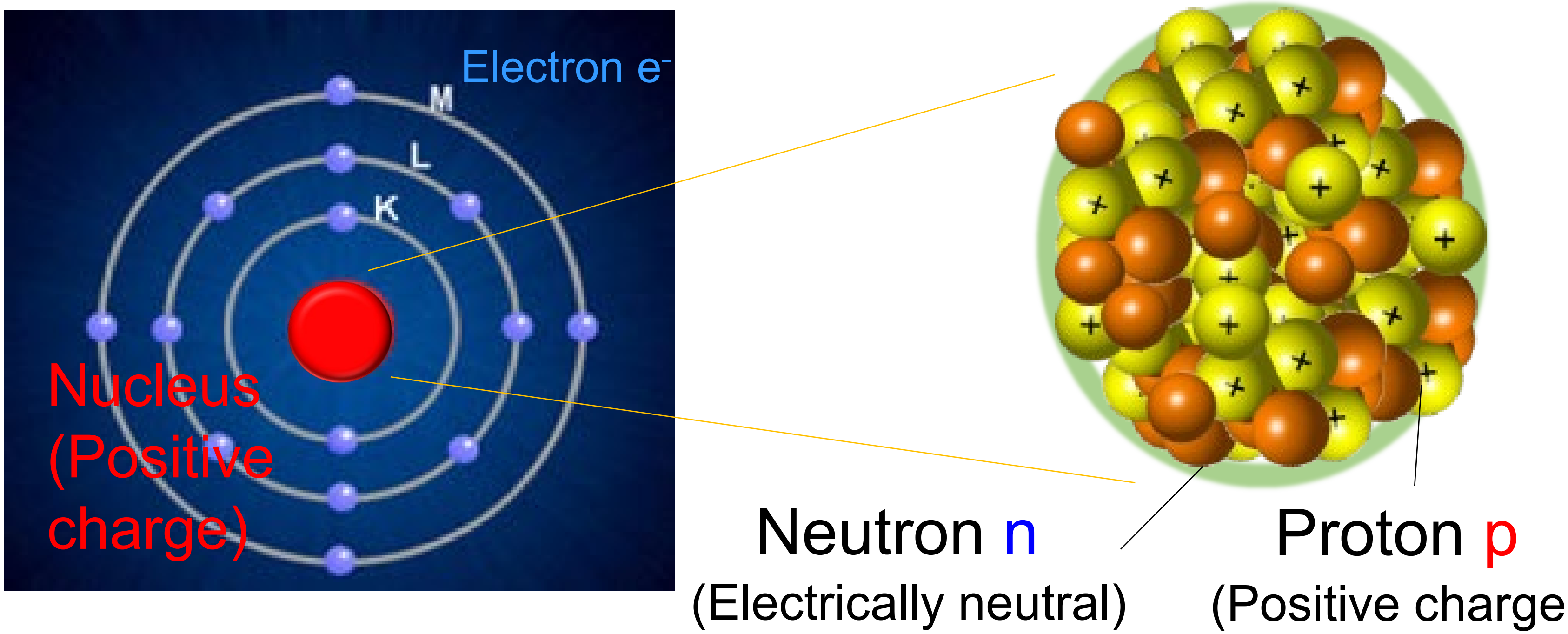
Superheavy Elements and Heavy Ion Fusion Reactions

Advanced Science Research Center, Japan Atomic Energy Agency
Research Fellow Katsuhisa Nishio

Nucleus



Including nuclei that can be synthesized artificially
There can be 6,000 different nuclei, including nuclei that can be artificially synthesized.
How many protons and neutrons can you pack?

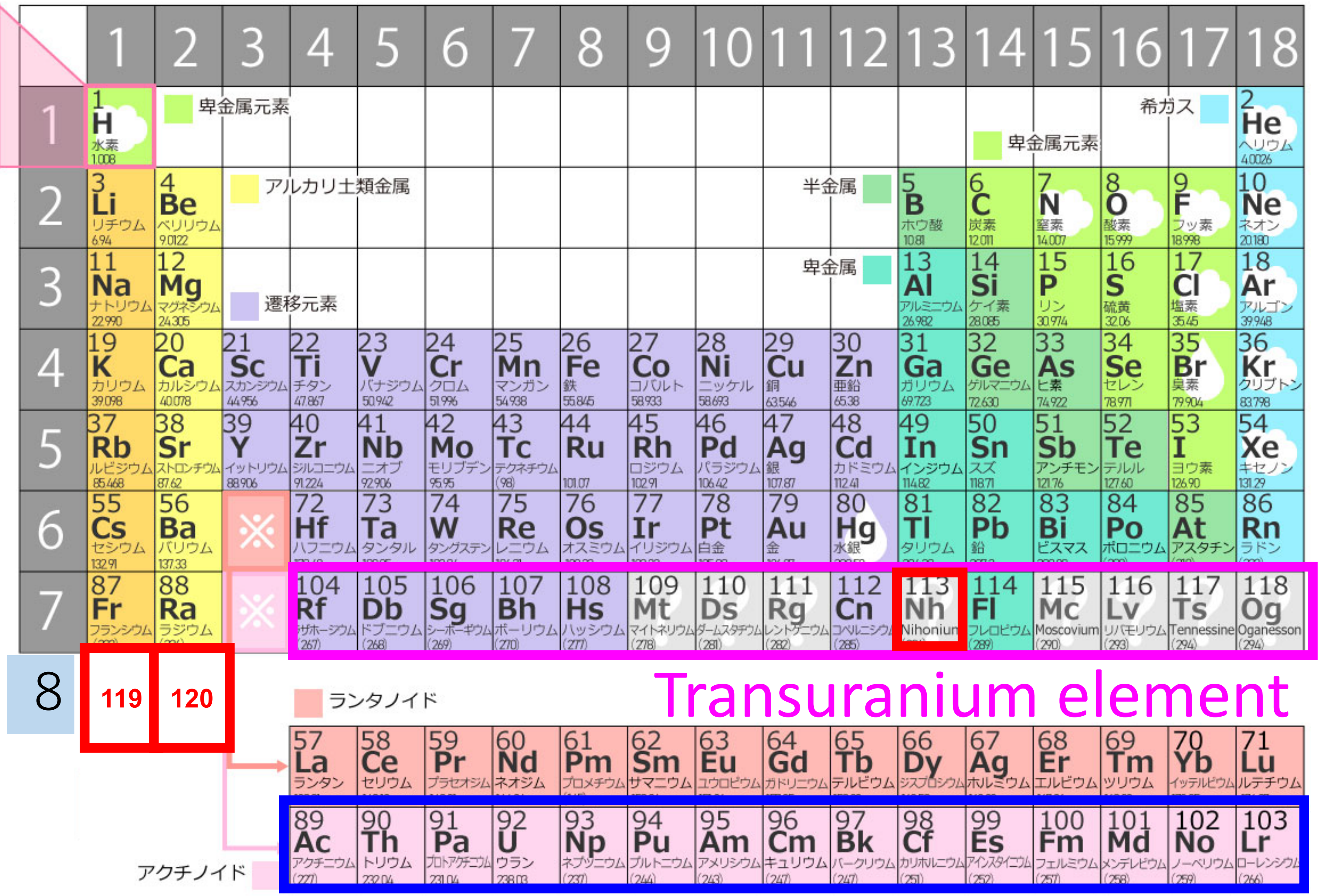
<u>Uranium235</u>

$^{235}_{92}U_{143}$

Mass number A = Number of protons Z + Number of neutron N

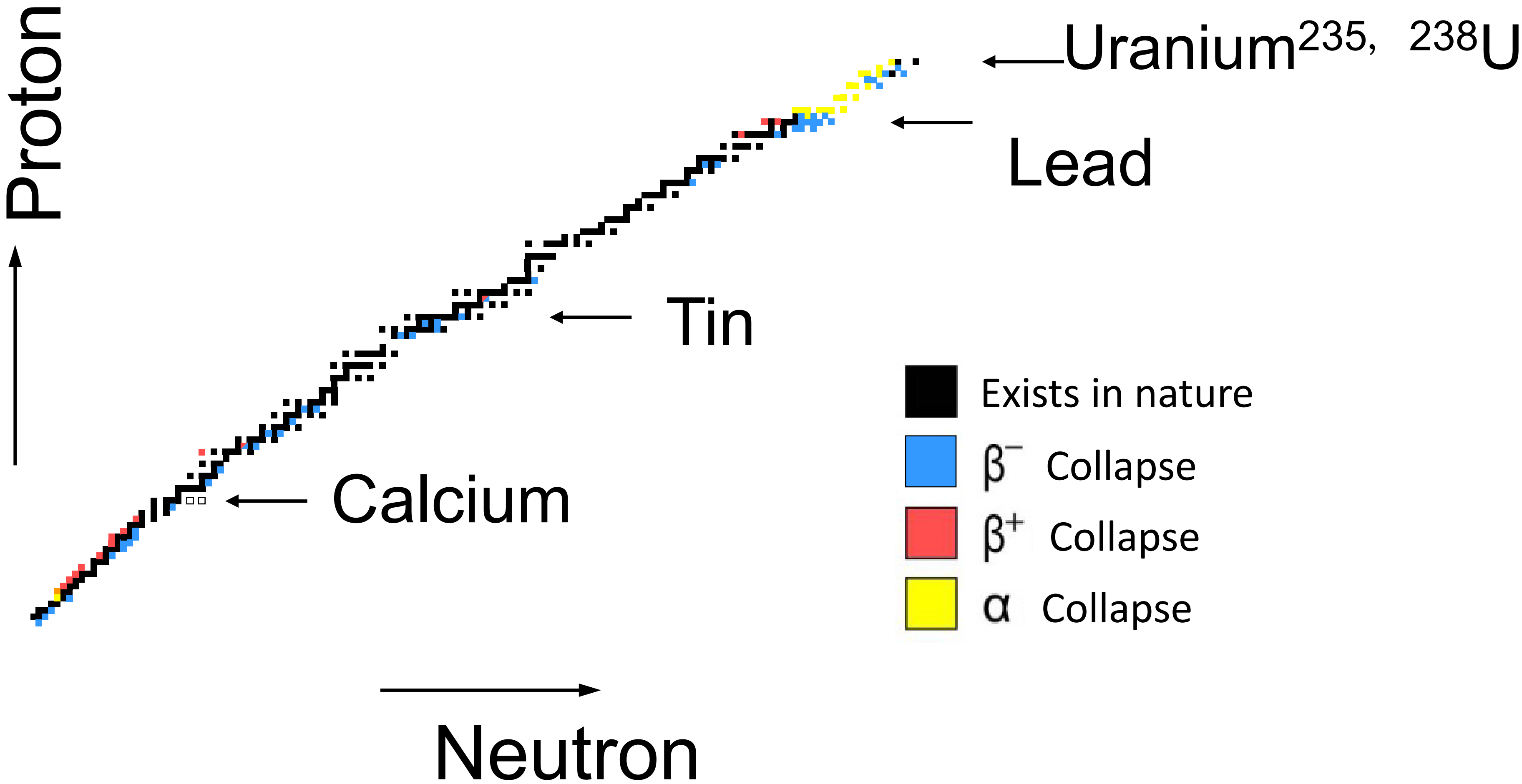
Periodic Table of the Elements

※For elements with unstable isotopes, the mass of the most half-life isotope is shown in parentheses.

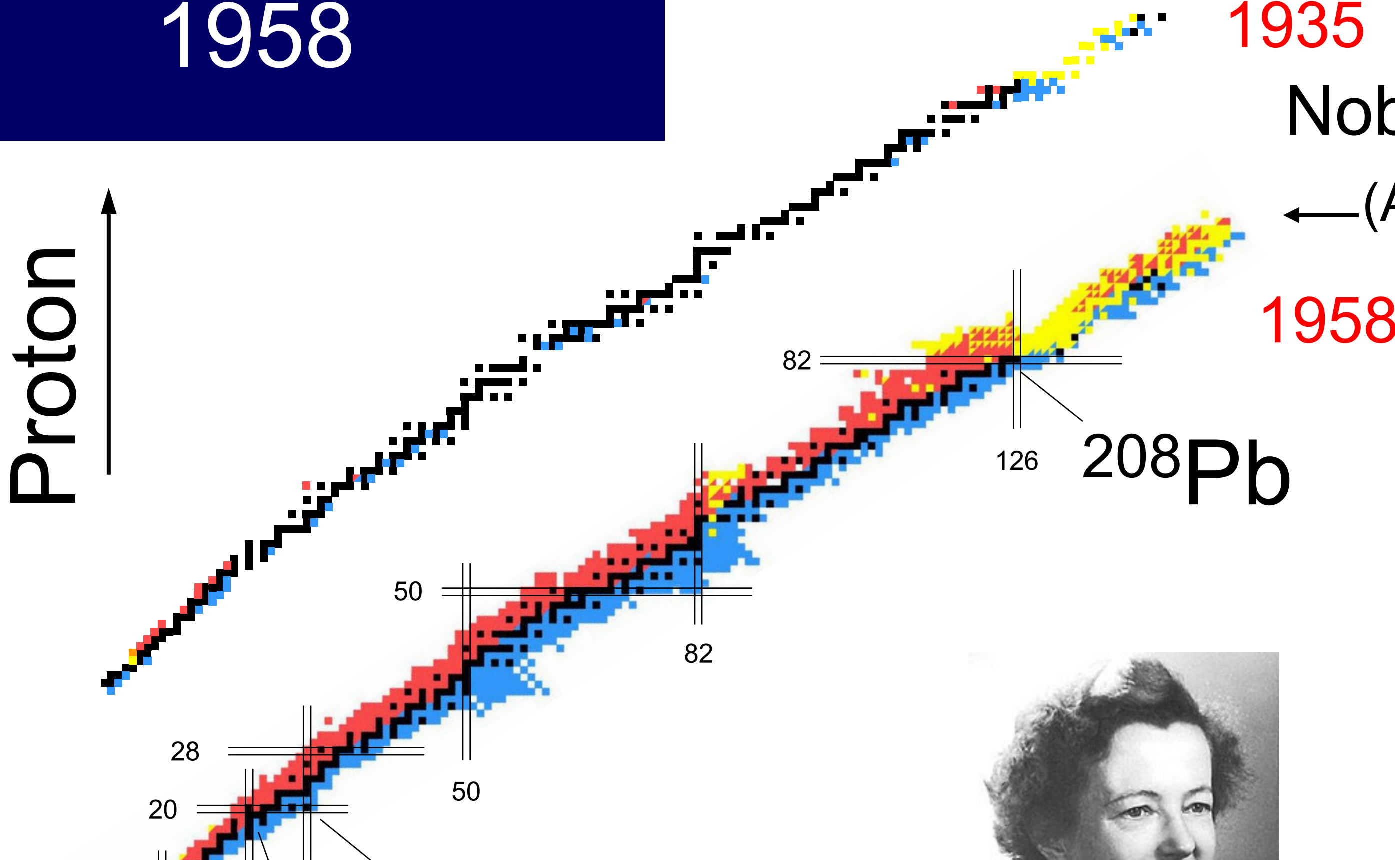


Actinides

1935 Nuclear Chart



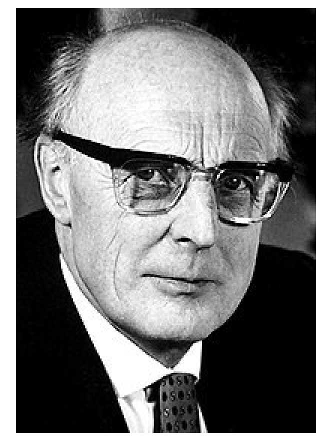
1958



Nobelium：No

←(Atomic number102)

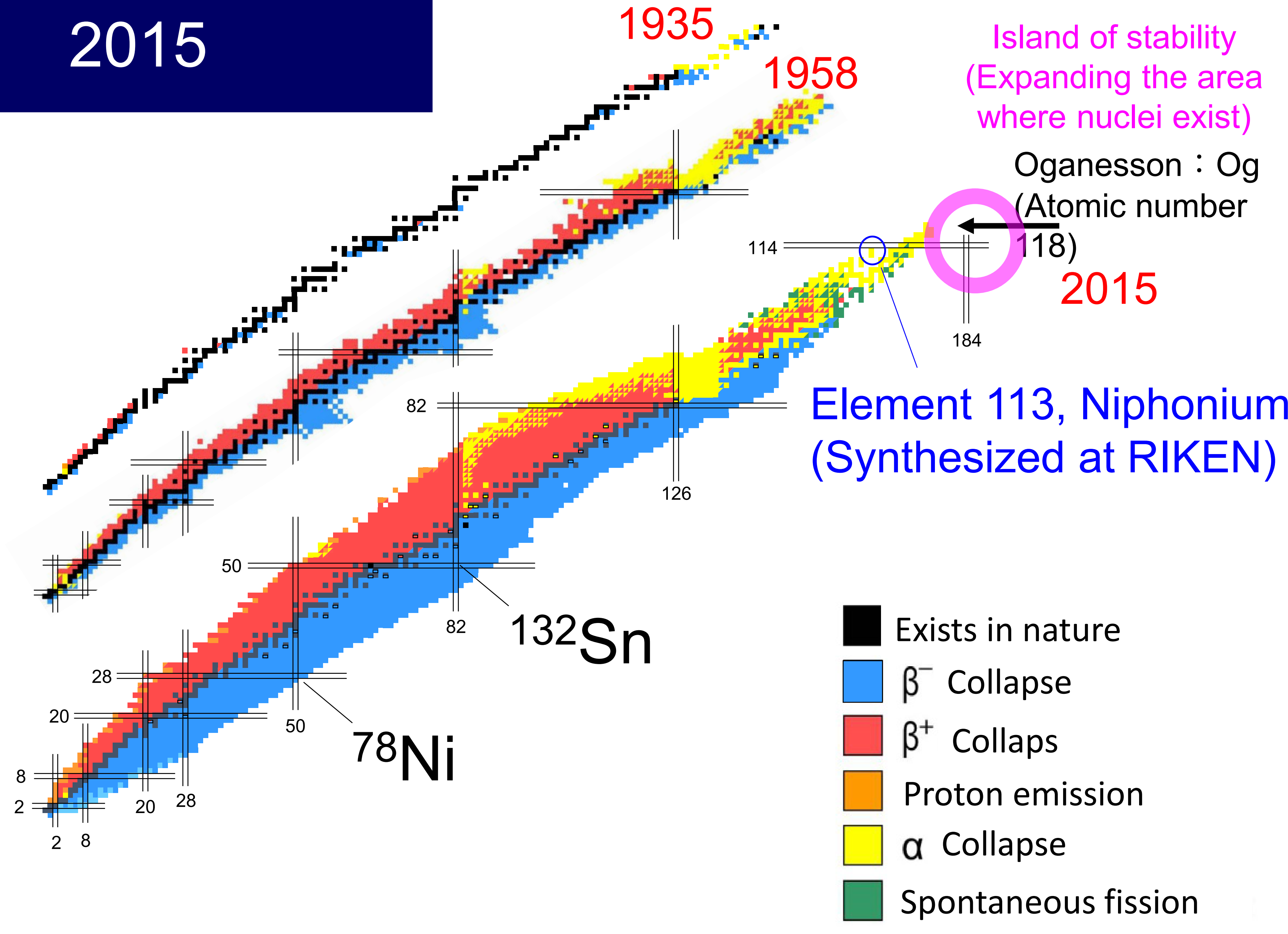
Maria G.-Mayer



Johannes H.D. Jensen

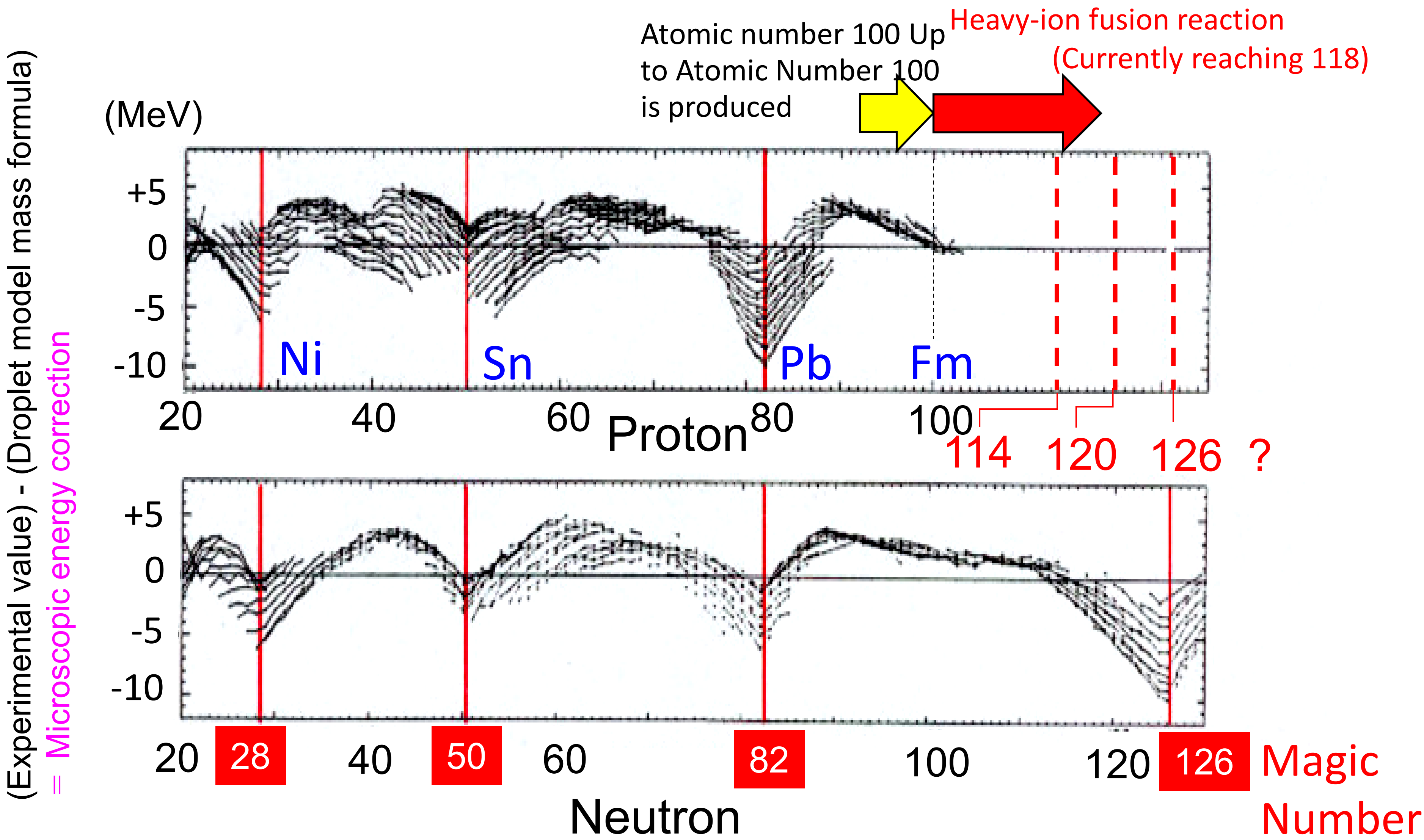
1963 Nobel prize

2015



1935
1958
Island of stability
(Expanding the area
where nuclei exist)
Oganesson：Og
(Atomic number
118)
2015
114
184
Element 113, Niphonium
(Synthesized at RIKEN)
82
126
50
82
132Sn
28
20
50
78Ni
8
2
20
28
2
8
Exists in nature
β⁻ Collapse
β⁺ Collaps
Proton emission
α Collapse
Spontaneous fission

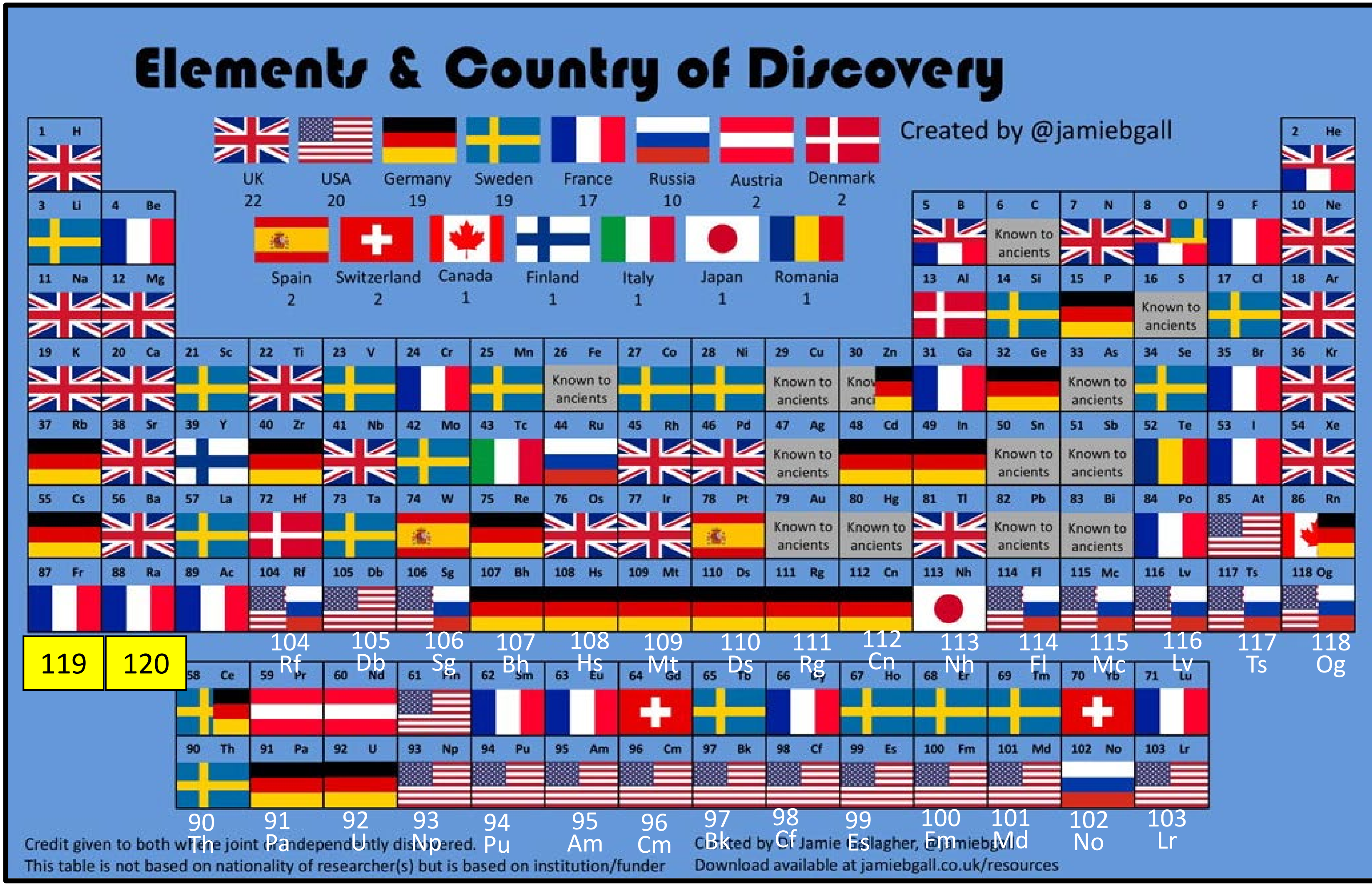
Shell structure in nuclear masses



W.D.Myers and W.J. Swiatecki (1966).

Periodic Table of the Elements

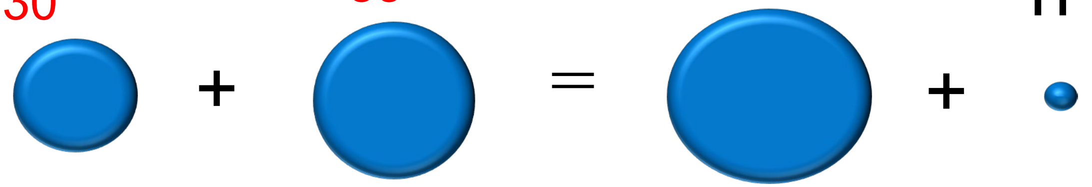
Period 7
Period 8



Synthesis of Element 113 in Japan

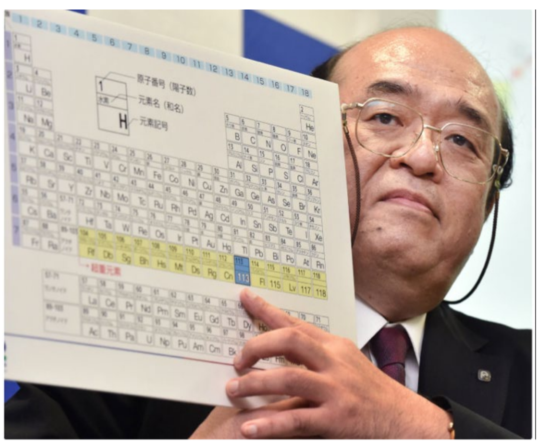
Eight years of experimentation and synthesis of three nihonium nuclei

$${}^{70}_{30}\mathrm{Zn} + {}^{209}_{83}\mathrm{Bi} = {}^{278}_{113}\mathrm{Nh} + \mathrm{n}$$



Transuranium element

Neutron



Kyushu University/RIKEN Mr. Morita

Pioneer of superheavy elements

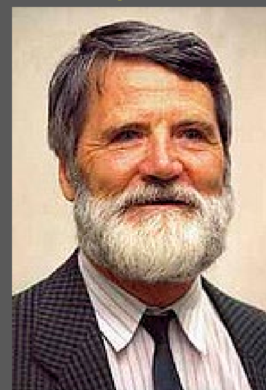
FLNR (Russia)

G.N. Flerov

Yu.Ts. Oganessian

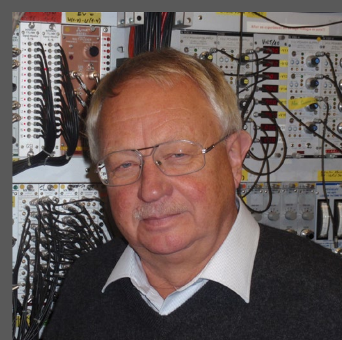
Fl (114)
Mc (115)
Lv (116)
Ts (117)
Og (118)
119,120
Synthesis
plan

GSI (Germany)



P. Armbruster

G. Münzenberg



S. Hofmann

Bh (107)
Hs (108)
Mt (109)
Ds (110)
Rg (111)
Cn (112)

RIKEN (Japan)

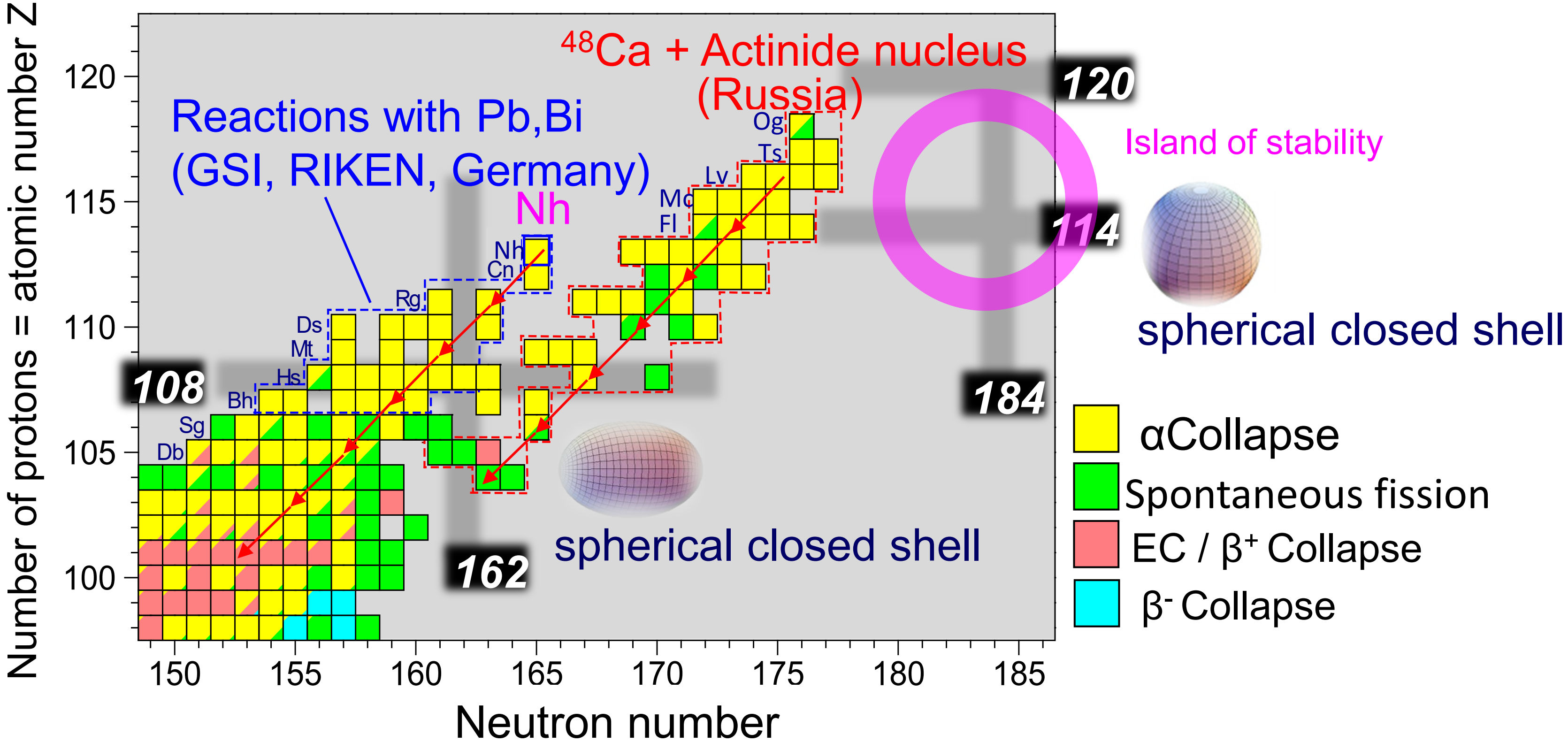
K. Morita

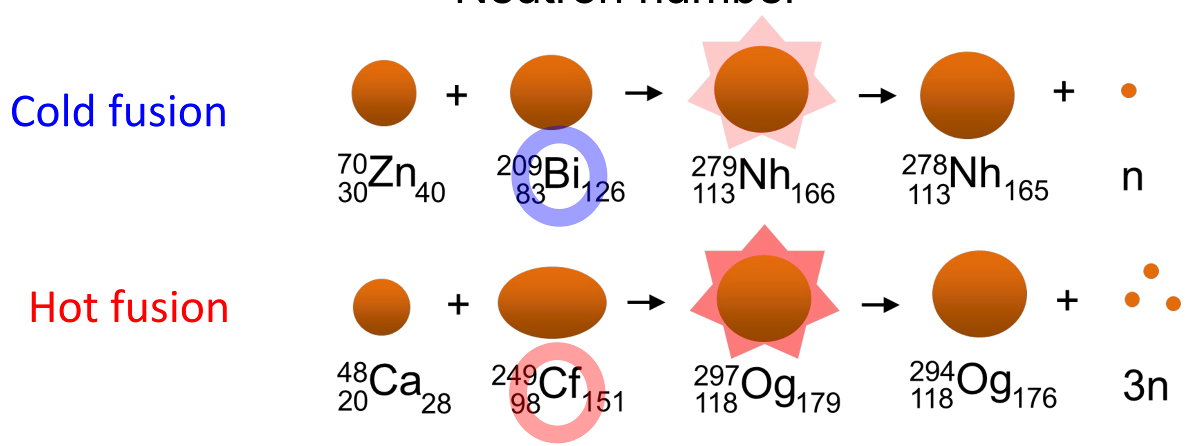
Nh (113)
119
synthesis
in progress

Use ^{48}Ca as a beam

Use ^{208}Pb, ^{209}Bi as a target

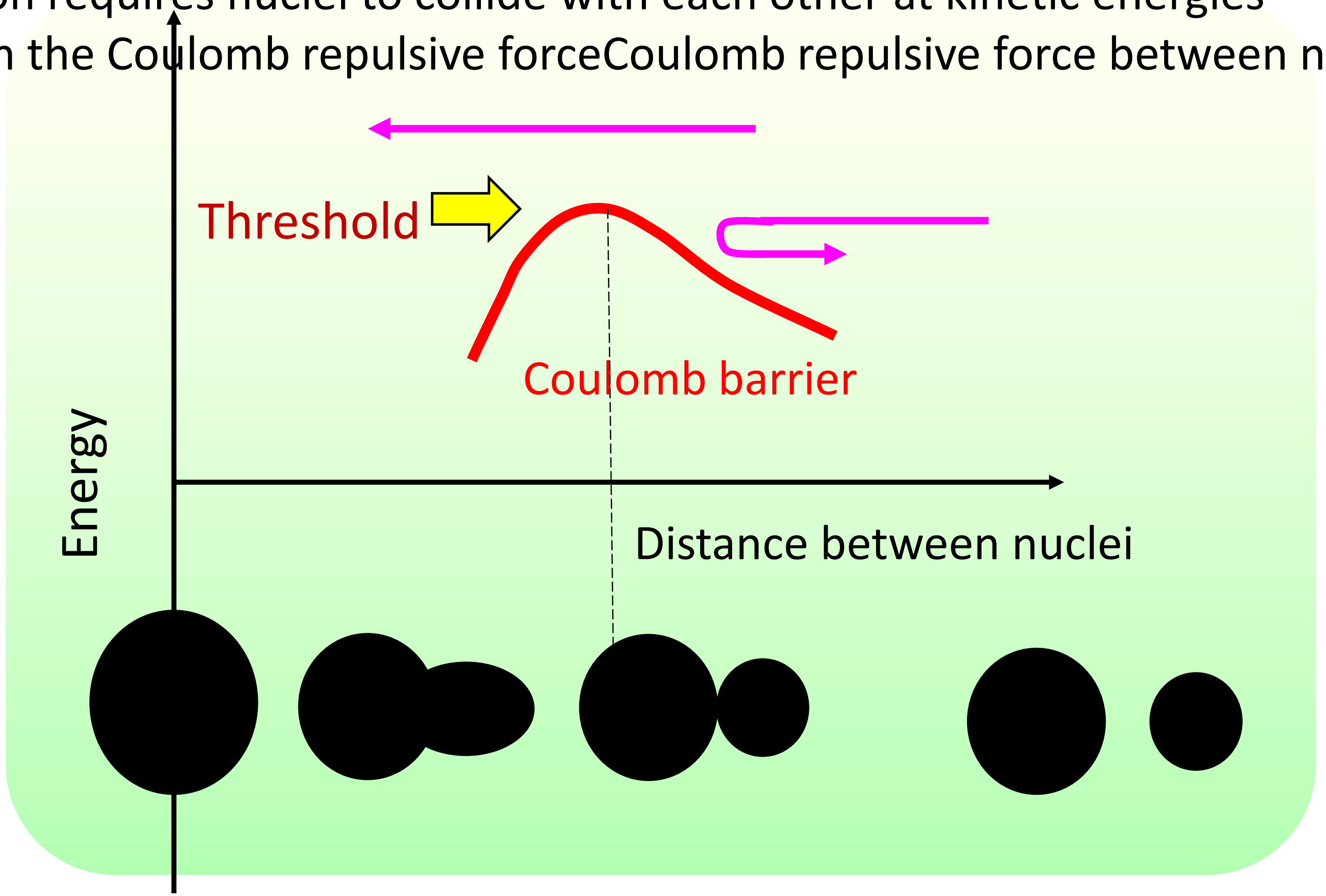
Nuclei in the superheavy element region that have been synthesized so far.



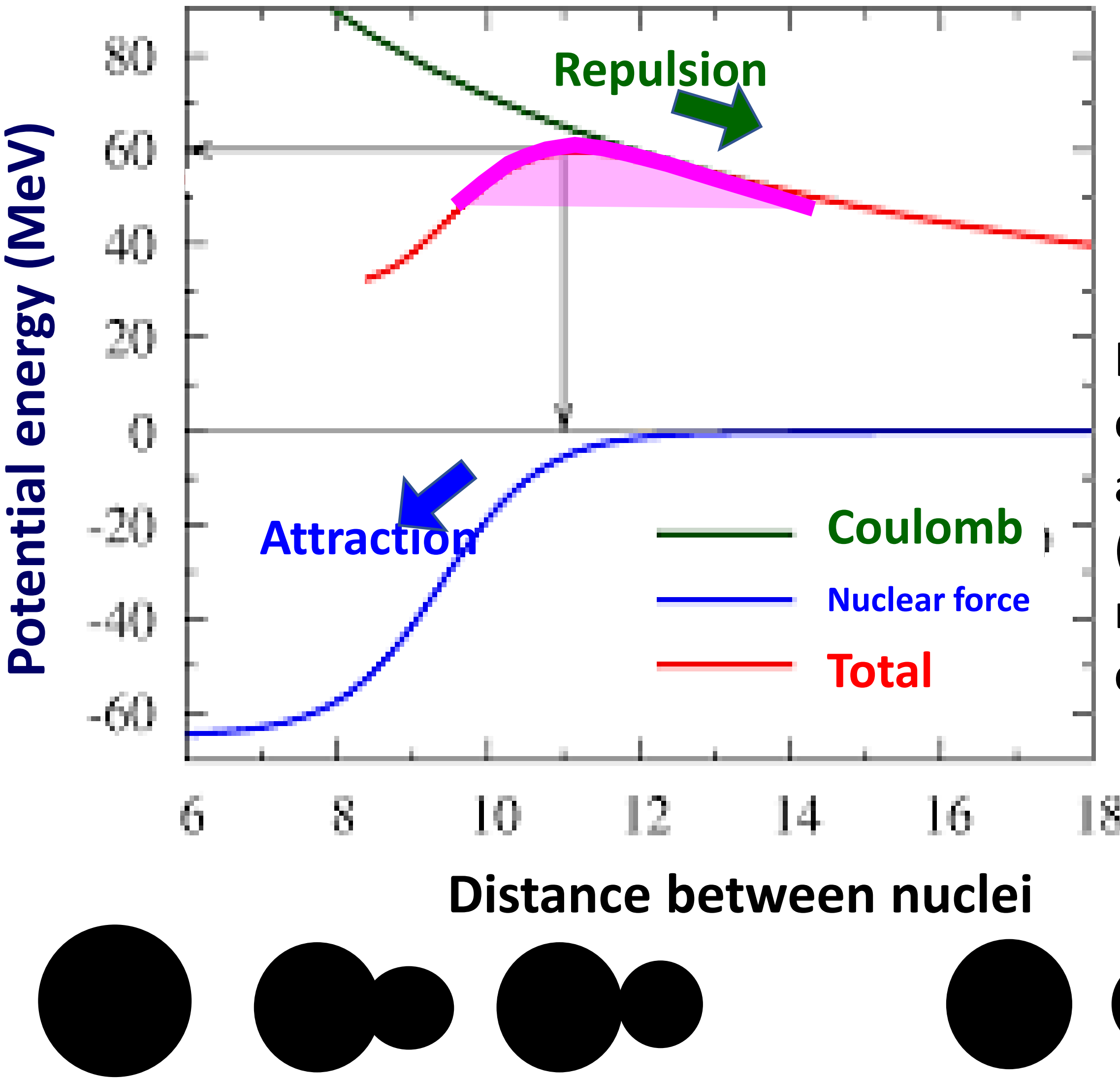


Heavy-ion fusion reaction

Nuclei heavier than the 100th element have been synthesized by fusion reactions using heavy ion beamsThe nuclei heavier than the 100th element have been synthesized by a nuclear fusion reaction using heavy ion beams. The reaction requires nuclei to collide with each other at kinetic energies higher than the Coulomb repulsive forceCoulomb repulsive force between nuclei.



Description of the Coulomb barrier
- Coulomb repulsive force and attraction due to nuclear forces -



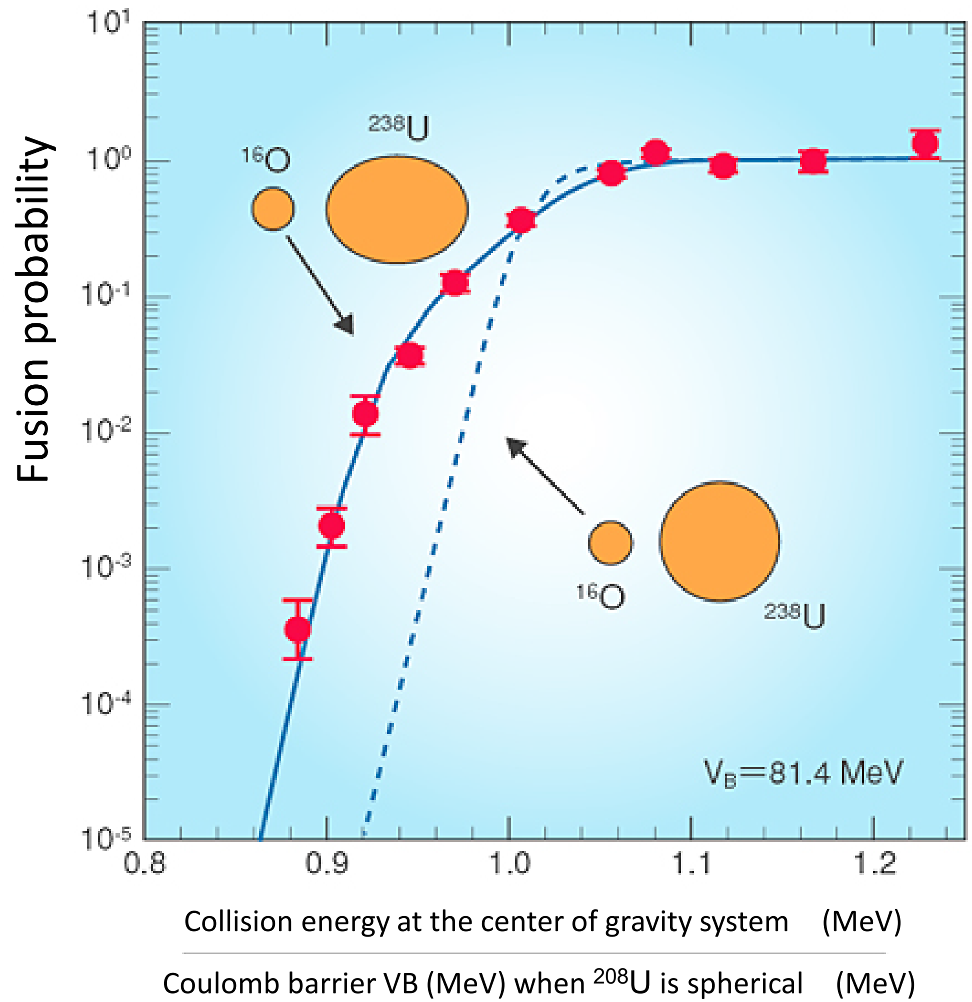
$^{16}O + ^{144}Sm$

If the Coulomb barrier is
If the Coulomb barrier is exceeded, fusion will automatically fusion will occur (But in the case of a light reaction system in the case of light reactive systems)

Fusion Probability
-Difference between spherical nuclei and deformed nuclei

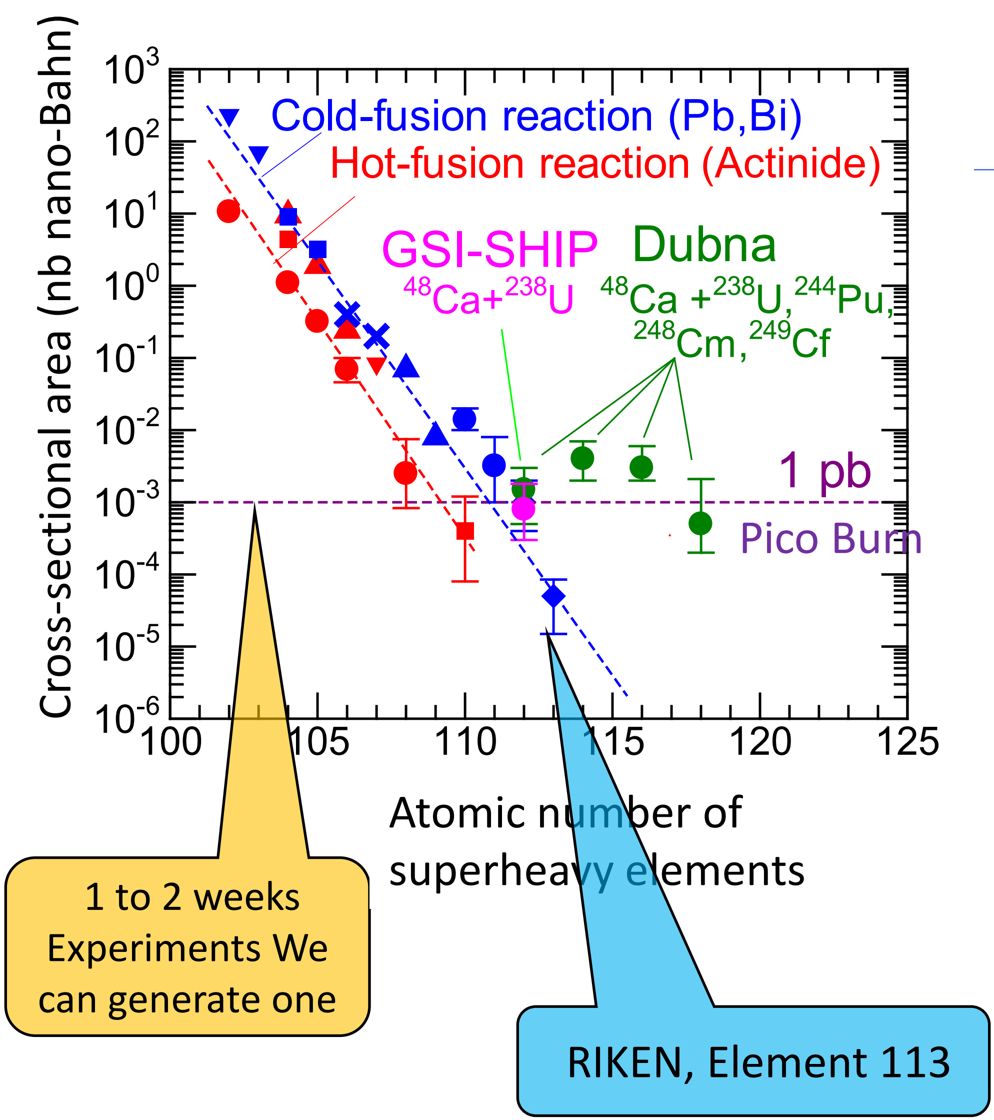
When nuclei are deformed, fusion reactions occur even at low energies.

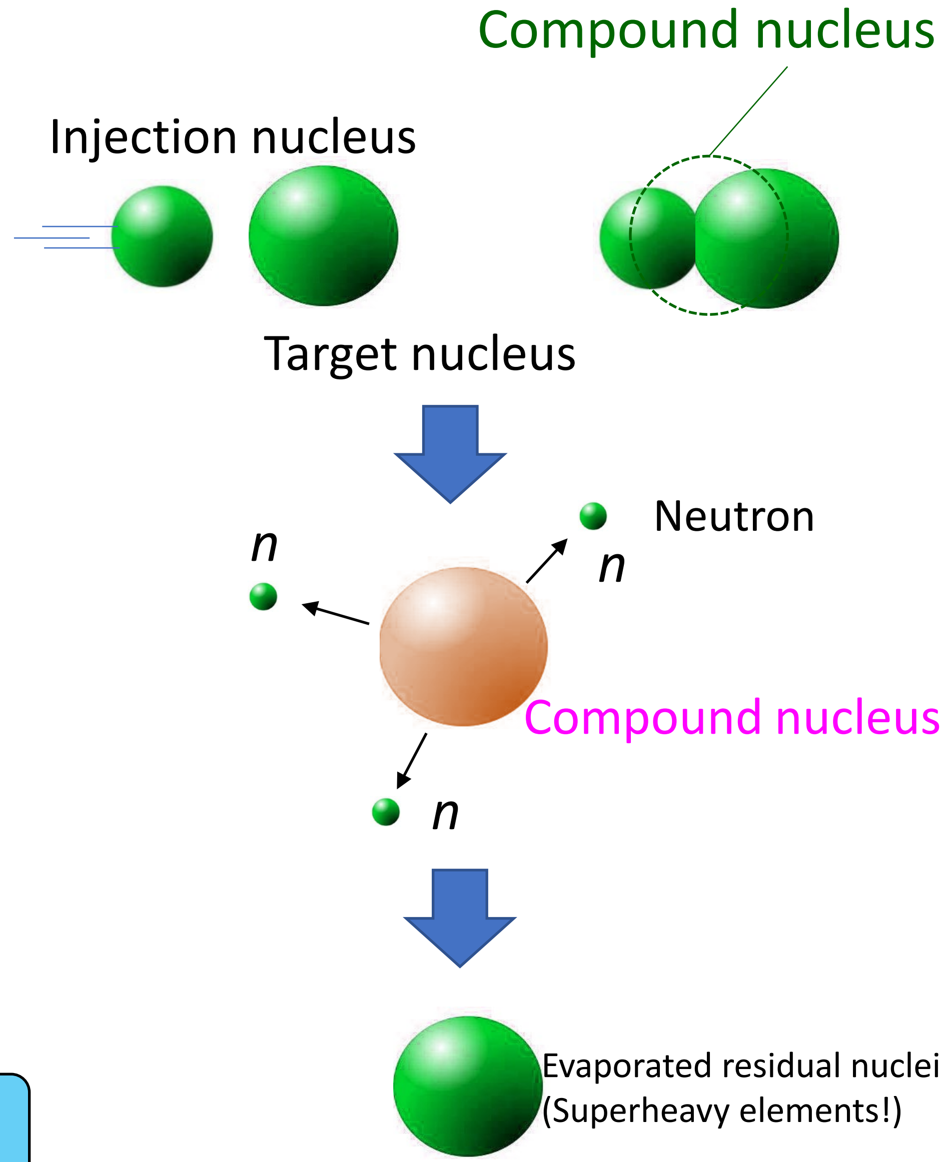
→ This is also evidence that the ^{238}U nucleus is deformed.



K. Nishio et al., Phys. Rev. Lett., 93, 162701 (2004).

Cross section to synthesize superheavy elements

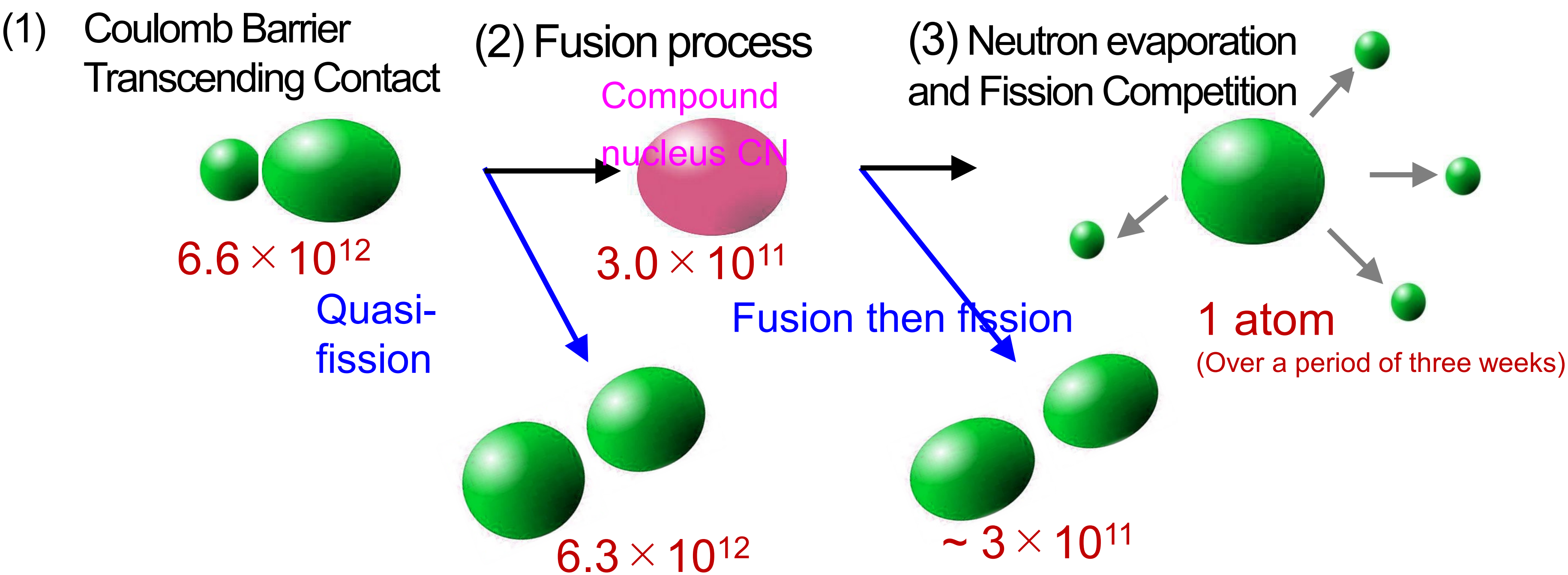




Why is it so difficult to make superheavy elements?
-Phenomena that occur in heavy reaction systems-

Three Steps of Superheavy Element Synthesis

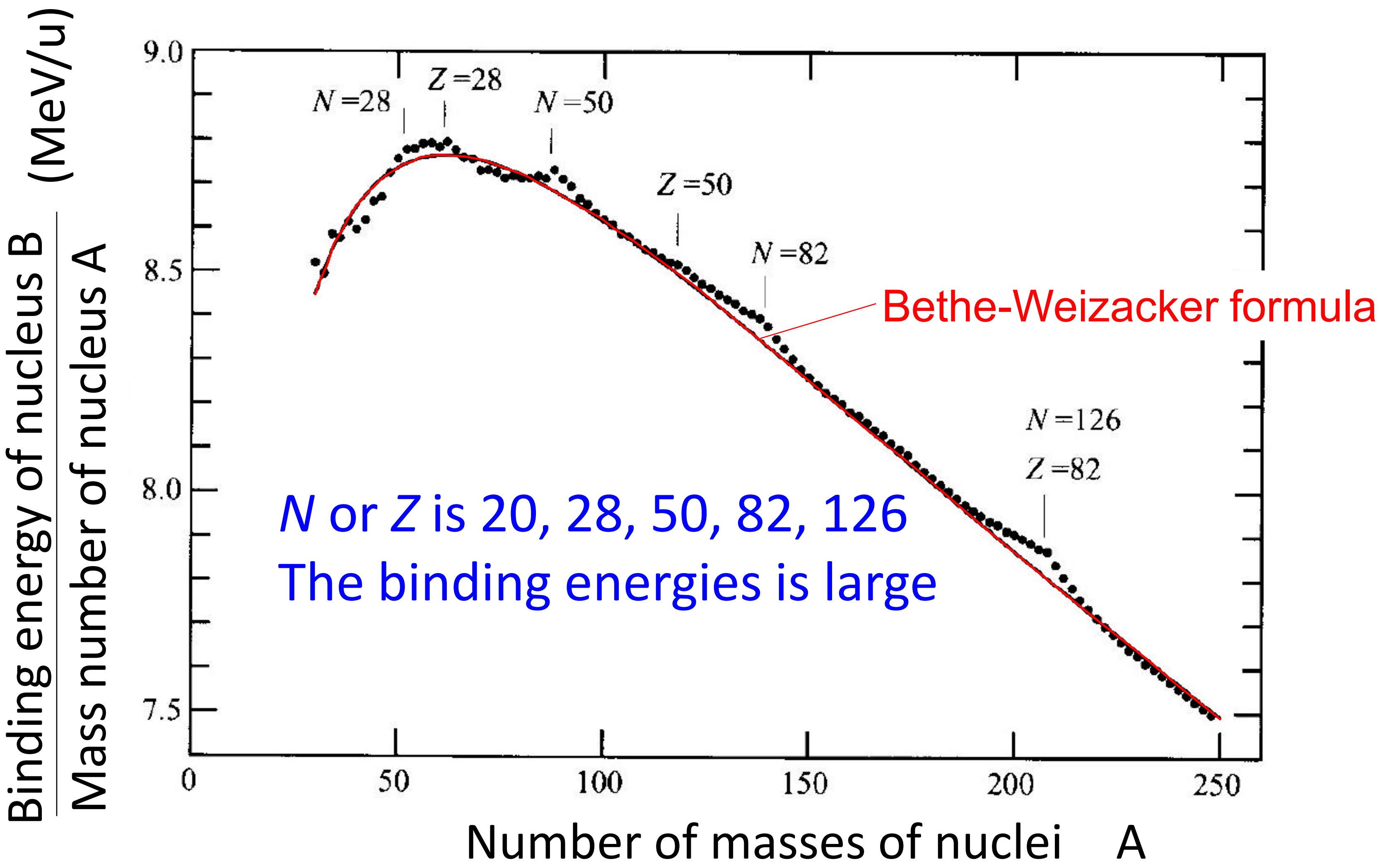
$$^{34}_{14}\mathrm{S} + ^{238}_{92}\mathrm{U} \longrightarrow ^{272}_{108}\mathrm{Hs}^* \longrightarrow ^{268}_{108}\mathrm{Hs} + 4\,^{1}_{0}\mathrm{n}$$



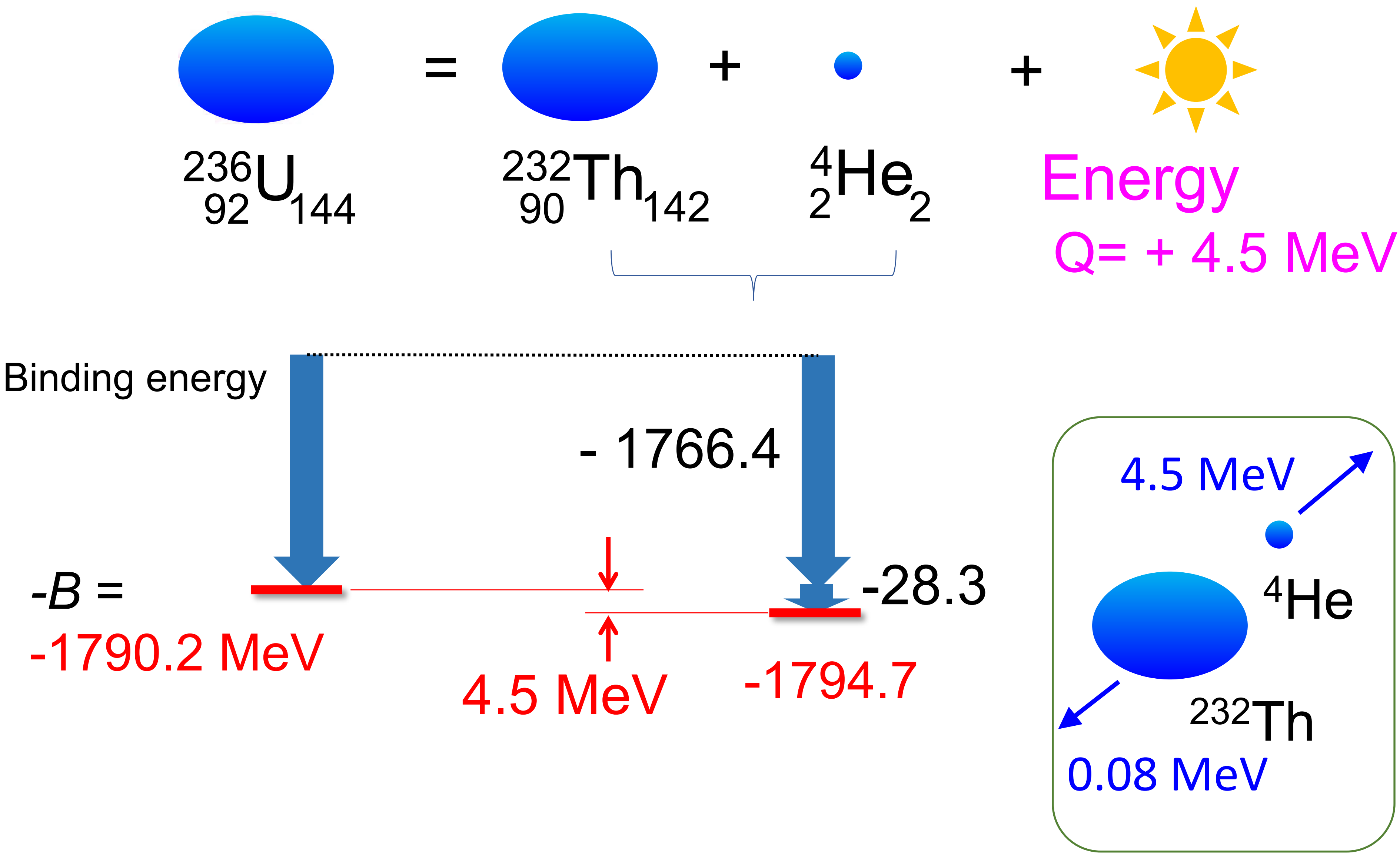
(1) Fusion is difficult in reactions between heavy nuclei.
(2) In superheavy elements, most of the compound nuclei are fissioned.

K. Nishio et al., Phys. Rev. C, 82, 024611 (2010).

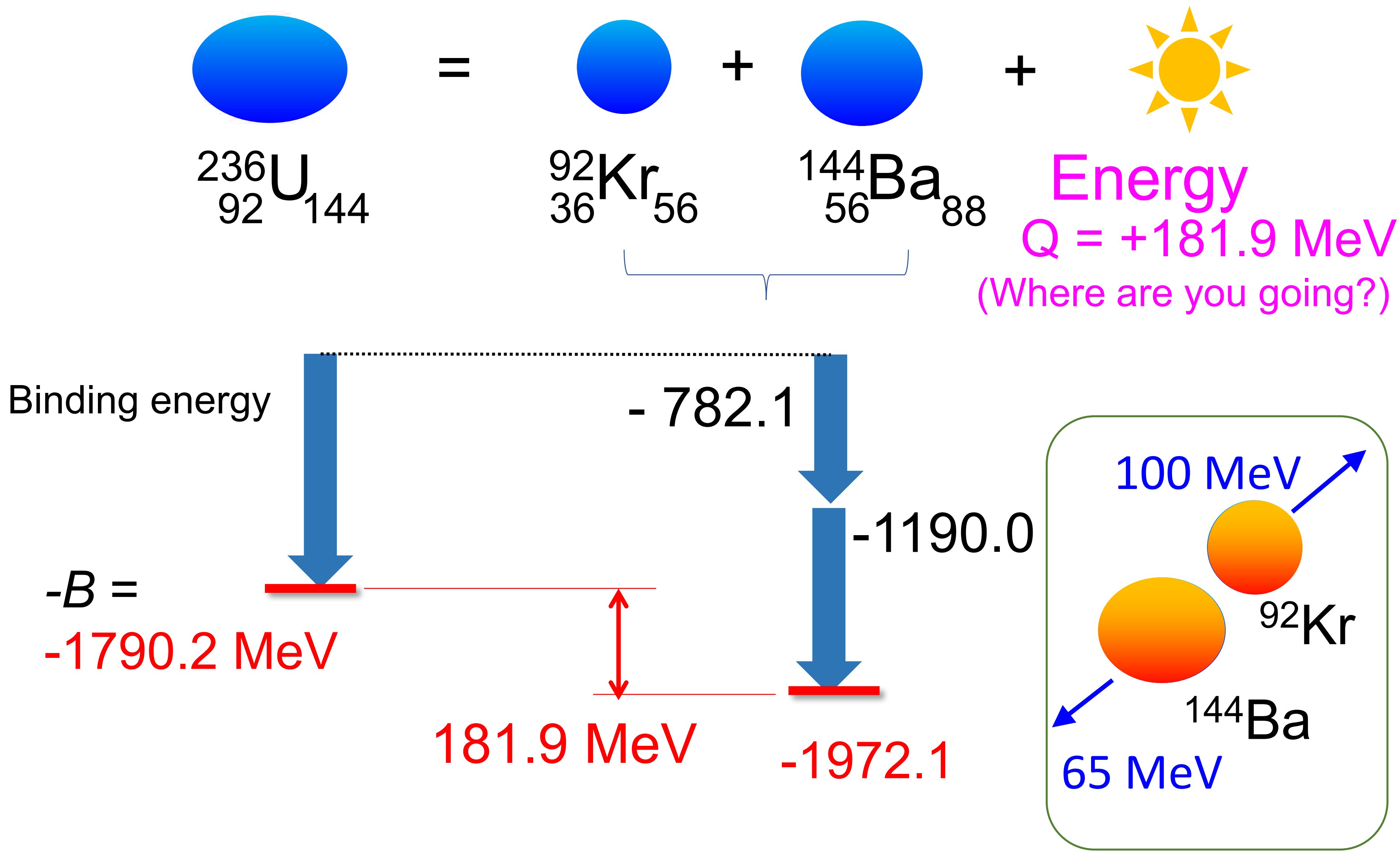
Binding energy per nucleon
-Mass model and actual nuclei-



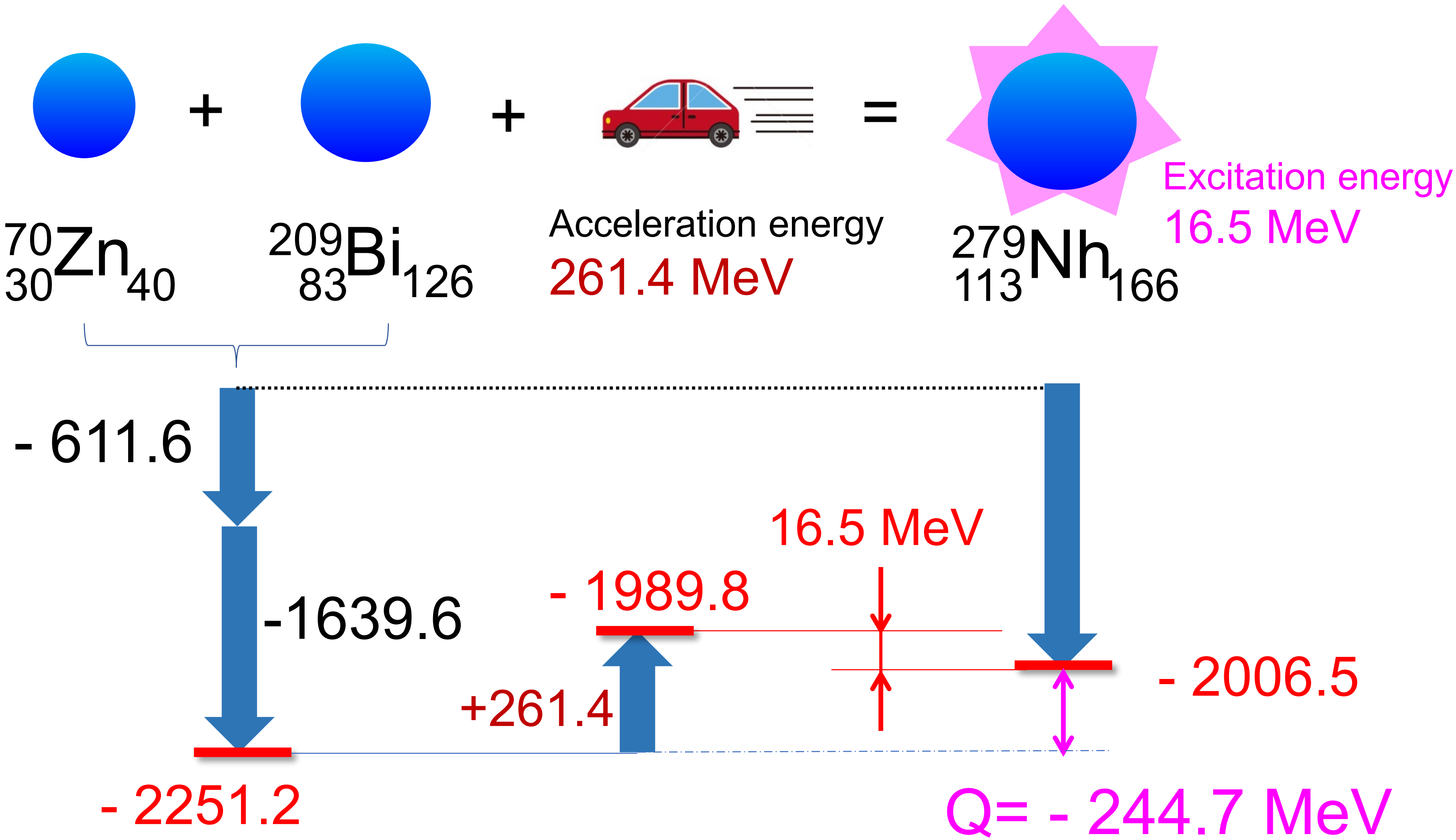
Q-value of α collapse



Q-value of fission

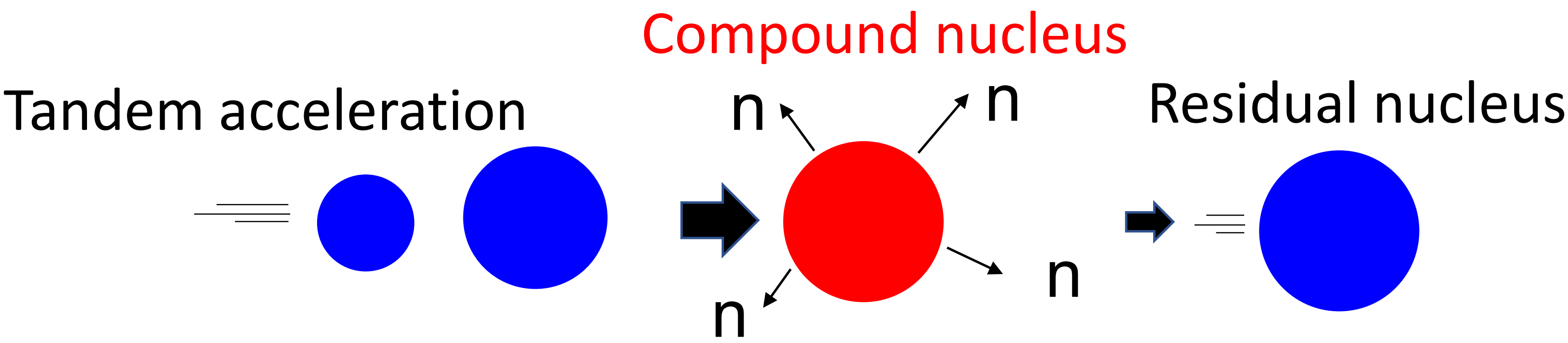


Nuclear fusion

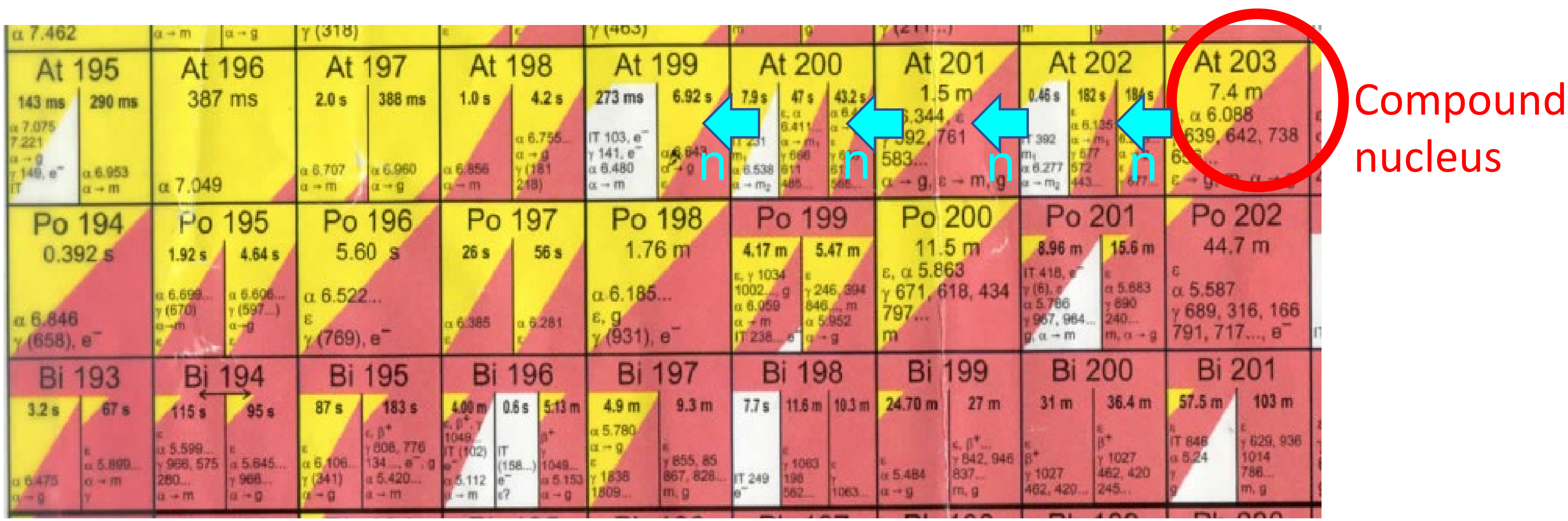


Practical experiment

Reactions learned in practice



$$^{34}_{16}S + ^{169}_{69}Tm = ^{203}_{85}At \qquad ^{199}At$$



Key Points of the Experiment

【 Experiments on fusion reactions 】

（1） **The same experimental apparatus and detectors are used to synthesize superheavy elements. The experimental approach is also the same. The experimental concept is also the same.**

→ What equipment is needed?

（2） **The experiment is conducted in an apparatus that is kept in an "ultra-high vacuum.**

→ The injection beam, the device that initiates the fusion reaction, and the device that separates the nuclei produced, where the produced nuclei are detected, and everything else.

（3） **Data acquisition uses state-of-the-art digital electronics.**

→ How does this differ from the conventional analog method?

（4） **The method of data analysis is the same as in the superheavy element synthesis experiment.**

→ How do we identify the nuclides of the nuclei produced?

（5） **It takes a long time to make superheavy elements, so we make lighter isotopes of the elements.**

→ Creates the astatine isotope (At) with atomic number 85 (not found naturally).