Competition between different decay modes in Bismuth

M.G.Srinivas[1&3], H.C. Manjunatha[2*], N. Sowmya[2*], P.S.Damodara Gupta[2], S.Alfred Cecil Raj[3]
[1]Department of Physics, Government First Grade College, Mulbagal, Karnataka, India.
[2]Department of Physics, Government College for Women, Kolar, Karnataka, India.
[3]Department of Physics, St.Joseph's college, Affiliated to Bharathidasan University, Tiruchirappalli-620002
Corresponding Author:manjunathhc@rediffmail.com, sowmyaprakash8@gmail.com

Introduction

During the last two decades, significant progress has been made in the experimental investigation of processes leading to super heavy nuclei, their decay properties and structure. The most stable super heavies are anticipated to be positioned along the β-stability line, which is unreachable by fusion reactions with stable beams. The literature studies shows the competition between different decay modes [1-2]. The proton decay half-lives of Lanthanides and actinides were studied[3-6]. Qian et al., [7] systematically studied α-decay half-lives of heavy and super heavy elements. Tan et al.,[8] investigated the β+ decays of some medium-mass nuclei.

Many theoretical models have been proposed to explore the half-lives of spherical and deformed nuclei. Earlier workers [9] have studied different decay modes of super heavy nuclei. Hence, in the present work we have examined possible decay modes such as proton decay using Coulomb and Proximity potential Model (CPPM), $\beta^{\pm}$-decay and an alpha decay are evaluated using semi-empirical relations in the isotopes of Bismuth.

Theoretical Frame work

The proton decay half-lives are evaluated using Coulomb and proximity potential model by including deformation effects and angular momentum. The assault frequency term in half-lives are evaluated using harmonic oscillator frequency is given by [3],

$$\nu = \frac{41}{hA^{1/3}} MeV \qquad (1)$$

The proton-nucleus total potential will consist of Coulomb V_C and Proximity potential V_P is expressed as

$$V = V_C + V_P \qquad (2)$$

The Coulomb interaction (V_C) potential is given by,

$$V_c = \frac{Z_1 Z_2 e^2}{r}\left[1 + \frac{3R^2}{5r^2}\beta_2 Y_{20}(\theta) + \frac{3R^4}{9r^4}\beta_4 Y_{40}\right] \qquad (3)$$

here Z_i is the atomic numbers of proton or daughter nuclei. The term 'r' is the separation distance. R is the radius of the nuclei, β is quadrupole deformation parameter and $Y_{20}(\theta)$ is the spherical hormanic function. Proximity potential is evaluated as follows;

$$V_P = 4\pi\gamma b\left[\frac{C_1 C_2}{C_1 + C_2}\right]\phi \qquad (4)$$

The penetration probability and half-lives are evaluated as explained in detail in literature [3]. The alpha-decay and beta decay half-lives are also evaluated using semi-empirical relations [3].

Results and Discussions:

The proton decay half-lives are studied in the isotopes of heavy nuclei Bismuth (Bi) using CPPM with harmonic oscillator frequency. However, an alpha-decay and $\beta^{\pm}$-decay half-lives are evaluated using semi-empirical relations. If the Q-value of the reaction in proton decay is positive, then the proton radioactivity is energetically feasible [6]. The mass excess values in order to evaluate Q-value of the reaction is taken by recent mass excess data available in literature [10].

The proton decay, an alpha-decay and beta-decay half-lives obtained from the present work are compared with available experiments. The figure 1 shows comparison of proton, an alpha and beta-decay half-lives using CPPM and semi-empirical relations with that of available experiments.

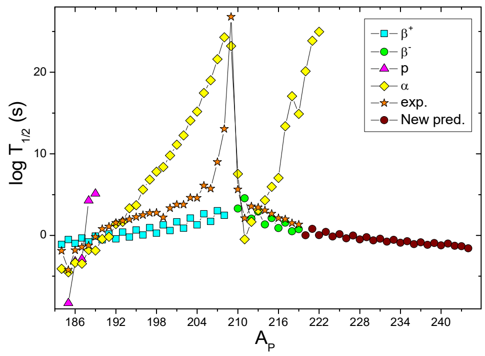

Fig 1: A comparison of proton-decay, an alpha-decay and beta-decay half-lives using CPPM and semi-empirical relations with that of available experiments.

From this comparison it is observed that the nuclei $^{184,186\text{-}189}$Bi and $^{191,209,211\text{-}212}$Bi which possess an alpha decay half-lives are in good agreement with the available experimental alpha decay half-lives. Similarly, the nuclei $^{190,192\text{-}208}$Bi, $^{210,213\text{-}244}$Bi and ^{185}Bi are having β^+ , β^- and proton decay half-lives respectively are in close agreement with the available experimental values.

Table-1: Prediction of logarithmic half-lives of β^--decay in the isotopes of heavy nuclei $^{220\text{-}244}$Bi.

A_P	$T_{1/2}$	A_P	$T_{1/2}$	A_P	$T_{1/2}$
^{220}Bi	0.01	^{229}Bi	-0.22	^{237}Bi	-0.85
^{221}Bi	0.79	^{230}Bi	-0.62	^{238}Bi	-1.16
^{222}Bi	0.04	^{231}Bi	-0.4	^{239}Bi	-0.94
^{223}Bi	0.42	^{232}Bi	-0.77	^{240}Bi	-1.22
^{224}Bi	-0.14	^{233}Bi	-0.55	^{241}Bi	-1.01
^{225}Bi	0.15	^{234}Bi	-0.9	^{242}Bi	-1.28
^{226}Bi	-0.35	^{235}Bi	-0.71	^{243}Bi	-1.33
^{227}Bi	-0.01	^{236}Bi	-1.08	^{244}Bi	-1.59
^{228}Bi	-0.49				

From this comparison it is clear that the values obtained using different decay modes are comparable with the experiments, hence we have extended our studies to isotopes of Bismuth from ^{220}Bi to ^{244}Bi. Then we have studied all possible decay modes such as proton, beta and an alpha decay half-lives. Among all the studied half-lives the β^--decay in the isotopes of heavy nuclei $^{220\text{-}244}$Bi shows shorter half-lives when compared to other decay modes. Hence, the possible decay mode in heavy nuclei $^{220\text{-}244}$Bi is β^--decay only. The table-1 shows the predicted β^--decay half-lives in the heavy nuclei $^{220\text{-}244}$Bi. These predicted half-lives are in seconds to ms.

Conclusions:

The different decay modes such as proton decay, beta-decay and an alpha decay have been evaluated using CPPM and semi-empirical relations in the isotopes of Bismuth. The values obtained from the present work were comparable with the experiments. Around 9 α emitters, one proton emitter, 18 β^+ emitters and 33 β^- emitters were identified. Among the β^- emitters, around 25 new emitters from ^{220}Bi to ^{244}Bi were newly identified. These identified new β^- emitters are useful in the field of radiotherapy.

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