Nuclear Stability

On p. 240, Moore gives us a graph of binding energy per nucleon for many isotopes. The graph gets cluttered if you include the more than 300 stable isotopes, so he has only included selected ones.

He has put binding energy per nucleon in MeV as the vertical axis (you will often see the axis upside down), so that the most stable nuclei are the lowest. In Moore's graph, the most stable nuclei are the highest.

We need to understand why Moore graphed binding energy per nucleon and not binding energy.

Consider Pu-239

Plutonium-239 is easy to make in reactors:

$$^{238}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{239}_{92}\mathrm{U} \xrightarrow[23.5\ \mathrm{min}]{\beta^-} {}^{239}_{93}\mathrm{Np} \xrightarrow[2.356\ \mathrm{d}]{\beta^-} {}^{239}_{94}\mathrm{Pu}$$

Since you get a different element, not just a different isotope from this process, it is easy to separate too.

A Simple Example

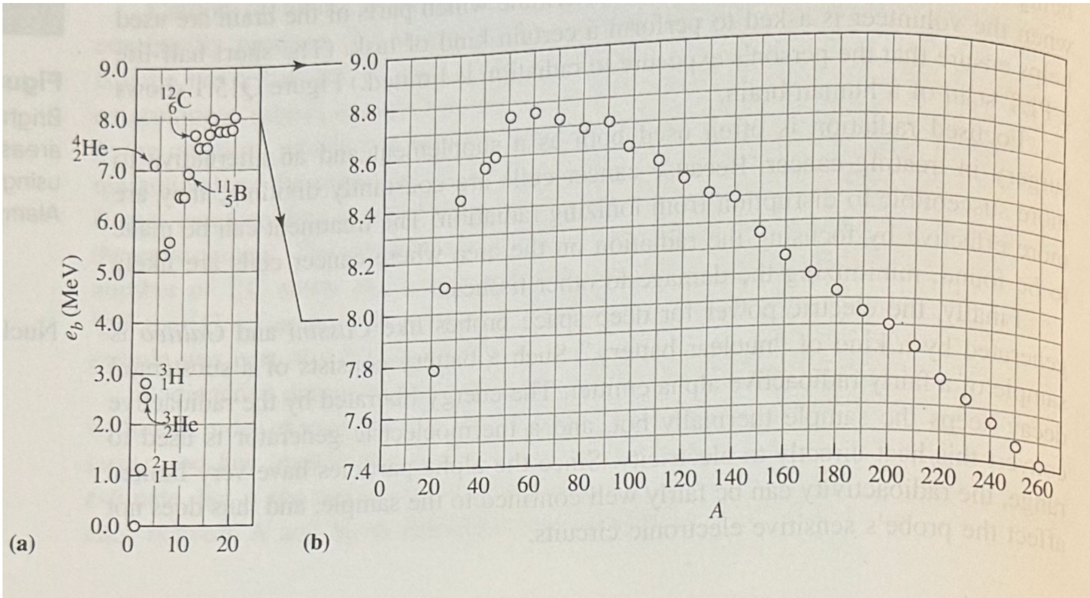
Let's imagine, for simplicity that Pu-239 fissioned into two nuclei (the "products") with Z=47 and A=118, with three neutrons to spare that go on and do additional fissions.

The binding energy of Plutonium is about 1800 MeV.

The binding energy of nuclei with A = 118 is about 1000 MeV.

Put those two data points on a graph: (239, 1800) and (118, 1000). It wouldn't be the slightest bit obvious just looking at the graph that this releases energy.

Moore’s Graph



A Simple Example

Using Moore’s graph, which graphs binding energy per nucleon, rather than binding energy, Pu-239 is at about (239, 7.55), and our imagined decay products are at about (118, 8.48), and because the binding energy per nucleon is higher, it is apparent that this fission releases energy

An Actual Example

Let’s do a more interesting, actual example, rather than my imagined simple one:

$$^{1}_{0}n + {}^{239}_{94}Pu \rightarrow [{}^{240}_{94}Pu] \xrightarrow{73\%} fission\ (e.g.\ {}^{134}_{54}Xe + {}^{103}_{40}Zr + 3\ {}^{1}_{0}n)$$

On Moore’s graph Xenon-134 and Zirconium-103 have higher binding energy per nucleon than Plutoni-um-239.

Can we estimate how much energy this fission releases?