Review

Beta emission

$$^{1}_{0}\text{n} \longrightarrow {}^{1}_{1}\text{p} + {}^{0}_{-1}\text{e}$$

Positron emission

$$^{1}_{1}\text{p} \longrightarrow {}^{1}_{0}\text{n} + {}^{0}_{+1}\text{e}$$

Electron capture

$$^{1}_{1}\text{p} + {}^{0}_{-1}\text{e} \longrightarrow {}^{1}_{0}\text{n}$$

Electron Capture

An electron is absorbed into the nucleus

$$^{81}_{37}\mathrm{Rb} + {}^{0}_{-1}\mathrm{e} \longrightarrow {}^{81}_{36}\mathrm{Kr}$$

atomic number decreases: 37 -1 = 36

decaying to low Z element

Electron capture has the effect of converting a proton to a neutron:

$$^{1}_{1}\mathrm{p} + {}^{0}_{-1}\mathrm{e} \longrightarrow {}^{1}_{0}\mathrm{n}$$

$$\boxed{p + e^{-} \rightarrow n}$$

The **nucleus captures** one of the **inner-orbital electrons**

$$^{201}_{80}\mathrm{Hg} + ^{0}_{-1}\mathrm{e} \rightarrow ^{201}_{79}\mathrm{Au} + ^{0}_{0}\gamma$$

half life ~26 min.

One of seven stable isotopes of mercury

Au has only one isotope
^{197}Au (abundance 100%)

***γ* rays are always produced to release excess energy**

Gamma Emission

Gamma emission is the loss of a *γ*-ray, which is **high-energy photon** that almost always accompanies the **loss of a nuclear particle**:

$$^{238}_{92}\mathrm{U} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{234}_{90}\mathrm{Th} + 2\,{}^{0}_{0}\gamma$$

Gamma radiation usually accompanies other radioactive emission because it **represents the energy lost when the nucleons in a nuclear reaction reorganize into more stable arrangements.**

Often gamma rays are not explicitly shown when writing nuclear equations. It **changes neither the atomic number nor the mass number** of a nucleus.

Practice

Potassium ion is present in foods and is an essential nutrient in the human body. One of the naturally occurring isotopes of potassium, potassium-40, is radioactive which has a natural abundance of 0.0117%. It undergoes radioactive decay in three ways: <u>98.2% is by electron capture</u>, <u>1.35% is by beta emission</u>, and <u>0.49% is by positron emission</u>.

(a) Write the nuclear equations for the three modes by which ^{40}K decays.

(b) How many $^{40}K^{+}$ ions are present in 1.00 g of KCl?

Nuclear Stability

Some nuclides, such as $^{12}_{6}C$ and $^{13}_{6}C$ are stable, whereas others, such as $^{14}_{6}C$, are unstable and undergo radioactive decay. Why does a small difference in the number of neutrons affect the stability of a nuclide? No single rule allows us to predict whether a particular nucleus is radioactive and, if it is, how it might decay. However, several empirical observations can help us predict the stability of a nucleus.

Stable nuclei with atomic numbers up to about 20 have approximately equal numbers of neutrons and protons. For nuclei with atomic number above 20, the number of neutrons exceeds the number of protons. Indeed, the number of neutrons necessary to create a stable nucleus increases more rapidly than the number of protons. Thus, **the neutron-to-proton ratios of stable nuclei increase with increasing atomic number**, as illustrated by the following isotopes:

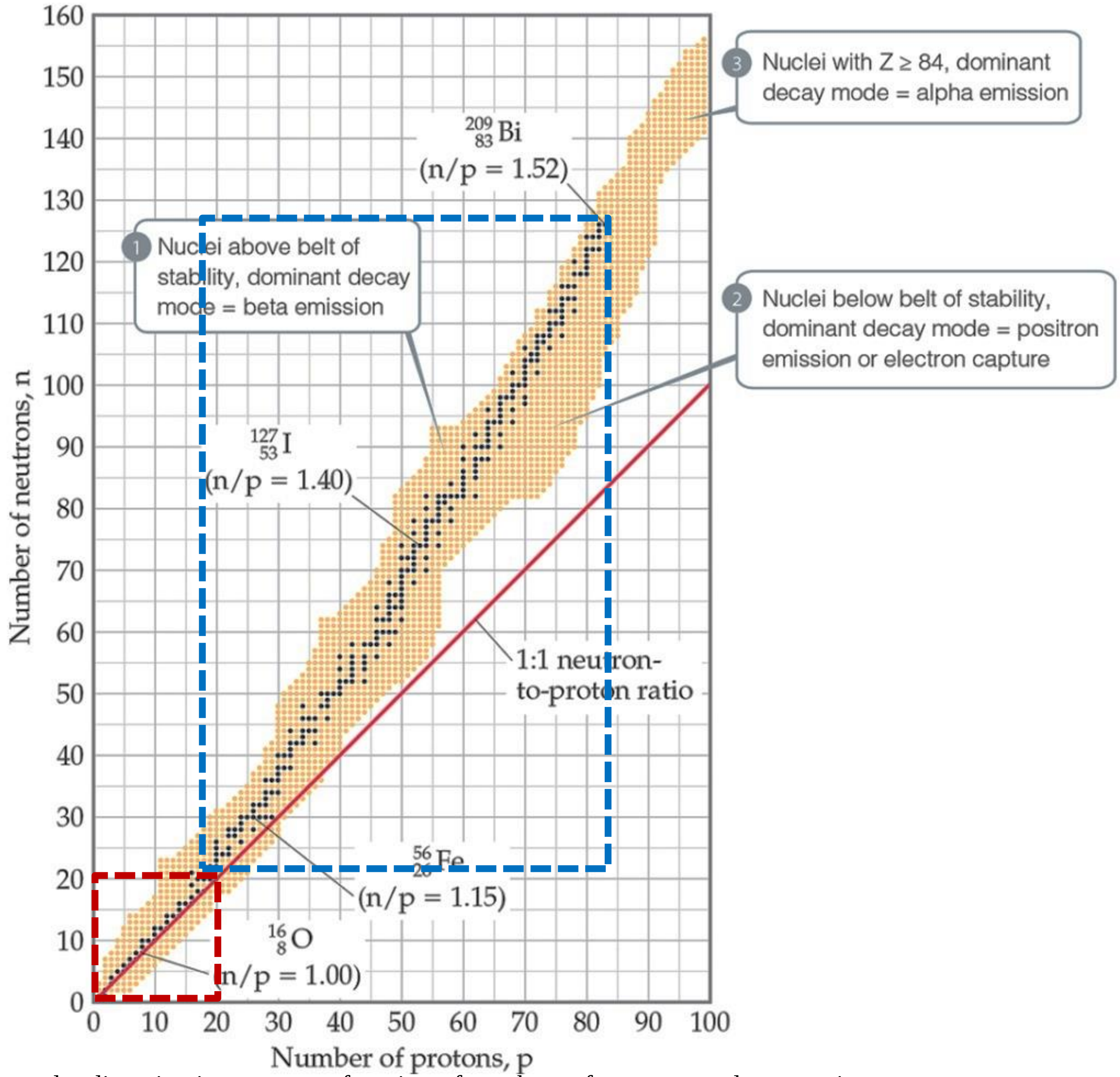
$^{12}_{6}C$ (n/p = 1), manganese, $^{55}_{25}Mn$ (n/p = 1.20), and

gold, $^{197}_{79}Au$ (n/p = 1.49).

Neutron–Proton Ratios and the Belt of Stability

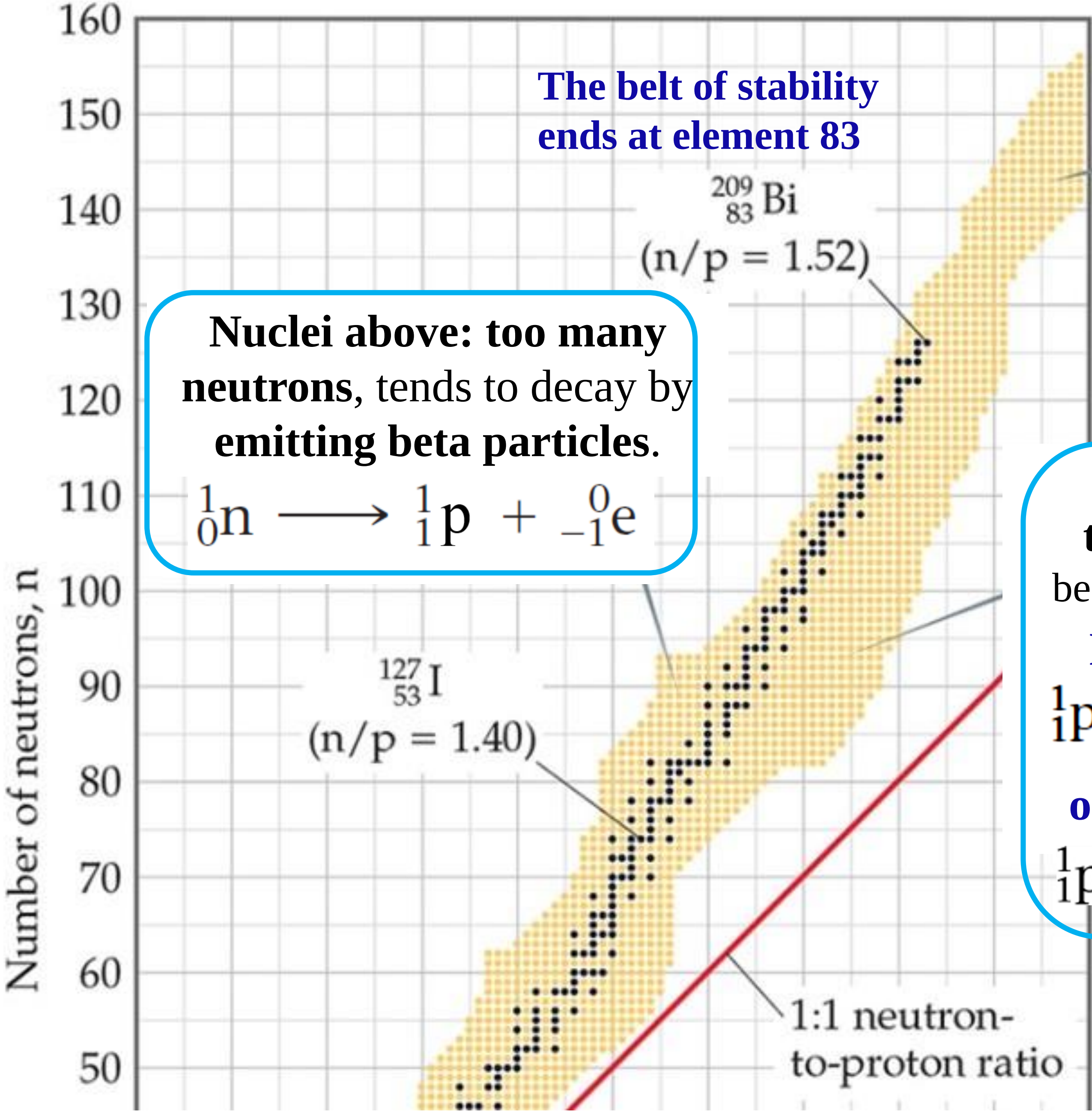
As nuclei get larger, it takes a larger number of neutrons to stabilize the nucleus.

when *Z* ≤ 20, n:p is close to 1:1 for a stable nuclei



21.1 Stable and radioactive isotopes as a function of numbers of neutrons and protons in a nucleus. The stable nuclei (dark blue dots) define a region known as the belt of stability.

Unstable Nuclei



Nuclei above: too many neutrons, tends to decay by **emitting beta particles**.

$$^{1}_{0}n \longrightarrow {}^{1}_{1}p + {}^{0}_{-1}e$$

all nuclei with $Z \geq 84$ are radioactive, decaying by **alpha emission**

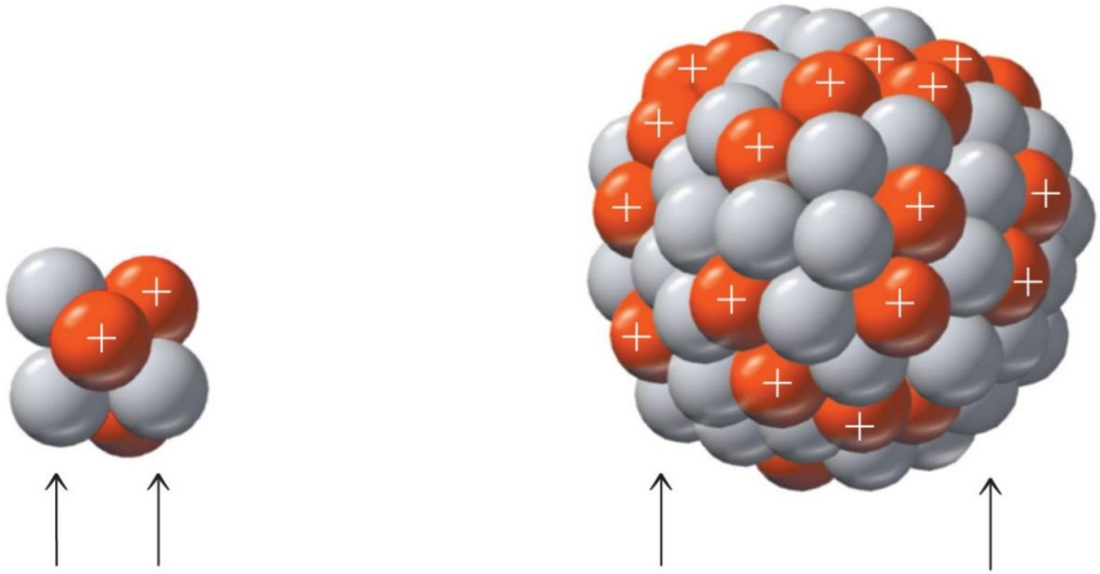
Nuclei above: too many protons, becoming more stable by **positron emission**

$$^{1}_{1}p \longrightarrow {}^{1}_{0}n + {}^{0}_{+1}e$$

or electron capture.

$$^{1}_{1}p + {}^{0}_{-1}e \longrightarrow {}^{1}_{0}n$$

Why are larger nuclei less stable than smaller nuclei?



(a) Nucleons close together (b) Nucleons far apart

Because the strong nuclear force decreases over distance.

A large atomic nucleus is more susceptible to the repulsive forces among protons. This means there is a limit to the size of the atomic nucleus. As evidence of this, we find that all nuclei having more than 83 protons are radioactive. Furthermore, the superheavy elements, such as those above uranium, atomic number 92, are not found in nature. These superheavy elements are difficult to make in the laboratory. When they are produced, they exist for only fractions of a second.

Nuclear Transmutations

In 1919, Ernest Rutherford performed the first conversion of one nucleus into another, using alpha particles emitted by radium-226 (atomic number 88) to convert nitrogen-14 into oxygen-17

$$^{14}_{7}\text{N} + ^{4}_{2}\text{He} \longrightarrow ^{17}_{8}\text{O} + ^{1}_{1}\text{H}$$

$$\text{or} \quad ^{14}_{7}\text{N} + \alpha \longrightarrow ^{17}_{8}\text{O} + \text{p}$$

A nucleus may decay spontaneously or it can change identity if it is **struck by a neutron or by another nucleus**. Nuclear reactions induced in this way are known as **nuclear transmutations**. **Such reactions have allowed scientists to synthesize hundreds of radioisotopes in the laboratory.**

Writing Nuclear Equations for Nuclear Transmutations

A shorthand notation often used to represent nuclear transmutations lists the target nucleus, the bombarding particle and the ejected particle in parentheses, followed by the product nucleus.

$$^{14}_{7}\mathrm{N} + \alpha \longrightarrow {}^{17}_{8}\mathrm{O} + \mathrm{p}$$

Target nucleus

Product nucleus

$$^{14}_{7}\mathrm{N}(\alpha, \mathrm{p})^{17}_{8}\mathrm{O}$$

Bombarding particle

Ejected particle

Most synthetic isotopes used in medicine and scientific research are made using **neutrons as the bombarding particles.**

For example, cobalt-60, which is used in cancer radiation therapy, is produced by neutron capture. Iron-58 is placed in a nuclear reactor and bombarded by neutrons to trigger the following sequence of reactions:

$$^{58}_{26}\mathrm{Fe} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{59}_{26}\mathrm{Fe}$$

$$^{59}_{26}\mathrm{Fe} \longrightarrow {}^{59}_{27}\mathrm{Co} + {}^{0}_{-1}\mathrm{e}$$

$$^{59}_{27}\mathrm{Co} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{60}_{27}\mathrm{Co}$$

Write the balanced nuclear equation for the process summarized as $^{27}_{13}\mathrm{Al}(\mathrm{n}, \alpha)^{24}_{11}\mathrm{Na}$.

Transuranium Elements

Nuclear transmutations have been used to produce the elements with **atomic number above 92**, collectively known as the **transuranium elements**

$$^{238}_{92}U + ^{1}_{0}n \longrightarrow ^{239}_{92}U \longrightarrow ^{239}_{93}Np + ^{0}_{-1}e$$

$$^{239}_{93}Np \longrightarrow ^{239}_{94}Pu + ^{0}_{-1}e$$

Elements with still larger atomic numbers are normally formed in small quantities.

The International Union for Pure and Applied Chemistry (**IUPAC**) **authorizes names** of new elements after their experimental discovery and confirmation.

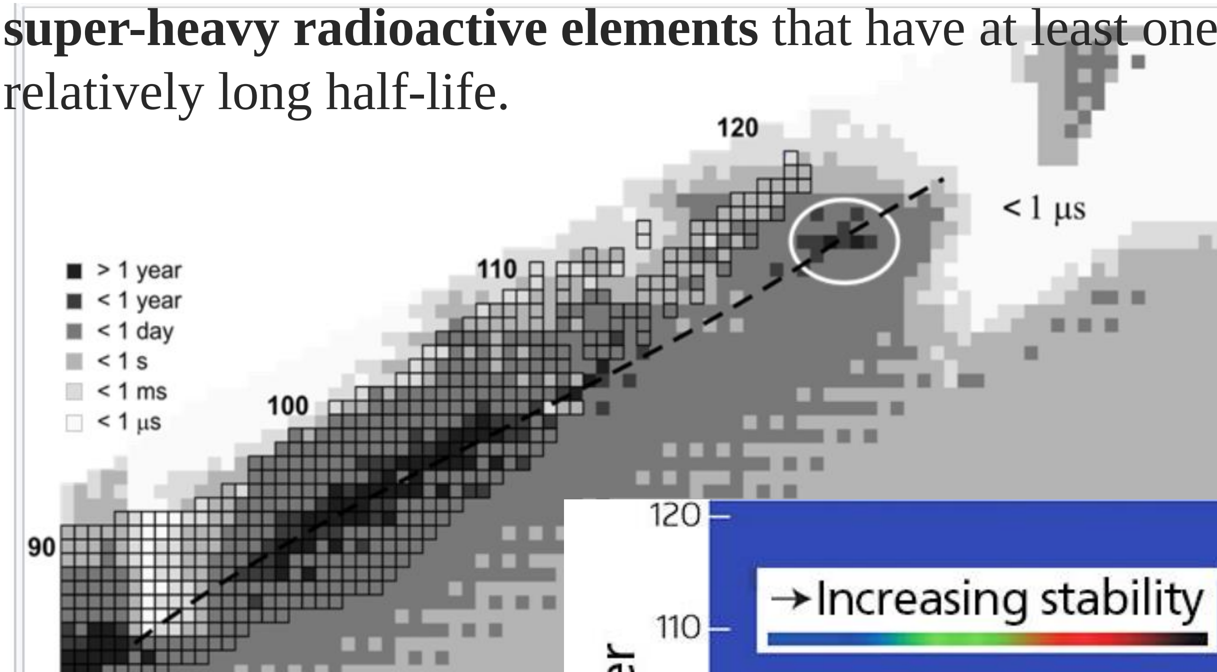
New elements can be named after a *mythological concept*, a mineral, a place or *country*, a property, or a scientist.

In 2016, IUPAC approved the following names and symbols as suggested by their discoverers: nihonium, Nh, for element 113; moscovium, Mc, for element 115; **tennessine, Ts, for element 117**; and organesson, Og, for element 118.

The synthesis of element 117 serves as definite **proof of** the existence of the **"island of stability".**

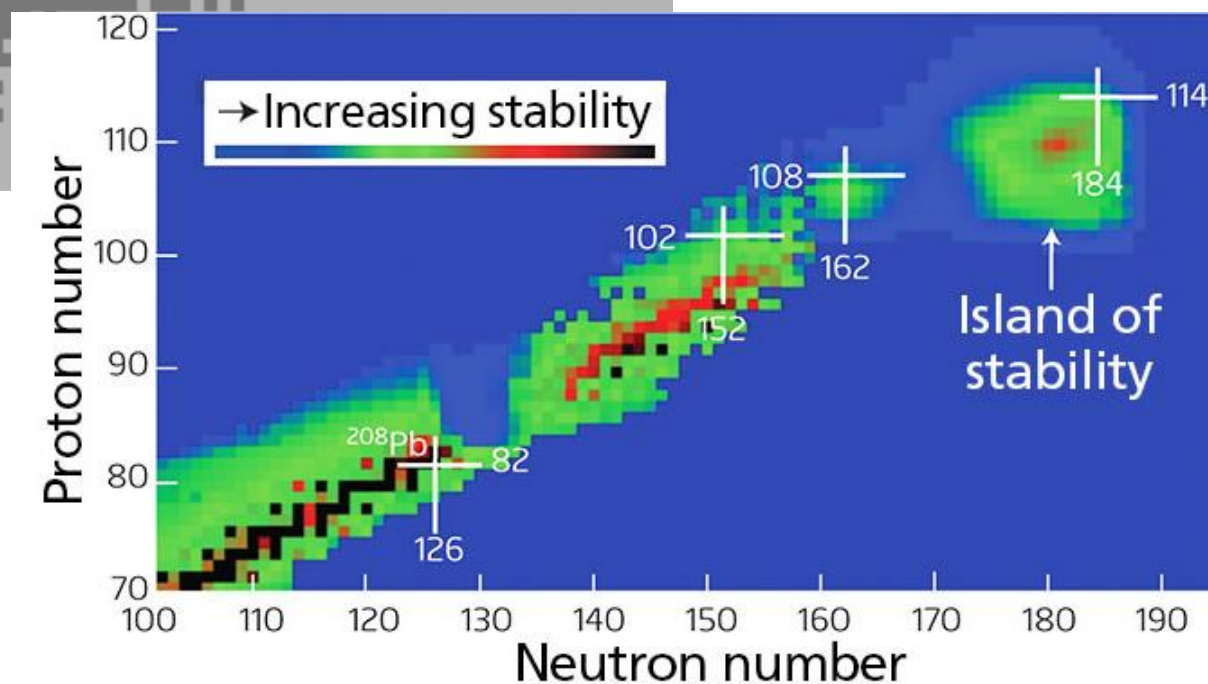
Existence of "Island of Stability from tennessine, Ts (element 117)

The **island of stability** refers to a region of the periodic table consisting of **super-heavy radioactive elements** that have at least one isotope with a relatively long half-life.



Ts-294:

n/p = = 1.513



FYI

$_{95}Am$

The only element beyond uranium to find a commercial application is americium, Am, which is a key component of nearly all household smoke detectors. This element completes an electric circuit by ionizing air within a chamber. Smoke particles interfere with this ionization, thus breaking the circuit and triggering the alarm.

^{241}Am and/or ^{243}Am ?

Write a nuclear equation for the decay of americium.