35.8	7.48	−6.0	98.95	−0.46(11)
^{160}Re	1.79	−61.8	7.40	−15.1	77.67	−3.06(6)	1.59	−36.8	7.33	−7.4	77.67	−3.02(6)
^{161}Re	0.00	−62.0	7.58	−12.4	79.33	−3.52(7)	0.00	−35.8	7.51	−6.1	79.33	−3.48(7)
^{161}Re*	3.93	−61.0	6.84	−27.1	77.47	−0.73(7)	3.45	−36.3	6.70	−13.6	77.47	−0.64(7)
^{164}Ir	3.95	−60.8	6.88	−27.0	59.97	−4.06(5)	3.44	−36.2	6.74	−13.5	59.97	−3.97(6)
^{165}Ir*	3.93	−61.0	6.89	−27.1	62.35	−3.65(5)	3.45	−36.3	6.76	−13.5	62.35	−3.56(5)
^{166}Ir	1.81	−62.1	7.49	−15.1	87.51	−1.18(10)	1.57	−36.8	7.39	−7.6	87.51	−1.13(10)
^{166}Ir*	3.93	−61.3	6.91	−27.2	80.67	0.07(8)	3.45	−36.5	6.77	−13.6	80.67	0.16(8)
^{167}Ir	0.00	−62.3	7.64	−12.8	91.08	−1.34(8)	0.00	−36.0	7.57	−6.3	91.08	−1.30(8)
^{167}Ir*	3.94	−61.4	6.92	−27.3	83.82	0.55(8)	3.43	−36.7	6.79	−13.6	83.82	0.64(8)
^{171}Au	0.00	−62.2	7.70	−12.7	69.09	−5.08(15)	0.00	−35.9	7.63	−6.2	69.09	−5.04(15)
^{171}Au*	3.94	−61.3	7.01	−26.4	64.25	−3.18(4)	3.46	−36.5	6.87	−13.2	64.25	−3.09(5)
^{177}Tl	0.00	−62.5	7.76	−13.2	88.25	−1.44(25)	0.00	−36.1	7.69	−6.4	88.25	−1.39(26)
^{177}Tl*	3.92	−61.5	7.10	−26.5	57.43	−4.63(6)	3.43	−36.8	6.96	−13.2	57.43	−4.54(6)
^{185}Bi	0.00	−62.7	7.88	−13.1	65.71	−5.52(13)	0.00	−36.3	7.81	−6.3	65.71	−5.47(13)

DDM3Y have been found to predict the general trend of the experimental data very well. The quantitative agreement with experimental data is good. The discrepancy between the results of present calculation and the experimental values for some cases may be because of the uncertainty in the measurements of the Q values to which the results are quite sensitive because of its proportionality with the zero-point vibration energies. The degree of reliability of the present estimates for the proton decay lifetimes are equivalent to the very recent UFM estimates. Changing the value of density-dependence parameter β to 1.668 fm^2 [12], obtained from nuclear matter calculations using saturation energy per nucleon obtained from fitting the masses of Audi-Wapstra-Thibault [13] mass table, causes insignificant changes in the second decimal places of logarithmic half-lives in some cases.

For an interesting comparison, the entire calculations have been redone with the recent global optical model potential (GOMP) for protons [15]. The real central part of the GOMP for protons using the lab energy $E = Q$ for the proton decay process in place of $V_N(R)$ of Eq. (5) along with the centrifugal and Coulomb potentials, with R_c of Eq. (6) taken equal to $[r_c A_d^{1/3}]$, where $r_c = 1.198 + 0.697 A_d^{-2/3} + 12.994 A_d^{-5/3}$ for the Coulomb potential, have been used to evaluate the action integral. Results of these calculations have been presented in Table II.

The isovector or the symmetry component of the DDM3Y folded potential $V_N^{\rm Lane}(R)$ [16] has been added to the isoscalar part of the folded potential whose results have already been presented in Table I. The nuclear potential $V_N(R)$ of Eq. (5), therefore, has been replaced by $V_N(R) + V_N^{\rm Lane}(R)$ [17], where

$$V_N^{\rm Lane}(R) = \int\int [\rho_{1n}(\vec{r_1}) - \rho_{1p}(\vec{r_1})][\rho_{2n}(\vec{r_2}) - \rho_{2p}(\vec{r_2})] v_1[|\vec{r_2} - \vec{r_1} + \vec{R}|] d^3r_1 d^3r_2, \quad (15)$$

where the subscripts 1 and 2 denote the daughter and the emitted nuclei respectively, whereas the subscripts n and p denote neutron and proton densities, respectively. With the simple assumption that $\rho_{1p} = (Z_d/A_d)\rho$ and $\rho_{1n} = [(A_d - Z_d)/A_d]\rho$, and for the emitted particle being proton $\rho_{2n}(\vec{r_2}) - \rho_{2p}(\vec{r_2}) = -\rho_2(\vec{r_2}) = -\delta(\vec{r_2})$, the Lane potential becomes $V_N^{\rm Lane}(R) = -[(A_d - 2Z_d)/A_d] \int \rho(\vec{r}) v_1[|\vec{r} - \vec{R}|] d^3r$, where $v_1(s) = t_1^{\rm M3Y}(s, E) g(\rho, E)$ and for the isovector part

t_1^{M3Y} [6] is given by the following:

$$t_1^{\mathrm{M3Y}} = -\left[4886\frac{e^{-4s}}{4s} - 1176\frac{e^{-2.5s}}{2.5s}\right] + 228(1 - 0.005Q\,m/\mu)\delta(s). \qquad (16)$$

The inclusion of this Lane potential causes insignificant changes in the lifetimes as can be seen from Table II. Although the lifetimes obtained using GOMP are rather close to that using isoscalar folded potentials with isovector Lane potentials (FMPL) but the GOMP and FMPL are quite different at the first and second turning points, while at third turning points only Coulomb potentials and centrifugal barriers are effective and nuclear potentials are negligibly small.

Summary and conclusions. The half-lives for proton radioactivity have been analyzed with microscopic nuclear potentials obtained by the single folding the DDM3Y effective interaction whose energy dependence parameters have been obtained from nuclear matter calculations. This procedure of obtaining nuclear interaction potentials are based on profound theoretical basis. The results of the present calculations are in good agreement over a wide range of experimental data. The discrepancy between the results of present calculation and the experimental values for some cases may be because of the uncertainties in measurements of the Q values. It is worthwhile to mention that using the realistic microscopic nuclear interaction potentials, the results obtained for the proton radioactivity lifetimes are noteworthy and are comparable to the best available theoretical calculations. It is therefore observed that the DDM3Y effective interaction provides unified descriptions of cluster radioactivity [18], scatterings of α and heavy ions [11] when used in a double folding model, and nuclear matter [7,12] and elastic and inelastic scattering of protons [8] when used in a single folding model. We find that it also provides reasonably good description of proton radioactivity.

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