Deciphering nuclear shell closure via cluster radioactivity in superheavy ^{316}118:cold valley method

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Introduction

Concepts of cluster radio activity is applied in the study of superheavy elements. In the study of superheavy elements, prediction and/or production of magic nucleus forms an integral part. We studied all even-even isotopes $^{270-318}$118. Cold valley plots are drawn. In the case of ^{316}118, cold valley plots are studied for neutron and proton shell closures for the range Z=2 to 118 and N=2 to 198.

The model

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

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

for z >0 . Here Z_1 and Z_2 are the atomic numbers of daughter and emitted cluster; 'r' is the distance between fragment centres, l the angular momentum, μ the reduced mass and V_p is the proximity potential. The barrier penetrability P is given as:

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

The turning points 'a' and 'b' are given by $V(a) = V(b) = Q$, where Q is the energy released during reaction known as decay energy or Q value of reaction.

The possibility to have a cluster 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 cluster, in order.

A quantity known as driving potential is defined as the difference between the interaction potential and the decay energy Q. The driving potential of the compound nucleus is calculated for all sensible, possible cluster daughter combinations. For a fixed pair of masses, fixed pair of charges is pin-pointed out such that driving potential involved is minimum. This is done for all pair of masses. Meanwhile a set of driving potential minimum is evolved. Graph is plotted between driving potential minima and mass of cluster. Minimum in the driving potential minima are known as cold valley. Compared to close by cold valleys, the smaller the driving potential minimum of a cold valley, the stronger the cohesion among the constituents of the cluster and/or the daughter nuclei, of the associated reaction.

The angular momentum l carried away in the cluster decay process is shown to be small [1] and is taken to be zero in the present work.

Results and discussion

Fig. 1 represents the cold valley plots for the isotope ^{316}118 with excluding proximity potential as well as including it.

The plots, contain some sagged regions or "troughs" (which are also known as mass-asymmetry valleys).

The first two minima are associated, with reactions ^{4}He+^{312}116 and ^{6}He+^{310}116. Making use of the facts that, the reaction with least driving potential contains one fragment with 2 protons and 2 neutrons, the reactions associated with the first two as well as closest possible cold valleys contained2 protons, increase in neutron number from 2 results in increase of driving potential, it is reasonable to consider that the result yields number 2 as magic proton number and/or magic neutron number.

The reactions associated with third and fourth

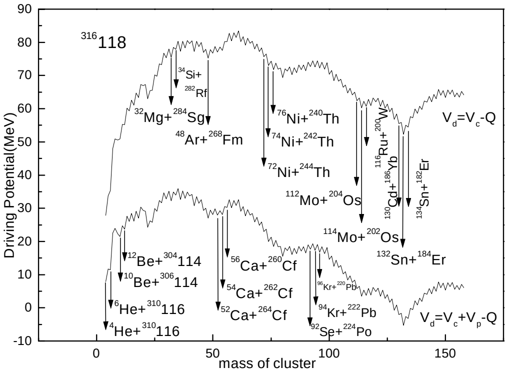

Fig.1. Cold valley plots with excluding proximity potential and including proximity potential.

minima, lying in a trough, are $^{10-12}$Be+$^{306-304}$114. In both, one fragment contains 114 protons. This is indicative of proton magicity at 114.

The reactions associated with fifth and sixth minima, arguably, lying in a trough, are $^{14-16}$C+$^{302-300}$112. Both these contain 112 protons Therefore, proton number 112 also can be considered as magic one.

Of the above reactions, the one, with one fragment containing 8 neutrons and having least driving potential, gives neutron magicity at 8.

In the next trough the reactions associated with two deep minima are $^{22-24}$O+$^{294-292}$110. This indicates proton magicity at 8.

Now, of the four successive reactions, ^{22}O+^{294}110, ^{24}O+^{292}110 , $^{26-28}$Ne+$^{290-288}$Hs, in the larger fragments, as the neutron value changes as 184(along with proton magic number), 182(along with the same proton magic number), 182, 180, the driving potential changes from the least value at 184 and steadily increases. This implies that the neutron number 184 is a magic one. The reaction ^{22}O+^{294}110 belongs to least minima in the trough because both the fragments contain magic numbers .

In the next trough, successive minima corresponding to reactions ^{32}Mg+ ^{284}Sg and ^{46}Si+^{282}Rf indicate neutron magicity at 20.

In the next trough, successive minima corresponding to reactions ^{44}S+^{272}No and ^{46}Ar+^{270}Fm indicate neutron magicity at 28 .

Least minima in a trough occurs for the reaction ^{48}Zn+^{268}Fm. This is indicative of neutron magicity at 168. But here, unlike other cases, only one reaction contains the magic number. This, in turn, indicates that magicity here is less strong.

In the set of reactions, ^{44}S+^{272}No ,^{46,50}Ar+^{270,266}Fm, $^{52-56}$Ca+$^{264-260}$Cf except for the presence of neutron magic number 168, as we move from proton number 16 to 20 the driving potential minima reduces. There are three reactions with proton number 20.This implies that 20 is a magic proton number.

In the next trough, three minima at the bottom part corresponds to the reactions $^{72-76}$Ni + $^{244-240}$ Th.This represents proton magicity at 28.

In the reactions $^{72-76}$Ni + $^{244-240}$Th ,^{78}Zn+^{238}Ra, ^{80}Zn+^{236}Ra, ^{82}Ge+^{234}Rn, as the neutron number changes as 44 , 46, 48, 48, 50 the driving potential changes to the least indicating 50 to be a neutron magic number.

Next, minima corresponding to reactions ^{92}Se+^{224}Po, $^{94-98}$Kr+$^{222-218}$Pb undergo continuous reduction with proton number of the larger fragment changing as 84, 82, 82,82 indicating that 82 is proton magic number.

In the next trough, for the successive reactions $^{112-114}$Mo+$^{204-202}$Os, $^{116-118}$Ru+$^{200-198}$W neutron number varies as 128,126,126,124 with minima reducing to the least value at126 indicating that neutron number 126 is a magic one.

In the last trough, in the five successive minima whose reactions are ^{128}Cd+^{188}Yb, ^{130}Cd+^{186}Yb, $^{132-136}$Sn+$^{184-180}$Er, as the neutron number of the smaller fragment changes as 80, 82, 82,84,86,the driving potential changes to the least value at 82 indicating that 82 is a neutron magic number.

In the case of the smaller fragments of the reactions ^{130}Cd+^{186}Yb, $^{132-136}$Sn+$^{184-180}$Er, ^{138}Te+^{178}Dy, as the proton number changes as 48,50,50,50,52, the driving potential minima changes to the least at 50 indicating that 50 is a magic proton number. ^{132}Sn+^{186}Er belongs to the least driving potential of the trough because ^{132}Sn is doubly magic.

Proton shell closures are understood to occur at proton numbers 2, 8, 20, 28, 50, 82, 112, 114. Neutron shell closures are understood to occur at neutron numbers 2, 8, 20, 28, 50, 82, 126, 168,184 .

References

[1] K P Santhosh and Antony Joseph, *Pramana-J.Phy.***62**,957(2004)