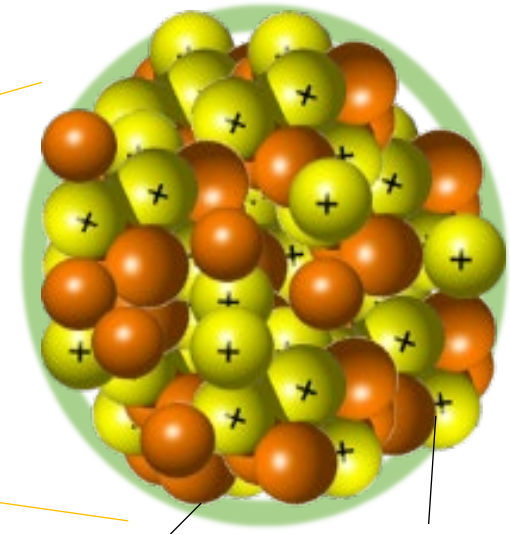
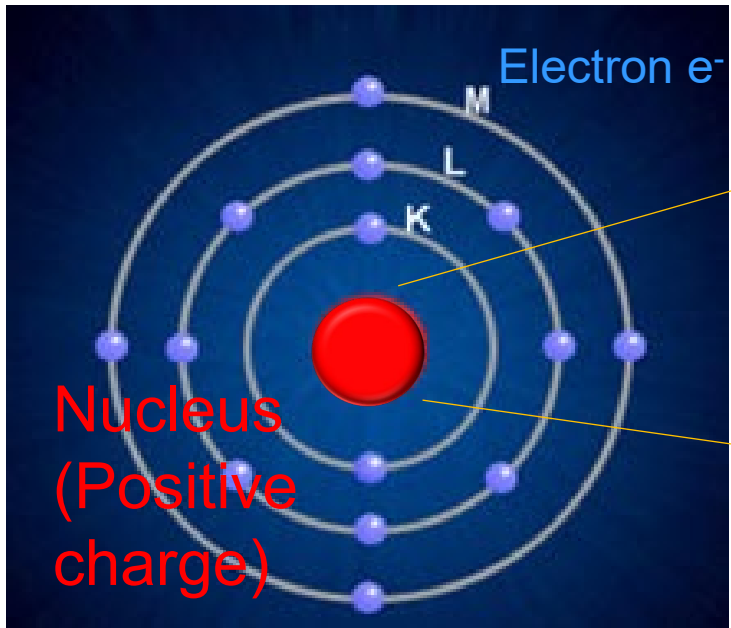


Superheavy Elements and Heavy Ion Fusion Reactions

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

Nucleus



Neutron **n**
(Electrically neutral)

Proton **p**
(Positive charge)

Uranium235



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?

$$\text{Mass number } A = \text{Number of protons } Z + \text{Number of neutron } N$$

Periodic Table of the Elements

① : 原子番号
 H : 記号
 水素 : 名前
 1.008 : 原子量

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

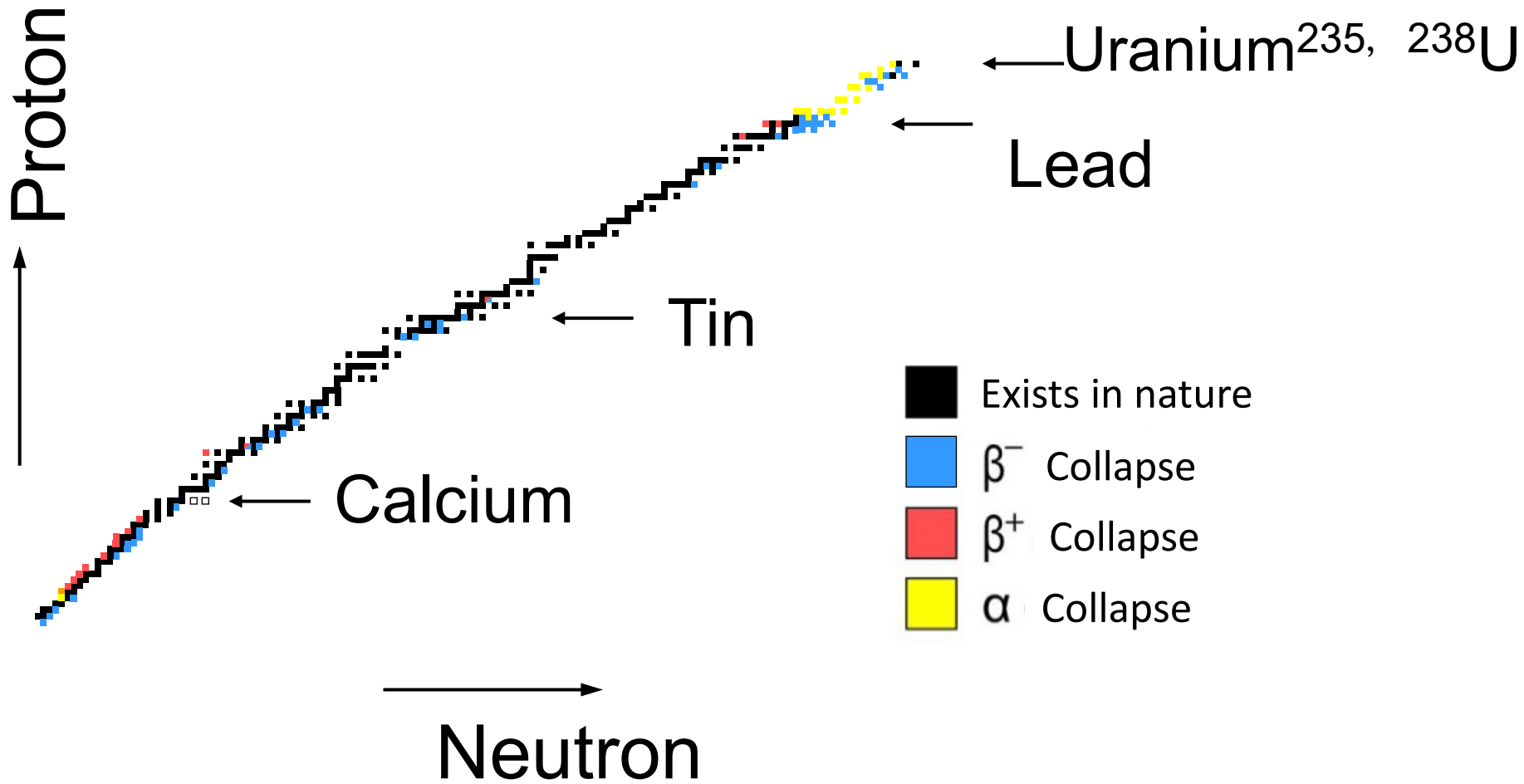
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18		
1	1 H 水素 1.008	■ 卑金属元素														希ガス	2 He ヘリウム 4.0026			
2	3 Li リチウム 6.94	4 Be ベリリウム 9.0122	■ アルカリ土類金属								■ 半金属		5 B ホウ酸 10.81	6 C 炭素 12.011	7 N 窒素 14.007	8 O 酸素 15.999	9 F フッ素 18.998	10 Ne ネオン 20.180		
3	11 Na ナトリウム 22.990	12 Mg マグネシウム 24.305	■ 遷移元素										■ 卑金属		13 Al アルミニウム 26.982	14 Si ケイ素 28.085	15 P リン 30.974	16 S 硫黄 32.06	17 Cl 塩素 35.45	18 Ar アルゴン 39.948
4	19 K カリウム 39.098	20 Ca カルシウム 40.078	21 Sc スカンジウム 44.956	22 Ti チタン 47.867	23 V バナジウム 50.942	24 Cr クロム 51.996	25 Mn マンガン 54.938	26 Fe 鉄 55.845	27 Co コバルト 58.933	28 Ni ニッケル 58.693	29 Cu 銅 63.546	30 Zn 亜鉛 65.38	31 Ga ガリウム 69.723	32 Ge ゲルマニウム 72.630	33 As ヒ素 74.922	34 Se セレン 78.971	35 Br 臭素 79.904	36 Kr クリプトン 83.798		
5	37 Rb ルビジウム 85.468	38 Sr ストロンチウム 87.62	39 Y イットリウム 88.906	40 Zr ジルコニウム 91.224	41 Nb ニオブ 92.906	42 Mo モリブデン 95.95	43 Tc テクネチウム (98)	44 Ru ルテチウム 101.07	45 Rh ロジウム 102.91	46 Pd パラジウム 106.42	47 Ag 銀 107.87	48 Cd カドミウム 112.41	49 In インジウム 114.82	50 Sn スズ 118.71	51 Sb アンチモン 121.76	52 Te テルル 127.60	53 I ヨウ素 126.90	54 Xe キセノン 131.29		
6	55 Cs セシウム 132.91	56 Ba バリウム 137.33	※	72 Hf ハフニウム 178.49	73 Ta タンタル 180.95	74 W タングステン 183.84	75 Re レニウム 186.21	76 Os オスミウム 190.23	77 Ir イリジウム 192.22	78 Pt 白金 195.08	79 Au 金 196.97	80 Hg 水銀 200.59	81 Tl タリウム 204.38	82 Pb 鉛 207.2	83 Bi ビスマス 208.98	84 Po ポロニウム (209)	85 At アスタチン (210)	86 Rn ラドン (222)		
7	87 Fr フランシウム (223)	88 Ra ラジウム (226)	※	104 Rf シホーニウム (261)	105 Db ドブニウム (268)	106 Sg シーホーニウム (269)	107 Bh ボーリウム (270)	108 Hs ハッシウム (277)	109 Mt マイトネリウム (276)	110 Ds ダムスタヂウム (281)	111 Rg レントゲニウム (282)	112 Cn コホニウム (285)	113 Nh ニホニウム (284)	114 Fl フレロビウム (289)	115 Mc モスコビウム (290)	116 Lv リボリウム (293)	117 Ts テネシウム (294)	118 Og オガネッソン (294)		

8	119	120	■ ランタノイド														
			57 La ランタン	58 Ce セリウム	59 Pr プラセオジム	60 Nd ネオジム	61 Pm プロメチウム	62 Sm サマリウム	63 Eu ユウロピウム	64 Gd ガドリニウム	65 Tb テルビウム	66 Dy ジスプロシウム	67 Ho ホルミウム	68 Er エルビウム	69 Tm ツリウム	70 Yb イットルビウム	71 Lu ルテチウム
			■ アクチノイド														
			89 Ac アクチニウム (227)	90 Th トリウム 232.04	91 Pa プロトアクチニウム 231.04	92 U ウラン 238.03	93 Np ネプツニウム (237)	94 Pu プルトニウム (244)	95 Am アメリシウム (243)	96 Cm キュリウム (247)	97 Bk バークリウム (247)	98 Cf カリホルニウム (251)	99 Es アインシュタイン (252)	100 Fm フェルミウム (257)	101 Md メンデルビウム (258)	102 No ノーベリウム (259)	103 Lr ローレンシウム (260)

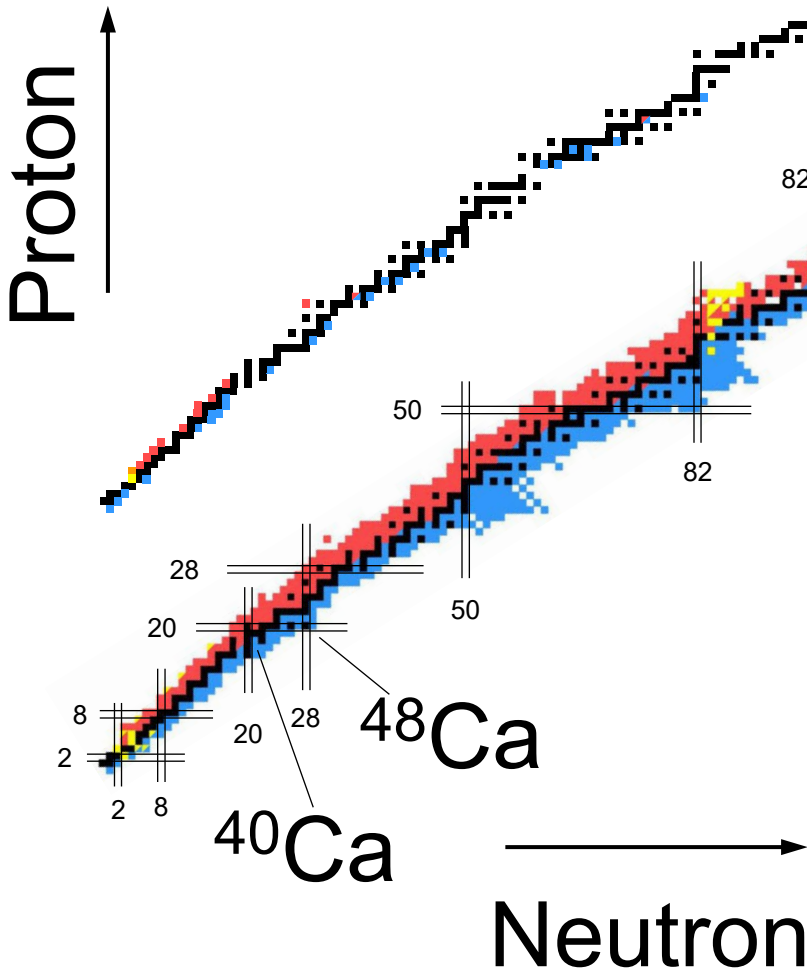
Transuranium element

Actinides

1935 Nuclear Chart



1958



1935

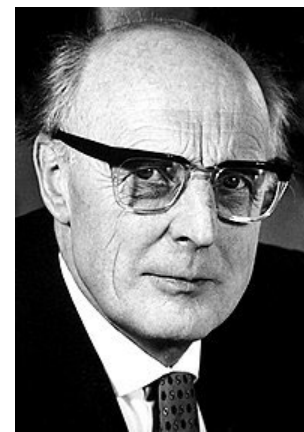
Nobelium : No

← (Atomic number 102)

1958



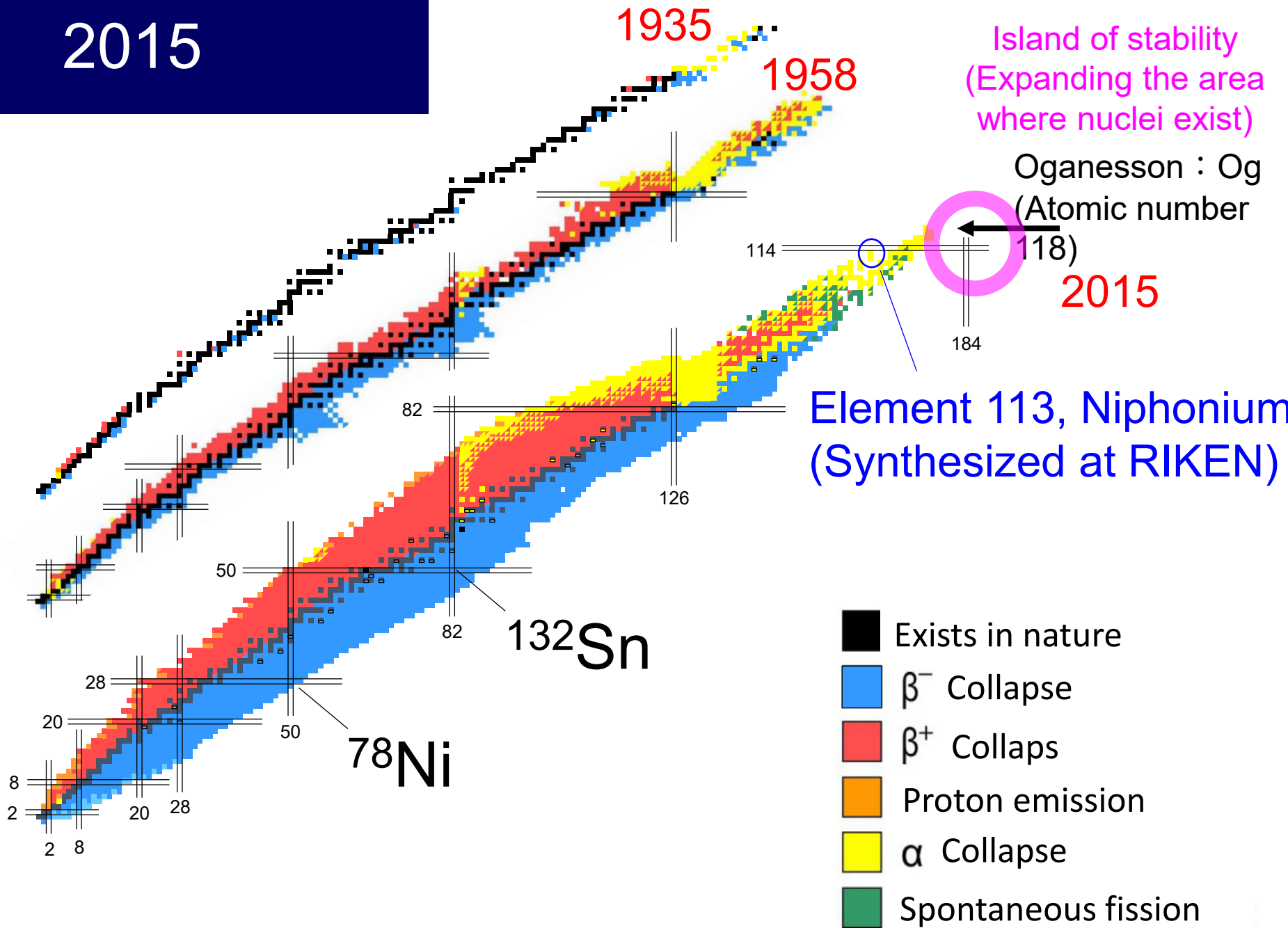
Maria G.-Mayer



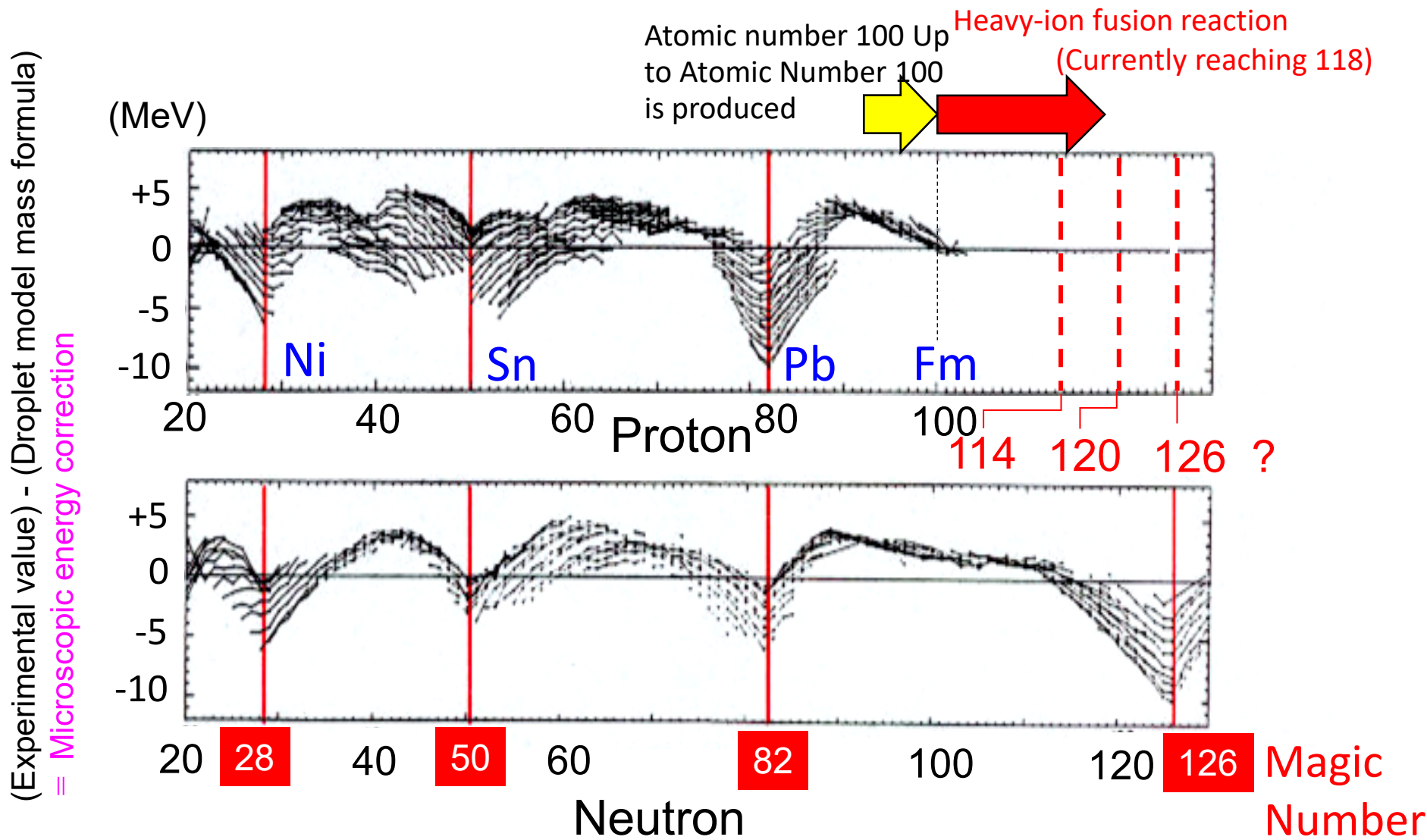
Johannes H.D. Jensen

1963 Nobel prize

2015



Shell structure in nuclear masses




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

Periodic Table of the Elements

Elements & Country of Discovery

Created by @jamiiegall

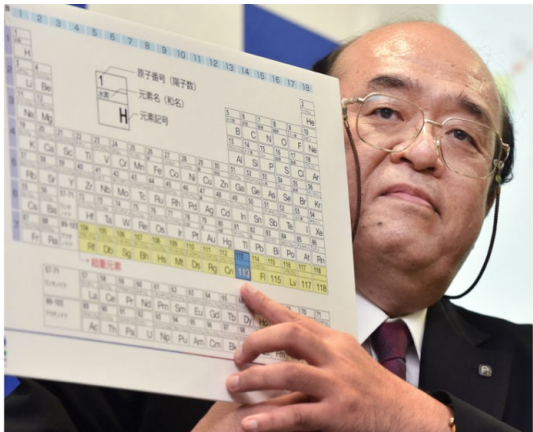
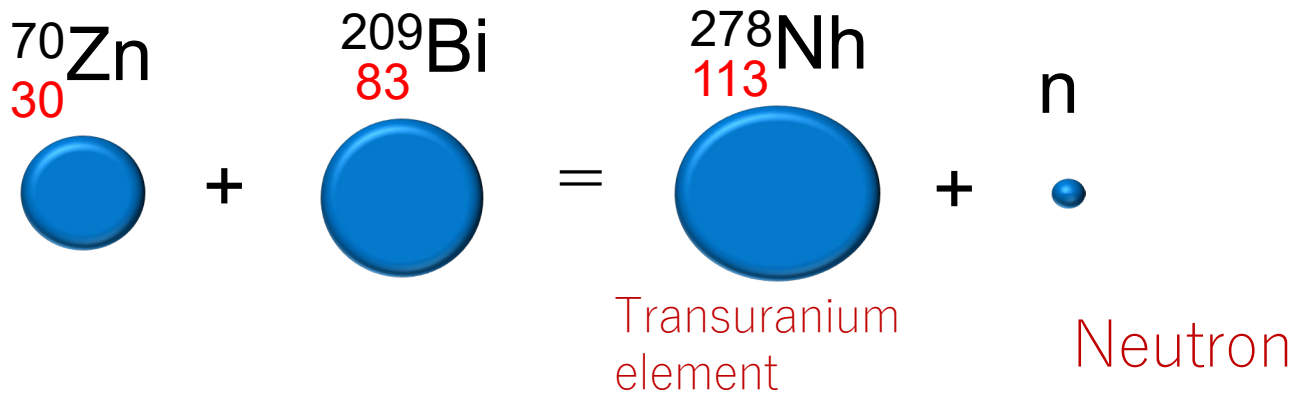
1 H	 UK 22 USA 20 Germany 19 Sweden 19 France 17 Russia 10 Austria 2 Denmark 2							2 He									
3 Li	4 Be	 Spain 2 Switzerland 2 Canada 1 Finland 1 Italy 1 Japan 1 Romania 1						5 B	6 C	7 N	8 O	9 F	10 Ne				
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og
119	120	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og	
90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr				
90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr				

Period 7
Period 8

Credit given to both where the joint discovery is independent. This table is not based on nationality of researcher(s) but is based on institution/funder. Download available at jamiiegall.co.uk/resources

Synthesis of Element 113 in Japan

Eight years of experimentation and synthesis of three nihonium nuclei



Kyushu University/RIKEN Mr. Morita

Pioneer of superheavy elements

FLNR (Russia)



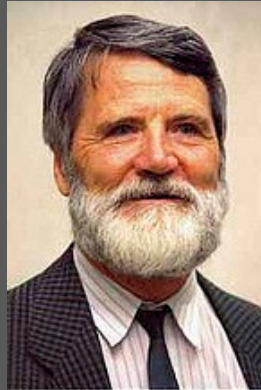
G.N. Flerov



Yu.Ts. Oganessian

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

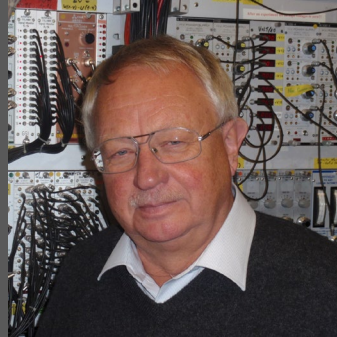
GSI (Germany)



P. Armbruster



G. Münzenberg



S. Hofmann

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

RIKEN (Japan)



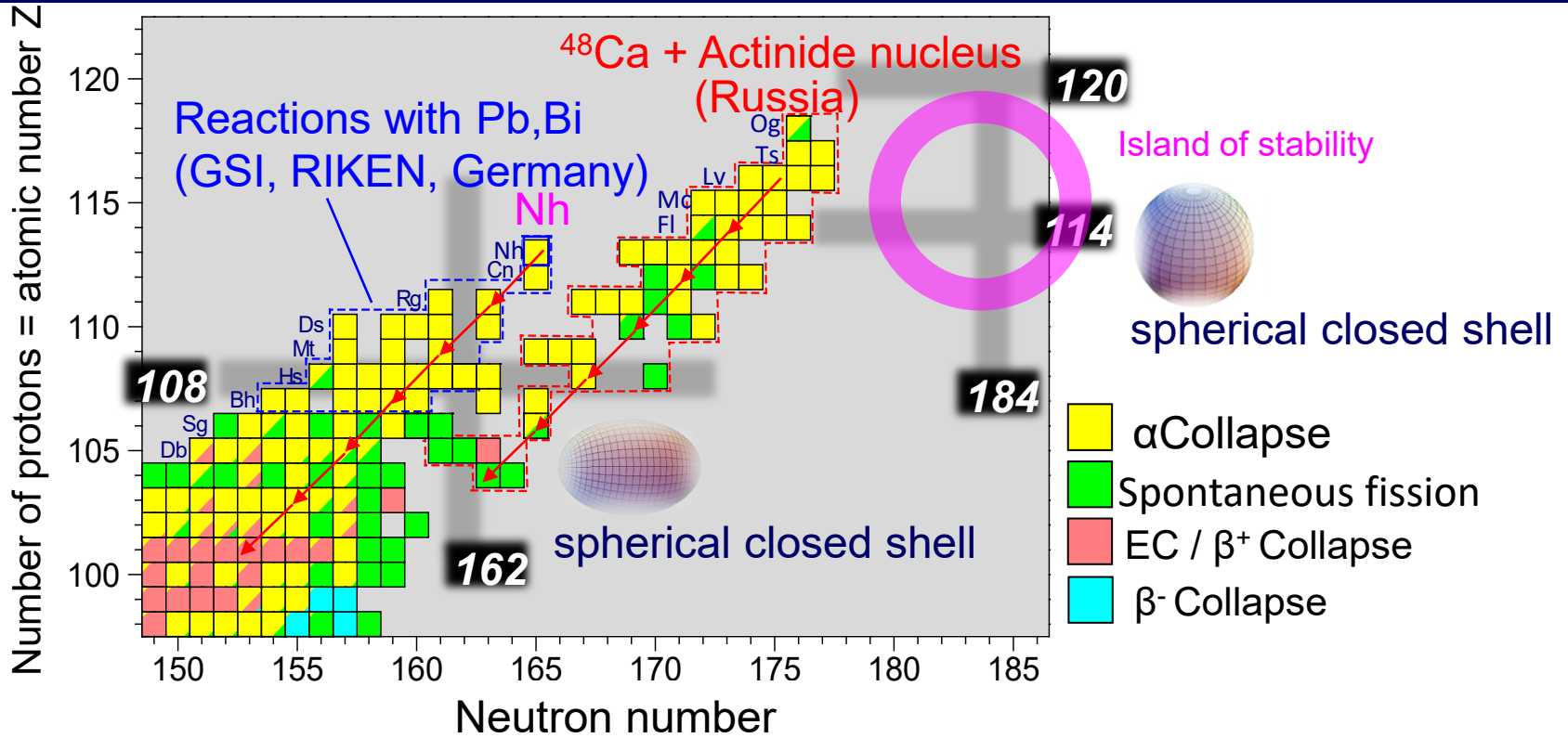
K. Morita

Nh (113)
119
synthesis
in progress

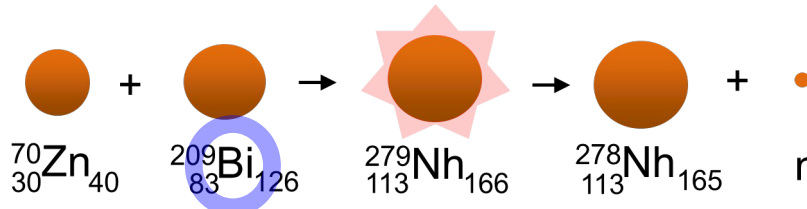
Use ^{48}Ca as a beam

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

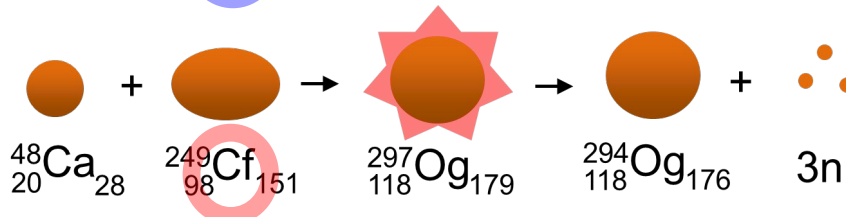
Nuclei in the superheavy element region that have been synthesized so far.



Cold fusion

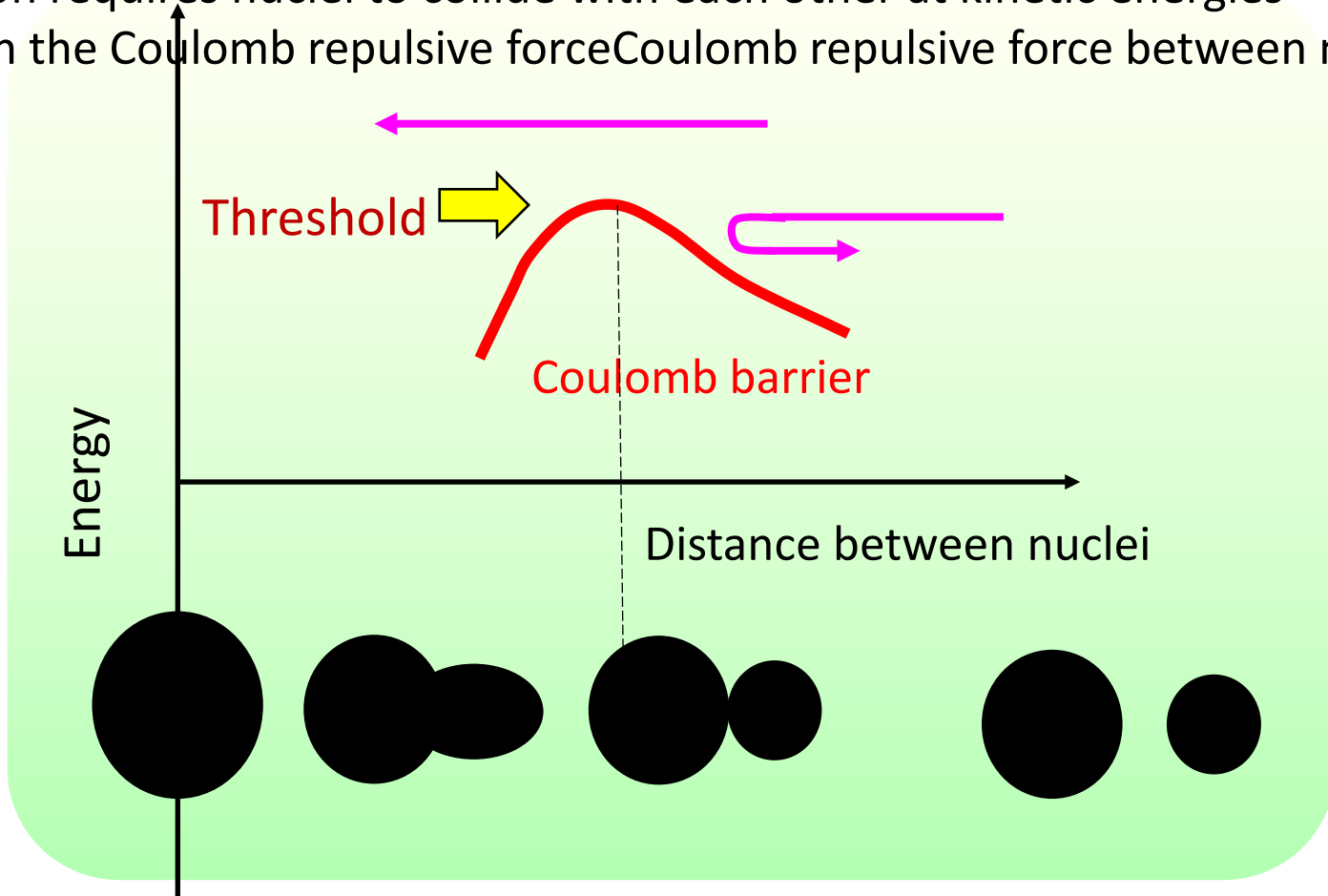


Hot fusion



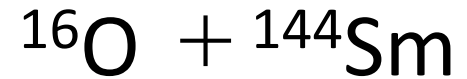
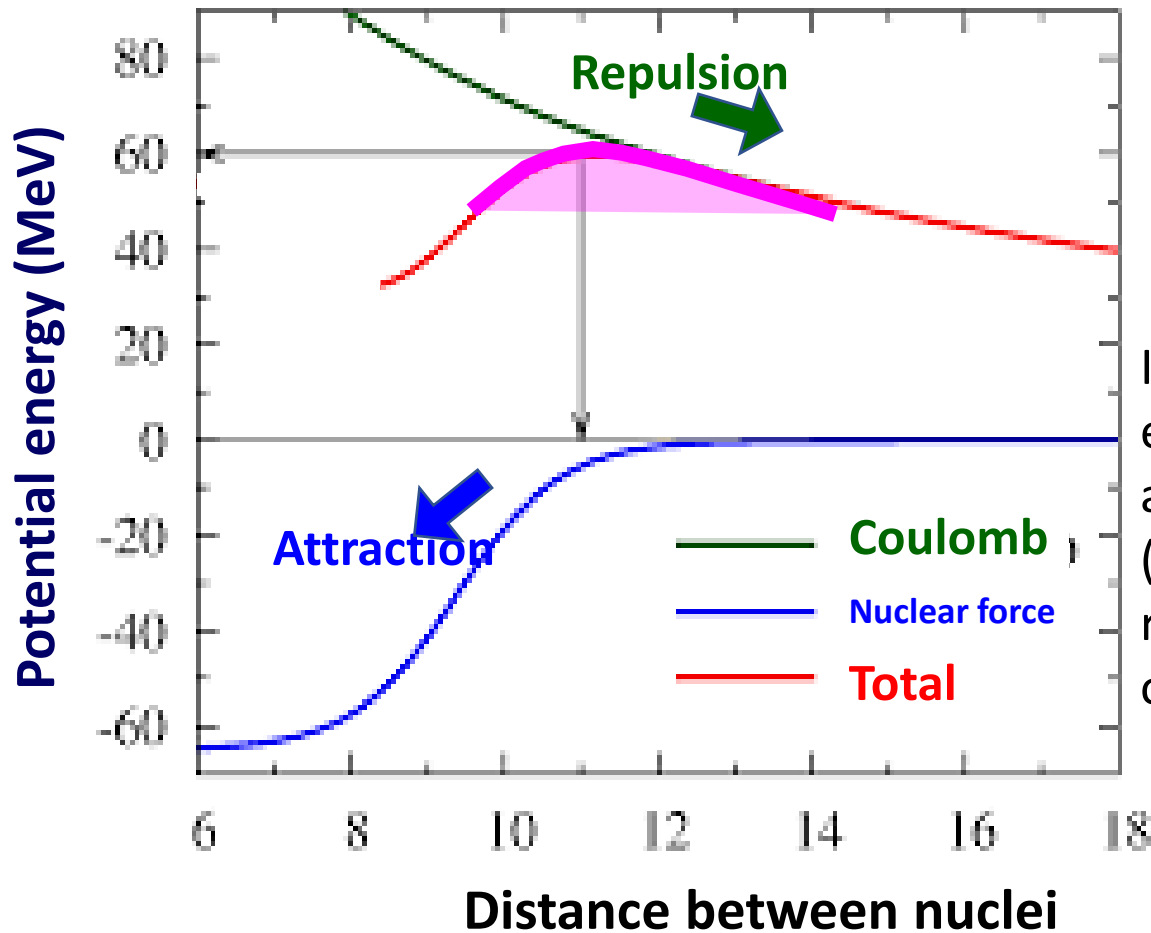
Heavy-ion fusion reaction

Nuclei heavier than the 100th element have been synthesized by fusion reactions using heavy ion beams. The 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 force between nuclei.

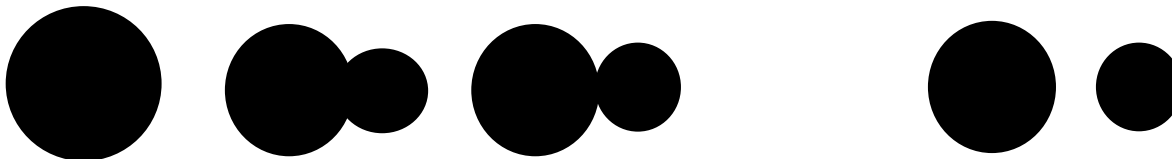


Description of the Coulomb barrier

- Coulomb repulsive force and attraction due to nuclear forces -



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

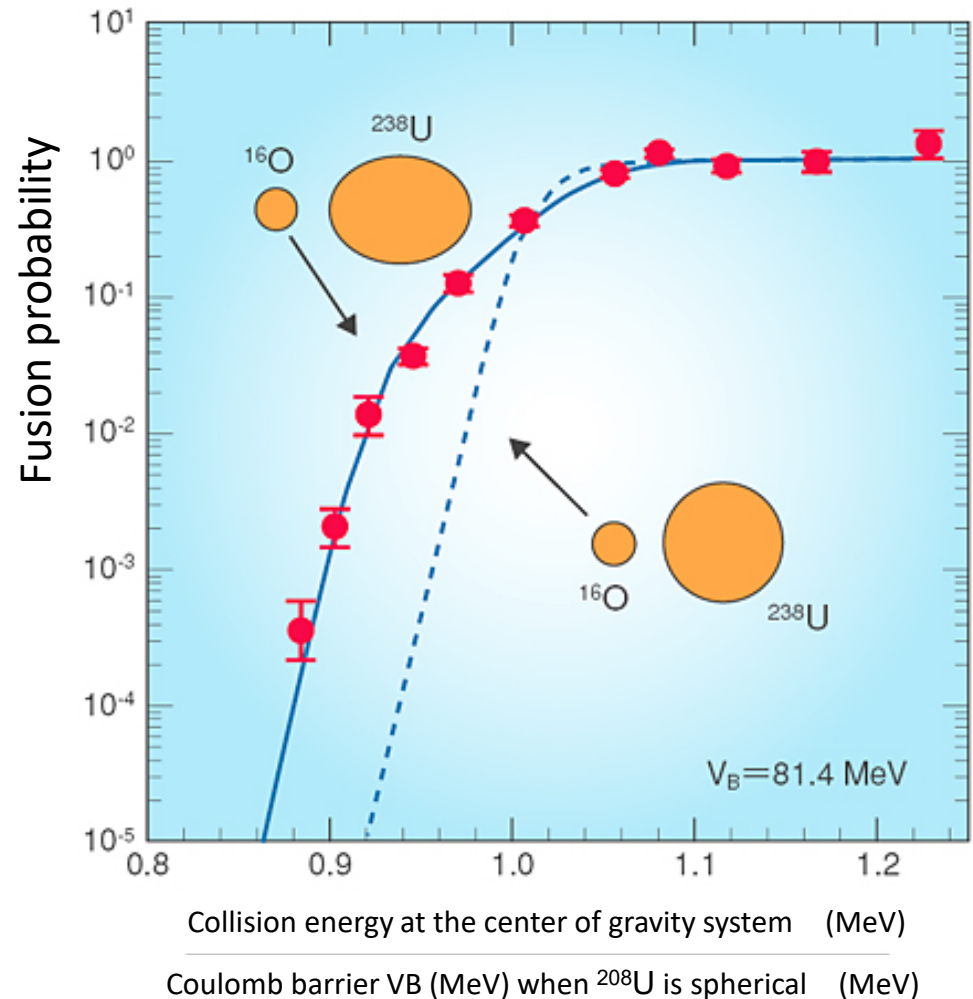


Fusion Probability

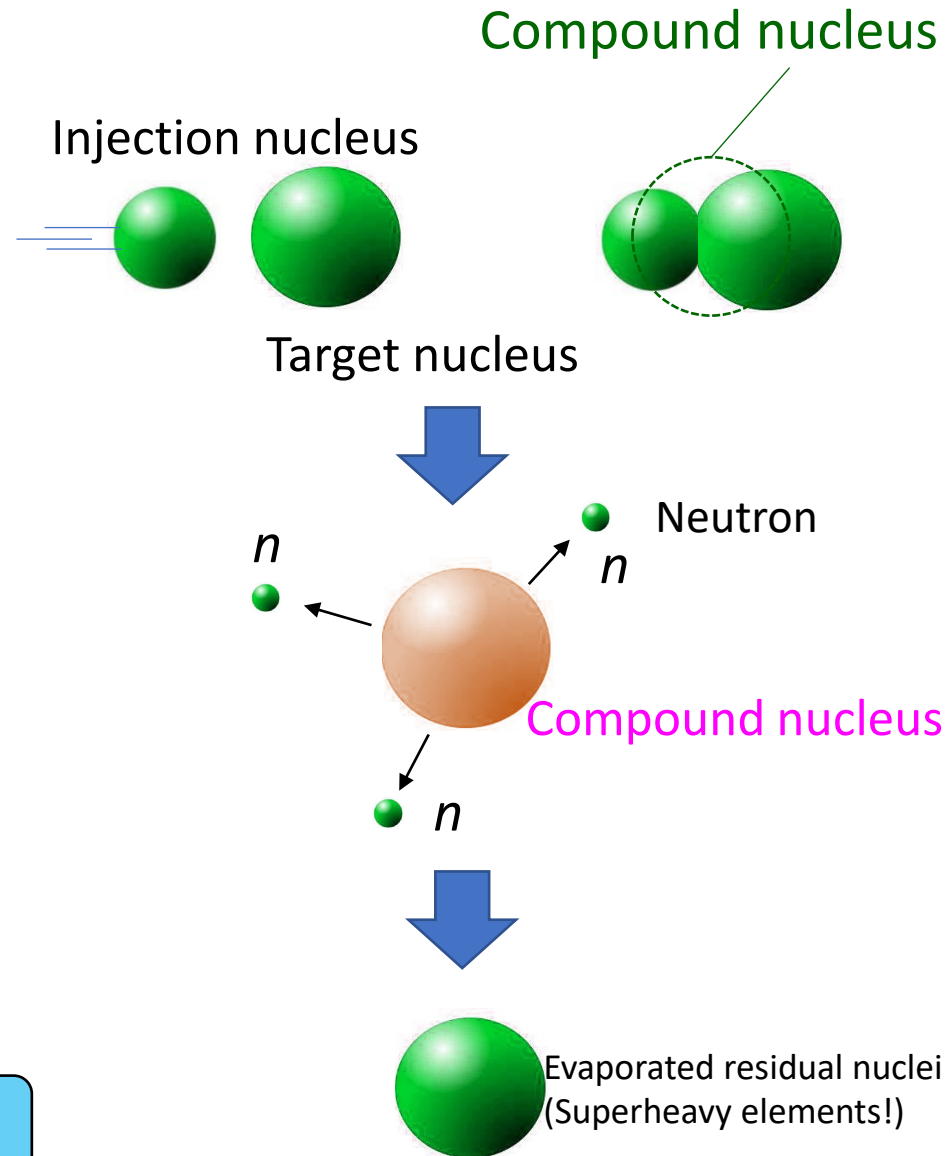
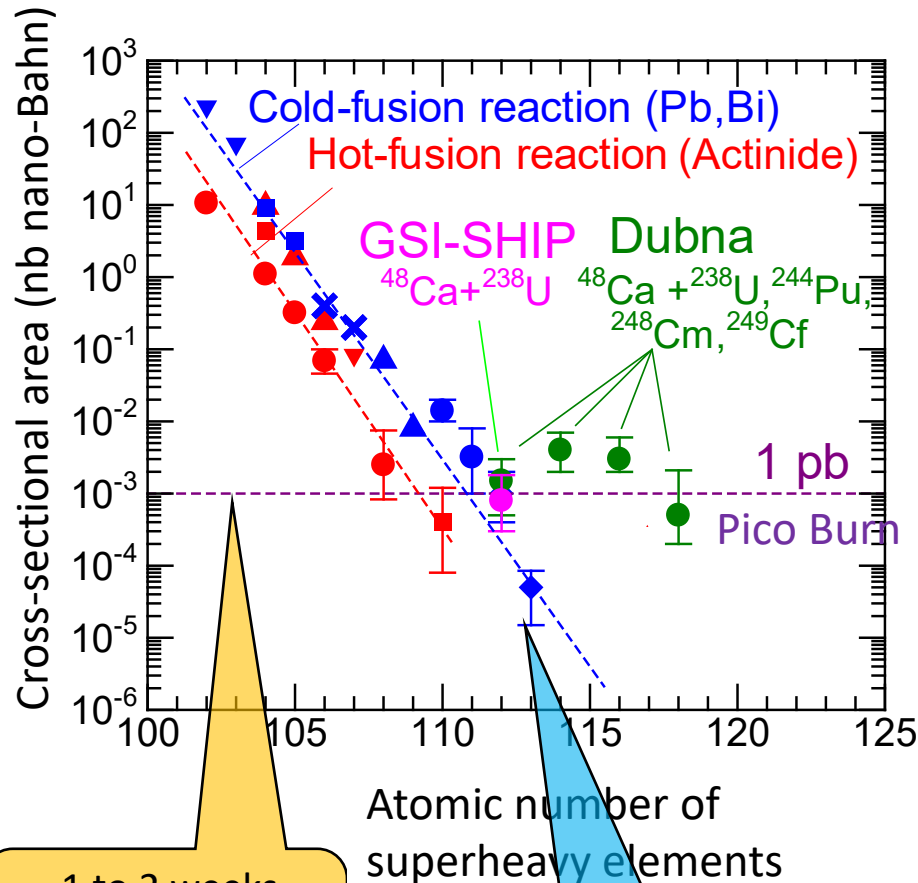
-Difference between spherical nuclei and deformed nuclei

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

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



Cross section to synthesize superheavy elements



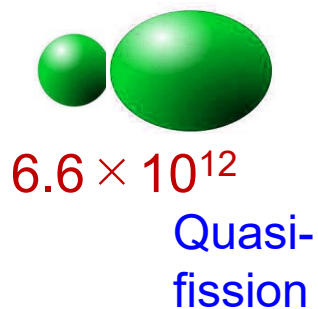
Why is it so difficult to make superheavy elements?

-Phenomena that occur in heavy reaction systems-

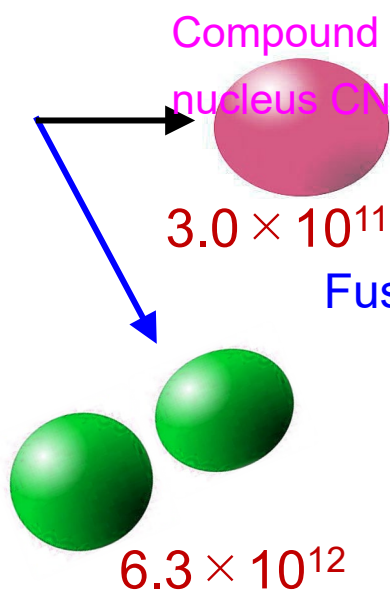
Three Steps of Superheavy Element Synthesis



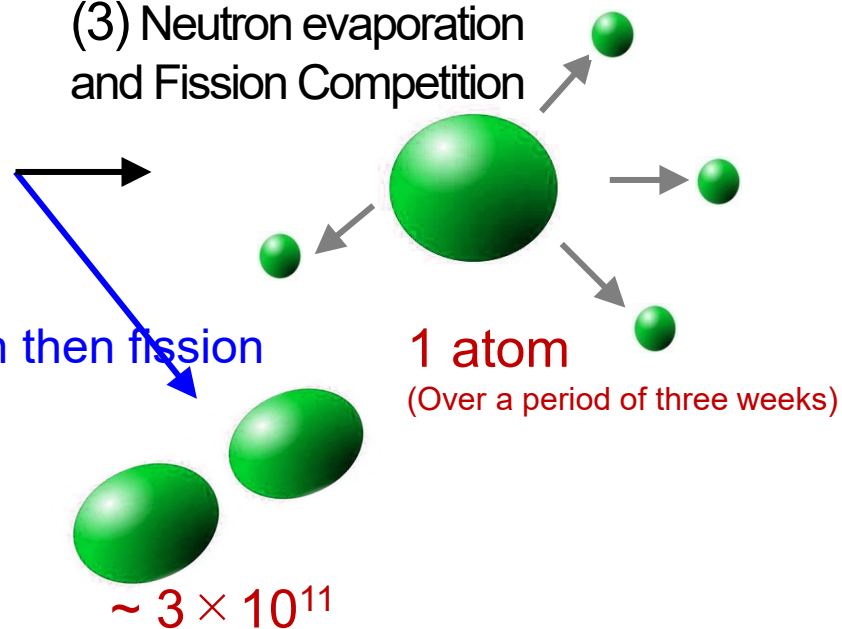
(1) Coulomb Barrier
Transcending Contact



(2) Fusion process



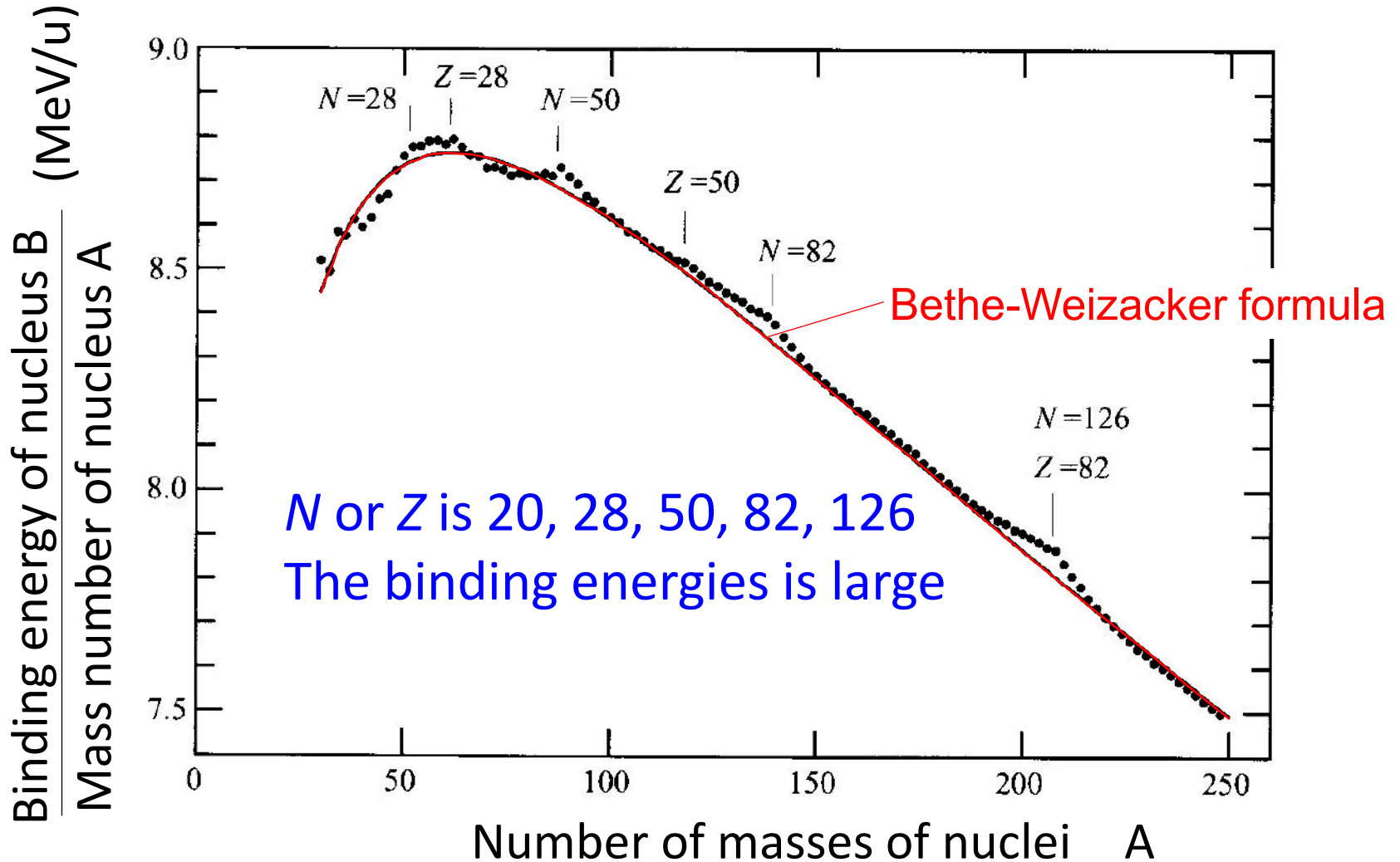
(3) Neutron evaporation
and Fission Competition



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

Binding energy per nucleon

-Mass model and actual nuclei-



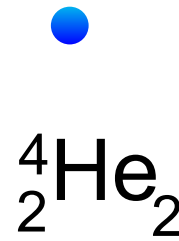
Q-value of α collapse



=



+

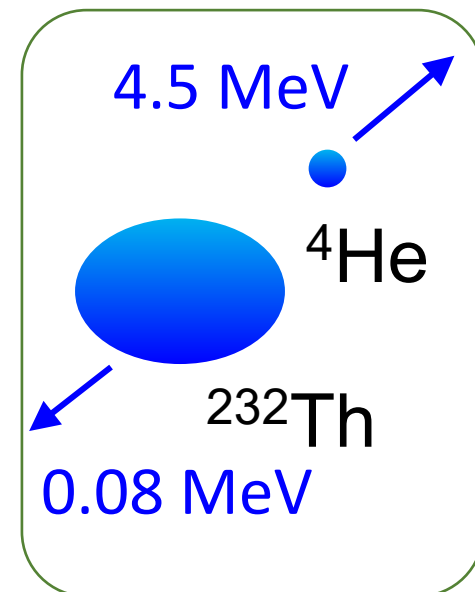
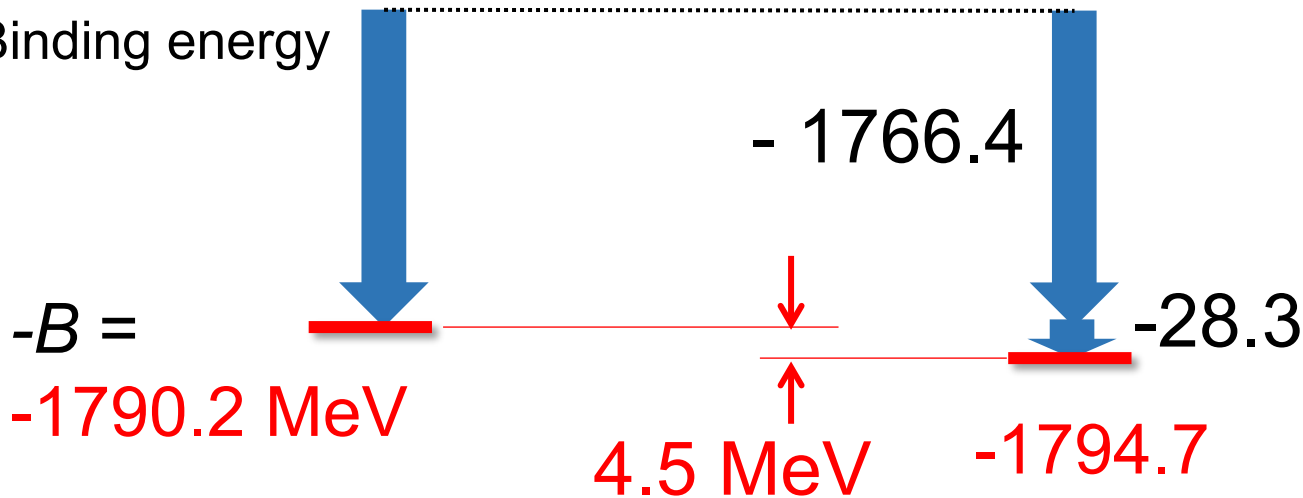


+

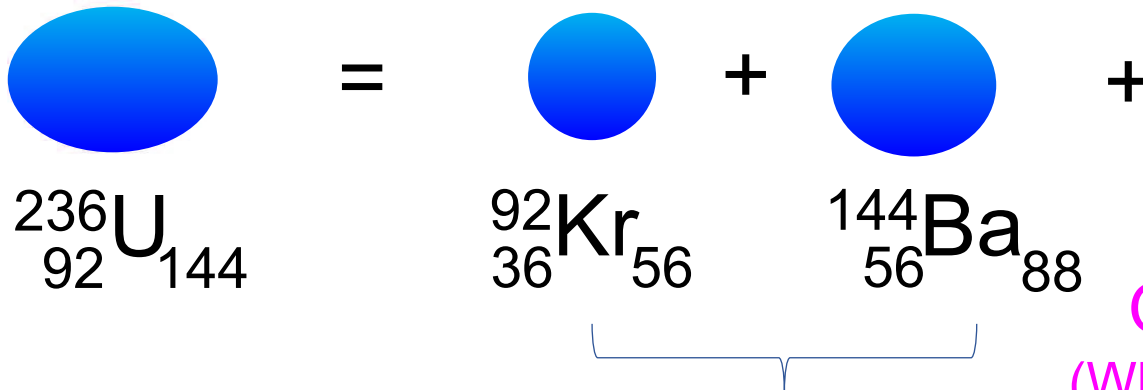


Energy
 $Q = + 4.5 \text{ MeV}$

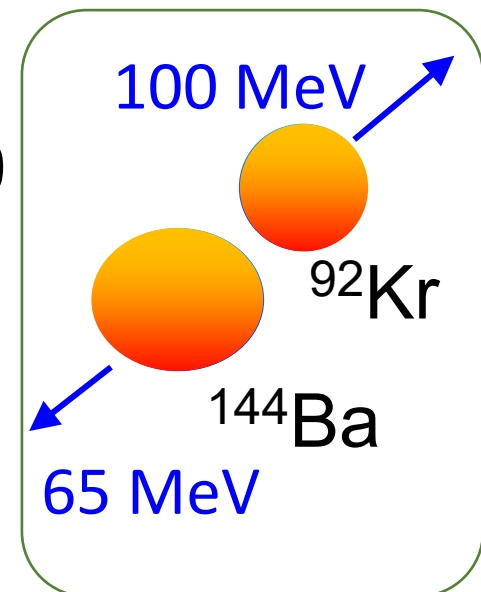
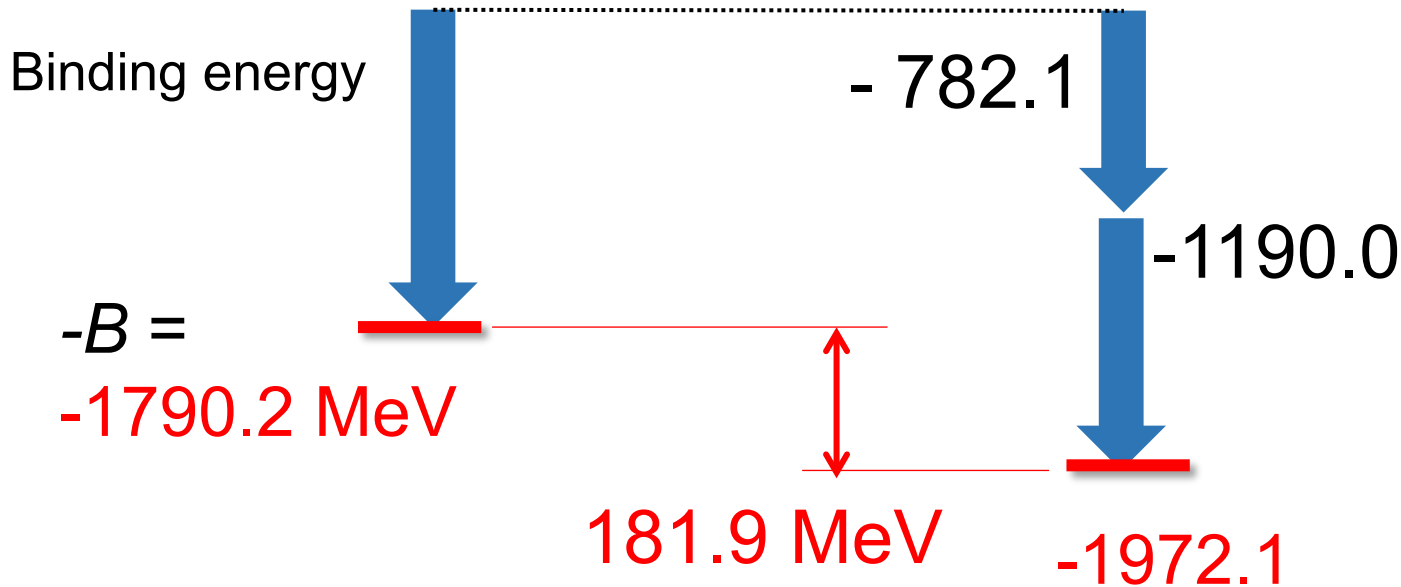
Binding energy



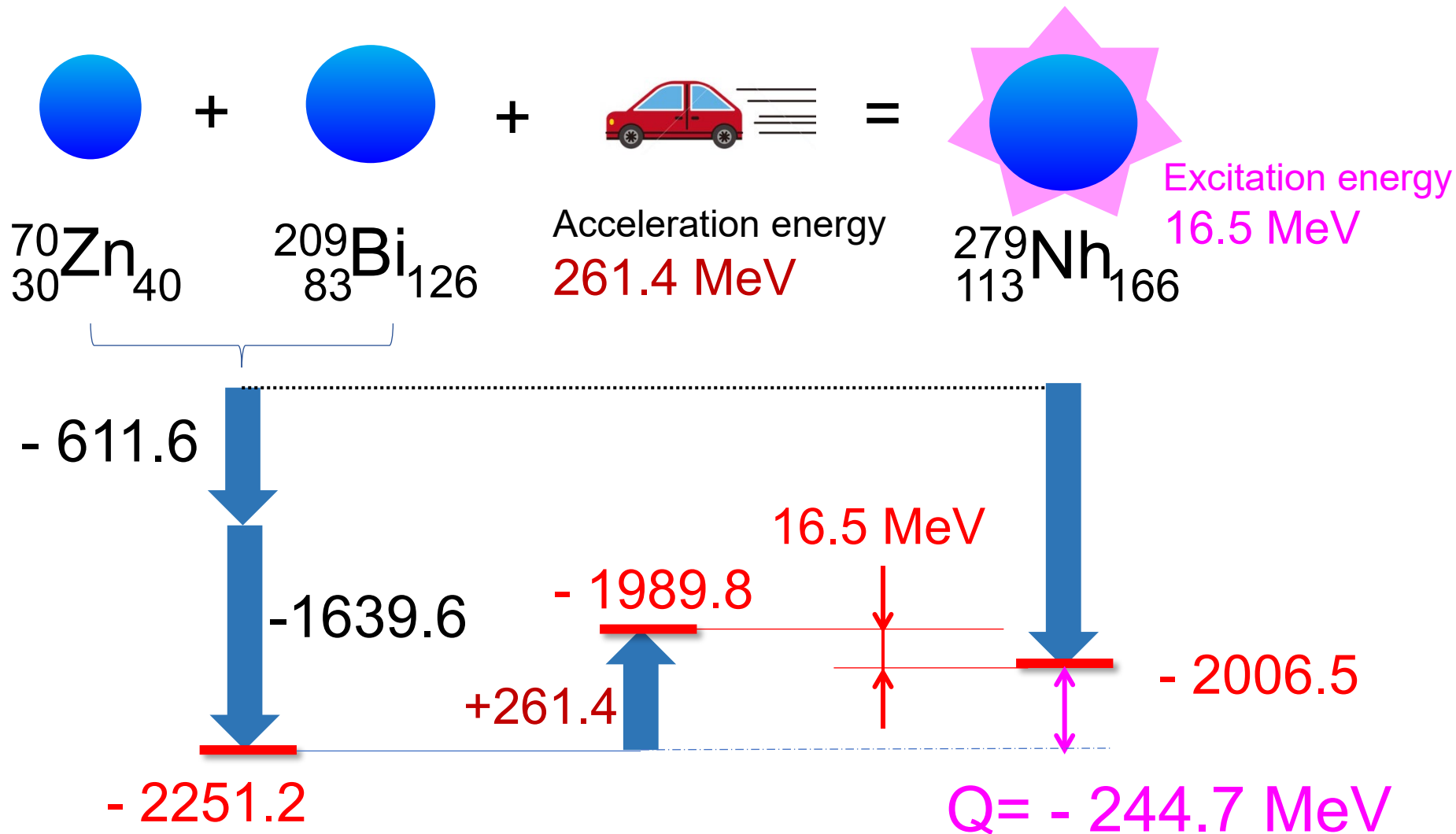
Q-value of fission



Energy
 $Q = +181.9 \text{ MeV}$
 (Where are you going?)



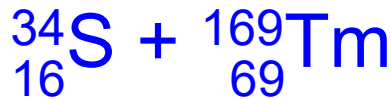
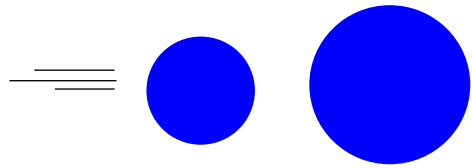
Nuclear fusion



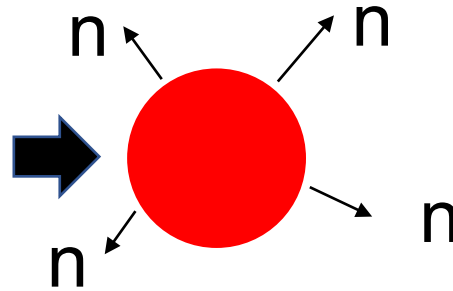
Practical experiment

Reactions learned in practice

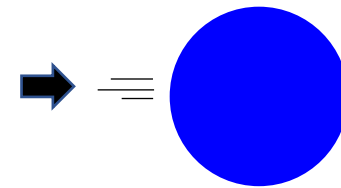
Tandem acceleration



Compound nucleus



Residual nucleus



At 195 143 ms α 7.075, 7.221 α → g γ 149, e ⁻ IT	At 196 290 ms α 6.953 α → m	At 197 387 ms α 7.049	At 198 2.0 s α 6.707 α → m	At 199 388 ms α 6.960 α → g	At 199 1.0 s α 6.856 α → m	At 199 4.2 s α 6.755 α → g γ 181 (218)	At 199 273 ms IT 103, e ⁻ γ 141, e ⁻ α 6.840 α → m	At 200 6.92 s α 6.841 α → m ₁ α 6.538 α → m ₂	At 200 7.9 s α 6.411 α → m ₁ α 6.660 α → m ₂	At 200 47 s α 6.344 α → m ₁ α 5.83 α → g	At 201 43.2 s α 6.344 α → m ₁ α 5.83 α → g	At 201 1.5 m α 6.344 α → m ₁ α 5.83 α → g	At 201 0.46 s α 6.135 α → m ₁ α 6.277 α → m ₂	At 202 182 s α 6.135 α → m ₁ α 6.177 α → m ₂	At 203 184 s α 6.088 α → m ₁ α 6.088 α → m ₂			
Po 194 0.392 s α 6.846 γ (658), e ⁻	Po 195 1.92 s α 6.699... γ (670) α → m	Po 195 4.64 s α 6.606... γ (597...) α → g	Po 196 5.60 s α 6.522... γ (769), e ⁻	Po 197 26 s α 6.385 α → m	Po 197 56 s α 6.281 α → m	Po 198 1.76 m α 6.185... e, g γ (931), e ⁻	Po 199 4.17 m e, γ 1034 1002... g α 6.059 α → m IT 238... e ⁻	Po 199 5.47 m e, γ 246, 394 840... m α 5.952 α → g	Po 200 11.5 m e, α 5.863 γ 671, 618, 434 797... m	Po 200 8.96 m IT 418, e ⁻ γ (6), e ⁻ α 5.786 γ 967, 964... g, α → m	Po 201 15.6 m e, α 5.683 γ 890 240... m, α → g	Po 202 44.7 m e, α 5.587 γ 689, 316, 166 791, 717... e ⁻						
Bi 193 3.2 s e, α 5.899... α → m γ	Bi 194 115 s α 5.599... γ 968, 575 260... α → m	Bi 194 95 s α 5.645... γ 966... α → g	Bi 195 87 s α 6.106... α → g	Bi 195 183 s e, β* γ 808, 776 134... e ⁻ , g α 5.420... α → m	Bi 196 4.00 m IT (102) IT (158...) α 5.112 α → m e?	Bi 196 0.6 s α 5.780 α → g	Bi 196 5.13 m α 5.780 α → g	Bi 197 4.9 m e, γ 855, 85 867, 828... m, g IT 249 196 562... e ⁻	Bi 197 9.3 m α 5.780 α → g	Bi 198 7.7 s e, γ 1063 196 562... e ⁻	Bi 198 11.6 m e, γ 1063 196 562... e ⁻	Bi 199 10.3 m e, γ 1063 196 562... e ⁻	Bi 199 24.70 m e, β* γ 842, 946 837... m, g	Bi 199 27 m e, β* γ 842, 946 837... m, g	Bi 200 31 m e, β* γ 1027 462, 420 245... g	Bi 200 36.4 m e, β* γ 1027 462, 420 245... g	Bi 201 57.5 m IT 848 e, γ 629, 936 1014 786... m, g	Bi 201 103 m IT 848 e, γ 629, 936 1014 786... m, g

Compound nucleus

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).