Decay chain of ^{222}Rn

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I. Introduction

There are several radon isotopes, among which ^{222}Rn is most dangerous threat to human health due to its gaseous nature. ^{222}Rn is produced in nature as a result of a series of radioactive disintegration events. The radioactive decay of uranium deposits in rocks produces ^{222}Rn. Due to the gaseous nature of radon, it may readily travel through rocks and through soils. When it leaks from the underlying soil into houses and other structures, it becomes a human health hazard. The characteristics of ^{222}Rn were found to correspond closely with those of ^{226}Ra, ^{232}Th, and ^{40}K radionuclides. Hence, there is importance in studying the decay products of ^{222}Rn. In the present work, we have studied the decay series of ^{222}Rn by comparing half-lives of different isotopes corresponding to different decay modes such as alpha decay, beta decay, proton decay and spontaneous fission.

Radioactive decay products are identified by studying decay process such as α-decay, β+ decay, β- decay, proton decay and spontaneous fission. To predict half-lives corresponds to different decay modes, several empirical models were used [1-5].

II. THEORY

II.1 Alpha decay

The empirical model of α-decay which includes terms related to the orbital moment and parity of α transition by including even-odd, odd-even, and odd-odd effects are available in the literature [1] and it is given by

$$\log T_{1/2}(\alpha) = a + b(A-4)^{1/6} Z^{1/2} + cZQ_\alpha^{-1/2} + dl(l+1)^{1/2} Q_\alpha^{-1} A^{1/6} + e\left[(-1)^l - 1\right] \quad (1)$$

Where a, b, c are fitting parameters defined in the Ref. [1].

II.2 Proton emission half-lives

By considering the dependence on the centrifugal barrier and the structure of the daughter [2], previous researcher proposed the empirical model and it is given as

$$\log T_{1/2}(p) = a + bA^{1/6} Z^{1/2} + cZQ^{-1/2} + d_2|\beta_2|^{p_2} + d_4|\beta_4|^{p_4}, \quad (2)$$

Where Z and A are charge and mass number of parent nucleus respectively. Where a, b, c, d_2, p_2, d_4 and p_4 are constants [2]. β_2 and β_4 are quadrupole and hexadecapole deformation parameters.

II.3 Beta decay

Zhang et al. [3] proposed a reliable formula to calculate the beta decay half-lives. They have established an exponential law between beta decay half-life and the nucleon number (Z, N) of parent nuclei far from the beta stable line. Zhang et al. [3] formula for β^- decay half-lives are used in the present work and it is given as;

$$log_{10} T_{1/2}(\beta^-) = (c_1 Z + c_2)N + c_3 Z + c_4 + shell(Z,N), \quad (3)$$

where shell correction term is expressed as;

$$shell(Z,N) = c_5\begin{pmatrix} e^{-(N-29)^2/15} + e^{-(N-50)^2/37} \\ + e^{-(N-85)^2/9} + e^{-(N-131)^2/3} \end{pmatrix} + c_6 e^{-\left[(Z-51.5)^2 + (N-80.5)^2\right]/1.9} \quad (4)$$

Z and N are the proton and neutron number of the parent nuclei respectively. $T_{1/2}$ is the half-life of β^- decay. The parameters are C_1=3.37x10^{-4}, C_2=-0.2558, C_3=0.4028, C_4=-1.01, C_5=0.9039 and C_6=7.7139.
Zhang et al., [4] also evaluated the empirical formula for β+ decay s and is given by

$$log_{10} T_{1/2}(\beta^+) = (c_1 Z + c_2)N + c_3 Z + c_4, \quad (5)$$

Z and N are proton and neutron numbers respectively. The fitting parameters c1, c2, c3 and c4 are defined in Ref. [3]. The even-odd effects are also considered in the above equation.

II.5 Spontaneous fission

Ren et al., [4] constructed a formula for spontaneous fission half-lives by considering pairing and valence nucleons and is given by

$$logT_{1/2}\ (SF) = 21.08 + c_1 \frac{\xi}{A} + c_2 \frac{\xi^2}{A} + c_3 \frac{\xi^3}{A} + c_4 \frac{\xi}{A}(N - Z - 52)^2, \quad (6)$$
$$where\ \xi = Z - 90 - \upsilon$$

C_1=-548.825, C_2=-5.359, C_3=0.767, C_4=-4.282. This formula includes the blocking effect of unpaired nucleon on the half-lives with different mechanisms. υ is seniority number and it is 0 for spontaneous fission of even–even nuclei. υ=2 for spontaneous fission of odd–A nuclei. The number υ=2 comes from the unpaired nucleon's blocking impact on the transfer of numerous nucleon-pairs during the fission process, in which a heavy nucleus can spontaneously transform into two light nuclei and a few neutrons.

III. Results and discussions

Present work identified the decay products of ^{222}Rn by studying the competition between the different possible decay modes such as α decay, β^- decay, β^+ decay, proton decay and spontaneous fission. In the competition between different decay modes, the decay process which is having shorter half-lives are considered as dominant decay of the nuclei. The competition between the different possible decay modes are shown in table 1. Also, the proton decay energies are negative, hence proton decay is not feasible. Among the studied decay modes for ^{222}Rn, alpha decay is having shorter half-lives and hence ^{222}Rn decays to ^{218}Po. Further, the decay product of ^{218}Po is identified by studying the different decay modes. In this procedure, we have identified the decay products of ^{222}Rn and this is tabulated in the table 1.

The identified decay chain of ^{222}Rn is graphically represented in the figure 1. From this study, it is observed that ^{222}Rn decays to ^{218}Po through alpha decay. ^{218}Po decays to ^{214}Pb again through alpha decay. ^{214}Pb decays to ^{214}Bi through β- decay. ^{214}Bi decays to ^{214}Po through β- decay. ^{214}Po decays to ^{210}Pb through α decay. ^{210}Pb decays to ^{210}Bi through β- decay. ^{210}Bi decays to ^{210}Po through β- decay. Finally, ^{210}Po decays to stable ^{206}Pb through alpha decay

IV. Conclusion

We have successfully identified the decay products of ^{222}Rn by studying the competition between different decay modes. From this study it is clear that ^{222}Rn decays to the stable nuclei ^{206}Pb by different decay modes such as α decay, β^- decay, β^+ decay, and spontaneous fission. We have represented the decay chain of ^{222}Rn. Present work will be useful in the environmental radioactivity.

Parent Nuclei	α	β+	β-	SF	Decay mode
^{222}Rn	5.77	7.14	6.78	29.36	α
^{218}Po	2.37	7.76	2.39	34.92	α
^{214}Pb	30.84	8.37	2.55	31.63	β-
^{214}Bi	4.24	6.02	3.48	27.64	β-
^{214}Po	-3.79	6.67	3.90	33.26	α
^{210}Pb	15.67	7.26	2.86	39.04	β-
^{210}Bi	7.44	4.92	3.49	44.94	β-
^{210}Po	5.93	5.98	6.16	50.87	α
^{206}Pb	70.68	6.15	3.73	46.08	Stable

Table 1: Decay products of ^{222}Rn with logarithmic half-lives corresponds to different decay modes

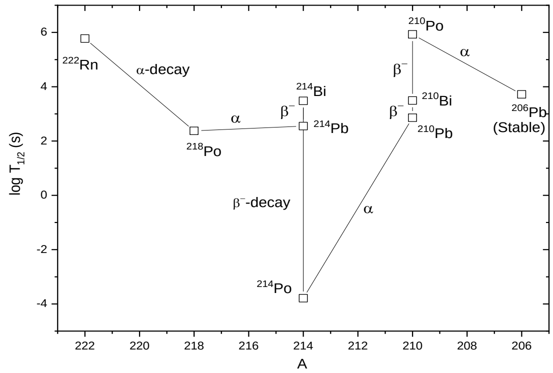

Fig1. Decay chain of ^{222}Rn

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