Superheavy Elements - Synthesis and Modes of Decay

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Introduction

Heavy and Superheavy elements (SHE) are mainly synthesized by heavy-ion fusion reactions and now nuclear reactions induced by heavy ions have become the principal tool in nuclear physics research. At present elements up to Z=118 have been synthesized in the laboratory [1]. SHEs are synthesized mainly by cold and hot fusion reactions. In the cold fusion reaction, which is based on the lead or bismuth target, superheavy elements up to Z=113 has been synthesized. In the hot fusion reactions, which is based on the fusion reactions involving ^{48}Ca with actinide target, elements with Z=113-118 has been synthesized and attempts to produce Z=119 and Z=120 are also done.

Synthesis of superheavy elements

In order to form a heavy nucleus, a relatively heavier projectile must be fused with heavy target nuclei. Initially the capture process in which the projectile is trapped inside the potential pocket formed from the interaction with target. This will lead to the formation of a highly excited completely fused system known as the compound nucleus (CN), and finally the excited CN decay by the evaporation of neutron without forming fission fragments. The production cross section of SHEs is the product of capture cross section, probability of CN formation and the survival probability of the excited CN.

Recently, we have studied the fusion excitation functions for the synthesis of isotopes of Z=114 [2], Z=115, Z=116 [3], Z=117 [4], Z=118, Z=119 and Z=120 using the phenomenological model for production cross section (PMPC) by taking Coulomb and proximity potential as the interaction barrier.

To calculate the production cross section for the isotopes of Z=114 ($^{289-292}$Fl), we used the fusion reactions ^{48}Ca+$^{236-244}$Pu and it was found that the reactions ^{48}Ca+^{243}Pu→^{291}Fl and ^{48}Ca+^{244}Pu→^{292}Fl were more favorable with a maximum ER cross section of 6.924 (3n) and 9.033 pb (4n) respectively. Our calculated ER cross section values for the reactions ^{48}Ca+^{240}Pu→^{288}Fl, ^{48}Ca+^{242}Pu→^{290}Fl and ^{48}Ca+^{244}Pu→^{292}Fl are in excellent agreement with available experimental values.

The production cross sections for the synthesis of isotopes of superheavy element Mc (Z=115) by the hot fusion reactions ^{48}Ca+^{241,243}Am→^{289,291}Mc, ^{45}Sc+^{240,242,244}Pu→^{285,287,289}Mc, ^{50}Ti+^{236,237}Np→^{286,287}Mc, ^{51}V+^{238}U →^{289}Mc, ^{36}S+^{253}Es→^{289}Mc, ^{46}K+^{248}Cm→^{294}Mc, and by the cold fusion reactions ^{78}As+ ^{208}Pb→^{286}Mc, ^{76}Ge+^{209}Bi→^{285}Mc have been systematically studied using PMPC.

To synthesize Z=116 (Lv), we identified the most probable reactions from the cold reaction valley plot and the reaction ^{48}Ca +^{248}Cm is found to be the most suitable projectile-target pair. Also the production cross sections for the synthesis of isotopes $^{291–295,298}$Lv using ^{48}Ca projectile on $^{243–247,250}$Cm targets are calculated. Among these reactions, the reactions ^{48}Ca +^{247}Cm→^{295}Lv and ^{48}Ca +^{250}Cm→^{298}Lv have maximum production cross section in 3n (10.697 pb) and 4n (12.006 pb) channel, respectively.

To synthesize Z=118, the fusion reactions ^{48}Ca+$^{249-254}$Cf→$^{297-302}$Og, ^{45}Sc+^{247,249}Bk→^{292,294}Og, ^{50}Ti+$^{242-248,250}$Cm→$^{292-298,300}$Og, ^{51}V+ ^{241,243}Am→^{292,294}Og, ^{54}Cr+$^{238-242,244}$Pu→$^{292-296,298}$Og, ^{55}Mn+$^{235-237}$Np→$^{290-292}$Og, ^{58}Fe+$^{232-236,238}$U → $^{290-294,296}$Og, ^{59}Co+^{231}Pa→^{290}Og, and ^{64}Ni+ $^{228-230,232}$Cm→$^{292-294,296}$Og have been used. Among all the reactions mentioned above, the 3n channel cross section (2458 fb) is larger for ^{48}Ca+^{251}Cf→^{299}Og; 4n channel cross section (212 fb) is larger for ^{48}Ca+^{252}Cf→^{300}Og and 5n channel cross section (34 fb) is larger for ^{48}Ca+^{253}Cf→^{301}Og. The second largest 3n channel cross section (1143 fb) is obtained for the reaction, ^{50}Ti+^{245}Cm→^{295}Og.

For the synthesis of isotopes of Z=119, using ^{42,44,46,48}Ca+$^{252-255}$Es and $^{46-50}$Ti+$^{246-249}$Bk

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in 3n, 4n, and 5n channel leading to $^{294-303}119$ and $^{292-299}119$ respectively are studied. It is found that, the 3n channel (952.173 fb) cross section is larger for the reaction ^{48}Ca+ ^{252}Es→^{300}119; 4n (155.026 fb) and 5n (23.11 fb) channel cross section is larger for the reaction ^{48}Ca+^{254}Es→^{302}119.

Probable target- projectile combinations for the superheavy element ^{302}120 have been identified from the cold reaction valleys and the reactions ^{44}Ar+ ^{258}No, ^{46}Ar + ^{256}No, ^{48}Ca +^{254}Fm, ^{50}Ca +^{252}Fm, ^{52}Ca+^{250}Fm, ^{54}Ti+^{248}Cf, ^{56}Ti+^{246}Cf, ^{58}Cr +^{244}Cm in the deep region I of cold valley, and the systems ^{60}Cr +^{242}Cm, ^{62}Fe +^{240}Pu, ^{64}Fe+ ^{238}Pu, ^{66}Fe+^{236}Pu, ^{68}Ni+^{234}U, ^{70}Ni+^{232}U, ^{72}Ni+ ^{230}U, ^{74}Zn+^{228}Th in the cold valleys are identified as the better projectile-target combinations for the synthesis of ^{302}120. The computed ER cross section for ^{54}Cr+^{248}Cm, ^{58}Fe+^{244}Pu, ^{64}Ni+^{238}U and ^{50}Ti+^{249}Cf combinations are compared with experimental data and other theoretical models.

Modes of decay of Superheavy Nuclei

The main modes of decay of superheavy nuclei (SHN) are alpha decay and spontaneous fission. Usually superheavy nuclei decay by the emission of a chain of alpha particles and ends with spontaneous fission (SF). The alpha decay half lives and spontaneous fission half lives are important in predicting the isotopes which are formed in the fusion reaction. The competition between alpha decay and SF can be considered as one of the key factor for determining the stability of SHN. The SHN with alpha half life less than SF half life will decay by alpha emission and can be synthesized and detected in the laboratory.

The modes of decay of even Z nuclei [5] in the region Z=104-136 are studied by comparing the alpha half lives and SF half lives of 1119 and their daughters. The alpha decay half lives are evaluated using the Coulomb and proximity potential model for deformed nuclei (CPPMDN) and SF half lives using our Shell effect dependent formula for spontaneous fission, and the values are compared with other theoretical models. The predicted half life values and decay modes are in good agreement with experimental data. It is observed that 166 nuclei exhibit proton emission, 164 nuclei show sequential alpha chains followed by SF, 2 nuclei will decay by alpha emission followed by proton emission, 54 nuclei exhibit full alpha chains, 642 nuclei will decay through SF and 91 isotopes have negative Q values for alpha decay.

For the completeness of research on the decay modes of superheavy nuclei, the half-lives and decay modes of 1051 odd Z nuclei [6] in the region Z=105-135 are evaluated. The predicted half lives and decay modes are in agreement with experiments. Our study reveals that 233 nuclei exhibit proton emission, 18 nuclei exhibit neutron emission, 92 nuclei show sequential alpha chains followed by SF, 9 nuclei will decay by alpha emission followed by proton emission, 39 nuclei exhibit full alpha chains, 595 nuclei will decay through SF and 56 isotopes are stable against alpha decay. As compared to even Z nuclei, number of proton emitters is greater in odd Z region and the number of isotopes showing alpha chains followed by SF is greater in even Z region.

Theoretical studies have been performed in order to explore the possibilities of heavy cluster emissions from superheavy nuclei. The alpha decay and heavy cluster decay probabilities of superheavy isotopes are investigated using a new formula for pre-formation probabilities which depends on the Q value of the decay. The model is successful in reproducing the experimental alpha half-lives in the superheavy region. The study suggests that heavy cluster radioactivity may be comparable or dominant to alpha decay for some of the isotopes of $Z \geq 118$. The isotopes $^{294-296}$Og, $^{297-301}$119 and $^{298,300-302}$120 are the probable candidates for cluster emission.

References

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