Modern Physics

\[ Z_e \quad e = 1.6 \times 10^{-19} \text{C} \]
\[ \text{nucleus charge} \]

a) \( 99.98\% \) mass in nucleus

b) radius \( \sim \) a few times \( 10^{-15} \text{m} = 1 \text{fm} \)
\[ \sim 10^{-14} \text{volume of an atom} \]

**Mass**

a) Atoms with same \( Z \) but different mass \( \rightarrow \) isotopes

\[ Q = Z \cdot e \quad A = Z + N \]
\[ \text{\# of protons} \quad \text{\# of neutrons} \]

Proton: \( Q = +e \), \( m_p c^2 = 938.272 \text{MeV} \)
\[ = 938.27 \text{MeV} \]

Neutron: \( Q = 0 \), \( m_n = 939.56 \text{MeV} \)

\[ M_A = Z \cdot m_p + N m_n \quad (Z m_e) \]
\[ \text{Atom} \quad \text{Proton} \quad \text{Neutron} \quad \text{Electron} \]

\[ \text{Adding } c^2 \text{ and BE} \]

\[ M_A = Z \cdot m_p c^2 + N m_n c^2 (Zm_e c^2) - \text{BE} \]

**Nuclear Binding Energy**

\[ \approx 7-8 \text{ MeV} \cdot A \]
Nuclear Force very strong because protons and neutrons are very close together and have high velocity (20%-30% C) so large amount of energy needed to "Bind" together

Proton \{ Nucleons \} Neutron

More nucleons, more "neighbors" so more BE

\[ \bullet \quad 7-8 \text{ MeV} \cdot A \]

Yet as nucleus becomes larger (+) energy of repulsive protons overcome BE (-) so energy starts a more (+) trend

\[ {^2}_1H + {^3}_1H \xrightarrow{\text{fission}} {^4}_2He + \text{Neutron} + 17.6 \text{ MeV} \]

huge gain of energy

\[ \approx 3.5 \text{ MeV/N} \]

\[ M_A / u \]

\[ u = \frac{1}{2} \text{mass}(^{12}_C) \]

"true mass" seen on Periodic table

\[ u = 931.4 \text{ MeV} / c^2 \]

\[ a = Z + N \]

Mass #

Proton has \( S = \frac{1}{2} \) thus Fermions and Pauli exclusion principle
Stable nuclei tend to have more neutrons than protons (less electrostatic repulsion)
(refer to graph online "Stable nuclei")

Size

\[
\text{Radius of nucleus } \approx \frac{R_b \cdot 3\sqrt{A}}{R_A} \quad \text{constant}
\]

Volume \(\frac{4}{3}\pi R^3\) directly proportional to \(A\)

Nucleons don't want to "squeeze" together or "separate"

Mutual attraction between nucleons called \textbf{Strong Force}

PE + Potential Energy

Radius \(\rightarrow\) shows distance between nucleons

Optimal position for nucleons

High PE when nucleons are real close

BE only dependent on near "neighbors"

Stable nucleus w/ neutrons

\(A = 1 \quad \ldots \quad A = 300 \quad \ldots \quad 10^{57}\)

\(\uparrow\)

Neutron star

Gravity helps w/ very neutral force to bind together