Effect of pairing correlations on two-proton emission

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The two-proton emission can be explained as the penetration of the two protons through the interaction potential barrier $V(r,\theta)$, comprising of the Coulomb potential $V_C(r,\theta)$ [1] and the proximity potential $V_P(r,\theta)$ [2] with θ as the orientation angle of the emitted diproton w.r.t. the symmetric axis of the deformed daughter nucleus. The penetration probability K through potential barrier can be evaluated as [3, 4]:

$$K = \int_0^{\pi/2} d\theta \frac{\sin\theta}{1+\exp\left(q(\theta)\right)} \quad (1)$$

where

$$q(\theta) = \frac{2}{\hbar}\int_{a'(\theta)}^{b'(\theta)} \sqrt{2\ \mu(V(r,\theta)-Q_{2p})}\ \ dr. \quad (2)$$

Here, Q_{2p} is the two-proton emission disintegration energy, the turning points $b'(\theta)$ and $a'(\theta)$ are fixed such that $V(b'(\theta)) = Q_{2p} = V(a'(\theta))$ and particularly for ^{67}Kr, we have taken $a'(\theta) = 1.24$ (sum of the nuclear radii of daughter products). For diproton, nuclear radius is taken as 1.7 fm. Also, $\mu = \frac{2A_d\ m_n}{A}$ is the reduced mass of daughter products with m_n as the mass of nucleon. We can now calculate two-proton decay half-life $T_{1/2}^{2p,th}(s)$ as

$$T_{1/2}^{2p,th}(s) = \frac{\ln 2}{K v_0 S}. \quad (3)$$

Here, $v_0 = \frac{1}{2R_p}\sqrt{\frac{2E_{2p}}{M_{2p}}}$ is the assault frequency and M_{2p}=1877.805 is the mass of diproton while $E_{2p} = 2\frac{Q_{2p}}{A}$ MeV is the kinetic energy of diproton [5]. S denotes the spectroscopic factor of the two-proton radioactivity [6]:

$$S = 0.0143\ G^2\left(\frac{A}{A-2}\right)^{2n} \quad (4)$$

and for an average principal proton oscillator quantum number $n \sim (3Z_p)^{1/3} - 1$ [7],

$$G^2 = \frac{2n!}{2^{2n} n!^2} \quad [8].$$

We have calculated the logarithmic values of half-lives of nuclei (see Table I) which decay with the emission of two protons and the obtained results are compared with the experimental ones. One may notice that our results are in good agreement with the experimental ones. As we know, the reduced decay width

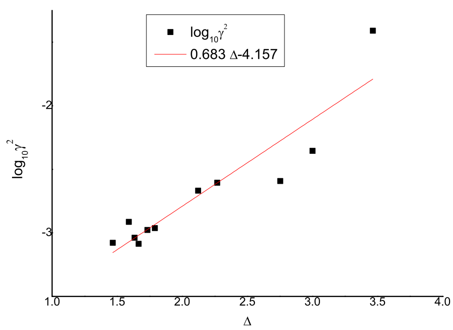

FIG. 1: The logarithmic values of reduced decay widths plotted w.r.t. pairing gaps.

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γ^2 is given as:

$$\gamma^2 = \frac{\hbar \ln 2}{T^{2p}_{1/2} K} = \hbar\, v_0 S. \quad (5)$$

We have also plotted $\log_{10}\gamma^2$ values in the case of two-proton emission w.r.t. pairing gap $\Delta = \frac{12}{\sqrt{A}}$. We found that these results fit linearly into following expression:

$$\log_{10}\gamma^2 = 0.683\Delta - 4.157. \quad (6)$$

Moreover, equation (5) represents the microscopic picture underlying the phenomena inside the parent nucleus before decay.

Nucleus	Q_{2p}(MeV)	$\log_{10}[T^{2p}_{1/2}(s)]$		δ
		Exp.	Calculated	
^{12}O	1.638(24)	>-19.40	$-19.244^{+0.03}_{-0.03}$	>-0.156
	1.820(120)	$-20.14^{+0.43}_{-0.21}$	$-19.433^{+0.04}_{-0.03}$	-0.707
	1.790(40)	$-20.31^{+0.18}_{-0.13}$	$-19.405^{+0.04}_{-0.04}$	-0.905
	1.800(400)	$-20.32^{+0.78}_{-0.26}$	$-19.414^{+0.003}_{-0.003}$	-0.906
^{16}Ne	1.330(80)	$-19.84^{+0.30}_{-0.18}$	$-16.771^{+0.25}_{-0.22}$	-3.069
	1.400(20)	$-19.58^{+0.20}_{-0.13}$	$-16.968^{+0.05}_{-0.05}$	-2.612
^{19}Mg	0.750(50)	$-11.40^{+0.14}_{-0.20}$	$-12.046^{+0.48}_{-0.43}$	0.646
^{45}Fe	1.100(100)	$-2.40^{+0.26}_{-0.26}$	$-2.234^{+1.34}_{-1.17}$	-0.166
	1.140(50)	$-2.07^{+0.24}_{-0.21}$	$-2.712^{+0.61}_{-0.57}$	0.642
	1.154(16)	$-2.55^{+0.13}_{-0.12}$	$-2.876^{+0.19}_{-0.19}$	0.326
	1.210(50)	$-2.42^{+0.03}_{-0.03}$	$-3.525^{+0.56}_{-0.53}$	1.105
^{48}Ni	1.290(40)	$-2.52^{+0.24}_{-0.22}$	$-2.667^{+0.44}_{-0.42}$	0.147
	1.350(20)	$-2.08^{+0.40}_{-0.78}$	$-3.285^{+0.20}_{-0.20}$	1.205
	1.310(40)	$-2.52^{+0.24}_{-0.22}$	$-2.876^{+0.42}_{-0.42}$	0.356
^{54}Zn	1.280(210)	$-2.76^{+0.15}_{-0.14}$	$-0.92^{+0.25}_{-0.24}$	-1.837
	1.480(20)	$-2.43^{+0.20}_{-0.14}$	$-3.013^{+0.19}_{-0.19}$	0.583
^{67}Kr	1.690(17)	$-1.70^{+0.02}_{-0.02}$	$-1.371^{+0.16}_{-0.16}$	-0.329

TABLE I: Disintegration energies and the results for two-proton decay half-lives (experimentally known cases) . δ represents the difference in the logarithmic values of half-lives determined using eq. (3) and the experimental ones [9].

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