Alpha decay studies of $^{186\text{-}224}$Po isotopes using Proximity 2010

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Introduction

Alpha decay is identified as one of the most important decay mode of heavy and superheavy nuclei as it provides information regarding nuclear structure. It can also be used to identify new elements and to obtain information on their degree of stability. The phenomenon of alpha decay was discovered by Rutherford and George Gamow explained it as a quantum tunneling process on the basis of quantum mechanics.

As far as a model is concerned, the proper selection of the interaction potential is very important as it must be able to explain the features of decays very well and must possess a good experimental matching. In that sense the Coulomb and proximity potential model (CPPM) of Santhosh et al., [1] in which the generalized proximity potential has been used as the nuclear potential, is a well established model for alpha decay study in the heavy and superheavy region. In the present paper we have predicted alpha decay half lives of Po isotopes by considering proximity 2010 as the nuclear potential.

The Model

The interacting potential barrier for the touching configuration and for separated cluster and daughter nucleus is taken as,

$$V = \frac{Z_1 Z_2 e^2}{r} + V_N(r) + \frac{\hbar^2 \ell(\ell+1)}{2\mu r^2} \qquad (1)$$

Here Z_1 and Z_2 are the atomic numbers of the daughter nucleus and emitted cluster, 'r' is the distance between the centers of the daughter nucleus and the emitted cluster and is given as $r = s + C_1 + C_2$, where, C_1 and C_2 are the Süsmann central radii of the daughter nucleus and the emitted cluster and's' is the distance between the near surfaces of the cluster and daughter nucleus. The term ℓ represents the angular momentum, μ is the reduced mass and $V_N(r)$ is the nuclear potential. Here Proximity 2010 is taken as the nuclear potential. By using a suitable set of the surface energy coefficient, nuclear radius, and universal function, the original proximity potential 1977 is modified by Dutt et al., [2] and the potential is named as Proximity 2010.The surface energy coefficient γ is given as,

$$\gamma = 1.25284[1 - 2.345(N-Z)^2 / A^2] MeV / fm^2 \qquad (2)$$

The nuclear charge radius, R_{00i}, is taken from the recent work of Royer and Rousseau and is given as,

$$R_{00i} = 1.2332 \; A_i^{1/3}$$
$$\left\{1 + \frac{2.348443}{A_i} - 0.151541\left(\frac{A_i - 2Z_i}{A_i}\right)\right\} fm \text{ for (i=1,2).} \qquad (3)$$

The universal function Φ is given as,

$$\Phi(\varepsilon) = -4.41 e^{-\varepsilon/0.7176}, \text{ for } \varepsilon > 1.9475 \qquad (4)$$

$$\Phi(\varepsilon) = -1.7817 + 0.9270\varepsilon + 0.0169\varepsilon^2 - 0.05148\varepsilon^3,$$
$$\text{for } 0 \le \varepsilon \le 1.9475 \;, \qquad (5)$$

Using one dimensional WKB approximation, the barrier penetrability P is given as,

$$\mathrm{P} = \exp\left\{-\frac{2}{\hbar}\int_a^b \sqrt{2\mu(V-Q)}\,dz\right\} . \qquad (6)$$

Here the reduced mass μ is given by $\mu = mA_1A_2/A$, where 'm' is the nucleon mass and A_1, A_2 are the mass numbers of the daughter nucleus and the emitted cluster, respectively. The turning points 'a' and 'b' are determined from the equation $V(a)=V(b)=Q$. The above integral can be evaluated numerically or analytically, and the half-life is given by,

$$T_{1/2} = \left(\frac{\ln 2}{\lambda}\right) = \left(\frac{\ln 2}{\nu P}\right) . \qquad (7)$$

Where, $\nu = \left(\frac{\omega}{2\pi}\right) = \left(\frac{2E_v}{h}\right)$ represents the number of assaults on the barrier per second, λ is the decay constant and E_v is the empirical vibration energy.

Results and discussion

The alpha decay half lives for the emission of the alpha particle from the isotopes of Po with mass number A=186-224 have been evaluated taking Proximity 2010 as the nuclear potential. For the decay process to be possible, the energy of the reaction, Q value, must be positive and is given by,

$$Q = \Delta M_p - (\Delta M_\alpha + \Delta M_d) + k(Z_p^\varepsilon - Z_d^\varepsilon) \quad (8)$$

where ΔM_p, ΔM_d, ΔM_α are the mass excesses of the parent nucleus, daughter nucleus and the alpha particle, respectively. The term $k(Z_p^\varepsilon - Z_d^\varepsilon)$ represents the screening effect of atomic electrons, with k = 8.7eV , ε = 2.517 for $Z \geq 60$ and k = 13.6eV, ε = 2.408 for $Z < 60$. The Q values are calculated using the mass excess values of Wang et al.

The half life evaluations of Po isotopes are done for zero angular momentum transfers since the ℓ values involved in alpha decay are small of the order of $5\hbar$ ($\approx 5\hbar$) and its contribution to half-life is small. The calculated half lives are then compared with the available experimental data. It is found that the estimated values are found to be in good agreement with the experimental data. We have also plotted the logarithmic values of half lives versus neutron number of the daughter nuclei and are shown in Fig. 1. We have noticed a dip at N=126, which can be attributed to the strong shell effect of the well known neutron magic number, N=126. A minimum in the decay half lives corresponds to the greater barrier penetrability due to smaller and thinner barrier, which in turn points to the doubly magic daughter, ^{208}Pb. The neutron magic number, N=126, obtained underlines the validity of the calculations we have carried out.

The standard deviations σ of logarithmic values of the calculated half-lives with the experimental data are obtained using the equation,

$$\sigma = \left\{ \frac{1}{n-1} \sum_{i=1}^{n} \left(\log_{10} T_i^{cal} - \log_{10} T_i^{\exp} \right)^2 \right\}^{1/2} \quad (9)$$

The standard deviation obtained is σ=1.291, which is a reasonably low value. Since the calculated half lives are in agreement with the experimental data, we have predicted the decay half lives of 18 Po alpha emitters that are not detected experimentally yet. The half lives of $^{186,197\text{-}207,219\text{-}224}$Po are evaluated and given in Table 1. The predictions will be helpful for the future studies and may be detectable in the future.

Table 1: The predicted half lives of Po isotopes that are not detected experimentally yet.

Parent nuclei	Daughter nuclei	Q_α (MeV)	$T_{1/2}$(s)
^{186}Po	^{182}Pb	8.537	1.367E-06
^{197}Po	^{193}Pb	6.441	9.758E+00
^{198}Po	^{194}Pb	6.346	2.307E+01
^{199}Po	^{195}Pb	6.111	2.201E+02
^{200}Po	^{196}Pb	6.017	5.503E+02
^{201}Po	^{197}Pb	5.835	3.541E+03
^{202}Po	^{198}Pb	5.736	9.947E+03
^{203}Po	^{199}Pb	5.532	9.350E+04
^{204}Po	^{200}Pb	5.521	1.030E+05
^{205}Po	^{201}Pb	5.361	6.471E+05
^{206}Po	^{202}Pb	5.363	6.146E+05
^{207}Po	^{203}Pb	5.252	2.282E+06
^{219}Po	^{215}Pb	5.952	6.482E+02
^{220}Po	^{216}Pb	5.394	3.029E+05
^{221}Po	^{217}Pb	5.145	6.186E+06
^{222}Po	^{218}Pb	4.651	4.766E+09
^{223}Po	^{219}Pb	4.411	1.717E+11
^{224}Po	^{220}Pb	3.851	8.040E+16

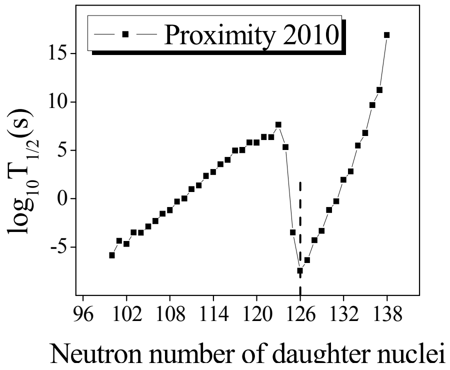

Fig.1 Plot of the computed $\log_{10}$ ($T_{1/2}$) values *vs.* neutron number of daughter nuclei using Proximity 2010 as the nuclear potential.

References

[1] K. P. Santhosh, and A. Joseph, Pramana **55**, 375 (2000).
[2] I. Dutt, and R. Bansal, Chin. Phys. Lett. **27**, 112402 (2010).