Conceptual Physics
Nuclear Physics

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Aug 9, 2017

Overview

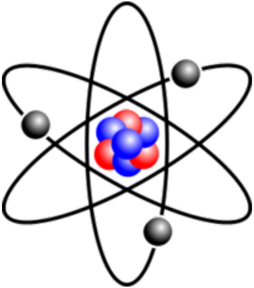
- strong nuclear force
- binding energy and mass defect
- types of nuclear decay
- nuclear fission

Atomic Structure

Atoms have a compact nucleus composed of **protons** and **neutrons**.

The nucleus therefore has an overall positive charge.

A cloud of electrons surrounds the nucleus, attracted by the electrostatic force.



[1]Figure from Wikipedia.

The Nucleus

Why is there an atomic nucleus? Why does it stick together?

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(Positive charges should repel each other.)

Nuclear researchers suggested there should be a "strong force" (stronger than electric repulsion) that would hold the nuclear particles together.

The Fundamental Forces

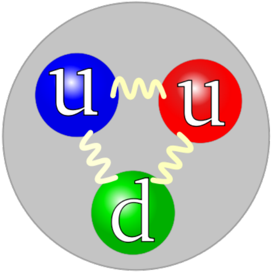
Force	$\sim$ Rel. strength	Range (m)
Gravitational	10^{-38}	∞
Electromagnetic	10^{-2}	∞
Weak Nuclear	10^{-13}	$< 10^{-18}$
Strong Nuclear	1	$< 10^{-15}$

The strong nuclear force holds the nucleons together, overcoming the electrical repulsion.

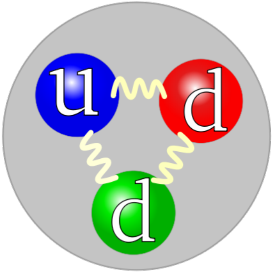
It is sometimes called the *residual strong force* because the fundamental strong interaction actually holds **quarks** together to make up protons and neutrons.

Neutrons and Protons

Proton



Neutron

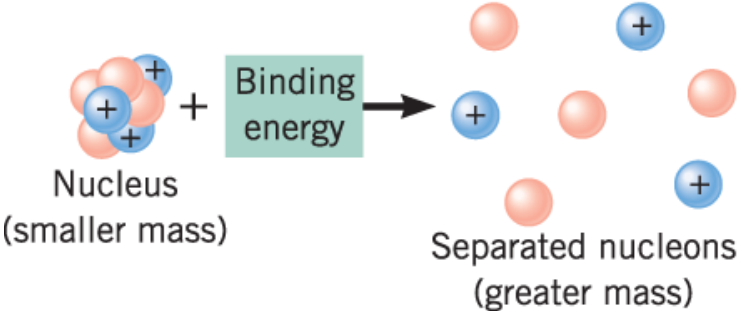


The fundamental strong interaction holds **quarks** together to make up protons and neutrons.

[1]Figures by Arpad Horvath, Wikipedia.

Binding Energy

The binding energy is the amount of energy needed to separate bound particles into individual free particles.



Mass Defect

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(Einstein – 1905)

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$\rightarrow$ **Yes.**

$$E = mc^2$$

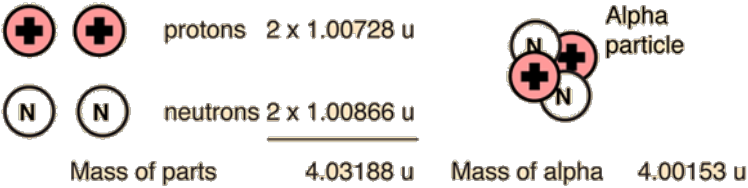
Bound systems have less inertia (relativistic mass) than the sum of the masses of their parts.

$$E_{\text{bind}} = (\Delta m)c^2$$

Δm is the mass defect.

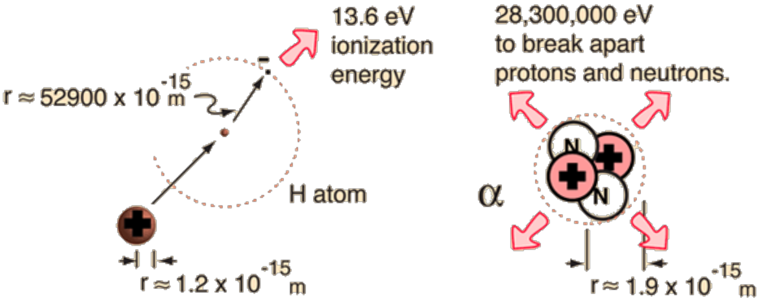
Mass Defect

The atomic mass unit (u) is 1/12 of the mass of a carbon-12 atom.



$1 \text{ u} = 1.66054 \times 10^{-27} \text{ kg} = 931.494 \text{ MeV/c}^2$

Binding Energy

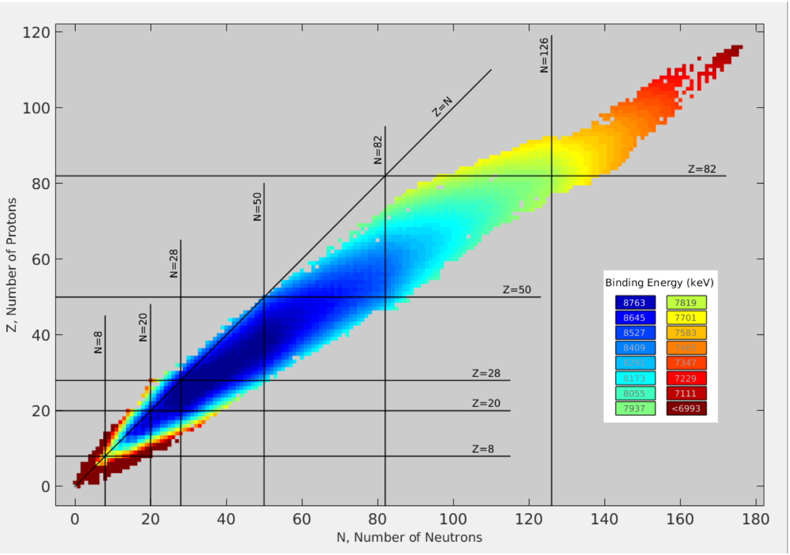


Comparison of atomic and nuclear scales and binding energy

H Atom:
$\Delta m = 2.45 \times 10^{-35}$ kg
(negligible)

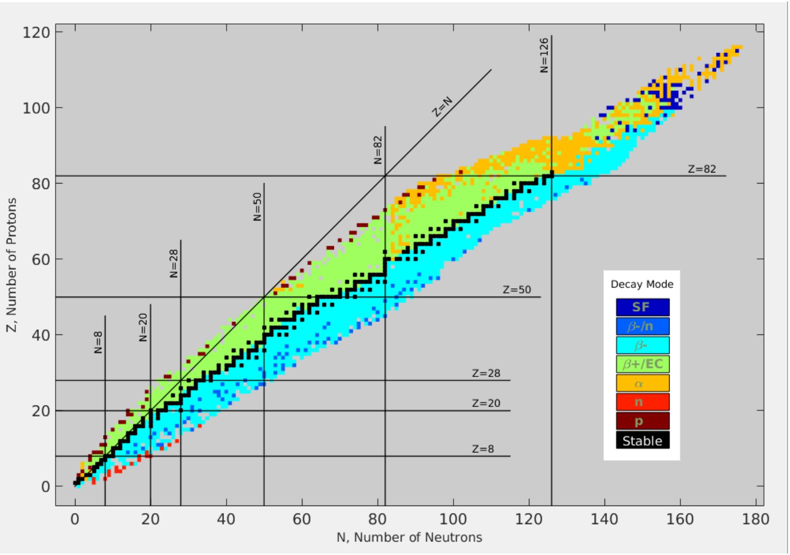
He Nucleus:
$\Delta m = 5.09 \times 10^{-29}$ kg

Binding Energy Per Nucleon



[1]Figure from Wikipedia, user Bdushaw.

Nuclear Stability and Decay Modes



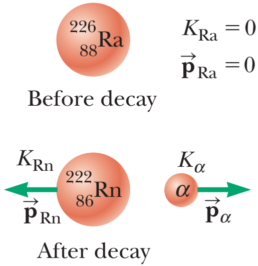
[1]Figure from Wikipedia, user Bdushaw.

Types of Radioactive Decay: α decay

A nucleus loses 2 protons and 2 neutrons, forming a new lighter element and ejecting and α particle (He nucleus).

Example, Radium transmutes to Radon:

$$^{226}_{88}\text{Ra} \rightarrow ^{222}_{86}\text{Rn} + ^{4}_{2}\text{He}$$



Alpha-emitters are used in smoke detectors.

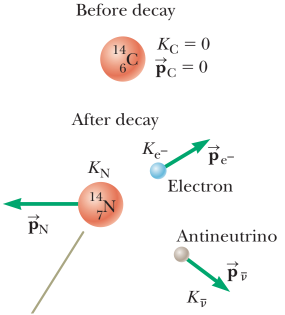
Types of Radioactive Decay: β decay

Neutrons are a little unstable.

A neutron decays to a proton and an electron (β particle) within a nucleus. The resulting nucleus has increased its atomic number by one.

Example, Carbon-14 transmutes to Nitrogen:

$$^{14}_{6}C \rightarrow\ ^{14}_{7}N + e^{-} + \bar{\nu}$$



Used for carbon dating of organic samples.

Types of Radioactive Decay: γ decay

Immediately after another radioactive process, for example alpha or beta decay, a nucleus can be left in an excited (high energy) state.

When that nucleus decays to a low energy state, it emits a high energy photon: a gamma ray.

$$^{12}_{6}\mathrm{C}^{*} \rightarrow ^{12}_{6}\mathrm{C} + \gamma$$

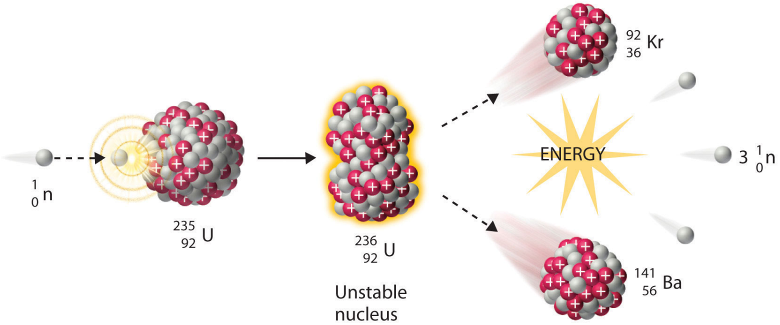
Used for medical imaging. Also to kill bacteria on food or medical equipment.

Nuclear Fission

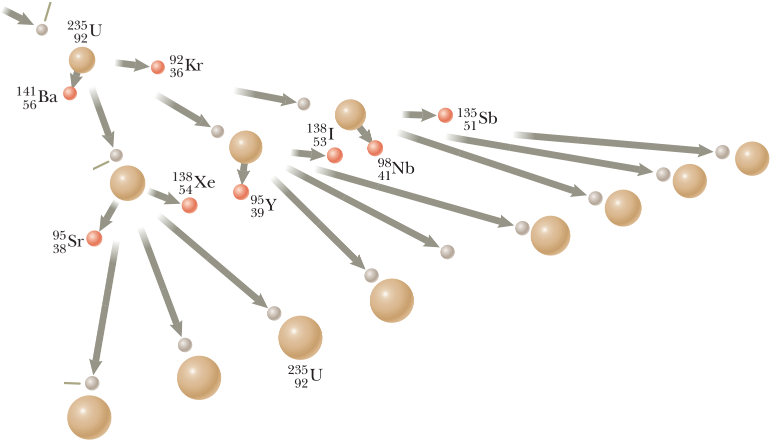
An large nucleus captures a free neutron. It splits into two more stable nuclei releasing a lot of energy.

Typical example:

$$ {}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3\left({}^{1}_{0}n\right) $$



Fission Chain Reaction



Fission Chain Reaction

[1]Photo, TVA Watts Bar Nuclear Power Plant, https://energy.gov/ne/nuclear-reactor-technologies

[2]http://www.atomicarchive.com/Effects/effects9.shtml

Summary

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- binding energy and mass defect
- types of nuclear decay
- nuclear fission

Final Thursday, Aug 10.