Two-proton emission of ^{45}Fe, ^{54}Zn and ^{67}Kr within deformed Yukawa-plus-exponential model

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I. INTRODUCTION

Following the studies of classical radioactivities like α, β and γ, the occurrence of one-proton (1p) and two-proton (2p) radioactivity was theoretically predicted by Goldansky and Zeldovich in 1960s [1]. With the recent advancement in the experimental techniques, exotic decay such as 1p and 2p are observed near the proton drip-line. The nuclei lying beyond the boundary limit reach stability, when their nuclear forces are no longer stable to bind the nucleons due to excess protons or neutrons. The process in which the 2p gets emitted simultaneously is called two-proton radioactivity and it is a complex process. The 2p radioactivity occurs in even-Z nuclei with Q_{2p} positive and $Q_{1p} < 0$. Thus far there are eight two-proton emitters identified experimentally. Theoretically 2p emission is considered to occur via three different ways. They are sequential emission, simultaneous emission and diproton emission. For the present study, we have used Yukawa-plus-exponential model (YEM) for the deformed nuclei.

II. METHODOLOGY

Yukawa-plus-exponential model is the generalized form of liquid drop model derived by Krappe *et al* [2]. They introduced the deformation term arising due to change in the nuclear interaction energy. Here we have considered both parent and emitted fragment as spheres and the daughter nucleus is assumed to be deformed and also the deformation is incorporated in the Coulomb potential which is taken from Ref. [3]. For the two separated spherical nuclei of equivalent sharp-surface radii R_1 and R_2, the nuclear interaction energy V_n is given by

$$V_n = -D\left[F + \frac{r - r_{12}}{a}\right]\frac{r_{12}}{r} exp[(r_{12} - r)/a] \tag{1}$$

Then, the change in the nuclear interaction energy due to the quadrupole deformation β_2 of daughter nucleus is taken from the Ref. [3] and is given by

$$V_d = \frac{4R_2^3 C_s^{'} A_2^{'} \beta_2}{a r_0^2}\left[\frac{5}{4\pi}\right]^{1/2} \tag{2}$$

III. RESULTS AND DISCUSSION

In the present work, we have assumed that 2p forms as a pair and it decays outside the nucleus. The experimentally identified two-proton emitters such as ^{45}Fe, ^{54}Zn and ^{67}Kr are taken for the study and their half-lives are calculated using deformed Yukawa-plus-exponential model. In table. 1, the first column represent the parent nucleus and the second column and fourth column represents the experimental Q_{2p}-values and half-lives taken from Ref. [1]. Third column represents the quadrupole deformation (β_2) of the daughter nucleus which are taken from Ref. [4]. The half-lives are calculated by considering the decay constant as the product of penetration probability and assault frequency and is listed in the fifth column. The deviation between the calculated and experimental half-lives is found to be high. Hence we have introduced spectroscopic factor. In shell model, the spectroscopic

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TABLE I: Half-lives of experimentally identified two-proton emitters are calculated without and with the use of spectroscopic factor are listed in fifth and seventh column respectively.

Parent nucleus	Q (MeV)	β_2	$\log_{10}T_{1/2}^{exp.}$ ($T_{1/2}$ in s)	$\log_{10}T_{1/2}^{cal.}$ ($T_{1/2}$ in s)	S_{2p}	$\log_{10}T_{1/2}^{S_{2p}}$ ($T_{1/2}$ in s)	$\log_{10}T_{1/2}^{Eq.(3)}$ ($T_{1/2}$ in s)
^{45}Fe	1.10	0.086	-2.42	-3.95	0.0296	-2.42	-1.98
^{45}Fe	1.14	0.086	-2.07	-4.43	0.0043	-2.07	-2.47
^{45}Fe	1.15	0.086	-2.40	-4.55	0.0071	-2.40	-2.58
^{45}Fe	1.21	0.086	-2.55	-5.22	0.0021	-2.55	-3.25
^{54}Zn	1.48	0.011	-2.76	-4.67	0.0123	-2.76	-2.76
^{67}Kr	1.69	0.208	-1.70	-2.62	0.1201	-1.70	-1.70

factor is obtained by measuring the amplitude of the single particle orbit components of parent nucleus and it is model dependent. However, the spectroscopic factor is arrived using cluster overlap approximation [1]. The spectroscopic factor of the two-proton emitters are calculated by varying χ from 10^{-4} to 1. Here, χ is used as a fitting parameter so that the spectroscopic values lies within the limit 0 to 1. The half-lives $\log_{10}T_{1/2}^{S_{2p}}$ calculated by incorporating the S_{2p} are listed in last but one column of Table. 1. For these three parent nuclei, the angular momentum values are considered to be zero in accordance with the spin-parity selection rule.

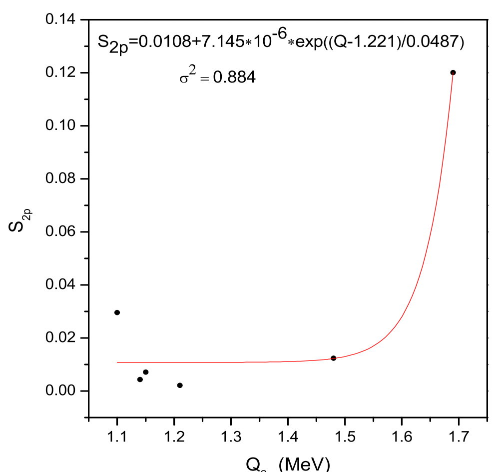

FIG. 1: Relation between S_{2p} and the Q_{2p}-value of the deformed 2p emitters.

An exponential fit is said to exist between the S_{2p} values and Q_{2p}-values and the relation is given in Eq. (3). The fitting is shown in Fig. 1. The half-lives calculated using Eq. (3), $\log_{10}T_{1/2}^{Eq.(3)}$ is listed in the last column of table.

$$S_{2p} = 0.0108 + 7.145 \times 10^{-6} \exp\left(\frac{Q - 1.221}{0.0487}\right) \tag{3}$$

The half-lives calculated using the fitted equation is found to match well with the experimental values, with a difference ranging between 0.002 to 0.704. The prediction of half-lives within the limits of a few seconds to minutes, in mass region of $10 \leq A \leq 100$ will be much helpful to the experimentalists. Hence by applying the above model, the characteristics of 2p emission of the above said mass region will be presented.

References

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