Application of ADNT2021 tables to estimate the chances of producing new elements

Michał Kowal

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journal homepage: www.elsevier.com/locate/adt

Properties of heaviest nuclei with $98 \leq Z \leq 126$ and $134 \leq N \leq 192$

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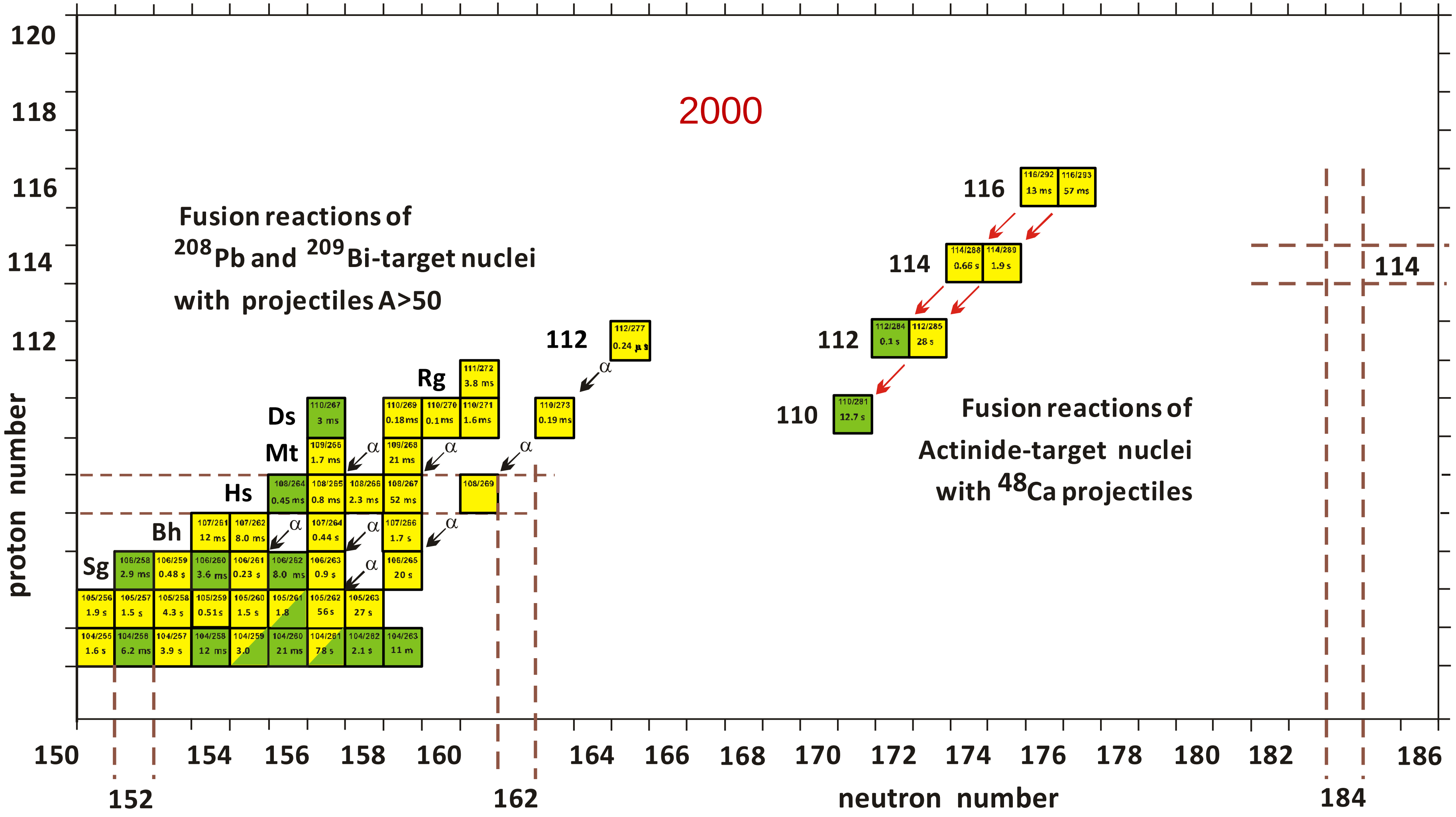
A R T I C L E I N F O

Article history:
Received 21 October 2020
Accepted 5 November 2020
Available online 19 December 2020

A B S T R A C T

We systematically determine ground-state and saddle-point shapes and masses for 1305 heavy and superheavy nuclei with $Z = 98$–126 and $N = 134$–192, including odd-A and odd–odd systems. From these we derive static fission barrier heights, one- and two-nucleon separation energies, and Q_α values for g.s. to g.s. transitions. Our study is performed within the microscopic–macroscopic method with the deformed Woods–Saxon single-particle potential and the Yukawa-plus-exponential macroscopic energy taken as the smooth part. We use parameters of the model that were fitted previously to masses of even–even heavy nuclei. For systems with odd numbers of protons, neutrons, or both, we use a standard BCS method with blocking. Ground-state shapes and energies are found by the minimization over seven axially-symmetric deformations. A search for saddle-points was performed by using the "imaginary water flow" method in three consecutive stages, using five- (for nonaxial shapes) and seven-dimensional (for reflection-asymmetric shapes) deformation spaces. Calculated ground-state mass excess, nucleon separation- and Q_α energies, total, macroscopic (normalized to the macroscopic energy at the spherical shape) and shell corrections energies, and deformations are given for each nucleus in Table 1. Table 2 contains calculated properties of the saddle-point configurations and the fission barrier heights. In Tables 3-7, are given calculated ground-state, inner and outer saddle-point and superdeformed secondary minima characteristics for 75 actinide nuclei, from Ac to Cf, for which experimental estimates of fission barrier heights are known. These results are an additional test of our model.

Contents



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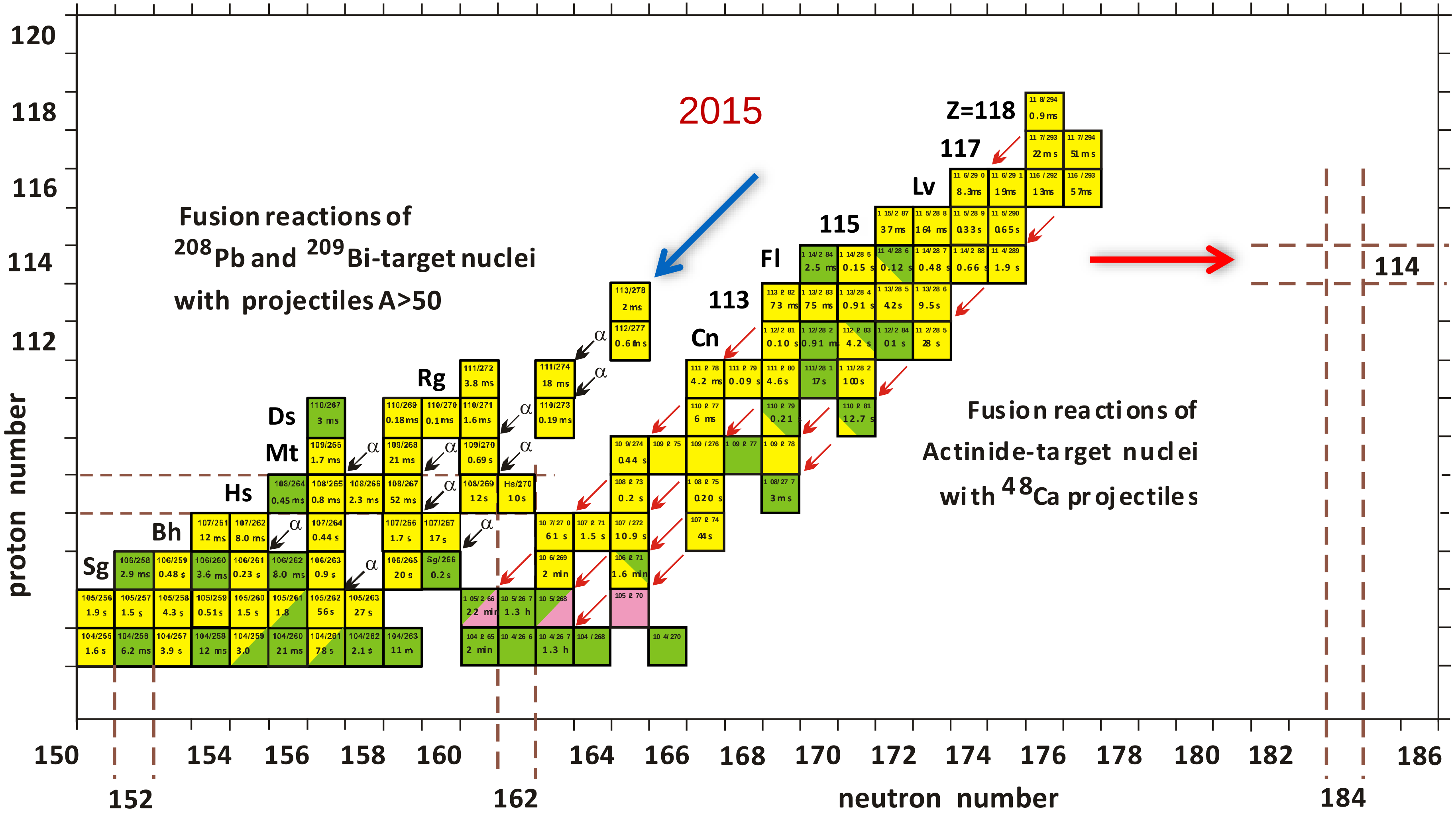


2015
Fusion reactions of
^{208}Pb and ^{209}Bi-target nuclei
with projectiles A>50
Fusion reactions of
Actinide-target nuclei
with ^{48}Ca projectiles
Z=118
117
Lv
115
Fl
113
Cn
Rg
Ds
Mt
Hs
Bh
Sg
α
114
proton number
neutron number
120
118
116
114
112
150
152
154
156
158
160
162
164
166
168
170
172
174
176
178
180
182
184
186

SYNTHESIS SCENARIOS

COLD ($102<Z<113$)

- the strongly bound target nuclei (208Pb or 209Bi) are bombarded with projectiles ranging from Ca to Zn;
- the excitation energy of the resulting compound nucleus is usually in the range of 10 to 20 MeV;
- as the target-projectile symmetry increases, the compound nucleus production cross section decreases.

HOT ($112<Z<118$)

- the deformed actinide target-nuclei (from U to Cm) are bombarded with a doubly magic 48Ca projectile;
- the excitation energy of the resulting compound nucleus is usually in the range of 30 to 40 MeV, and the dominant evaporation channels are 3n and 4n channels;
- the evaporation residue cross sections do not show any strong dependence on the target-projectile symmetry and are at the picobarn level.

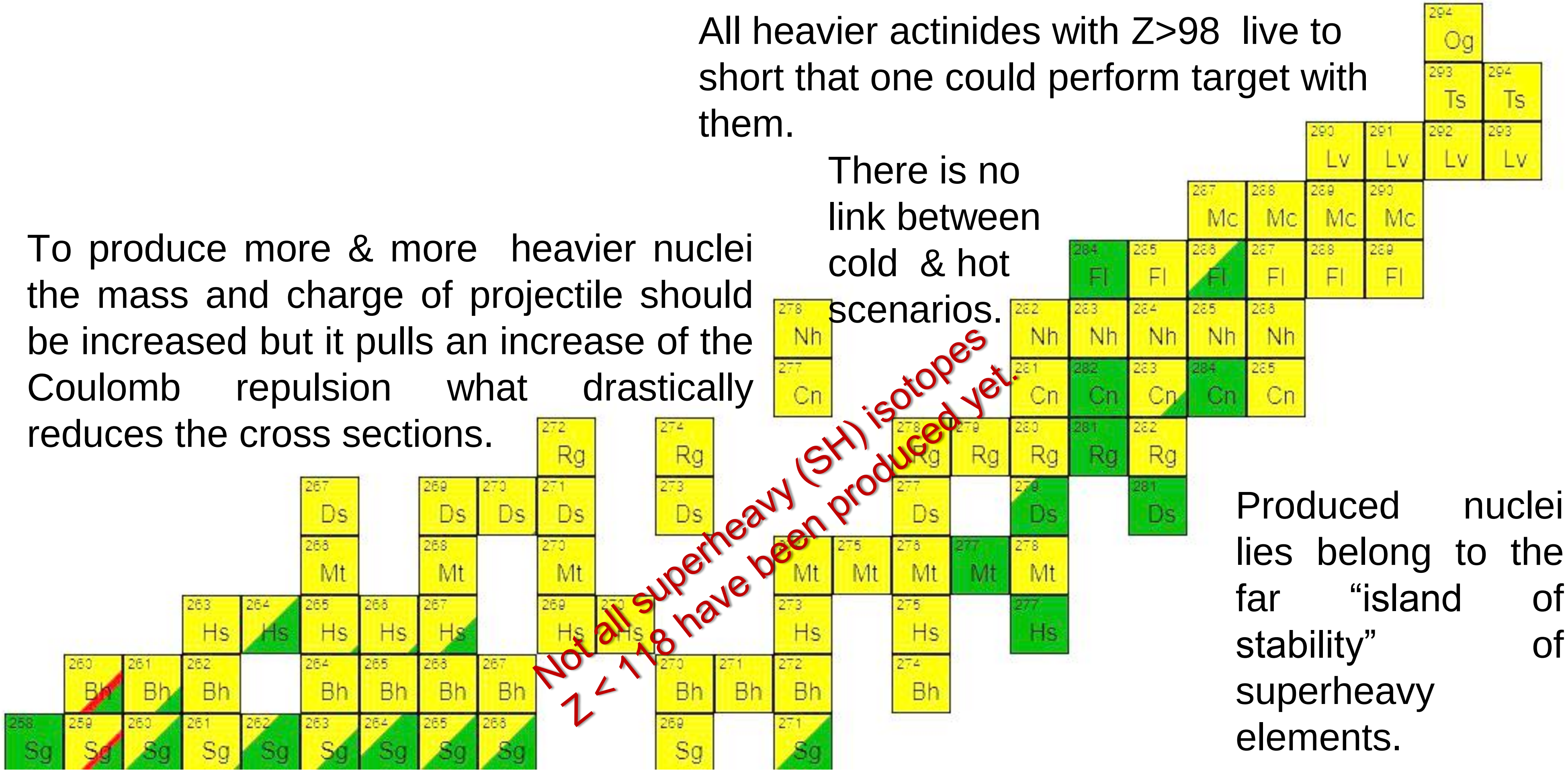
the issues

Attempts of going beyond the reactions Act. + ^{48}Ca by using heavier projectiles like ^{50}Ti, ^{54}Cr, ^{58}Fe, and ^{64}Ni gave no results so far.

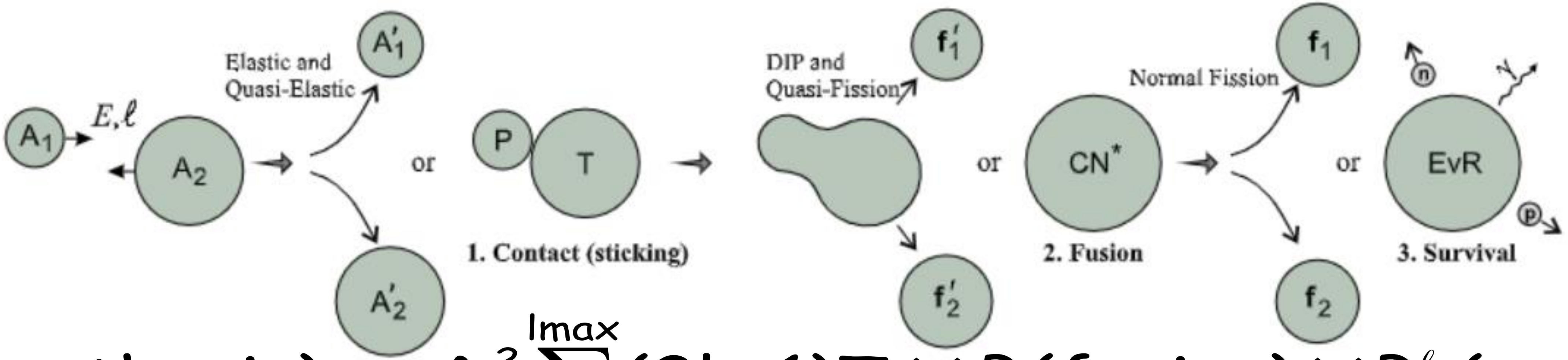
All heavier actinides with Z>98 live to short that one could perform target with them.

There is no link between cold & hot scenarios.

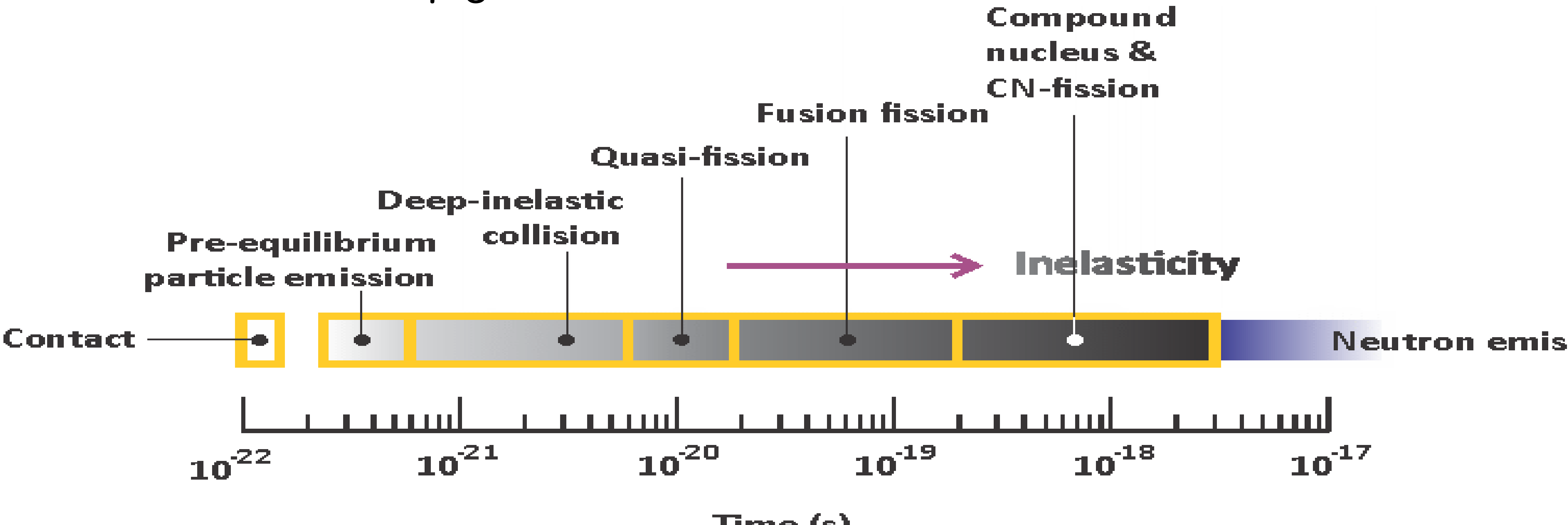
To produce more & more heavier nuclei the mass and charge of projectile should be increased but it pulls an increase of the Coulomb repulsion what drastically reduces the cross sections.

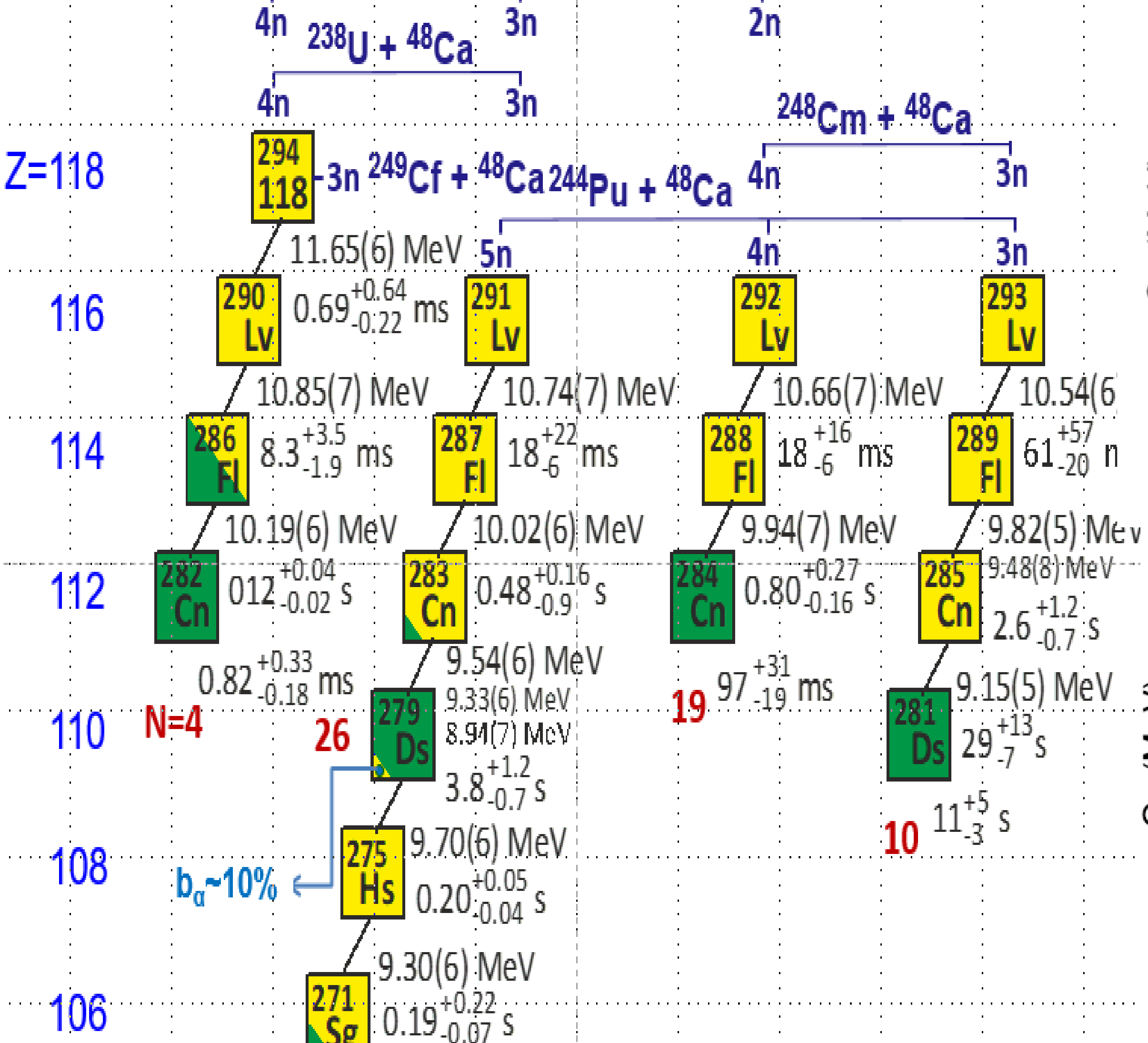


Produced nuclei lies belong to the far “island of stability” of superheavy elements.

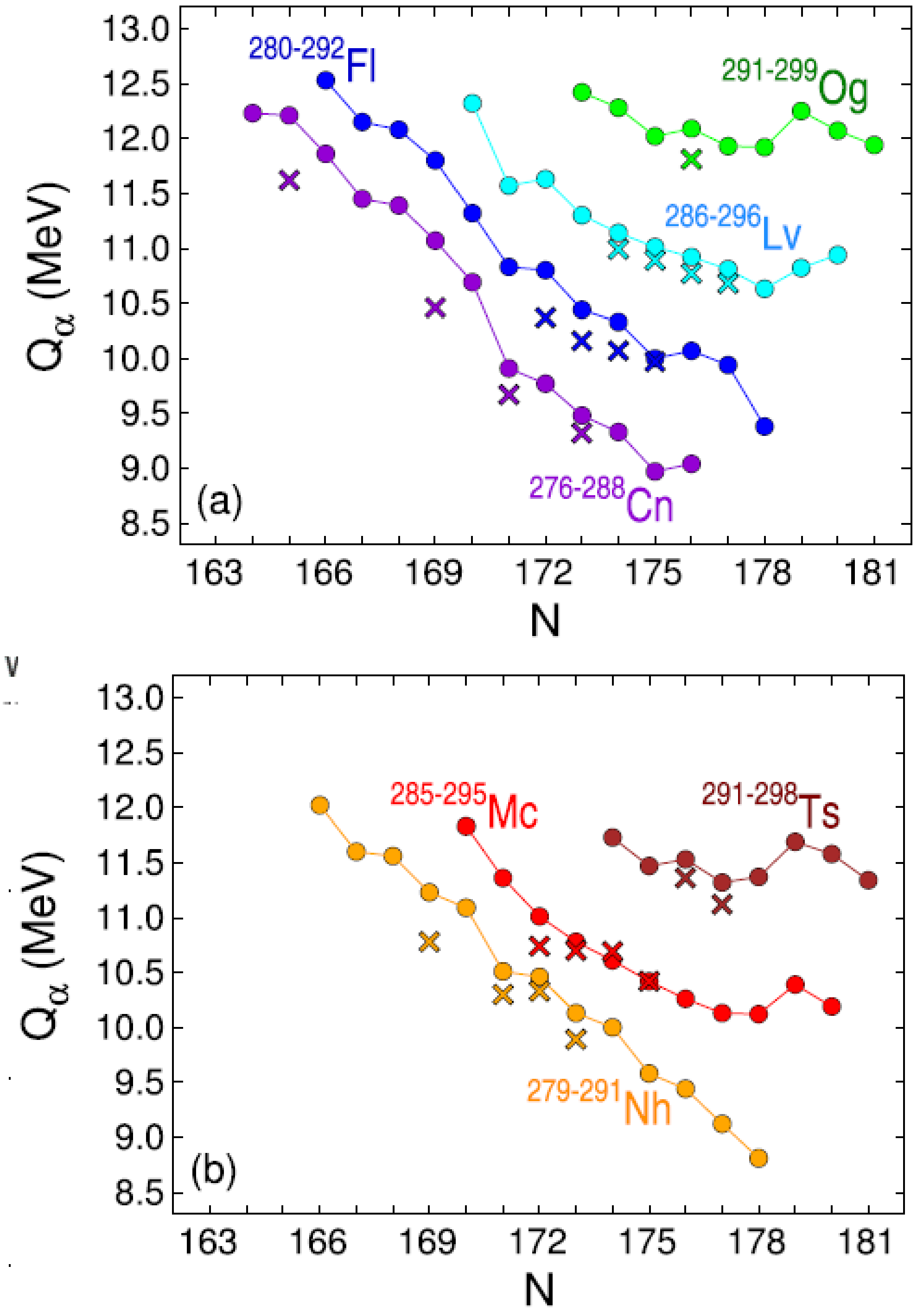


$$\sigma(synthesis) = \pi\lambda^2 \sum_{l=0}^{lmax}(2l+1)T_l \times P_l(fusion) \times P_{xn}^{\ell}(survive)$$



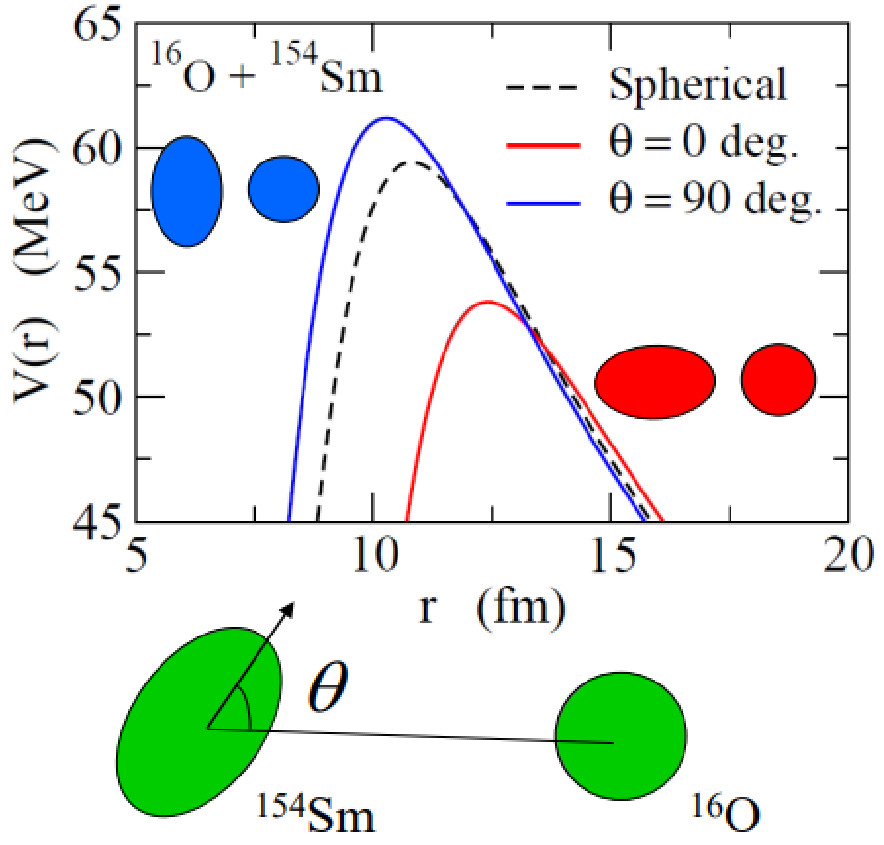


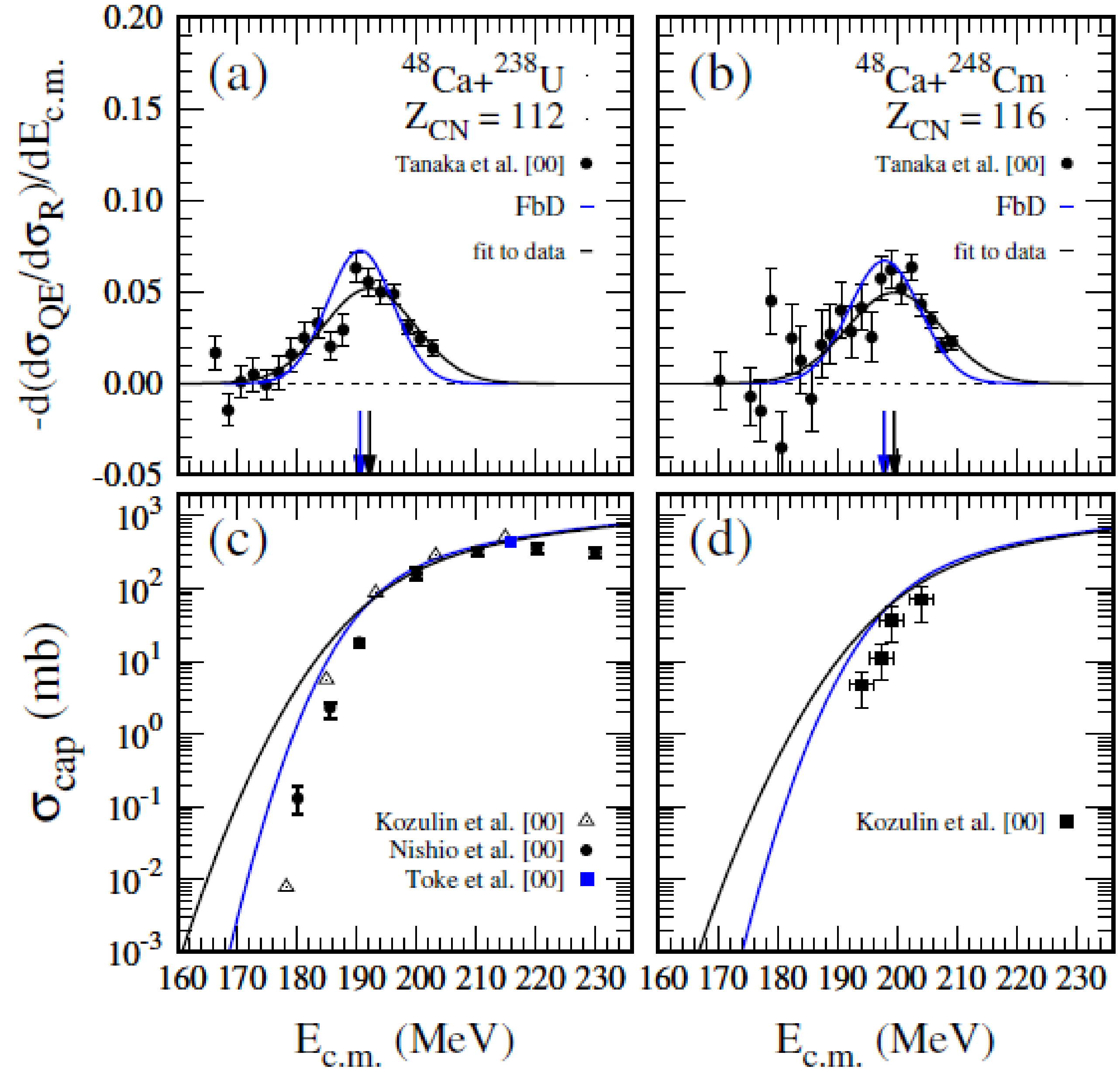
^{238}U + ^{48}Ca
4n
3n
2n
^{248}Cm + ^{48}Ca
^{249}Cf + ^{48}Ca
^{244}Pu + ^{48}Ca
5n
Z=118
116
114
112
110
108
106
294 118
11.65(6) MeV
290 Lv
291 Lv
292 Lv
293 Lv
10.85(7) MeV
10.74(7) MeV
10.66(7) MeV
286 Fl
287 Fl
288 Fl
289 Fl
10.19(6) MeV
10.02(6) MeV
9.94(7) MeV
9.82(5) MeV
282 Cn
283 Cn
284 Cn
285 Cn
9.48(8) MeV
9.54(6) MeV
9.33(6) MeV
8.94(7) MeV
9.15(5) MeV
279 Ds
281 Ds
N=4
26
19
10
9.70(6) MeV
275 Hs
b_α~10%
9.30(6) MeV
271 Sg



(a)
Q_α (MeV)
N
$^{280-292}$Fl
$^{291-299}$Og
$^{286-296}$Lv
$^{276-288}$Cn
(b)
$^{285-295}$Mc
$^{291-298}$Ts
$^{279-291}$Nh

CAPTURE





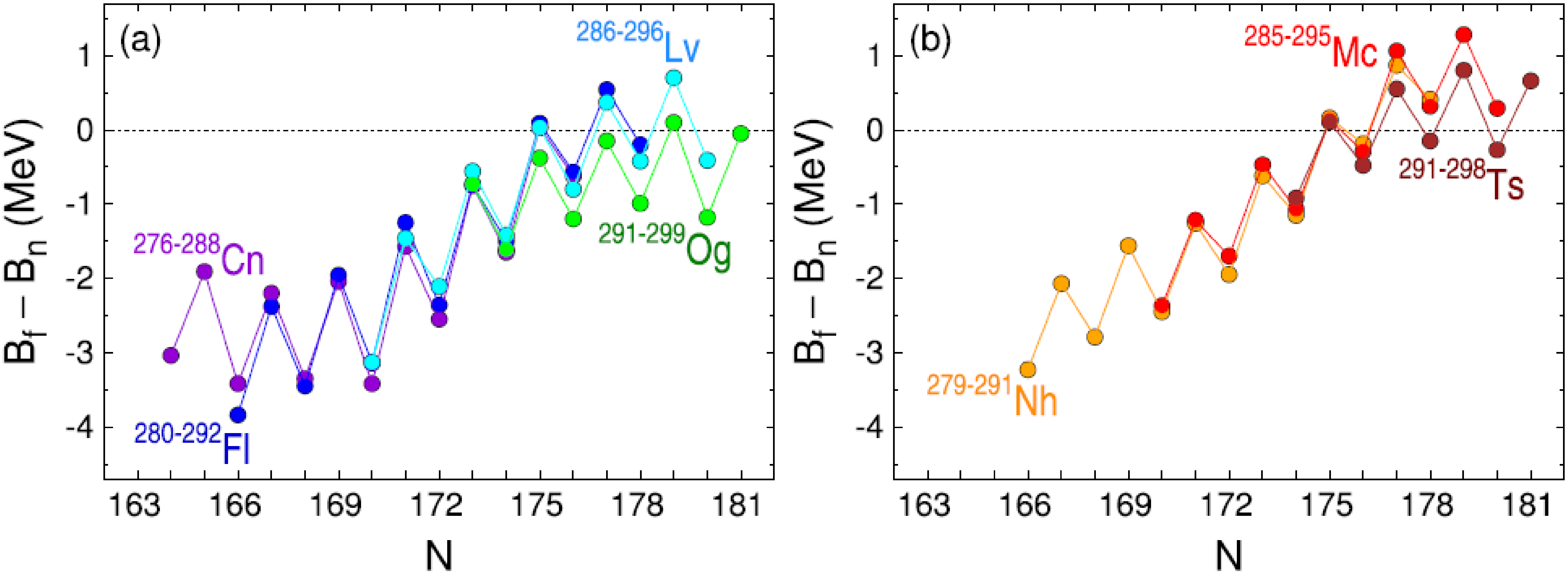
T. Cap, M. Kowal,, K. Siwek-Wilczynska, Eur. Phys. J. A In preparation

SURVIVAL

$$\frac{\Gamma_n}{\Gamma_f} = \frac{4mR_0^2}{\hbar^2} \frac{\int_0^{E^*-B_n} \epsilon\rho(E^* - B_n - \epsilon)d\epsilon}{\int_0^{E^*-B_f} \rho(E^* - B_f - K)dK},$$

$E^* > B_n > B_f > T,$ ⇒

$$\frac{\Gamma_n}{\Gamma_f} = \frac{4mR_0^2}{\hbar^2} \exp\left(-\frac{B_n - B_f}{T}\right).$$



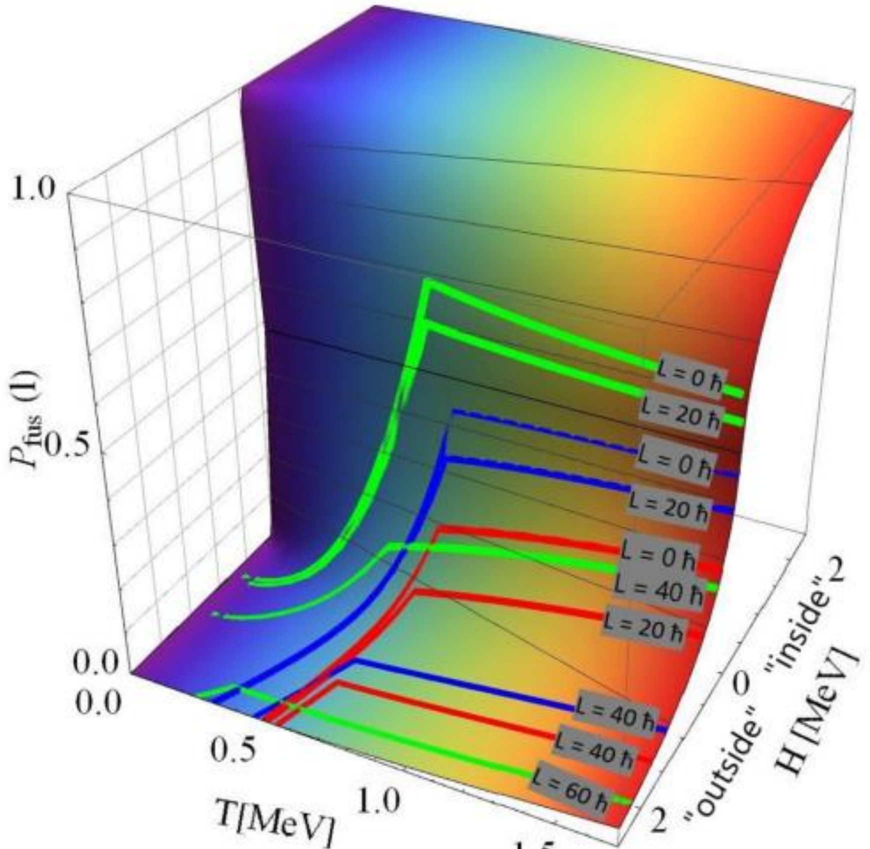
PHYSICAL REVIEW C
covering nuclear physics

Diffusion as a possible mechanism controlling the production of superheavy nuclei in cold fusion reactions

T. Cap, M. Kowal, and K. Siwek-Wilczyńska
Phys. Rev. C **105**, L051601 – Published 16 May 2022

Langevin in the overdamped limit:

$$P_{\mathrm{CN}}(E) = \frac{1}{2}\left[1 - \mathrm{erf}\left(\frac{\Delta V}{T}\right)\right]$$



PHYSICAL REVIEW C
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Level-density parameters in superheavy nuclei

A. Rahmatinejad, A. N. Bezbakh, T. M. Shneidman, G. Adamian, N. V. Antonenko, P. Jachimowicz, and M. Kowal

Phys. Rev. C **103**, 034309 – Published 9 March 2021

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Energy dependent ratios of level-density parameters in superheavy nuclei

A. Rahmatinejad, T. M. Shneidman, G. G. Adamian, N. V. Antonenko, P. Jachimowicz, and M. Kowal

Phys. Rev. C **105**, 044328 – Published 28 April 2022

PHYSICAL REVIEW C
covering nuclear physics

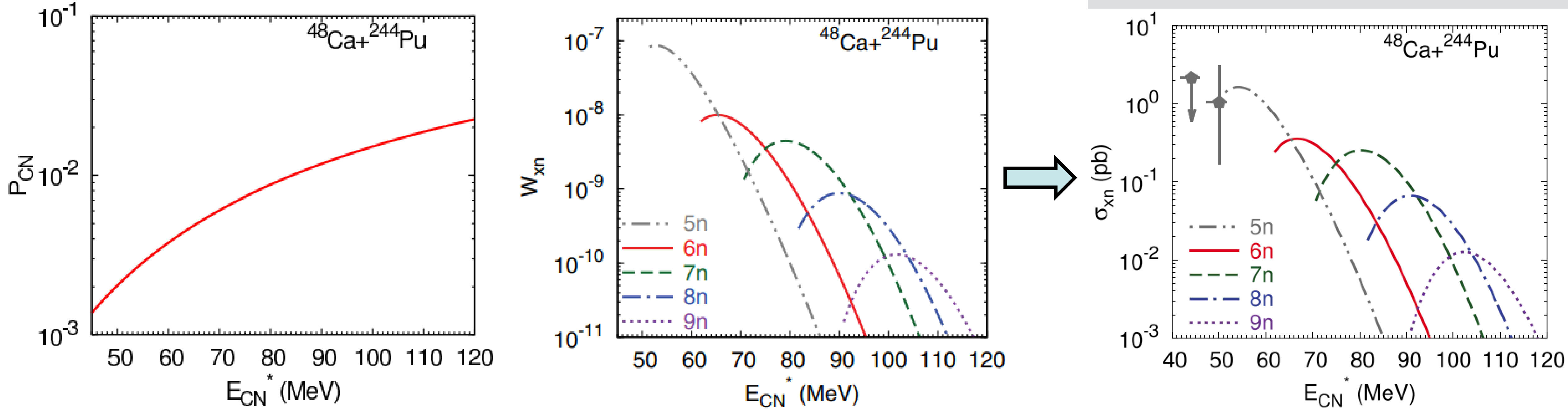
Letter

Rate of decline of the production cross section of superheavy nuclei with $Z = 114–117$ at high excitation energies

J. Hong, G. G. Adamian, N. V. Antonenko, P. Jachimowicz, and M. Kowal

Phys. Rev. C **103**, L041601 – Published 20 April 2021

the decline of the cross section with increasing excitation energy unexpectedly turned out to be relatively weak. This intriguing behavior may open up a new window for the study and the production of new isotopes



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Physics Letters B

www.elsevier.com/locate/physletb

Possibilities of direct production of superheavy nuclei with Z=112–118 in different evaporation channels

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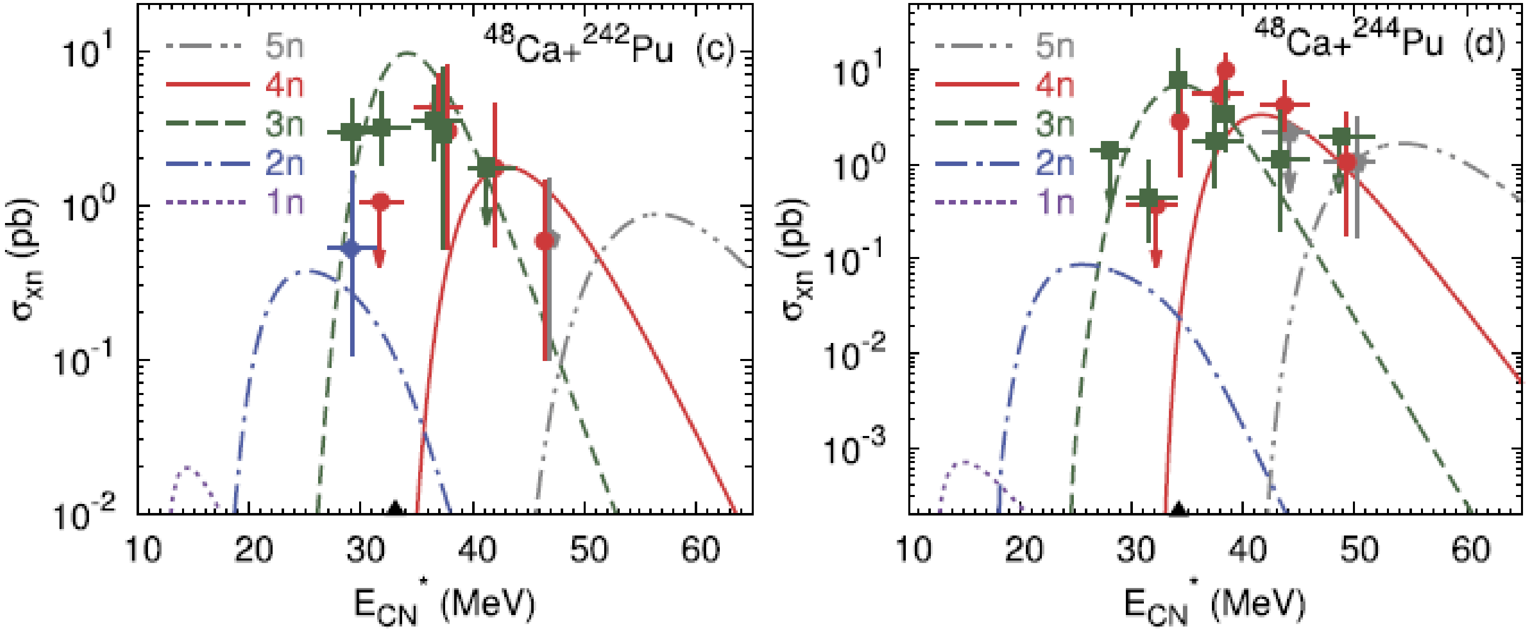
[d] Institute of Physics, University of Zielona Góra, Szafrana 4a, 65-516 Zielona Góra, Poland
[e] National Centre for Nuclear Research, Pasteura 7, 02-093 Warsaw, Poland



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GRANTS

IUPAC IS NAMING THE FOUR NEW ELEMENTS NIHONIUM, MOSCOVIUM, TENNESSINE, AND OGANESSON

8 June 2016

IUPAC is naming the four new elements nihonium, moscovium, tennessine, and oganesson

Following earlier reports that the claims for discovery of these elements have been fulfilled [1, 2], the discoverers have been invited to propose names and the following are now disclosed for public review:

Nihonium and symbol Nh, for the element 113,
Moscovium and symbol Mc, for the element 115,
Tennessine and symbol Ts, for the element 117, and
Oganesson and symbol Og, for the element 118.

The IUPAC Inorganic Chemistry Division has reviewed and considered these proposals and recommends these for acceptance. A five-month public review is now set, expiring 8 November 2016, prior to the formal approval by the IUPAC Council.

SCIENTIFIC AMERICAN
THE SCIENCES
4 New Superheavy Elements Verified
Cztery nowe pierwiastki chemiczne otrzymały nazwy
The New York Times
Newsweek
Tablica Mendelejewa zyskała cztery nowe pierwiastki
Cztery nowe pierwiastki otrzymały oficjalne nazwy
PHYSICS TODAY
DOI:10.1063/PT.5.9059
10 Jun 2016 in Research & Technology
Four superheavy elements are nameless no more
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Cztery nowe pierwiastki na tablicy Mendelejewa
Odkryto 4 nowe pierwiastki. Nie mają jeszcze swoich nazw
The Washington Post
Democracy Dies in Darkness
What will scientists name the newest

IUPAC Periodic Table of the Elements

Key:

atomic number **Symbol** name abridged standard atomic weight

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 **H** hydrogen 1.0080 ± 0.0002																	2 **He** helium 4.0026 ± 0.0001
3 **Li** lithium 6.94 ± 0.06	4 **Be** beryllium 9.0122 ± 0.0001											5 **B** boron 10.81 ± 0.02	6 **C** carbon 12.011 ± 0.002	7 **N** nitrogen 14.007 ± 0.001	8 **O** oxygen 15.999 ± 0.001	9 **F** fluorine 18.998 ± 0.001	10 **Ne** neon 20.180 ± 0.001
11 **Na** sodium 22.990 ± 0.001	12 **Mg** magnesium 24.305 ± 0.002											13 **Al** aluminium 26.982 ± 0.001	14 **Si** silicon 28.085 ± 0.001	15 **P** phosphorus 30.974 ± 0.001	16 **S** sulfur 32.06 ± 0.02	17 **Cl** chlorine 35.45 ± 0.01	18 **Ar** argon 39.95 ± 0.16
19 **K** potassium 39.098 ± 0.001	20 **Ca** calcium 40.078 ± 0.004	21 **Sc** scandium 44.956 ± 0.001	22 **Ti** titanium 47.867 ± 0.001	23 **V** vanadium 50.942 ± 0.001	24 **Cr** chromium 51.996 ± 0.001	25 **Mn** manganese 54.938 ± 0.001	26 **Fe** iron 55.845 ± 0.002	27 **Co** cobalt 58.933 ± 0.001	28 **Ni** nickel 58.693 ± 0.001	29 **Cu** copper 63.546 ± 0.003	30 **Zn** zinc 65.38 ± 0.02	31 **Ga** gallium 69.723 ± 0.001	32 **Ge** germanium 72.630 ± 0.008	33 **As** arsenic 74.922 ± 0.001	34 **Se** selenium 78.971 ± 0.008	35 **Br** bromine 79.904 ± 0.003	36 **Kr** krypton 83.798 ± 0.002
37 **Rb** rubidium 85.468 ± 0.001	38 **Sr** strontium 87.62 ± 0.01	39 **Y** yttrium 88.906 ± 0.001	40 **Zr** zirconium 91.224 ± 0.002	41 **Nb** niobium 92.906 ± 0.001	42 **Mo** molybdenum 95.95 ± 0.01	43 **Tc** technetium [97]	44 **Ru** ruthenium 101.07 ± 0.02	45 **Rh** rhodium 102.91 ± 0.01	46 **Pd** palladium 106.42 ± 0.01	47 **Ag** silver 107.87 ± 0.01	48 **Cd** cadmium 112.41 ± 0.01	49 **In** indium 114.82 ± 0.01	50 **Sn** tin 118.71 ± 0.01	51 **Sb** antimony 121.76 ± 0.01	52 **Te** tellurium 127.60 ± 0.03	53 **I** iodine 126.90 ± 0.01	54 **Xe** xenon 131.29 ± 0.01
55 **Cs** caesium 132.91 ± 0.01	56 **Ba** barium 137.33 ± 0.01	57-71 lanthanoids	72 **Hf** hafnium 178.49 ± 0.01	73 **Ta** tantalum 180.95 ± 0.01	74 **W** tungsten 183.84 ± 0.01	75 **Re** rhenium 186.21 ± 0.01	76 **Os** osmium 190.23 ± 0.03	77 **Ir** iridium 192.22 ± 0.01	78 **Pt** platinum 195.08 ± 0.02	79 **Au** gold 196.97 ± 0.01	80 **Hg** mercury 200.59 ± 0.01	81 **Tl** thallium 204.38 ± 0.01	82 **Pb** lead 207.2 ± 1.1	83 **Bi** bismuth 208.98 ± 0.01	84 **Po** polonium [209]	85 **At** astatine [210]	86 **Rn** radon [222]
87 **Fr** francium [223]	88 **Ra** radium [226]	89-103 actinoids	104 **Rf** rutherfordium [267]	105 **Db** dubnium [268]	106 **Sg** seaborgium [269]	107 **Bh** bohrium [270]	108 **Hs** hassium [269]	109 **Mt** meitnerium [277]	110 **Ds** darmstadtium [281]	111 **Rg** roentgenium [282]	112 **Cn** copernicium [285]	113 **Nh** nihonium [286]	114 **Fl** flerovium [290]	115 **Mc** moscovium [290]	116 **Lv** livermorium [293]	117 **Ts** tennessine [294]	118 **Og** oganesson [294]

57 **La** lanthanum 138.91 ± 0.01	58 **Ce** cerium 140.12 ± 0.01	59 **Pr** praseodymium 140.91 ± 0.01	60 **Nd** neodymium 144.24 ± 0.01	61 **Pm** promethium [145]	62 **Sm** samarium 150.36 ± 0.02	63 **Eu** europium 151.96 ± 0.01	64 **Gd** gadolinium 157.25 ± 0.03	65 **Tb** terbium 158.93 ± 0.01	66 **Dy** dysprosium 162.50 ± 0.01	67 **Ho** holmium 164.93 ± 0.01	68 **Er** erbium 167.26 ± 0.01	69 **Tm** thulium 168.93 ± 0.01	70 **Yb** ytterbium 173.05 ± 0.02	71 **Lu** lutetium 174.97 ± 0.01
89 **Ac** actinium [227]	90 **Th** thorium 232.04 ± 0.01	91 **Pa** protactinium 231.04 ± 0.01	92 **U** uranium 238.03 ± 0.01	93 **Np** neptunium [237]	94 **Pu** plutonium [244]	95 **Am** americium [243]	96 **Cm** curium [247]	97 **Bk** berkelium [247]	98 **Cf** californium [251]	99 **Es** einsteinium [252]	100 **Fm** fermium [257]	101 **Md** mendelevium [258]	102 **No** nobelium [259]	103 **Lr** lawrencium [262]

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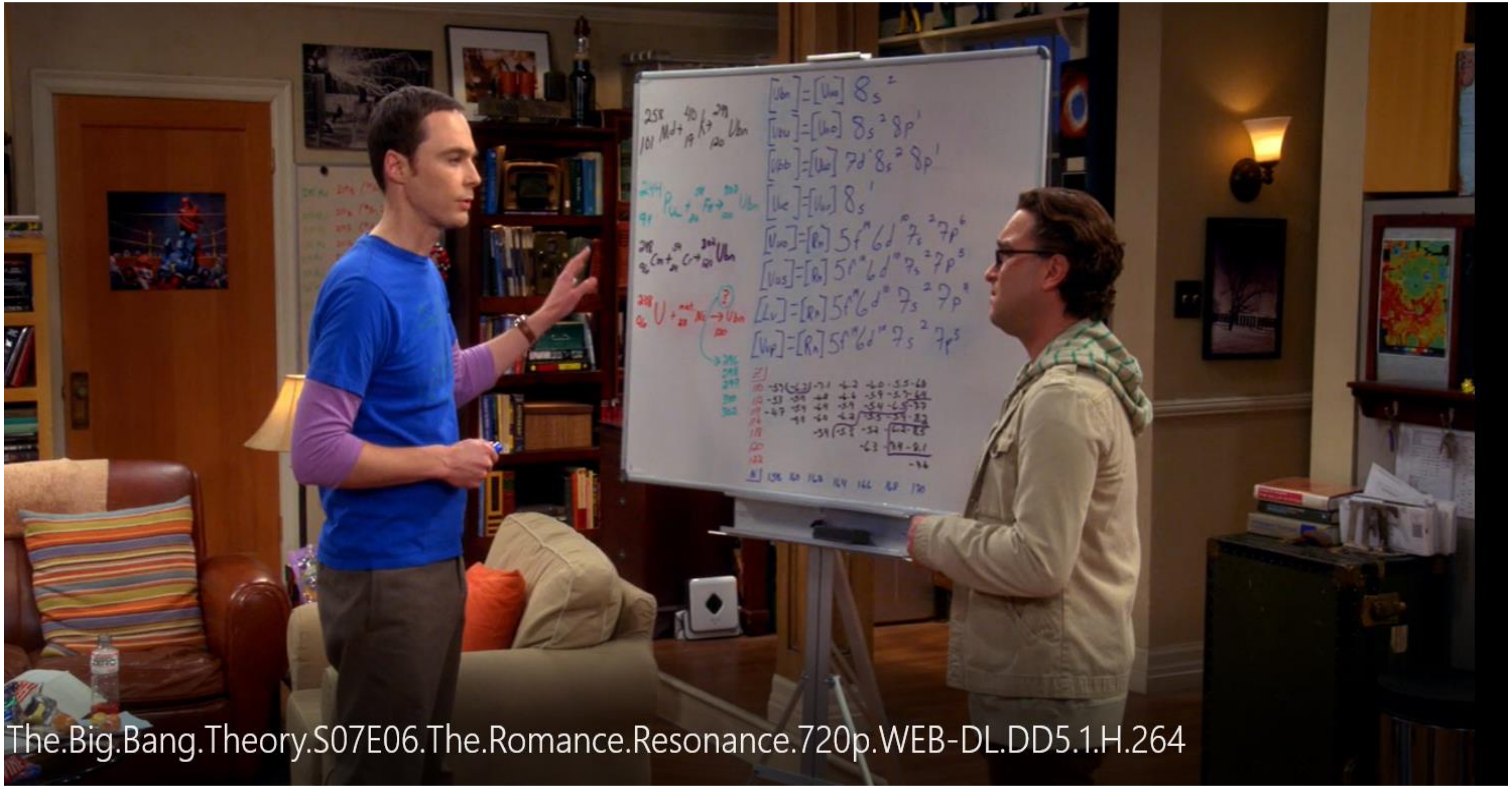
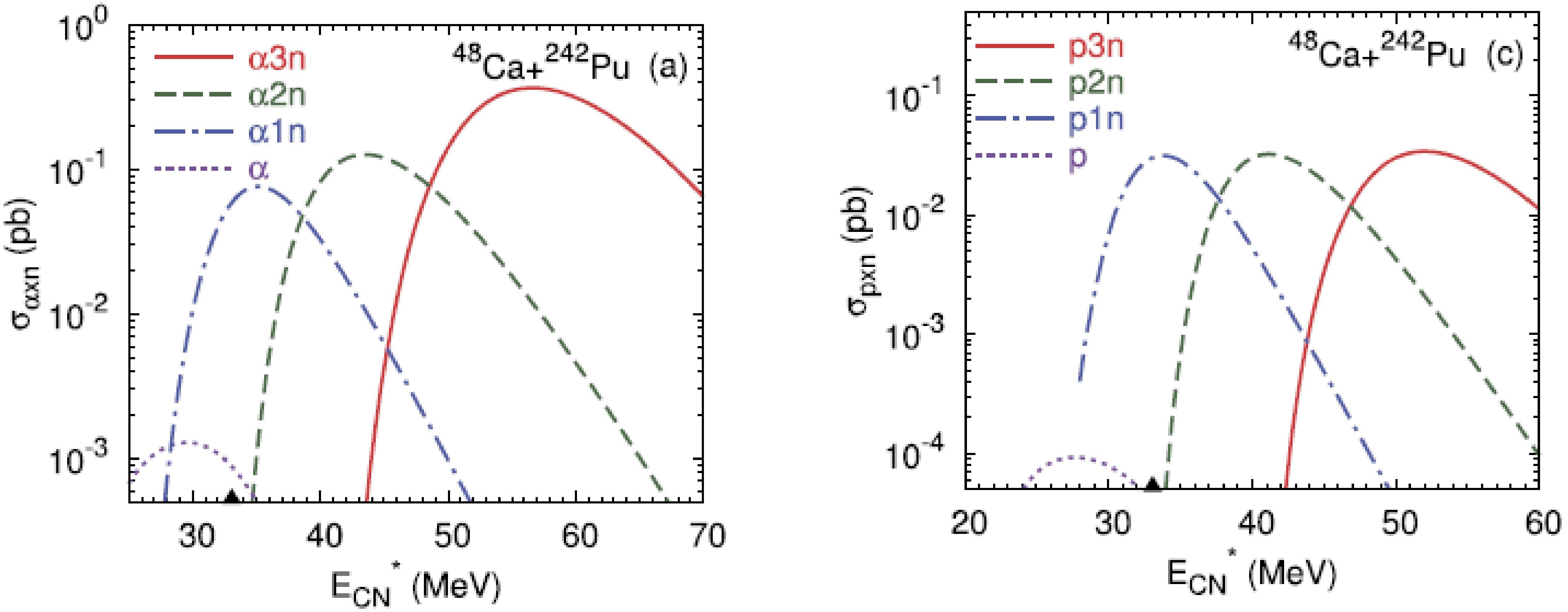
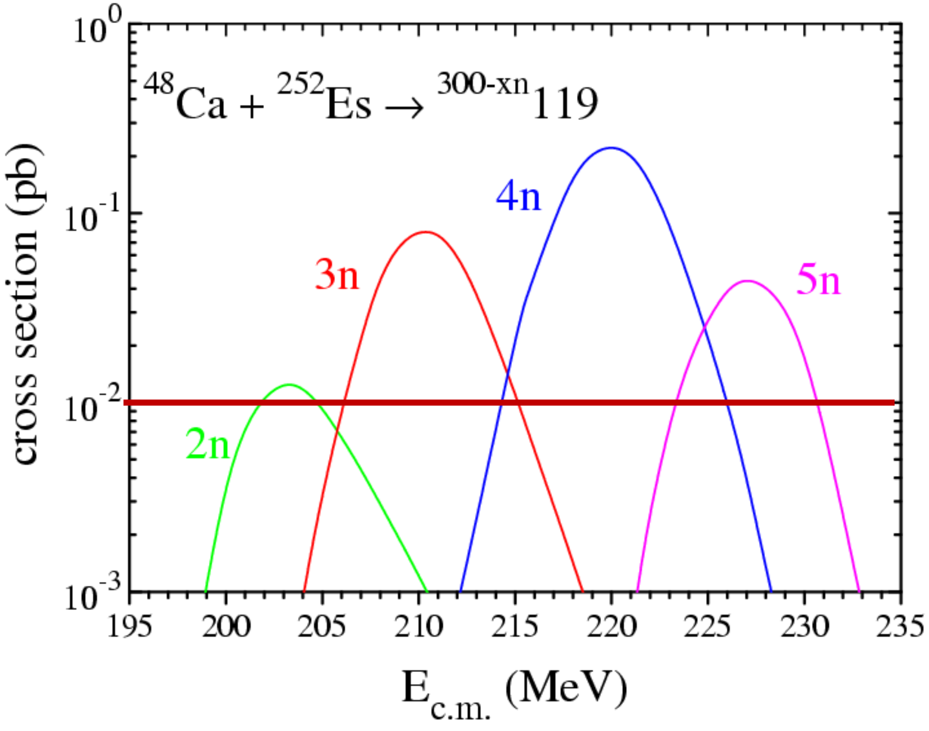
What Next ?

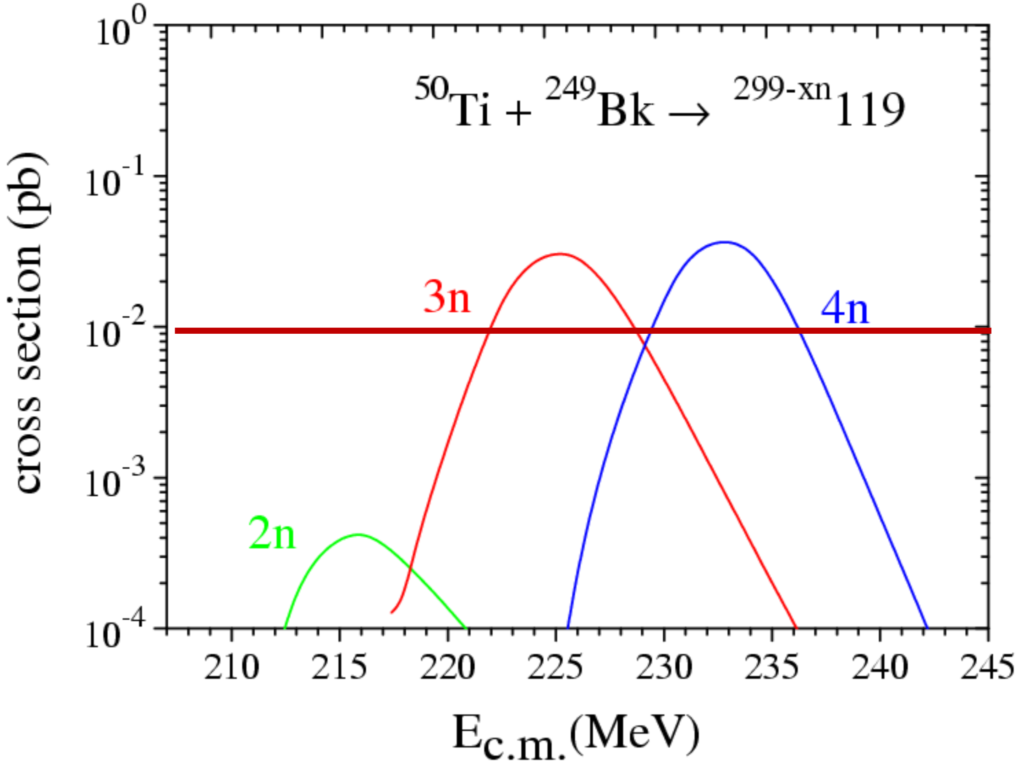

The.Big.Bang.Theory.S07E06.The.Romance.Resonance.720p.WEB-DL.DD5.1.H.264

The *pxn*−and *αxn*−evaporation channels allow us to obtain an access to the isotopes which are unreachable in *xn*−evaporation channels due to the lack of proper projectile-target combination. Thus, employing the reactions suggested, one can produce the heaviest isotopes closer to the center of the island of stability.



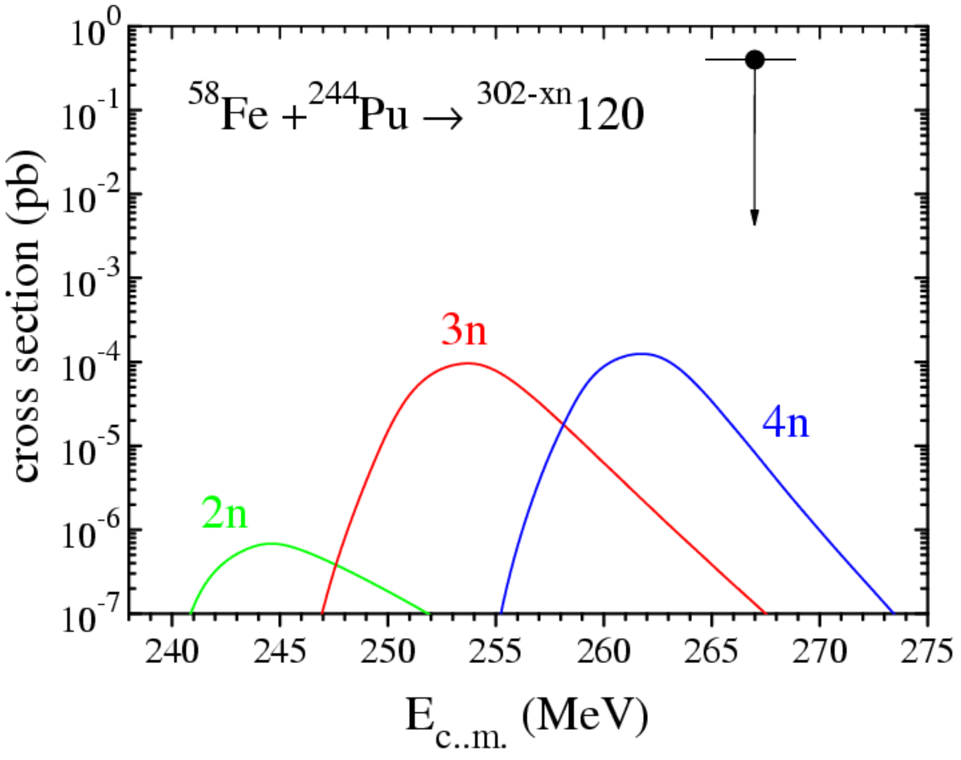
The systematics of the s_{inj} used to predict cross sections for Z = 119

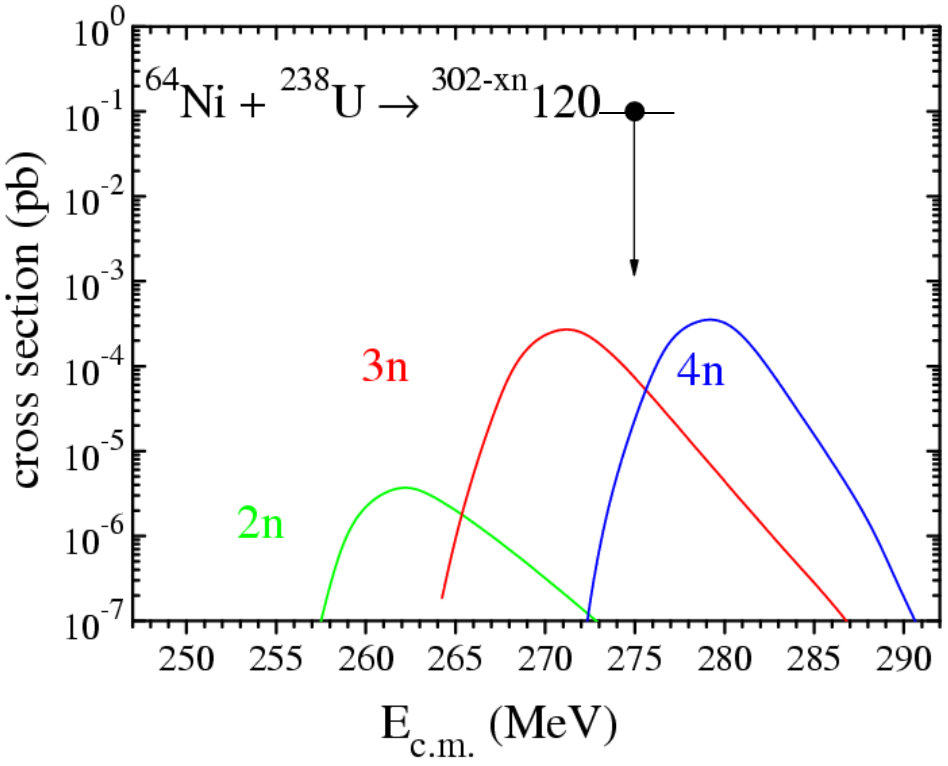




The reaction $^{48}Ca + ^{252}Es$ predicted to have measurable cross section

Z = 120





These values of the evaporation residue cross sections are much smaller (at least one order of magnitude) than previously published predictions.

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