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# Single Proton Radioactivity from Drip Line Nuclei

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**Abstract.** In this work, proton decay from drip line nuclei is discussed, Shanmugam–Kamalaharan model is used which consists of a cubic barrier in the pre scission region connected by a Coulomb plus Yukawa plus exponential potential for the post scission region. Since proton decay transition rates are extremely sensitive to the orbital angular momentum of the proton, a centrifugal barrier is added to the post scission potential. Without any adjustable parameters this model is shown to give proton emissions half lives which are in excellent agreement with the recent experimental data.

**Keywords**: Proton radioactivity, proton drip line, centrifugal barrier

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## 1 Introduction

Radioactivity has been known for over 100 years but it continues to bring new surprises. Radioactivity occurs when a nucleus–core of an atom-spontaneously spews out one or more particles. The various kinds of radioactivity can provide wide information about nuclear spectroscopy

The proton drip line defines one of the fundamental limits to nuclear stability. Nuclei lying on or beyond this line are energetically unbound to the emission of a constituent proton from the ground state. A number of such proton emitters have been recently discovered [1–12]. Various models have been recently formulated to obtain proton emission half lives theoretically [13–15]. A model developed by Shanumugam et.al. for cluster radioactivity and alpha emission [18] uses realistic potential [19, 20] and does not have and adjustable parameters. In this work the above model is extended to determine proton emission half lives from drip line proton emitters.

# 2 Materials and methods

A finite range Yukawa plus Exponential potential along with the Coulomb potential is used for the post scission region and a third order polynomial is used for the overlapping region. While the centrifugal barrier has negligible role to play in cluster radioactivity, it becomes appreciable in the case of alpha decay. For proton emission the centrifugal effect should become very much considerable [17, 21]. Hence a centrifugal barrier is added to the post scission region for considering proton radioactivity.

The half-life of the meta-stable system is

$$T = \frac{\ln 2}{\nu P} \tag{1}$$

where

$$\nu = \frac{\omega}{2\pi} = \frac{E_\nu}{h} \tag{2}$$

represents the number of assaults on the barrier per second. That is the characteristic frequency of the collective model. The probability per unit time of penetration $P$

through the barrier is

$$P = \frac{1}{1+\exp K} \tag{3}$$

Substituting $v$ and $P$ values in $T$ we get

$$T = \frac{h\ln(1+\exp K)}{2E_v}. \tag{4}$$

Expressing the time in seconds, the energies in MeV and the lengths in fm for the lifetime on has

$$T = \frac{1.433\times 10^{-21}(1+\exp K)}{E_v} \tag{5}$$

The action integral $K$ is given by

$$K = K_L + K_R \tag{6}$$

where

$$K_L = \frac{2}{h}\int_{r_a}^{r_t}[2B_r(r)V(r)]^{1/2}dr \tag{7}$$

and

$$K_R = \frac{2}{h}\int_{r_t}^{r_b}[2B_r(r)V(r)]^{1/2}dr. \tag{8}$$

Here the $K_L$ and $K_R$ are the left and right integrals of the potential chosen. The limits of integration $r_a$ and $r_b$ are the two appropriate limits of the integral which are found by Newton–Raphson method. This method is applied first to calculate the life time ($T$) in seconds for the spontaneous emission of heavier fragments from certain actinide nuclei. The branching ratios are then obtained by using the experimental half-lives of the respective $\alpha$ disintegration.

The interaction potential is given by

$$V(r) = \frac{Z_1Z_2e^2}{r} + \frac{l(l+1)h^2}{2B_r(r)r^2} + V_n(r) \tag{9}$$

where the first, second and third terms on the right hand side are the Coulomb, centrifugal and finite range potentials respectively. Here the centrifugal effect should become very much considerable. Hence a centrifugal barrier is added to the post-emission region for considering proton radioactivity.

The post-scission potential used by us incorporates the most important finite range effects in the calculations. Thus the proton when it is emitted from the contact point is greatly influenced by the finite range effects. Thus this turns out to be a new approach when compared with the other calculation. The nuclear inertia $B_r(r)$ is associated with the motion in the fission direction.

# 3 Results

The possible proton emitters are identified by calculating the separation energy of the last proton using the relation.

$$S_P(Z,N) = -M(Z,N) + M(Z--1,N) + m_P \tag{10}$$

The separation energies are calculated for the low and medium mass nuclei in the periodic table. The Figure 1 shows the single proton separation energy for different isotones with $N$ values 3, 6, 8, 10, 11, 12, 14, 18, 20, 22. One of the necessary condition for any parent nucleus to decay by proton emission is that the separation energy of its last proton is less than 0. It implies that the last proton is unbound [20]. Few of the parent nuclei identified are $Sc^{39}$, $Mn^{44}$, $Co^{50}$, $Cu^{55}$, $Ni^{48,49}$, $As^{63}$, $Br^{68,69}$, $Tc^{84,85}$, $Rh^{88,89}$, $In^{96,97}$, $Sb^{105}$, $I^{109}$, $Cs^{112,113}$, $Tm^{146,147}$, $Lu^{150,151}$, $Ta^{156}$, $Re^{160,161}$ etc. SK model is applied to these proton emitters in calculating the half lives. Our calculated values are compared with the experimental data [16] as shown in Table 1. It is smooth to find that SK model gives the values which are in agreement with the experimental

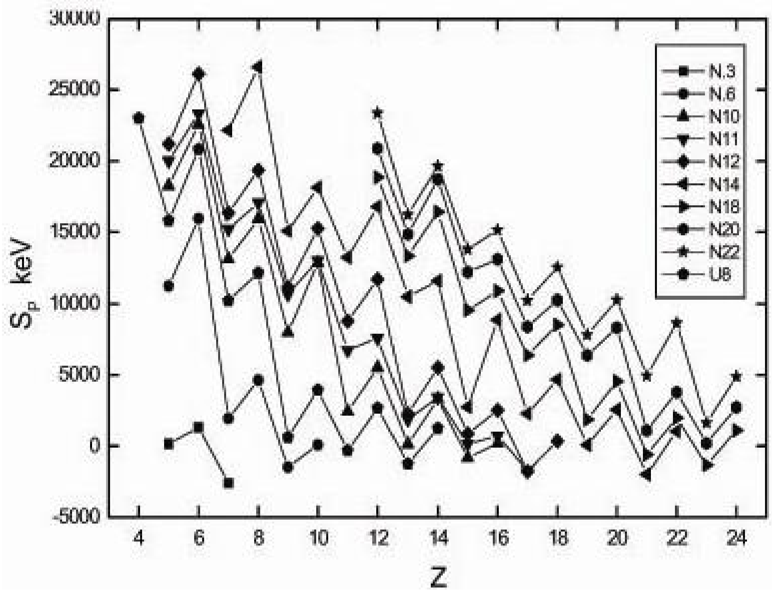


Figure 1: Single proton separation energy vs Atomic number for different neutron numbers.

values.

# 4 Discussion

Since SK model uses finite range Yukawa plus exponential potential, the barrier heights are reduced to proper values without adjusting $r_0$. The potential uses a cubic in the prescission region the joining of this with the post scission potential is smooth.

In proton decay unlike cluster decay no preformation factor is required and the decay process becomes simpler. Thus the problem of formation of the escaping particle does not arise in this case since protons are present in the nucleus in the ready-made form.

Proton has negligible mass and very small radius. It is point charge which is on

Table 1: Experimental and calculated half lives of ground state proton emitters.

| Nucleus | $S_P$ (MeV) | $\log_{10} T$ ($T$ in s) | |
|---|---|---|---|
| | | Calculated | Expt. [16] |
| $^{105}Sb_{54}$ | $-0.481$ | 2.0020 | – |
| $^{109}I_{56}$ | $-0.821$ | $-4.4010$ | $-4.0000$ |
| $^{112}Cs_{57}$ | $-0.821$ | $-3.5500$ | $-3.3010$ |
| $^{113}Cs_{58}$ | $-0.981$ | $-5.6910$ | $-4.7695$ |
| $^{146}Tm_{77}$ | $-1.1$ | $-1.4130$ | $-0.6289$ |
| $^{147}Tm_{78}$ | $-1.05$ | $-0.5420$ | $-0.4310$ |
| $^{150}Lu_{79}$ | $-1.271$ | $-2.4600$ | $-1.3979$ |
| $^{151}Lu_{80}$ | $-1.24$ | $-2.1710$ | $-3.8860$ |
| $^{156}Ta_{83}$ | $-1.01$ | $-0.3970$ | $-0.8416$ |
| $^{157}Ta_{84}$ | $-0.93$ | $-0.4300$ | $-0.5229$ |
| $^{160}Re_{85}$ | $-1.2$ | $-3.0570$ | $-3.0604$ |
| $^{161}Re_{86}$ | $-1.1$ | $-2.7020$ | $-3.4318$ |
| $^{165}Ir_{88}$ | $-1.54$ | $-4.9140$ | $-3.4560$ |
| $^{166}Ir_{89}$ | $-1.15$ | $-1.0790$ | $-0.8180$ |
| $^{167}Ir_{90}$ | $-1.07$ | $-0.3920$ | $-0.9586$ |
| $^{171}Au_{92}$ | $-1.45$ | $-4.3640$ | $-2.6536$ |

the surface of the nucleus at the point of emission. Therefore the penetration integral in the pre-scission is almost zero and the inner potential form reduced to a square well in the case of proton emission. So the rate of proton emission very weakly depends on the form of nuclear potential in the interior part of the nucleus. However, when we use cubic potential for the pre-scission region it exhibits a small inner tail which gives a small contribution from the inner part of the potential to the total penetrability. In our calculations in the case of proton radioactivity from drip line proton emitters it is observed that 2–5% contribution from the pre-scission integral area to the total penetrability area.

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