Fission & Fusion (ch. 15) - the incredible might of **$E = mc^2$**

Nuclear Energy Curve – gaining E from fusion or fission
Chain Reaction
    Critical Mass
    Nuclear Weapons

Three important addenda to last class:

1) Strong/nuclear force, while strong, is very short-ranged (~10^{-15}m)

2) Apart from $F_{nuclear}$, $F_{Coulomb}$ also matters *significantly* in nuclei. Why?

3) More n(eutrons) than p(rotons) in heavy nuclei. Why?

Fusion (the fire of stars): two *light* nuclei stick together, releasing $E_{thermal} + E_{radiation}$

Fission: one *heavy* nucleus splits into two (or more) lighter nuclei, again releasing $E_{thermal} + E_{radiation}$

Simple example of fusion: formation of the d(euteron) = ${}^{2}_{1}H$, (as atom called "deuterium"). Also a reminder of the concept of $E_{binding}$.

(Analog: 2 bar magnets)

$n + p \rightarrow d$ (= ${}^{2}_{1}H$) + $E_{radiation}$ (a 2.2 MeV photon)

So…..how's m_d (rest mass m_0 !) related to $m_p + m_n$(again, m_0) ?

More relevant for fusion in the sun: $p + d \rightarrow {}^{3}_{2}He$ + energy

→ Why does this reaction require the intense heat inside the sun?

Even heavier H isotope: ${}^{3}_{1}H$ (= triton t, as atom "tritium")

$d + t \rightarrow {}^{4}He + n$ is the H-bomb reaction (& eventually in fusion reactor, perhaps in your lifetime??)

Nomenclature: superscript = # of (n + p) subscript = # of p

Example: ${}^{14}_{6}C$ - how many p, how many n? (and how many e^- ?)

Quiz # 107: Is $F_{Coulomb}$ between a p(roton) and a d(euteron) always repulsive?

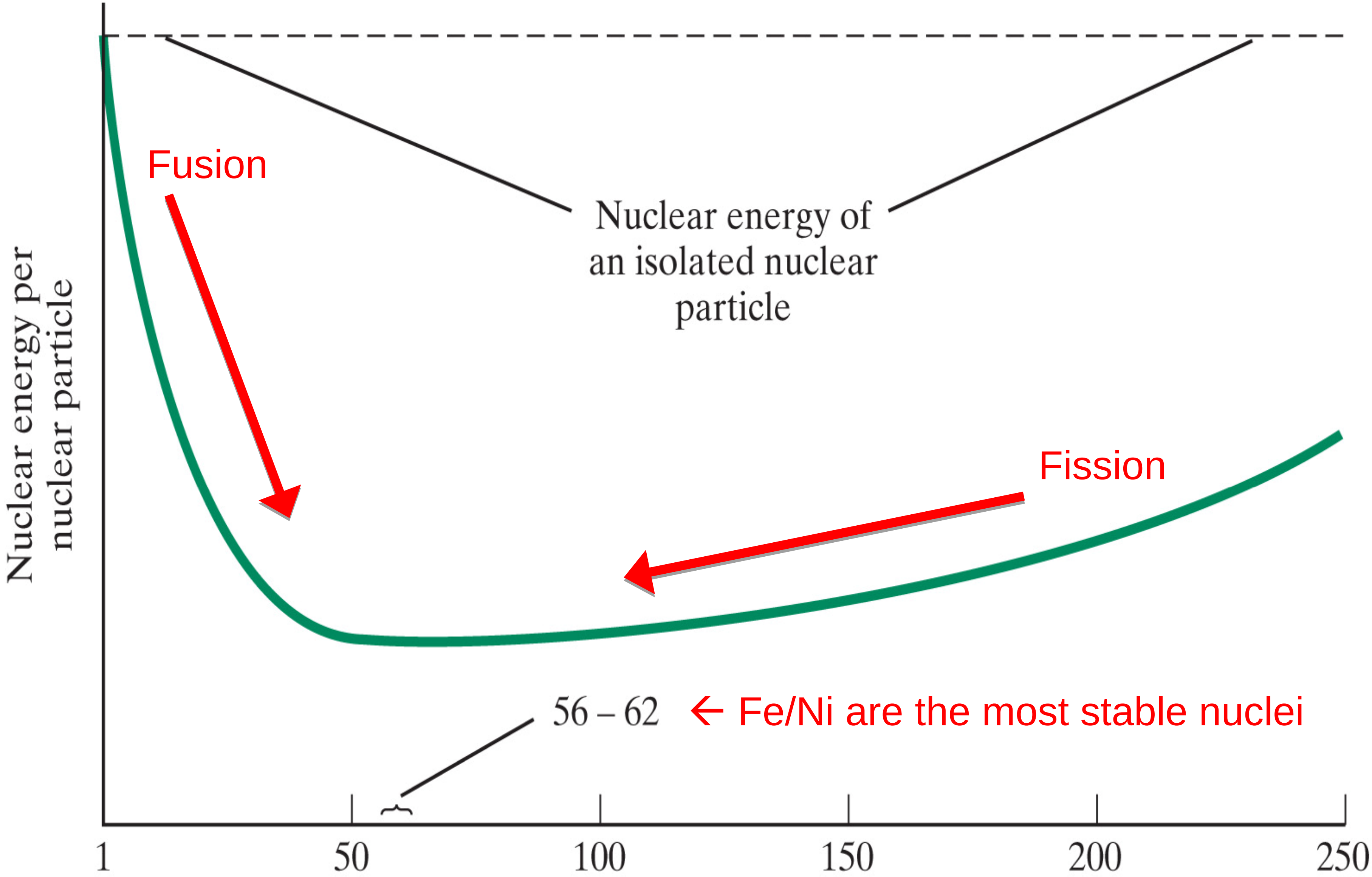
(a) yes (b) no (c) depends on distance (d) it's zero

Quiz # 108: ${}^{1}H$ (= p) and ${}^{2}H$ (= d) fuse. The element created is

(a) H again (b) He (c) Li (3rd element in periodic table)

(d) something heavier than Li

It’s all in the “nuclear energy curve” – energy per proton or neutron:

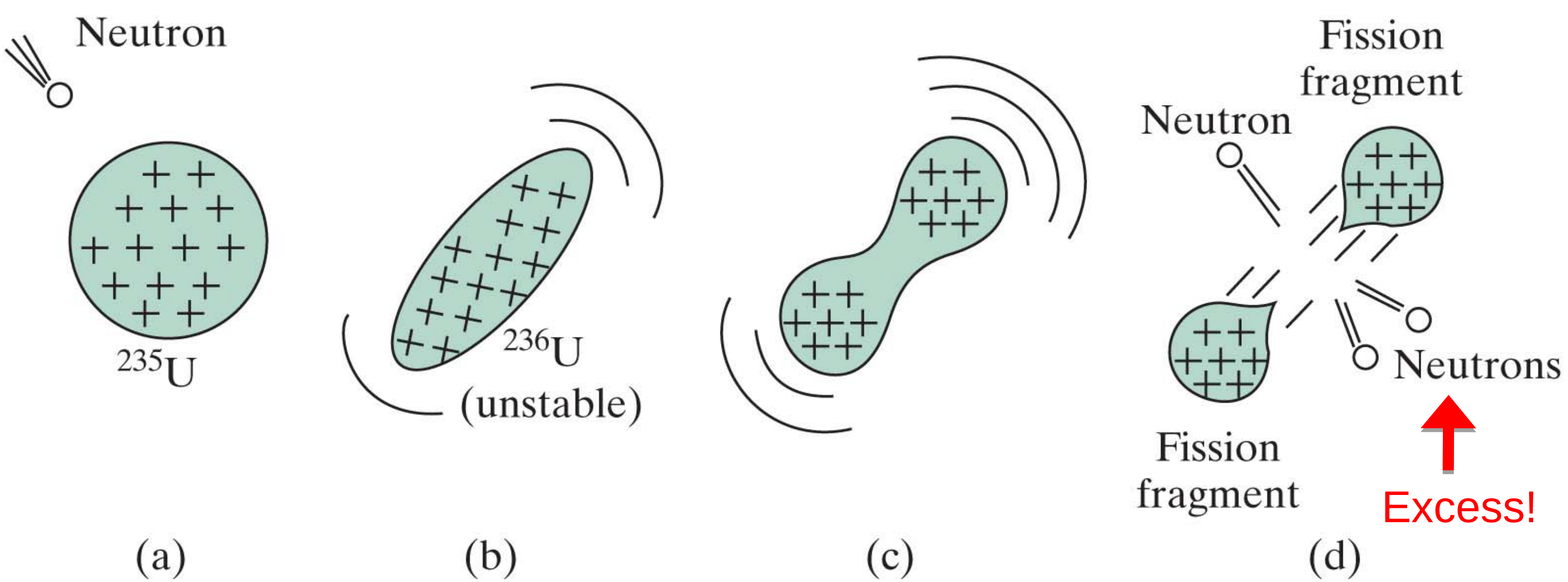


→ Nuclear energy can be released by the fusion of light nuclei but also by the fission of heavy nuclei.

Read about the cosmological origin of all but the three lightest elements (hydrogen, helium, lithium), 15.3, and also the utterly fascinating history of the discovery of fission in the 1930s, 15.4.

→ We're made of exploding star stuff!

Fission: crucial role of *neutron* (discovered in 1932) – zero charge!



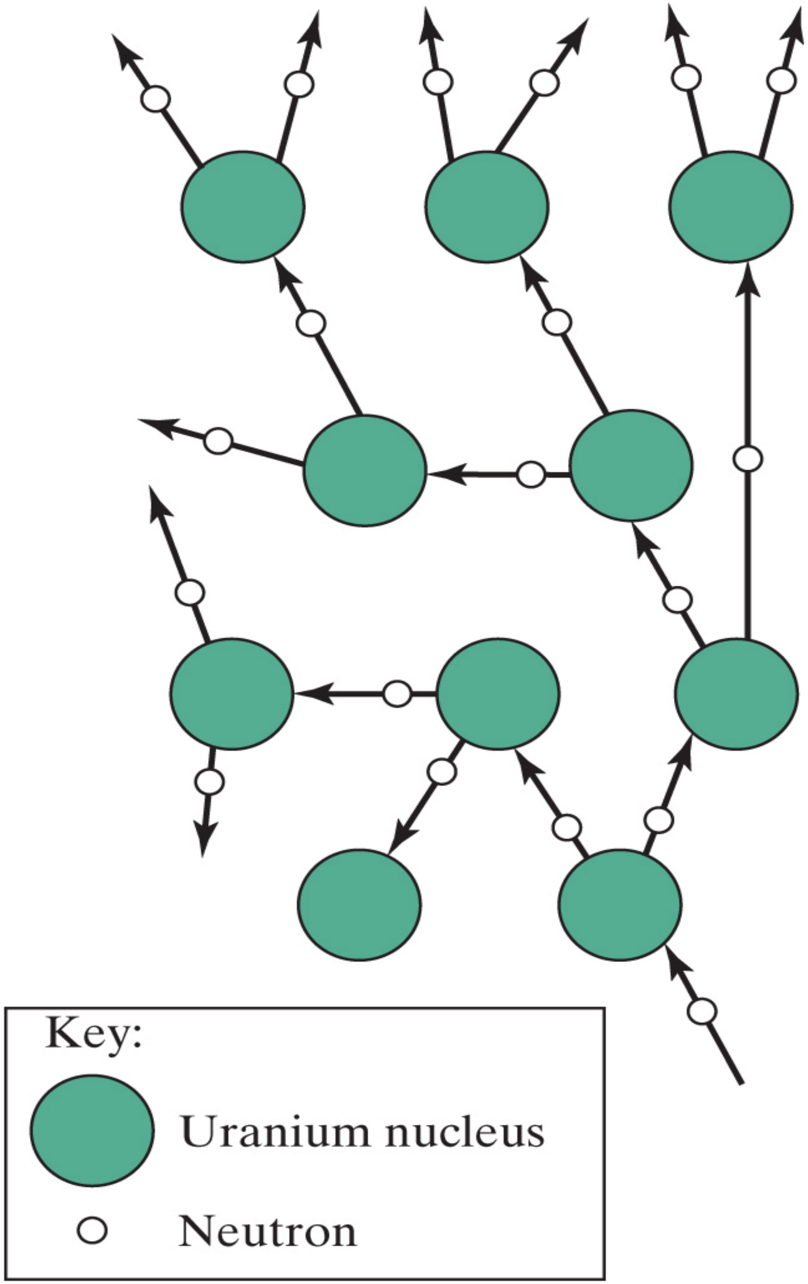
Chain Reaction

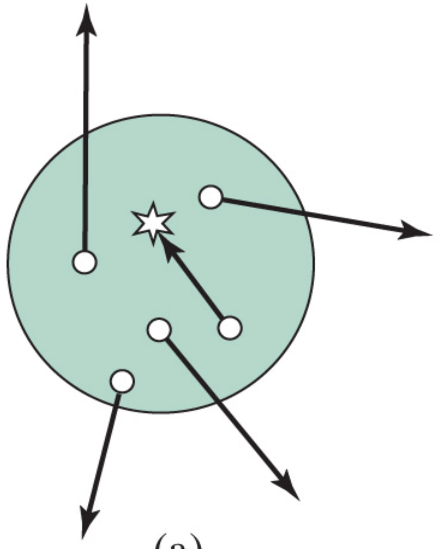
Remarkable fact: excess neutrons, and hence possibility of large-scale fission, exists for only one naturally occurring isotope: ^{235}U (<1% in natural U!)

→ U enrichment issues (see plenty of international politics!)

Non-naturally occurring ^{239}Pu also yields excess neutrons.

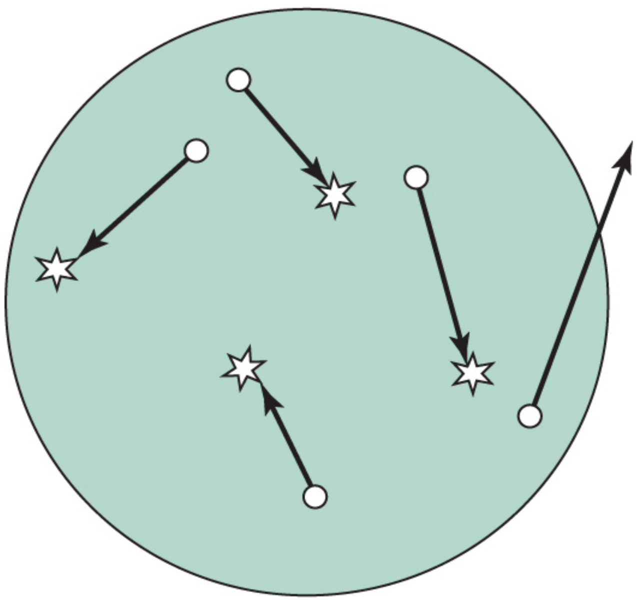
And both isotopes can be used for fission bombs.





Critical Mass

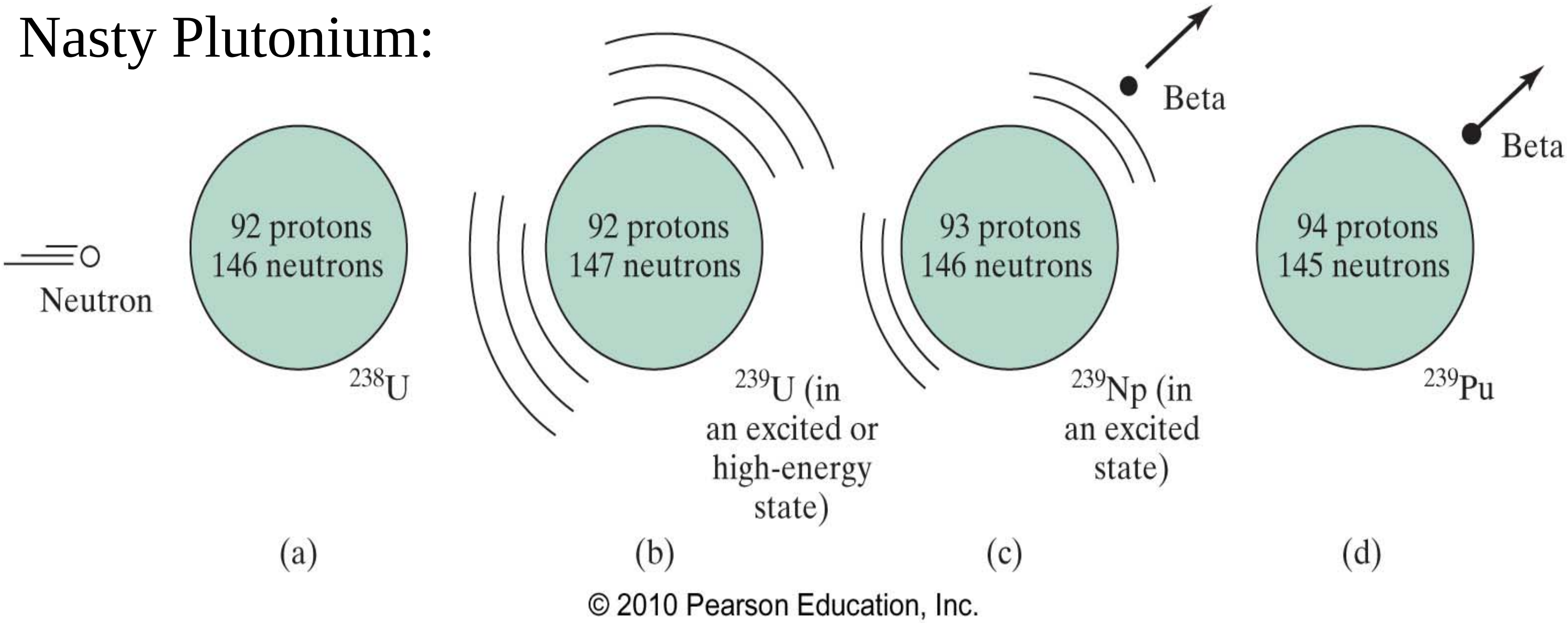
Lump too small: most neutrons escape, no sustained chain reaction



Lump large enough: most neutrons will strike other nuclei before escaping, triggering a chain reaction

Only ~25 kg needed for ^{235}U, and only ~8 kg for ^{239}Pu!

Nasty Plutonium:



Manhattan Project: must read for NM students & residents!

→ Go visit the Trinity site on White Sands Missile Range. Nowadays only mildly radioactive.

→ Do read the remainder of ch. 15 on nuclear weapons and nuclear terrorism. Related issues will remain relevant for our societies for many years to come, for instance the threat of a "dirty bomb".