Slides for Nuclear Mass and Stability

2024

Let's Agree on Notation

$${}^{A}_{Z}Name^{\pm q}$$

A – Atomic mass (number of nucleons)

Z – Atomic number (number of protons)

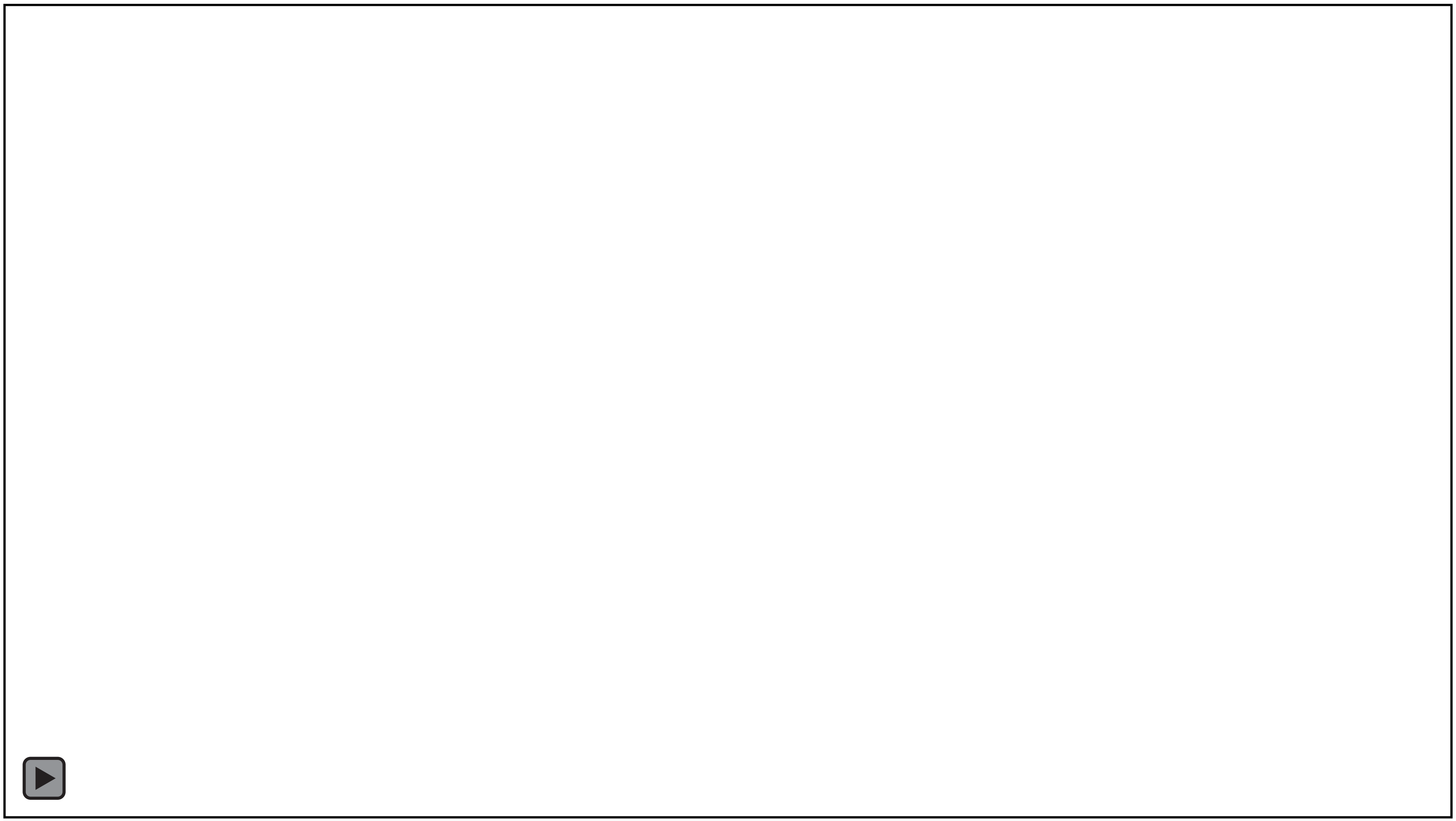
q – Charge (zero if not an ion)

$${}^{10}_{5}B + {}^{1}_{0}n \rightarrow {}^{7}_{3}Li + {}^{4}_{2}He + Q$$

is the same as…

$${}^{10}B(n,\alpha)\ {}^{7}Li$$

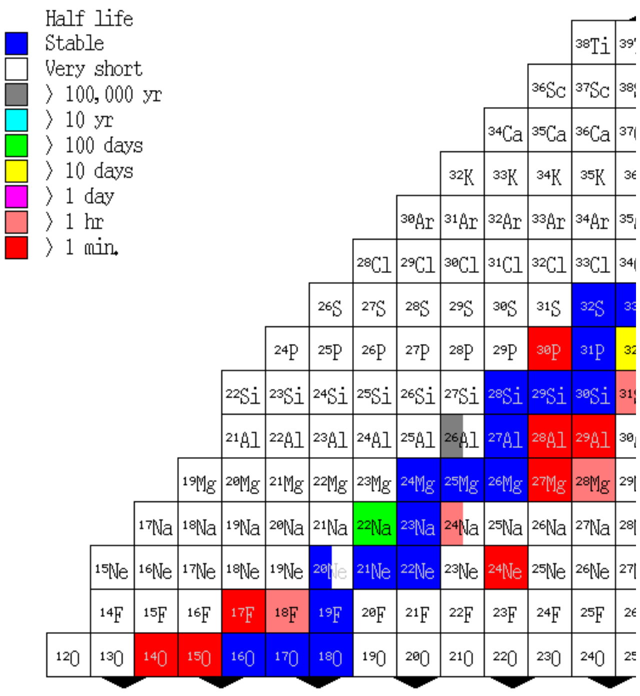
An Aside: Boron Neutron Capture Therapy (BNCT)



Explaining BNCT

- Why 30MeV
    - Look up (p,n) cross sections on JANIS
- Why beryllium?
    - Think about nuclear reactions
- How does the boron only get into cancer cells?
    - Think about the “blood/brain barrier”
- Why was boron selected for the therapy?
    - Think about range and energy loss of radiation

Reading the KAERI Table



16-S-32

basic
n-XS
summary
XS graphs

element

16-sulfur-32

- Atomic Mass: 31.9720707 +- 0.0000001 amu
- Excess Mass: -26015.981 +- 0.112 keV
- Binding Energy: 271780.656 +- 0.120 keV
- Beta Decay Energy: B- -12685.287 +- 6.782 keV

"The 1995 update to the atomic mass evaluation" by G.Audi and A.H.Wapstra, Nuclear Physics A595 vol. 4 p.409-480, December 25, 1995.

- Atomic Percent Abundance: 95.02%
- Spin: 0+
- Stable Isotope

- Possible parent nuclides:
  Beta from P-32
  Electron capture from Cl-32
  EC + P from Ar-33

R.R.Kinsey, et al.,*The NUDAT/PCNUDAT Program for Nuclear Data*,paper submitted to the 9 th International Symposium of Capture-Gamma_raySpectroscopy and Related Topics, Budapest, Hungary, Octover 1996.Data extracted from NUDAT database (Jan. 14/1999)

Explaining Terms

- **Atomic mass**

1 AMU = 931.49 MeV

1 amu	1.660540×10^{-27} kg	1.000 u	931.49 MeV/c^2
neutron	1.674929×10^{-27} kg	1.008664 u	939.57 MeV/c^2
proton	1.672623×10^{-27} kg	1.007276 u	938.28 MeV/c^2
electron	9.109390×10^{-31} kg	0.00054858 u	0.511 MeV/c^2

- **Excess mass**

$$\Delta = M - A$$

What does "excess mass" really mean?

- **Binding energy**

$$B(A, Z) \equiv [ZM_H + NM_n - M(A, Z)]c^2$$

Let's Try Some Examples

Calculate the binding energy of:

^{32}S

^{33}S

^{48}S

Nuclear Reaction Energies

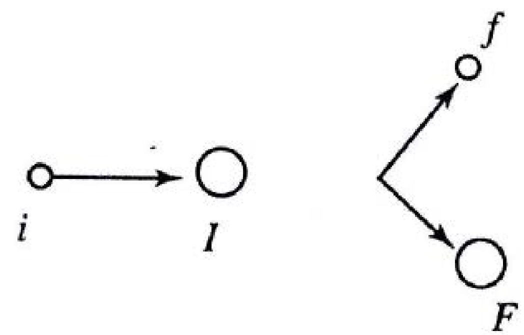
Let's look at BNCT again…

$$^{10}_{5}B + ^{1}_{0}n \rightarrow ^{7}_{3}Li + ^{4}_{2}He + Q$$

$$i + I \rightarrow f + F + Q$$

How do we find Q?

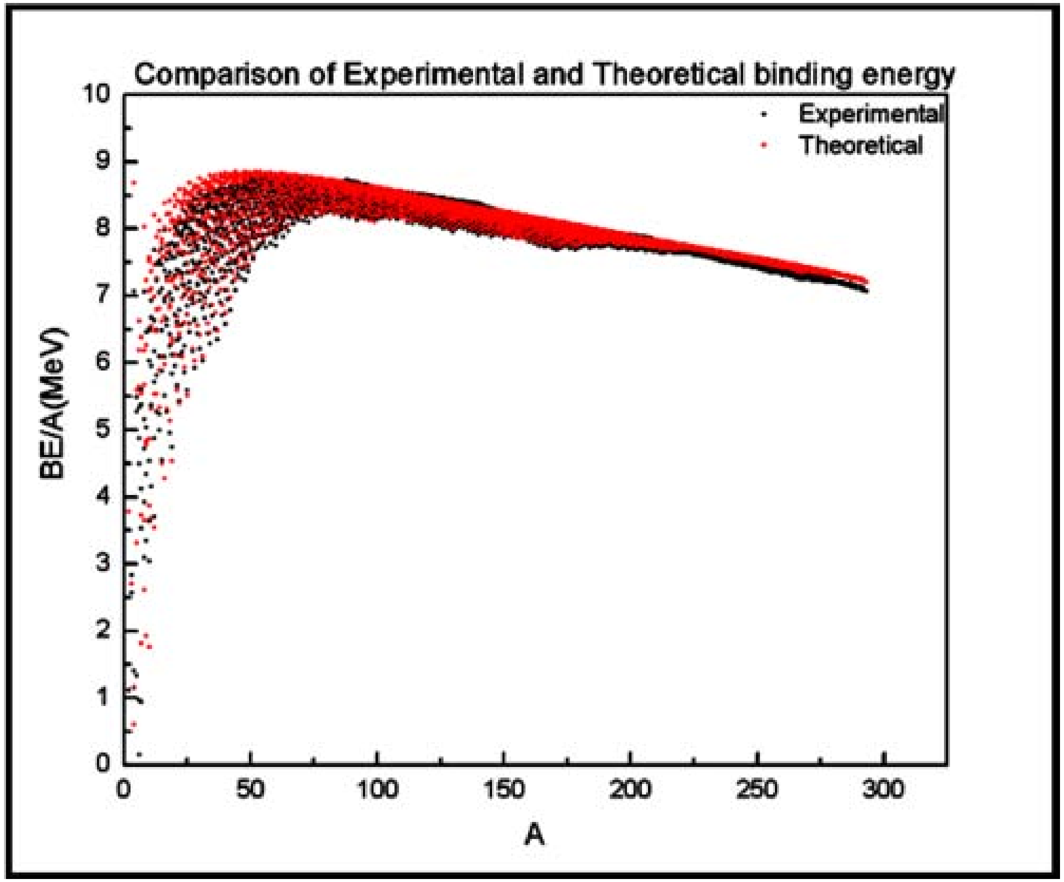
Conserve mass and energy, of course!



Method 1	Method 2	Method 3
Use masses	Kinetic energies	Binding energies

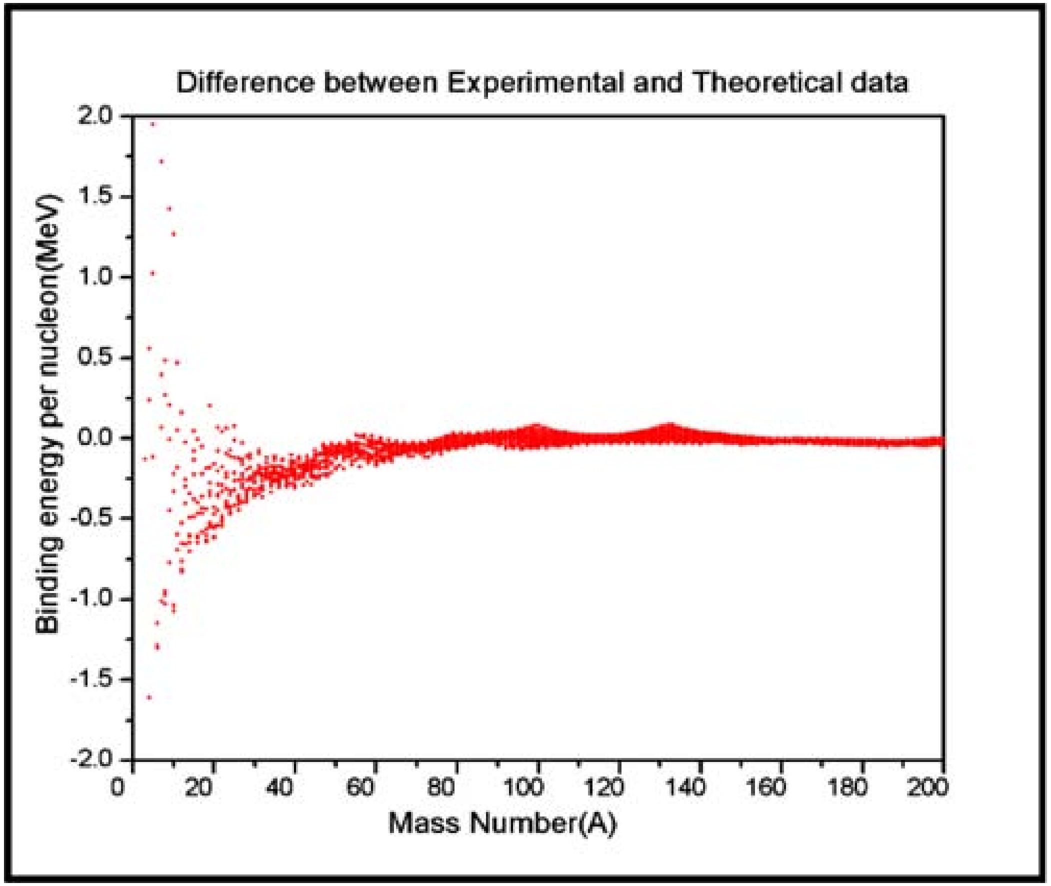
Binding Energy Curve

http://ictwiki.iitk.ernet.in/wiki/index.php/The_LDM_and_Semi-empirical_Mass_formula



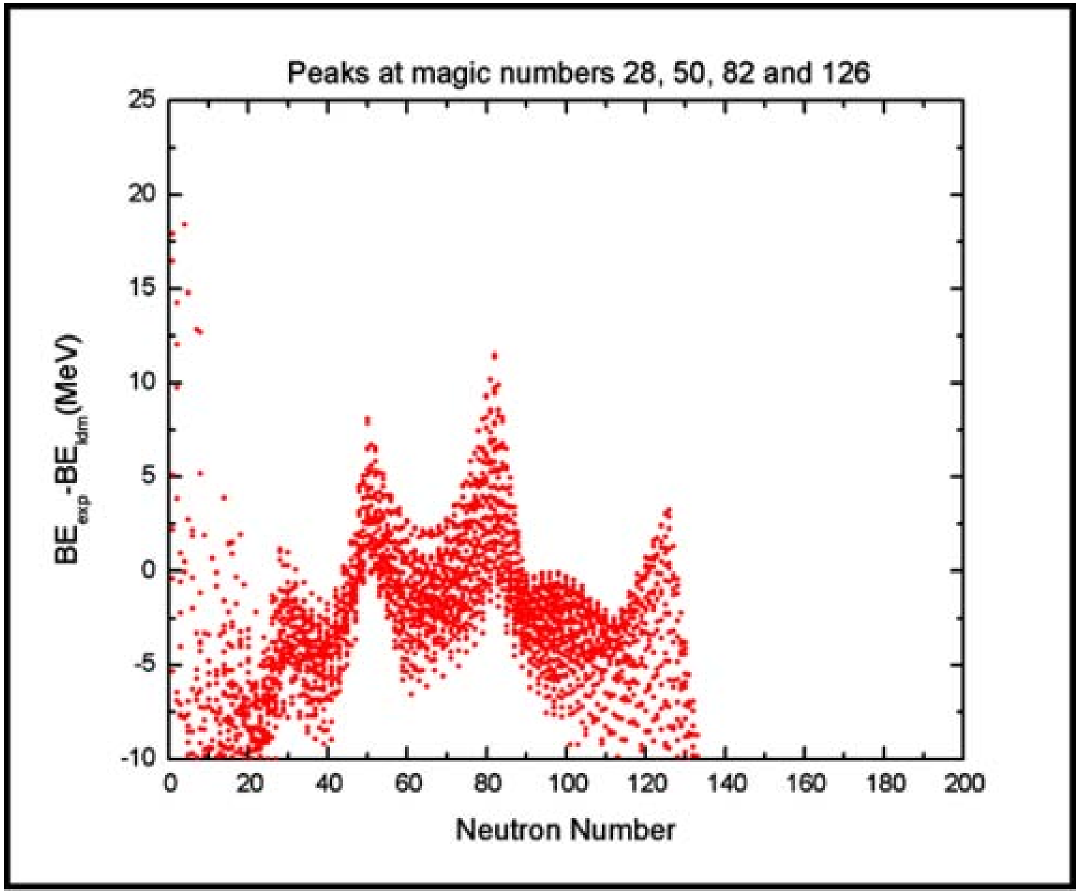
Binding Energy Curve

http://ictwiki.iitk.ernet.in/wiki/index.php/The_LDM_and_Semi-empirical_Mass_formula



Binding Energy Curve

http://ictwiki.iitk.ernet.in/wiki/index.php/The_LDM_and_Semi-empirical_Mass_formula



The Liquid Drop Mass Formula

Also called the "semi-empirical mass formula"

Derive and explain on the board

Semi-Empirical Mass Formula

$$B(A, Z) = a_v A - a_s A^{2/3} - a_c \frac{Z(Z-1)}{A^{1/3}} - a_a \frac{(N-Z)^2}{A} + \delta \qquad (4.10)$$

a_v	a_s	a_c	a_a	a_p	
16	18	0.72	23.5	11	MeV

$\delta = a_p/\sqrt{A}$ even-even nuclei

$= 0$ even-odd, odd-even nuclei

$= -a_p/\sqrt{A}$ odd-odd nuclei

Stability Trends

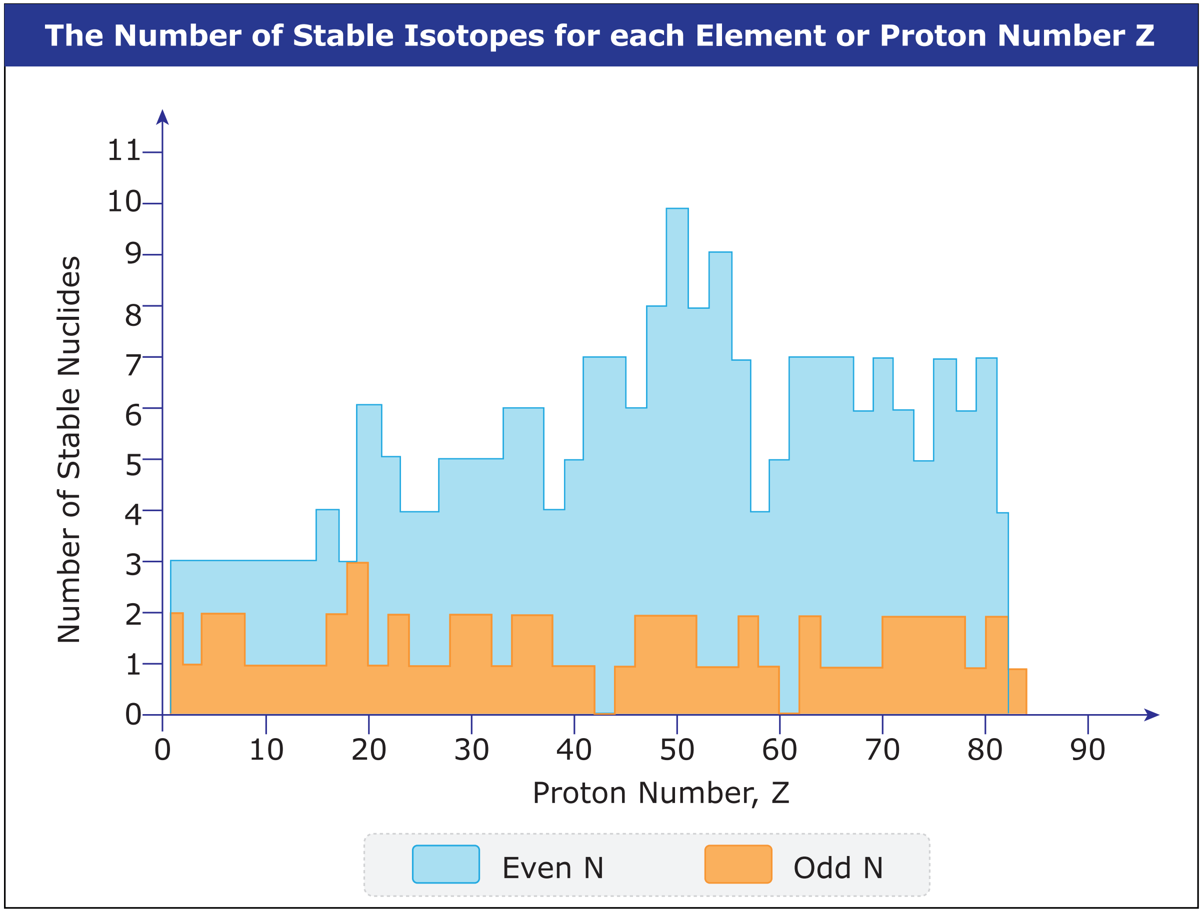


Image by MIT OpenCourseWare.

Stability Trends

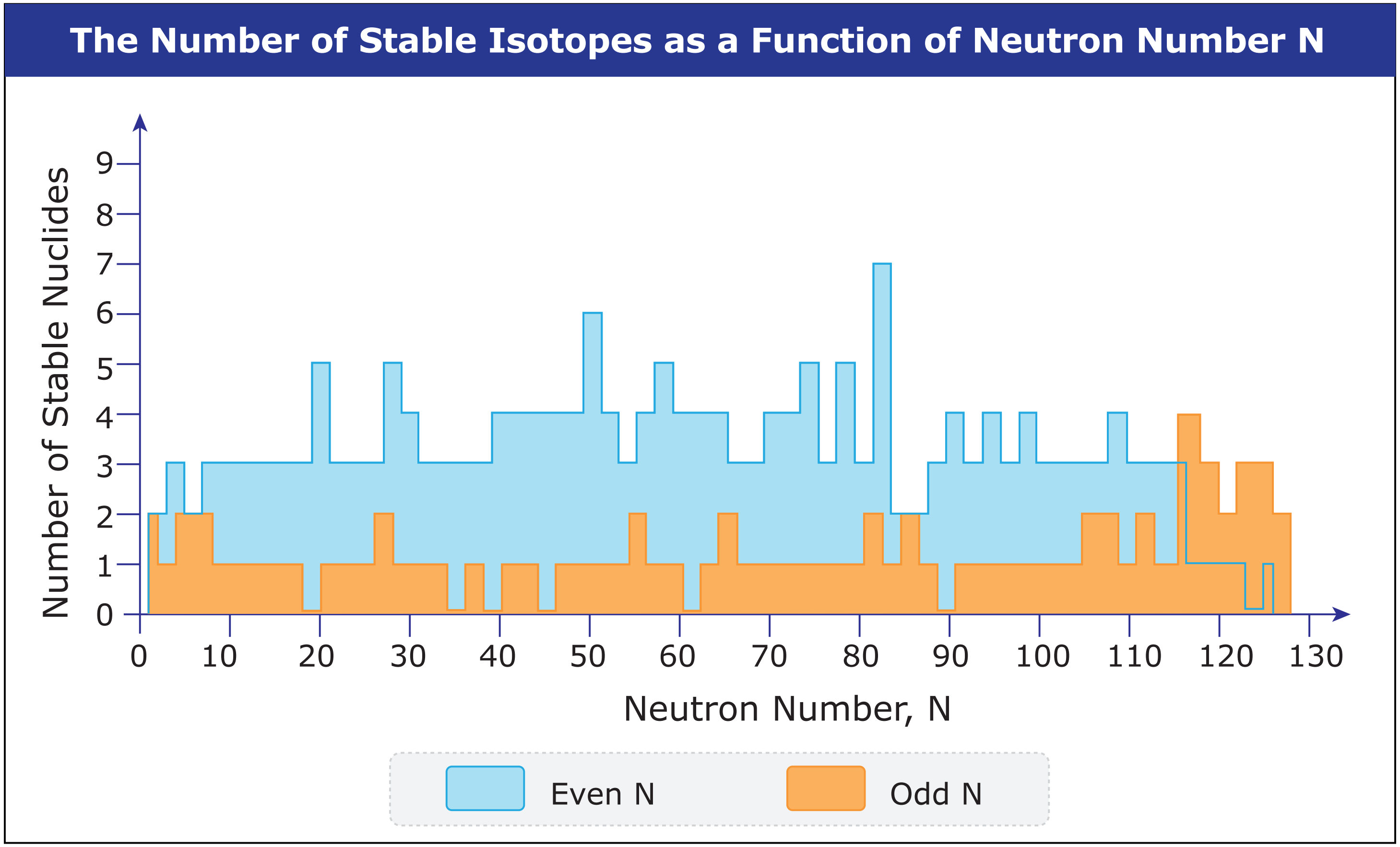
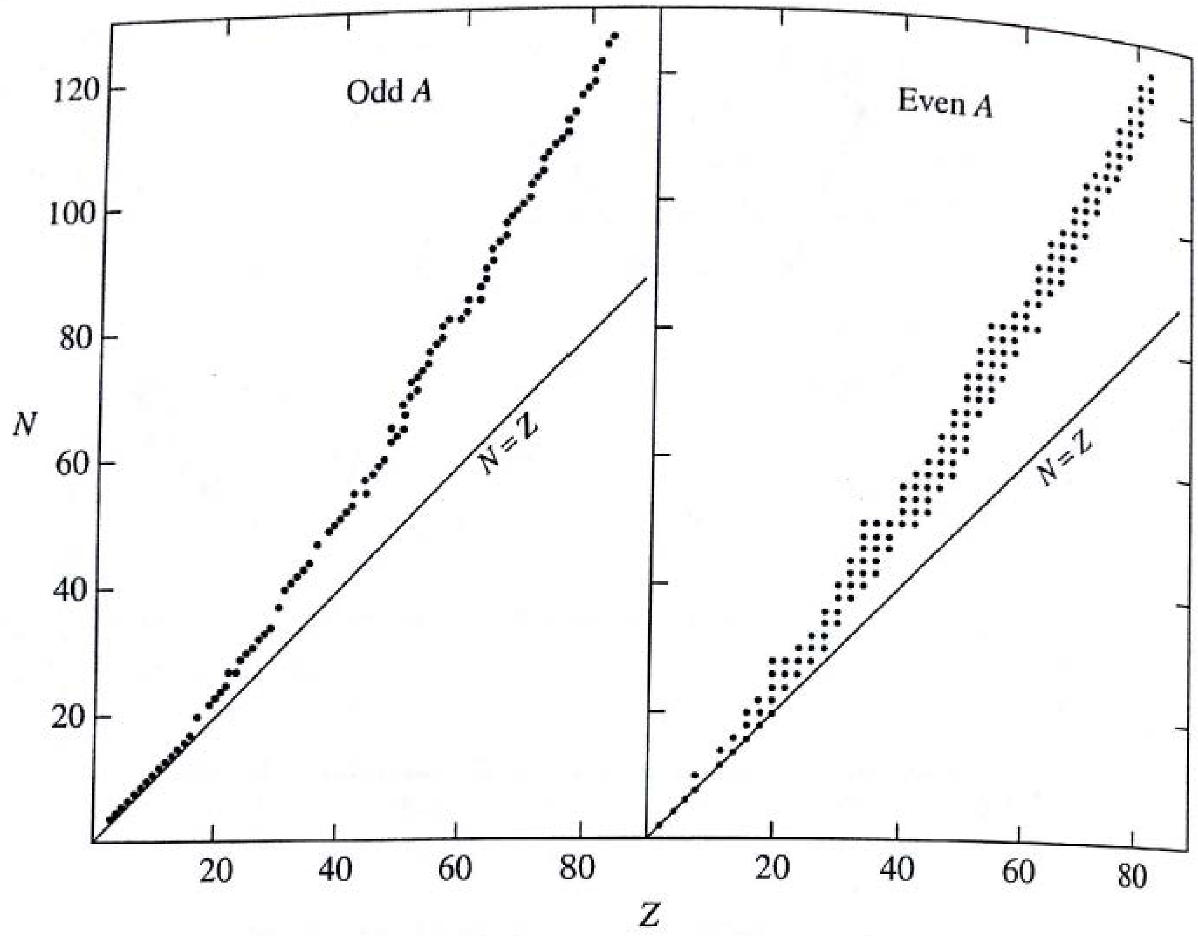
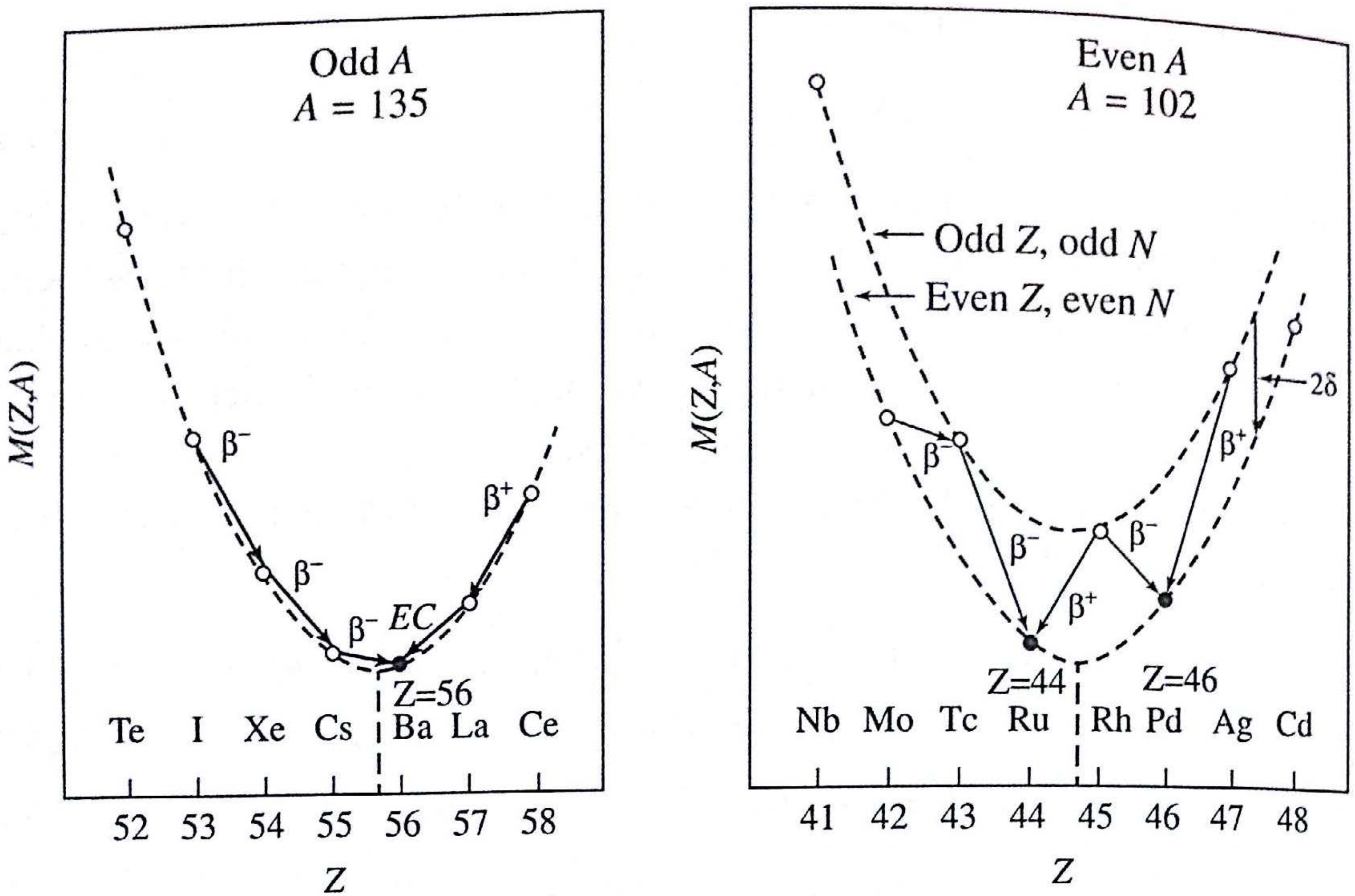


Image by MIT OpenCourseWare.

Stability Trends



Mass Parabolas – Plotting Stability



An Island of Stability?

Y. T. Oganessian, K. P. Rikaczewski. *Physics Today*, 32-38 (Aug. 2015).

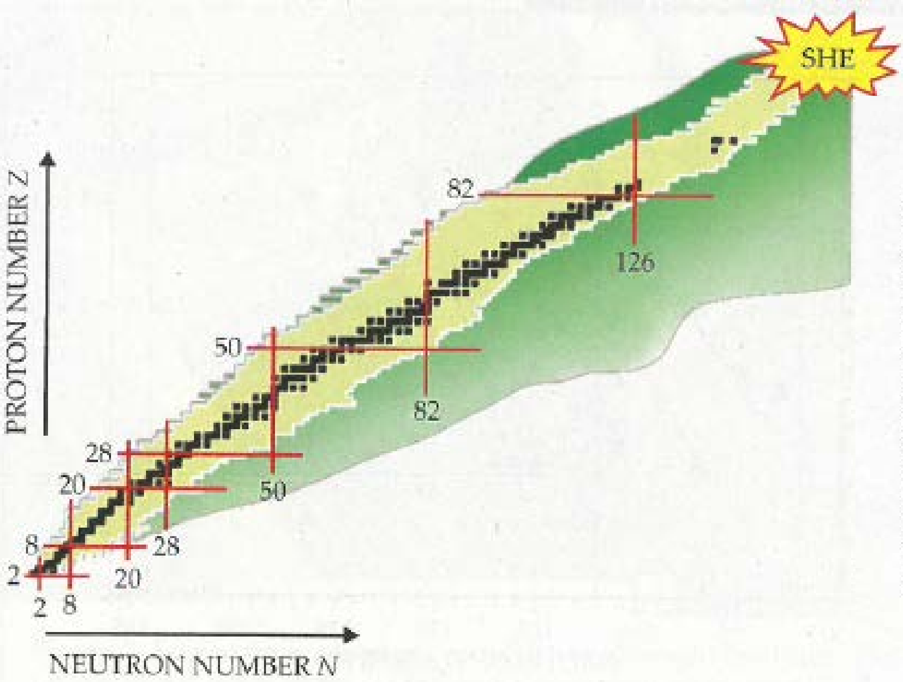


Figure 1. The grand nuclear landscape. Nuclei that have been experimentally identified are inside the yellow region, whereas nuclei only predicted to exist are roughly indicated by the green area. Black squares mark stable isotopes. Magic proton and neutron numbers, at which nuclei have enhanced stability, are indicated by red lines. The star labeled SHE indicates the region of superheavy elements. (Courtesy of Witold Nazarewicz).

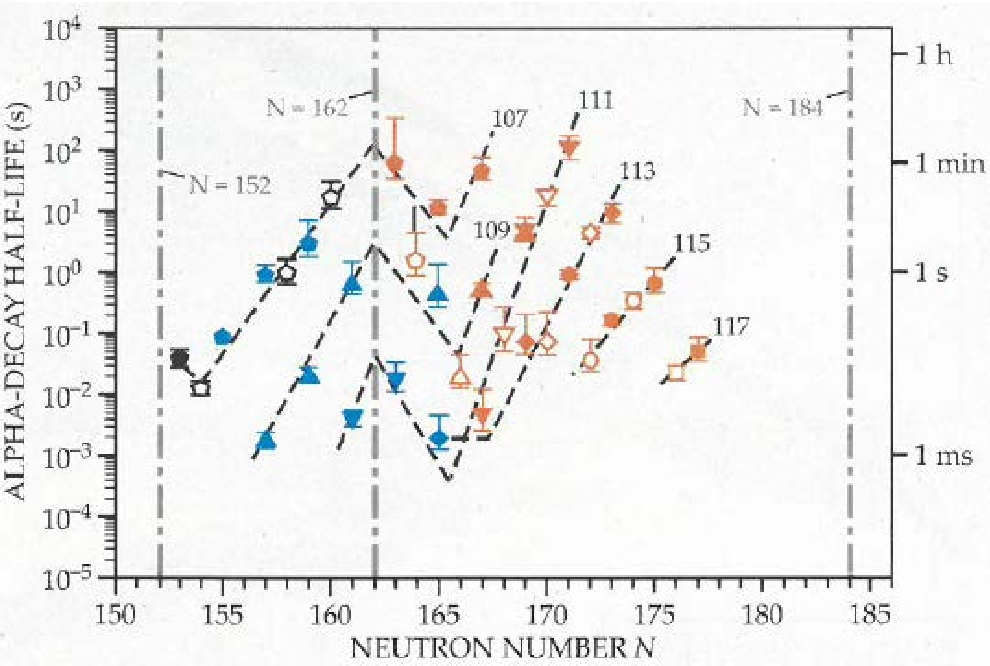


Figure 2. The dependence of alpha decay half-lives on neutron number.

An Island of Stability?

Y. T. Oganessian, K. P. Rikaczewski. *Physics Today*, 32-38 (Aug. 2015).

How are superheavy elements synthesized?

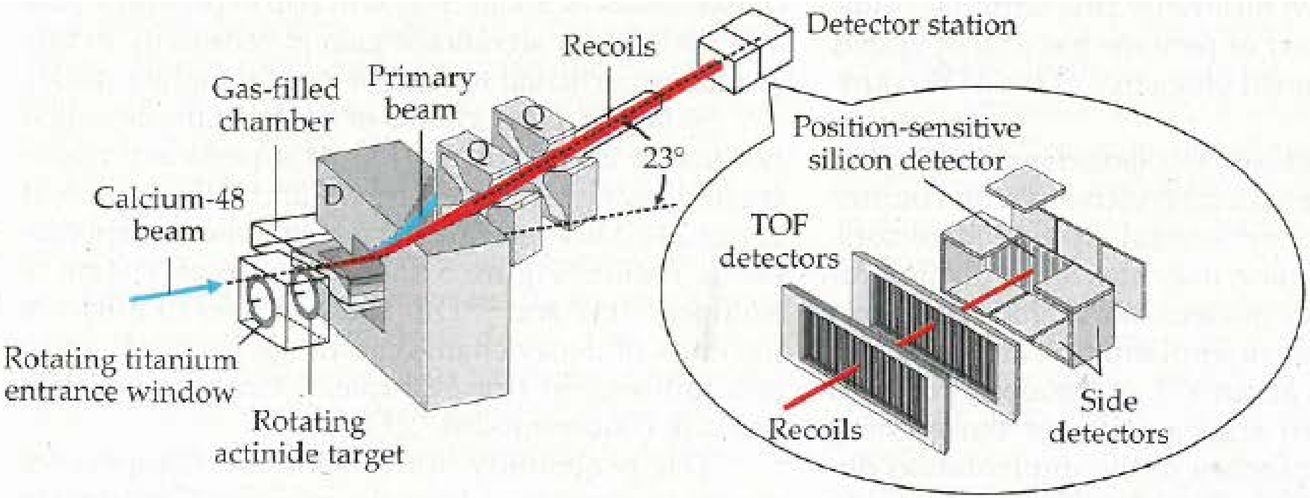


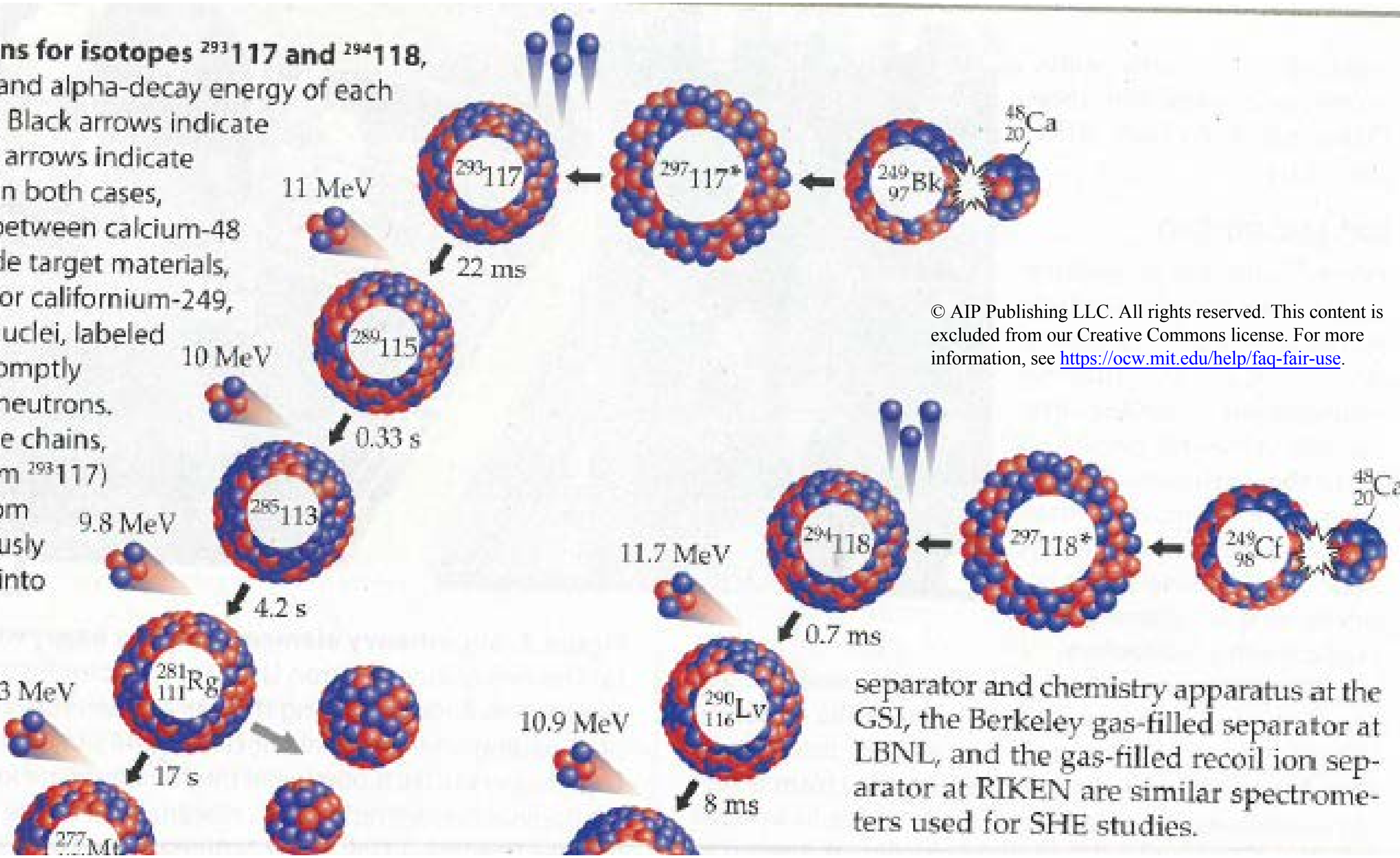
Figure 4. The Dubna gas-filled recoil separator is outfitted with a dipole bending magnet (D) and two ion-focusing quadrupole magnets (Q) to select and guide the superheavy recoils (red) from collisions between calcium-48 projectiles (blue) and a rotating actinide target to a set of detectors. The inset shows the detector station with two time-of-flight detectors and silicon-stack detectors. (Adapted from Y. T. Oganessian et al., *Phys. Rev. C* **83**, 054315, 2011.)

www.physicstoday.org August 2015 Physics Today 35

An Island of Stability?

Y. T. Oganessian, K. P. Rikaczewski. *Physics Today*, 32-38 (Aug. 2015).

Figure 5. Decay chains for isotopes $^{293}117$ and $^{294}118$, showing the half-life and alpha-decay energy of each nucleus in the chains. Black arrows indicate alpha decay and gray arrows indicate spontaneous fission. In both cases, hot-fusion reactions between calcium-48 projectiles and actinide target materials, either berkelium-249 or californium-249, produce compound nuclei, labeled with asterisks, that promptly evaporate off several neutrons. Toward the ends of the chains, roentgenium-281 (from $^{293}117$) and flerovium-286 (from $^{294}118$) can spontaneously fission or alpha decay into meitnerium-277 and copernicium-282, respectively. Both end-chain nuclei undergo spontaneous fission.



separator and chemistry apparatus at the GSI, the Berkeley gas-filled separator at LBNL, and the gas-filled recoil ion separator at RIKEN are similar spectrometers used for SHE studies.