Phyx 320
Modern Physics

April 19, 2021

Reading: 42.1-42.4

Homework #12 Due Next Tuesday

Atomic Physics

Electrons are spin-1/2 particles

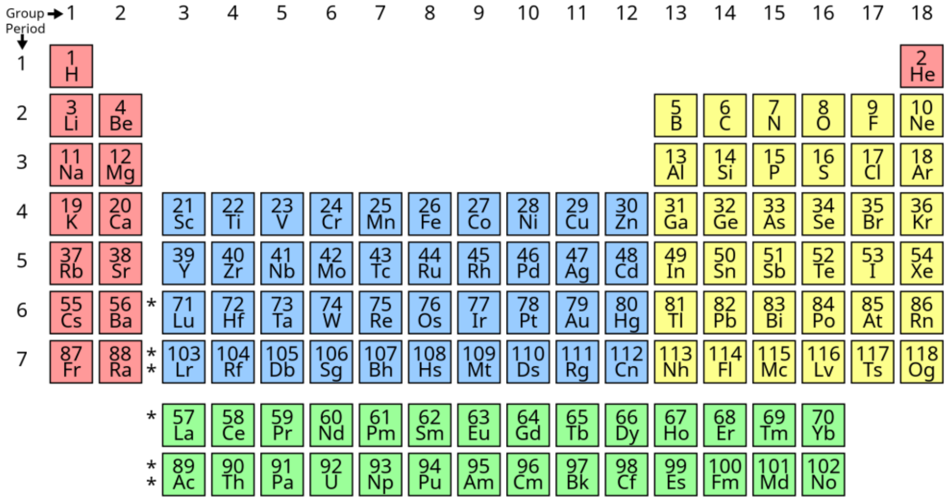
This makes it impossible to put two electrons in the same state (same quantum numbers)

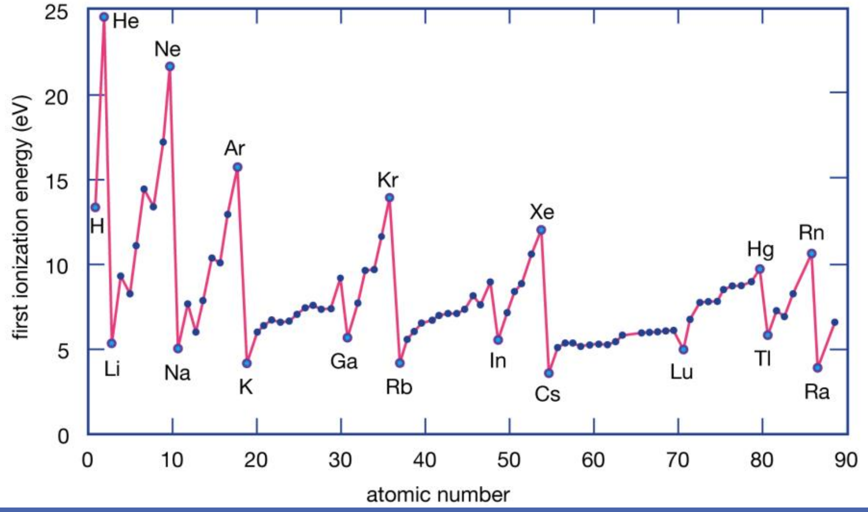
Causes each ground state of elements to have unique orbital structure

Electron orbital transitions leads to emission or absorption of photons

Photons can stimulate electron transitions to emit identical photon (stimulated emission)

This is exploited in a laser to make a coherent high-power beam of monochromatic light





Nuclear Structure

Atoms are made of electrons orbiting a nucleus

Nucleus is 1/10,000 the size of the atom

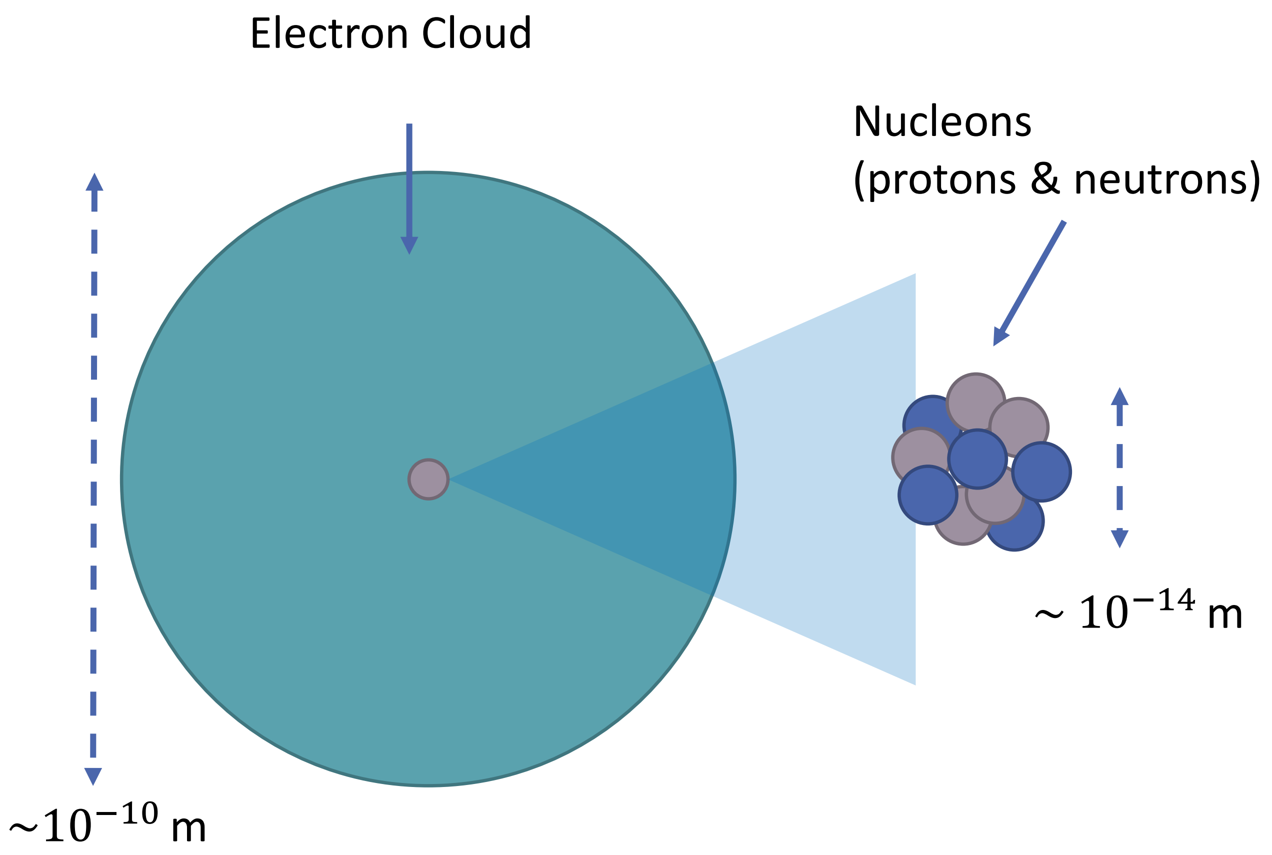
Nucleus is made up of nucleons:

- Proton – number: Z, charge: +e, spin: ½, mass: 938.3 MeV
- Neutron - number: N, charge: 0, spin: ½, mass: 939.6 MeV

Proton and neutrons also obey the Pauli exclusion principle

Atomic number (Z): # of protons

Mass number (A=Z+N): # of nucleons



Isotopes

Nuclei of a given element (Z) can have different number of neutrons (N)

The chemical properties are determined by the electrons but do not change with different number of neutrons

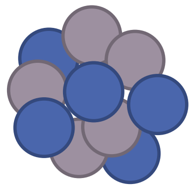
Almost all isotopes are unstable and eventually break down (radioactive)

Only 266 isotopes are stable

Since stable isotopes last forever, these are the most abundant isotopes we find naturally

The fraction of nuclei of a given isotope found in natural samples of an element is the isotopes natural abundance

Nucleons
(protons & neutrons)



Mass Number → ^{A}Z ← Element

Atomic Masses

Atomic masses are measured in two units

- Atomic mass units (u) – mass of ^{12}C = 12 u
  Protons and neutrons ≈ 1 u
- MeV/c^2 (MeV) – Using $E = mc^2$
  1 u = 931.49 MeV

The isotopes of hydrogen have special name

- ^2H: Deuterium – water made with deuterium is called heavy water
- ^3H: Tritium

The chemical atomic mass shown on the period table is the weighted average of the naturally occurring isotopes

Particle	Mass (MeV)
Electron (e)	0.51
Proton (p)	938.28
Neutron (n)	939.57
Hydrogen (^1H)	938.79
Deuterium (^2H)	1876.12
Helium (^4He)	3728.40

$m_p + m_n + m_e = 1877.58\ MeV$

Larger than mass of deuterium

Nuclear Density

The nucleus is very compact and has a sharp boundary unlike the electron cloud

The radius can be found with:

$$R = r_0 A^{1/3}$$

$$r_0 = 1.2\ fm = 1.2 \times 10^{-15} m$$

Since the radius is proportional to $A^{1/3}$ the volume of the nucleus is proportional to A

This means that:

- Nucleons are incompressible
- Nucleons are tightly packed
- Nuclear matter has a constant density

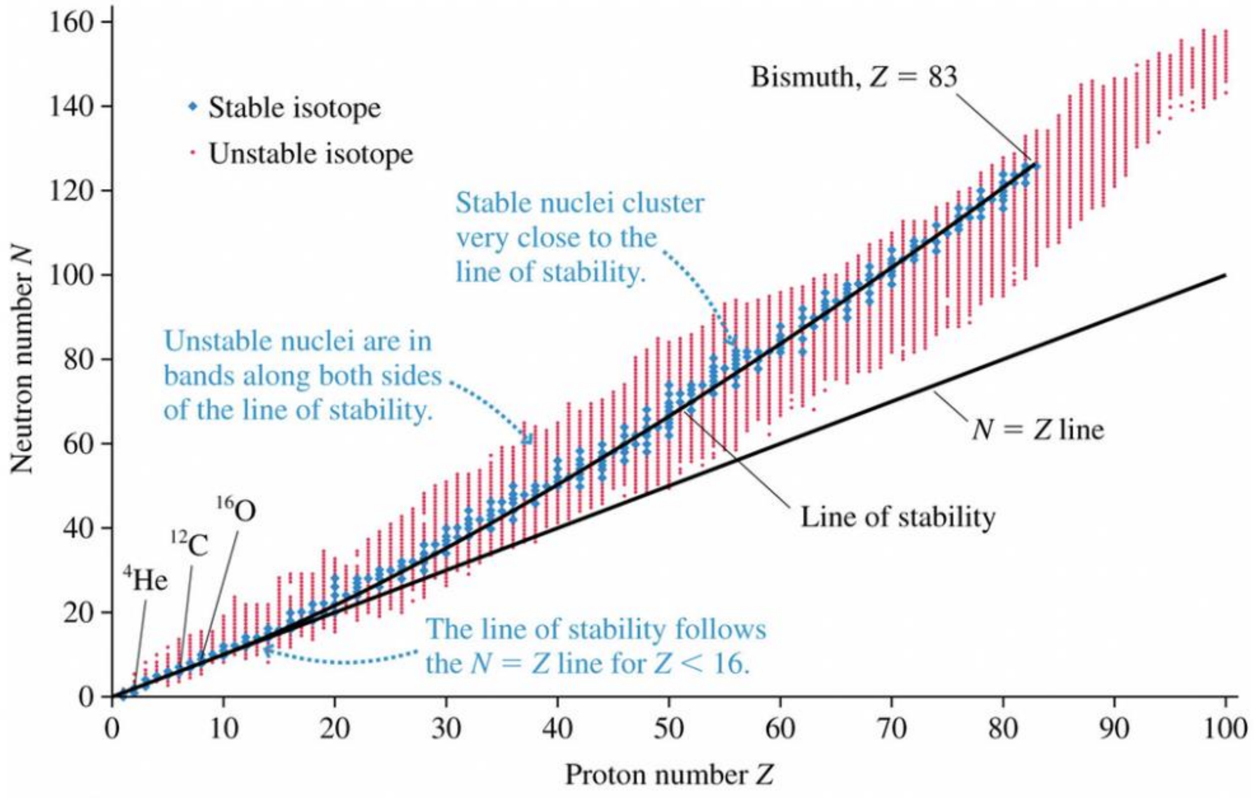
Nuclear Stability

Less than 10% of isotopes are stable

Having either too many or too few neutrons can cause an isotope to be unstable

For element $Z > 16$, the nucleus needs more neutrons than protons to remain stable

No element above Bismuth ($Z > 83$) is stable, but they can live for a very long time
(^{238}U half-life = 4.468 billion years)



Binding Energy

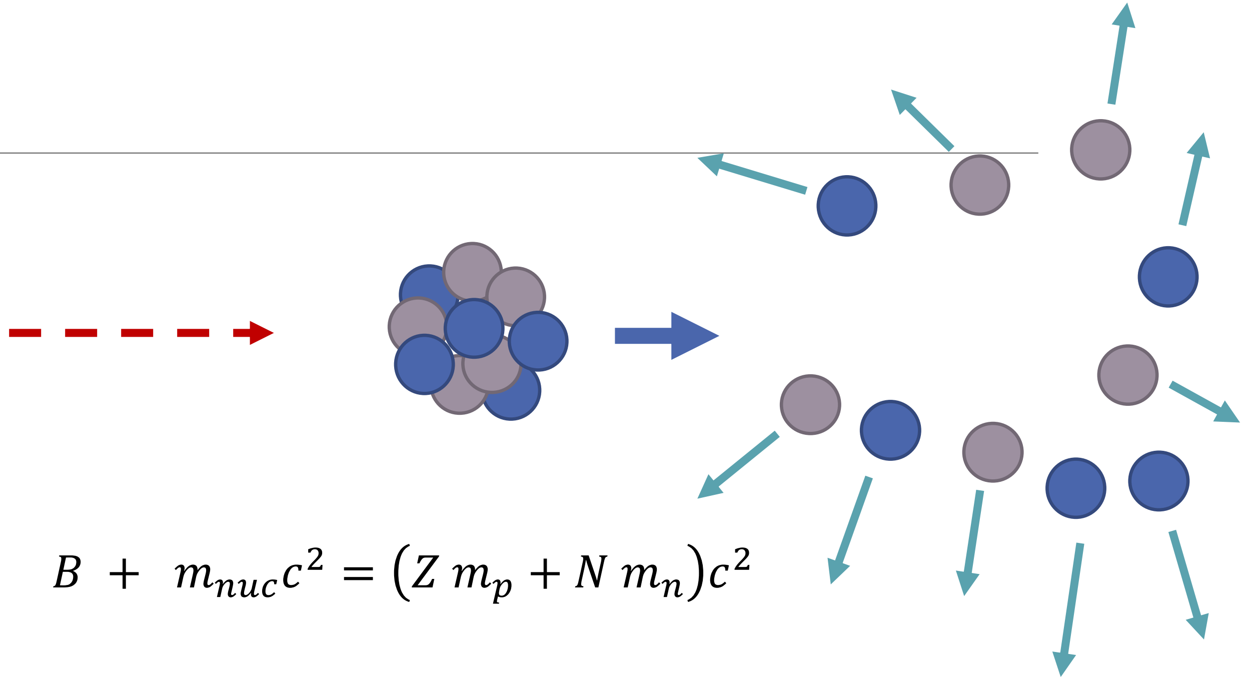
Let's return to that missing mass

When we looked at atomic energy levels, the energy of a hydrogen atom was always lower than that of a free electron and proton

We had to supply ionization energy to pull the electron away

Similar idea for the nucleus, you need to supply energy to pull nucleus apart called binding energy

Due to energy-mass equivalence, this binding energy decreases the mass of the nucleus



$$B + m_{nuc}c^2 = (Z\, m_p + N\, m_n)c^2$$

Binding Energy

Nuclei with more binding energy per nucleon are more strongly held together

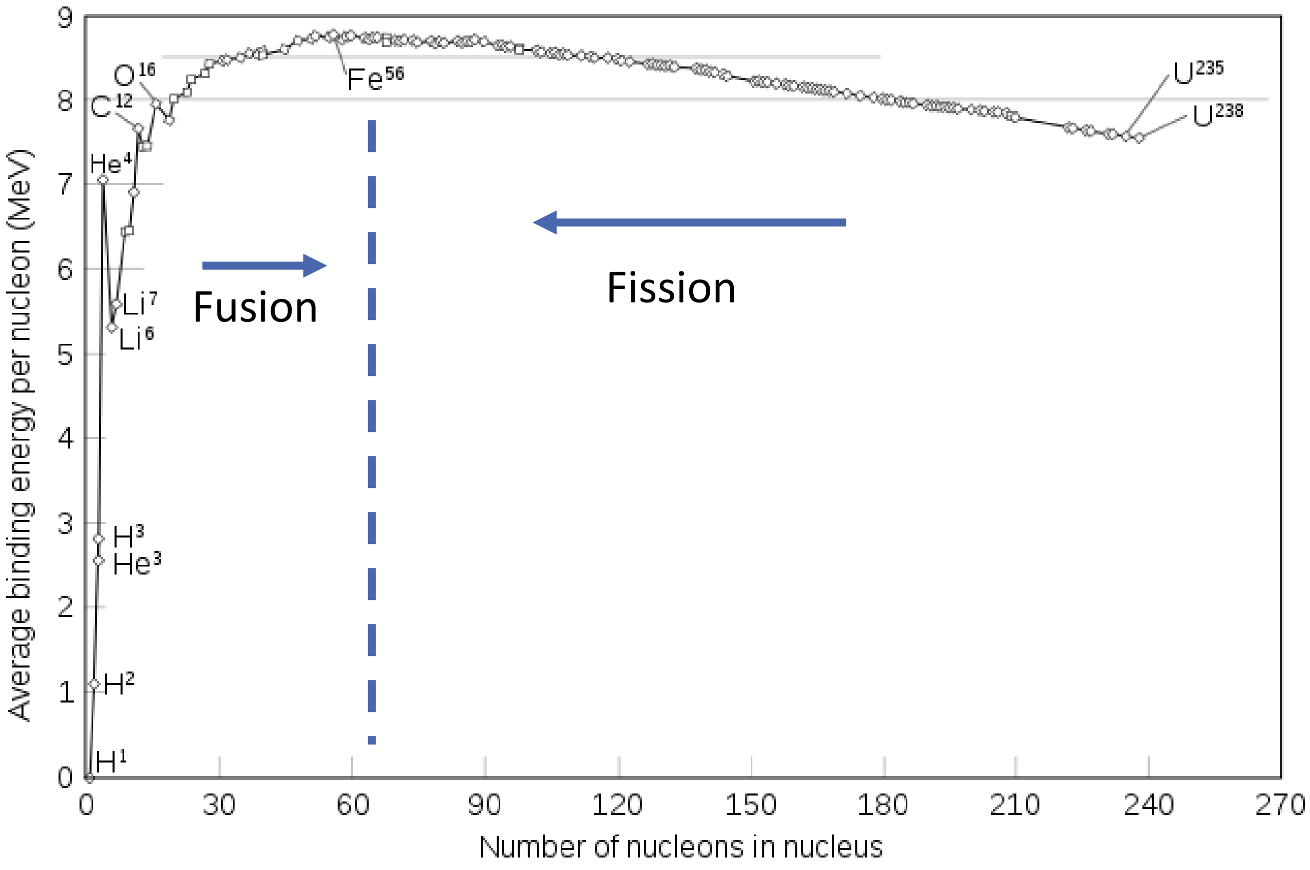
The binding energy per nucleon peaks at iron (^{56}Fe)

Binding energy is roughly constant at ~8 MeV for $A > 20$, this shows that the nuclear force is a short-range force

Nucleons only interact with their nearest-neighbors

It is energetically favorable for nuclei to try to become iron:

- Heavy nuclei can break apart (fission)
- Light nuclei can join together (fusion)



Strong Force

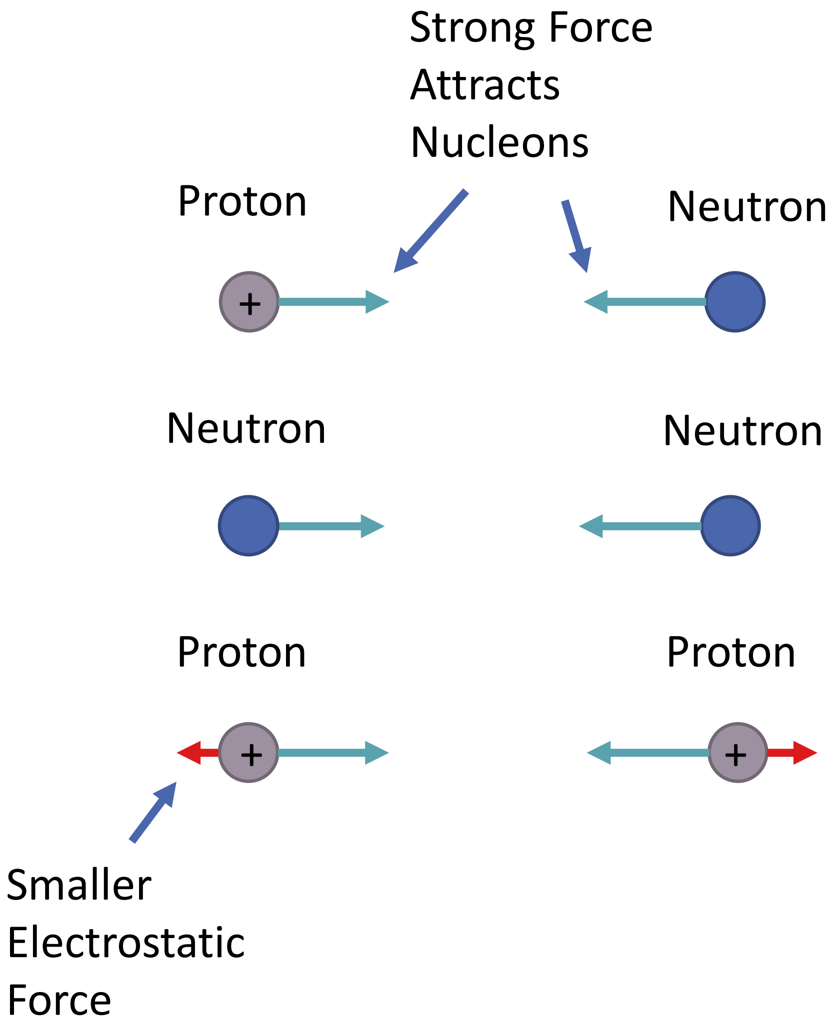
What holds a nucleus together?

New force of nature that is overwhelms the electrostatic force pushing protons apart

Properties:

- Attractive between any two nucleons
- Does not interact with electrons
- Short-range force, decays in strength over distances greater than nuclear distances
- Where it acts, it's stronger than the electrostatic force

Protons and neutrons feel identical strong force



Potential Energy

What holds a nucleus together?

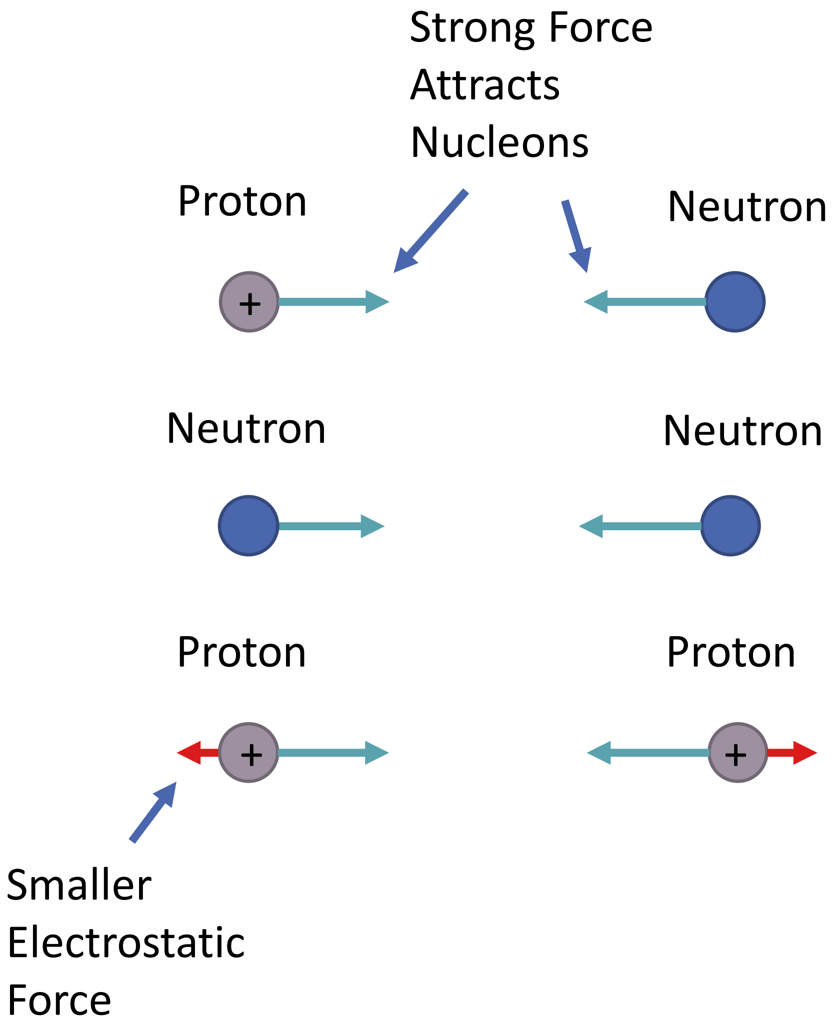
New force of nature that is overwhelms the electrostatic force pushing protons apart

Properties:

- Attractive between any two nucleons
- Does not interact with electrons
- Short-range force, decays in strength over distances greater than nuclear distances
- Where it acts, it's stronger than the electrostatic force

Protons and neutrons feel identical strong force

Since adding neutrons doesn't add electrostatic repulsive force but adds attractive strong force, the neutrons help hold nuclei together



Homework Questions

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