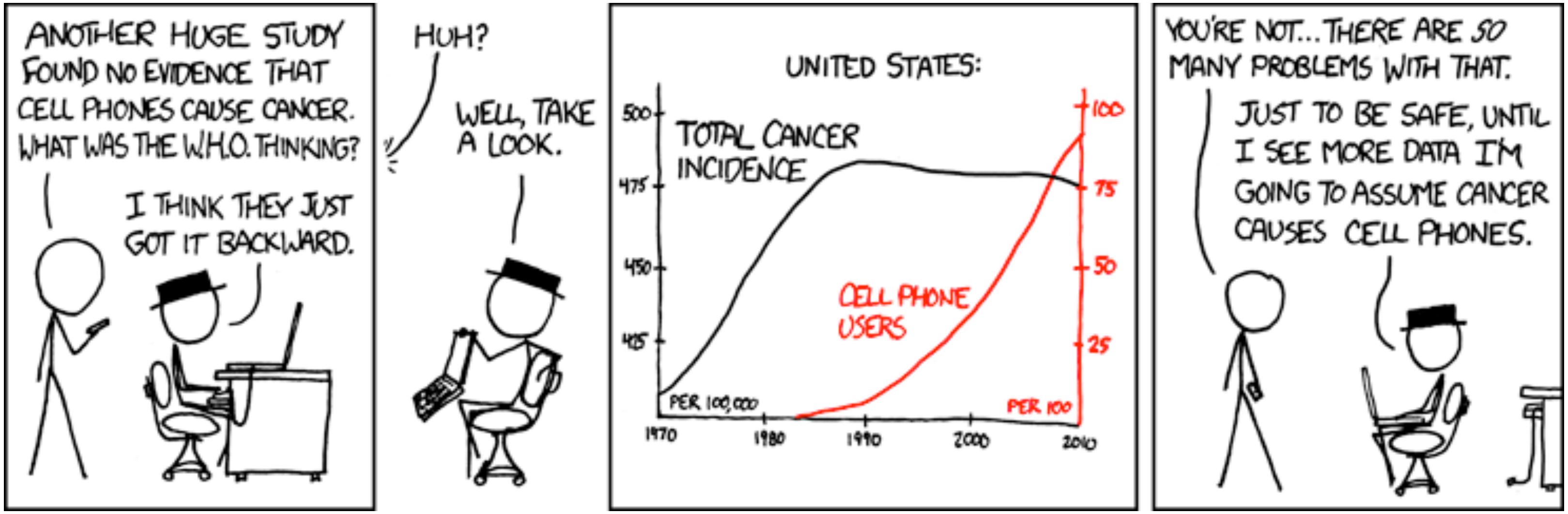


http://imgs.xkcd.com/comics/cell_phones.png

Announcements:

Thursday: Group A to Hayes 105 for hands-on experience
Group B comes here to work on worksheet

Next Tuesday (9/20/2016):

In class quiz!

- ½ hour at end of class
- covers material on worksheet
- will need calculator
- no laptops, phones allowed

My office hours: M 1:10-2PM, T 10:10-11AM, TWTh 4:10-5PM
Gordon Loveland: TTh 1:30-2:30PM, drop by or make appointment

Conservation of Energy

Kinetic Energy: is energy associated with motion (on microscopic scale) with heat and pressure (on macroscopic level)

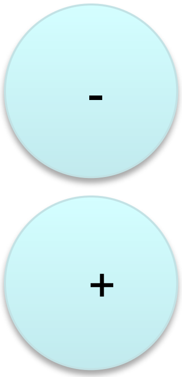
Potential Energy: is energy associated with relative position

Conservation of energy states that the sum or kinetic and potential energy is a constant, so changes in one cause the opposite change in the other

High potential energy,
low binding energy

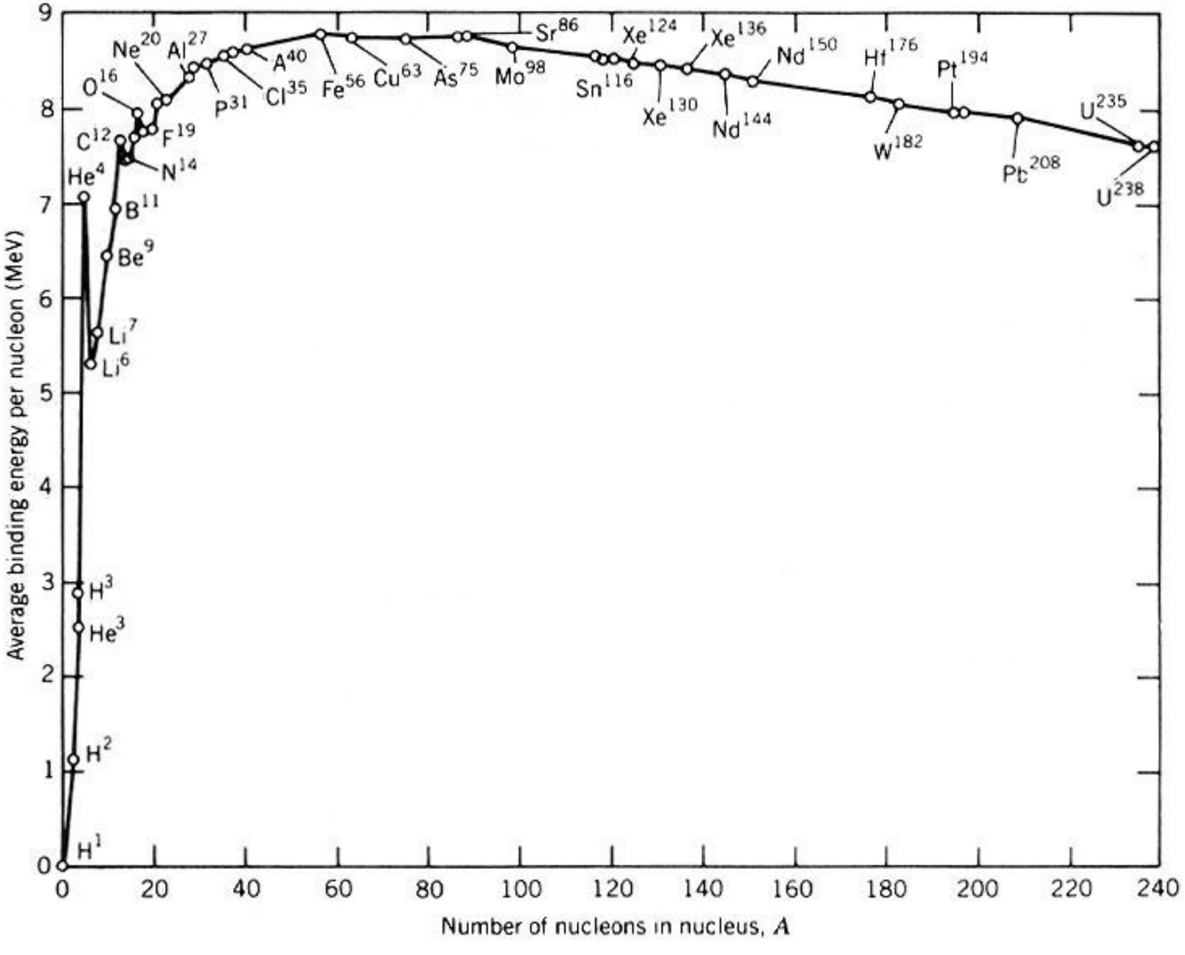
Binding energy is the negative of potential energy, so increasing binding energy means decreasing (more negative) potential energy, means increasing kinetic energy.

Low potential energy,
high binding energy



Binding energy is the energy that it takes to pull particles apart.

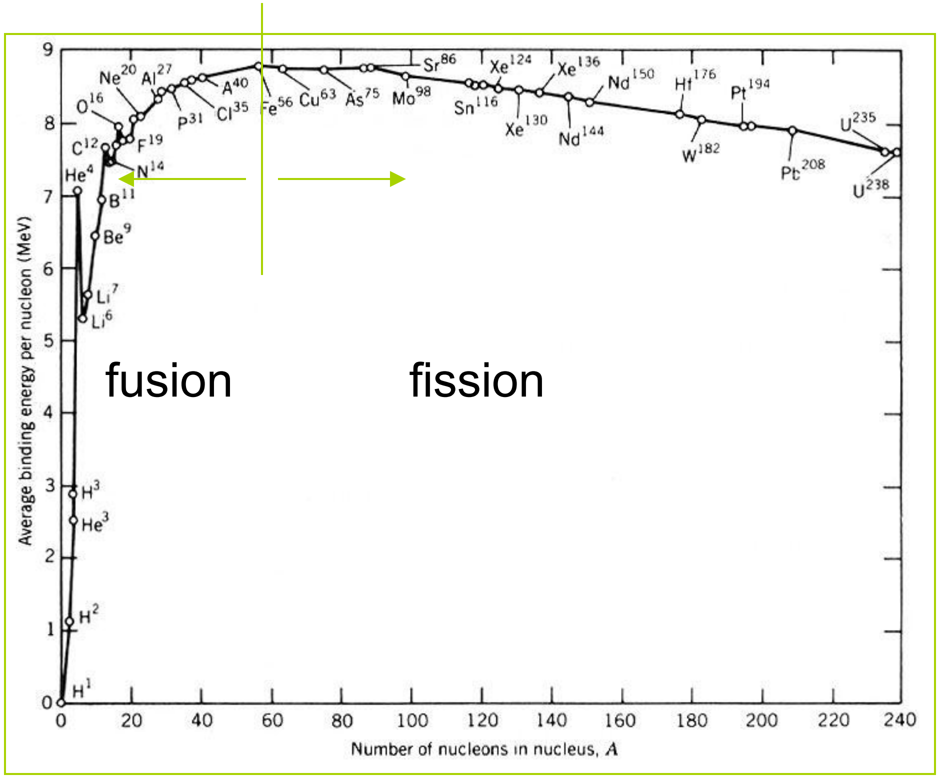
A useful quantity is the average binding energy of a particle in the nucleus, *a.k.a.* the binding energy/nucleon. The “Curve of Binding Energy”



Why useful? Can tell at a glance whether energy is going to be released if you split a nucleus *(fission)* or combine two nuclei *(fusion)*.

If the total binding energy increases, then energy is released in form of heat and pressure.

In the nuclear reactions to be considered, the total number of nucleons will be the same before and after the reaction, so the average binding energy and total binding energy are proportional.



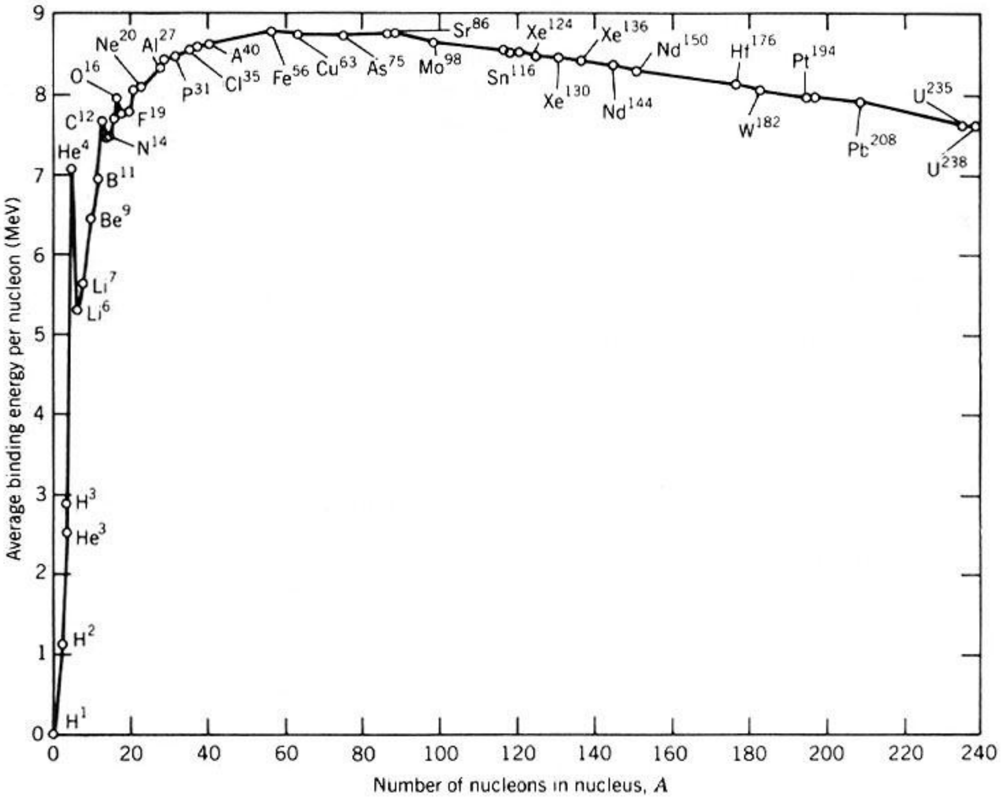
fusion

fission

What sets shape of the curve of binding energy?

For small nuclei, small number of protons so relatively weak repulsion, small number of nucleons, so relatively weak attraction by strong force.

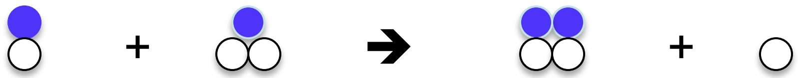
For large nuclei, large number of protons so relatively strong repulsion, short range of strong force means saturation of strong force.



Ex: D-T (deuterium-tritium) fusion

Combine deuterium ^2_1D (= ^2_1H) and tritium ^3_1T (= ^3_1H) to form ^4_2He and a neutron.

$$^2_1H + ^3_1H \rightarrow ^4_2He + n^0$$



This is the reaction used in the *hydrogen bomb.* Also the reaction scientists want to use in *controlled thermonuclear fusion*. Hard to overcome electric repulsion between nuclei. In bomb, use fission to produce fusion.

Can calculate energy released using Einstein's $E=mc^2$:

(data from www.webelements.com)

Mass of deuterium: 2.014101779 amu
Mass of tritium: 3.01604927 amu

Total mass before reaction: 5.030151049 amu

Mass of helium-4 4.00260324 amu
Mass of neutron 1.0086649 amu

Total mass after reaction: 5.01126814 amu

Change in mass: 0.018882909 amu

If the total mass after the reaction is less than the total mass before the reaction, then energy is released in the reaction.

Energy released (0.018882909 amu)x(931.5 MeV/amu) = 17.59 MeV.

An *electron-volt (eV)* is the kinetic energy a proton (or electron) acquires in accelerating through an electric potential difference of 1V.

Convenient unit of energy on atomic/nuclear scale.

Typical chemical reaction energy releases are about 1 eV.

Typical nuclear energy releases are about 1 MeV.

Fusion in stars:

Different fusion cycles depending on the mass and phase of life of a star:
the Sun is in the first stage (hydrogen burning)

$$ {}_{1}^{1}H + {}_{1}^{1}H \rightarrow {}_{1}^{2}H + e^{+} + \nu_{e} $$

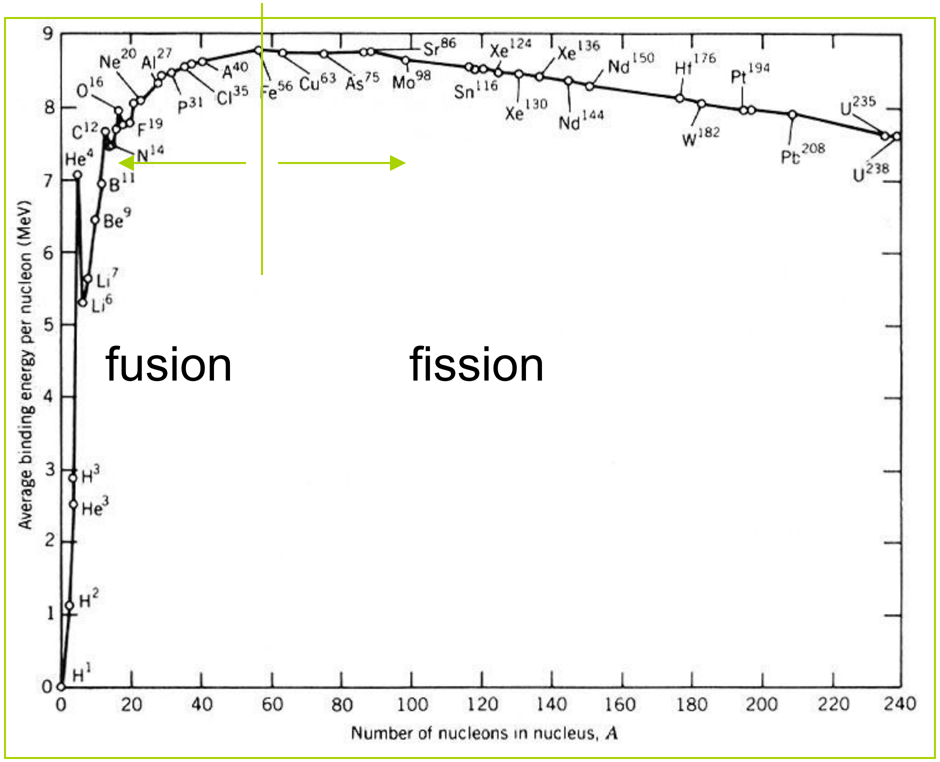
$$ {}_{1}^{2}H + {}_{1}^{1}H \rightarrow {}_{2}^{3}He + \gamma $$

$$ {}_{2}^{3}He + {}_{2}^{3}He \rightarrow {}_{2}^{4}He + 2\,{}_{1}^{1}H $$

Later stages produce heavier elements, but curve of binding energy limits fusion to create elements only up to iron-56

No massive elements made in Big Bang. Only supernovas create more massive elements than iron-56. We are made of more massive elements.

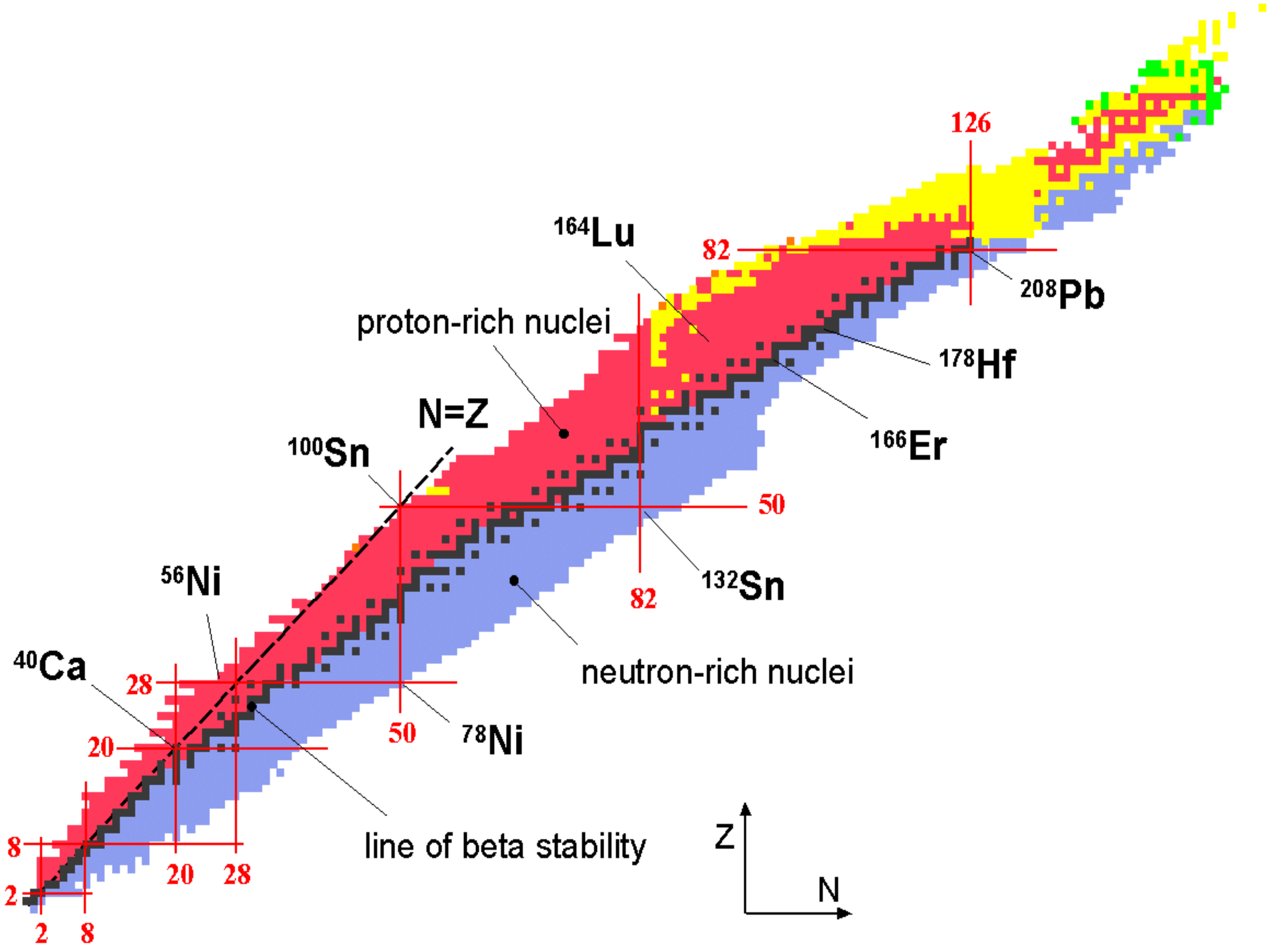
Therefore, we are made of stardust! The result of an ancient supernova.



fusion

fission

Recall: rare solution to problem of too many protons is *spontaneous fission.*



Key to getting useful energy from fission is some process that causes fission To happen in a controlled way. The path was open when the phenomena of *neutron-induced fission* was discovered.

E.g., $$n^0 + {}^{235}_{92}U \rightarrow {}^{102}_{42}Mo + {}^{131}_{50}Sn + 3n^0$$

Nuclei that can undergo neutron-induced fission are called *fissionable.*

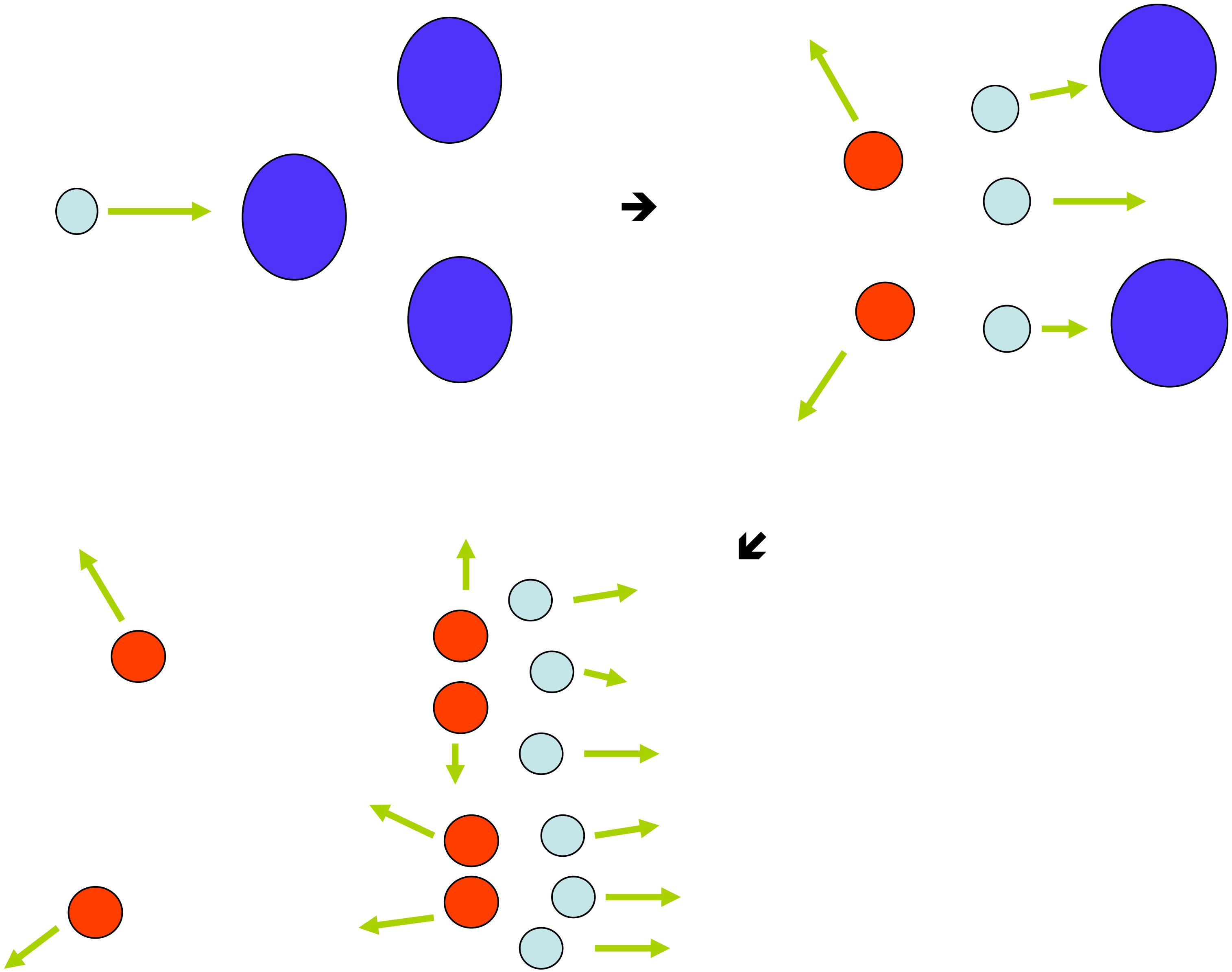
But key distinction: most fissionable nuclei require energetic neutrons *(fast neutrons)* in order to fission. Turns out, hard to create sustained reaction with these nuclei.

But some nuclei will fission with even low energy neutrons *(slow neutrons)* and these nuclei are called *fissile.*

Key fact: Only three! ($^{233}_{92}$U, $^{235}_{92}$U, $^{239}_{94}$Pu) Only one naturally occurring!

Others can be produced in nuclear reactors.

Cartoon chain reaction



Energy release in “typical” fission reaction

$$n^0 + {}^{235}_{92}U \rightarrow {}^{102}_{42}Mo + {}^{131}_{50}Sn + 3n^0$$

Mass of neutron: 1.0086649 amu
Mass of U-235: 235.0439242 amu

Total mass before reaction: 236.0525891 amu

Mass of Mo-102: 101.9102972 amu
Mass of Sn-131 130.9169191 amu
Mass of neutrons 3.0259947 amu

Total mass after reaction: 235.853211 amu

Change in mass: 0.1993781 amu

Energy released = (0.1993781 amu)x(931.5 MeV/amu) = 185.7 MeV

Reaction products neutron rich, so radioactive