α-decay chains relevant with superheavy isotopes

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Introduction

Understanding the decay modes and knowing the involved half-lives are of prime importance to identify the decay chains of superheavy elements, which are the experimental signature of the formation of the elements in fusion reactions. In the present study α-decay half-lives are found out using coulomb and proximity potential model[1] and spontaneous fission half-life are found out using the formula of Ren et al., [2]. The range of isotopes in which α-decay shall occur are found out by making use of the difference in α-decay half-life and the fission decay half-life as criterion. It is done in the case of 275 even-even isotopes of the isotopic chains from 270-318118 to 230-27898. From that it has been found that there exist an upper transition point in which α-decay half-life becomes smaller to fission half-life and a lower transition point in which fission decay half-life becomes smaller to α-decay half-life, for all the elements from Z=118 to 98. From the result, probable α-decay chains are elucidated. In the case of few chains which do not cease at Z=98, above type of calculation is carried forward until the point where α-decay is forbidden with negative Q-value (described later) or α-chain ceases with spontaneous fission (SF). Thus we considered decay up to Z=76.

The model

The interacting potential barrier for a parent nucleus exhibiting exotic decay is given by

\[ V = Z_1 Z_2 e^2 / r + V_p (z) + \frac{\hbar^2 l(l+1)}{2 \mu r^2} \]

\[ P = \exp \left\{ -\frac{2}{\hbar} \int_a^b \sqrt{2\mu(V - Q)} dz \right\} \]

The possibility to have an α-decay process is:

\[ Q = M(A,Z) - M(A_1,Z_1) - M(A_2,Z_2) > 0 \]

where M’s are the atomic masses of the parent, daughter and α-particle, in order.

The α-decay half-life \( T_{1/2} = \ln 2 / \nu \), where \( \nu \) is the number of assaults on the barrier per second. SF half-lives are calculated by the formula proposed by Ren at al [2]

\[ \log_{10}[T_{1/2}(yr)] = C_1 \frac{(Z-90-\nu)}{A} + C_2 \frac{(Z-90-\nu)^2}{A} + \]

\[ C_3 \frac{(Z-90-\nu)^3}{A} + C_4 \frac{(Z-90-\nu)(n-Z-52)^2}{A} + d \]

where \( C_1 = -548.825021; C_2 = -5.359139; C_3 = 0.767379; C_4 = -4.282220; d = 21.08; \nu = 0 \) for even-even nuclei and \( \nu = 2 \) for odd A and odd-odd nuclei.

Results and discussion

Fig.1. α-decay half life and SF half life for Z=118 isotopes.

If α-decay half-life (denoted as a.h.l) is smaller than SF half-life (denoted as f.h.l), α-decay would occur and if SF half-life is smaller to α-decay half-life, SF would take place. Therefore, (a.h.l-f.h.l) is taken as a criterion to know as to which decay shall occur. Provided a.h.l is smaller, the larger the magnitude of the above quantity, the larger the chance for α-decay to occur.
Of the range of isotopes of each Z value, a window exists where α-decay would occur. In
294118 to 288118, 290116 to 287116, 284114 to 277114, 280112 to 272112, 272110 to 268110, 270108
to 265108, 266106 to 262106, 264104 to 258104, 258102 to 254102, 254100 to 248100, 250100 to 242100
isotopes, α-decay shall take place.

The transition points have got no definite relationship to magic neutron numbers.

Various isotopes having the same Z value have got different chances of α-disintegration as
evined by the various values of (a.h.l.-f.h.l).

We found that the isotopes associated with 1st (highest) value of each Z are related as
α-decay parent and successive daughters. Thus a chain of nuclei exist with parent and many
successive daughters. In a similar manner, generally, nuclei associated with the 2nd values,
the 3rd values, the 4th values etc. form their own chains.

The chains of α-decay in order of probability are shown below:

first \[ \begin{array}{c} 288118 \rightarrow 276112 \rightarrow \ldots \rightarrow 264106 \rightarrow \ldots \rightarrow 206104 \rightarrow \ldots \rightarrow 252100 \rightarrow 258108 \rightarrow SF \# second \rightarrow 2561108 \rightarrow SF \# third \rightarrow 258104 \rightarrow SF \# fourth \rightarrow 258110 \rightarrow SF \# fifth \rightarrow 272108 \rightarrow SF \# sixth \rightarrow 272110 \rightarrow SF \# seventh \rightarrow 284118 \rightarrow SF \# eighth \rightarrow 284110 \rightarrow SF \# ninth \rightarrow 287116 \rightarrow SF \# tenth \rightarrow 286110 \rightarrow SF \# eleventh \rightarrow 286112 \rightarrow SF \# twelfth \rightarrow 286110 \rightarrow SF \# sixteenth \rightarrow 284112 \rightarrow SF \# seventeenth \rightarrow 284110 \rightarrow SF \# eighteenth \rightarrow 284110 \rightarrow SF \# nineteenth \rightarrow 284110 \rightarrow SF \# twentieth \rightarrow 284110 \rightarrow SF \# twenty-first \rightarrow 284110 \rightarrow SF \# twenty-second \rightarrow 284110 \rightarrow SF \# twenty-third \rightarrow 284110 \rightarrow SF \# twenty-fourth \rightarrow 284110 \rightarrow SF \# twenty-fifth \rightarrow 284110 \rightarrow SF \# twenty-sixth \rightarrow 284110 \rightarrow SF \# twenty-seventh \rightarrow 284110 \rightarrow SF \# twenty-eighth \rightarrow 284110 \rightarrow SF \# twenty-ninth \rightarrow 284110 \rightarrow SF \# thirtieth \rightarrow 284110 \rightarrow SF \# thirty-first \rightarrow 284110 \rightarrow SF \# thirty-second \rightarrow 284110 \rightarrow SF \# thirty-third \rightarrow 284110 \rightarrow SF \# thirty-fourth \rightarrow 284110 \rightarrow SF \# thirty-fifth \rightarrow 284110 \rightarrow SF \# thirty-sixth \rightarrow 284110 \rightarrow SF \# thirty-seventh \rightarrow 284110 \rightarrow SF \# thirty-eighth \rightarrow 284110 \rightarrow SF \# thirty-ninth \rightarrow 284110 \rightarrow SF \# forties \rightarrow 284110 \rightarrow SF \# fiftieth \rightarrow 284110 \rightarrow SF \# sixties \rightarrow 284110 \rightarrow SF \# seventies \rightarrow 284110 \rightarrow SF \# eighties
\end{array} \]

Production of isotopes which belongs to the most probable α-decay chain, which has got
the largest (a.h.l.-f.h.l) in each value of Z, shall be, comparatively most easy to be
accomplished with that Z value. Production of isotope which belongs to chains subsequent to
the first one shall be having a lesser degree of easiness. In the case of isotopes where a.h.l.>
f.h.l., fission shall occur with such rapidity that the production of elements can hardly be
identified. These shall serve as guiding aspects for future experiments.

For the production of elements of various Z values, isotopes belonging to the corresponding α-decay window might be attempted. Relative easiness mentioned here
in production of isotopes is to be understood in the context of using projectile nuclei of same
energy and having the same beam dosage.

Fission half-lives of isotopes revealed that maximum values of half-lives are obtained to
those having N-Z=52, in the case of elements with Z=118 to Z≥90. This is in true conformity
with the experimental observation that there is long life time for SF of elements having N=Z+52
with Z≥90[3].

However, for elements with 90>Z>76 a diametrically opposite effect is found to exist. This
is worthy of considering for experimental verification.

The 294118 which has been produced at J.I.N.R., Dubna falls within the range predicted
here for Z = 118 and belongs to the 7th chain. Decay chains originating from 294118, consisted
of 2 or 3 consecutive α-decays and terminated by a spontaneous fission were observed. The
present prediction mentions that 2 consecutive α-decays would take place and then spontaneous
fission would occur.

In, officially recognized first-productions of

291118, 290116(J.I.N.R.,Dubna); 287114, 286114 (J.I.N.R.,Dubna); 277114(G.S.I., Darmstadt); 269118 (G.S.I., Darmstadt); 265118(Hs (G.S.I., Darmstadt and Dubna); 263118(Sg; 259118(Rf(Dubna)); 257118(Rf, 258118(Rf (Berkeley); 254118(Not(Dubna);
255118(Fm(University of California), 254118(Fm (L.B.N.L.), (at present A=250, 252, 253, 256);
245118(Cf ( University of California,) (at present A=246,248,249,250,252,254) are obtained.

Most of the isotopes produced are either member of the presented chains, or comes within
the range predicted. Also chains found experimentally have got good closeness to the
presented ones. All these indicate that our scheme of decay is in good agreement with
available experimental facts. This shall pave way for discovering newer isotopes in the heavy and
superheavy regions.

References