

Introduction to Nuclear Physics

Introduction to Nuclear Physics – Study Notes

1. What Is Nuclear Physics?

- **Definition:** The branch of physics that investigates the properties, structure, and interactions of atomic nuclei and the particles they contain.
 - **Scope:**
 - Composition of nuclei (protons, neutrons, quarks)
 - Nuclear forces and binding energy
 - Radioactive decay and transmutation
 - Nuclear reactions (fission, fusion, scattering)
 - Applications (energy, medicine, industry, astrophysics)
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2. Basic Concepts & Terminology

Term	Meaning / Typical Value
Nucleus	Central core of an atom containing protons (Z) and neutrons (N). Radius $\approx 1-10\text{ fm}$ ($1\text{ fm} = 10^{-15}\text{ m}$).
Atomic number (Z)	Number of protons; defines the element.
Mass number (A)	Total nucleons, $A = Z + N$.
Isotope	Nuclides with same Z but different N (e.g., ^{12}C , ^{13}C).
Binding Energy (BE)	Energy required to separate a nucleus into its constituent nucleons.
Binding Energy per Nucleon	BE/A ; peaks near iron-56 ($\sim 8.8\text{ MeV}$), indicating most stable nuclei.
Radioactivity	Spontaneous emission of particles or photons from an unstable nucleus.
Half-life ($T_{1/2}$)	Time for half of a sample of radionuclides to decay.
Cross-section (σ)	Effective area that quantifies the probability of a specific nuclear reaction (units: barn, $1\text{ b} = 10^{-28}\text{ m}^2$).

3. Forces Inside the Nucleus

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Force

Characteristics

Strong Nuclear Force	- Attractive at distances $\sim 1\text{ fm}$.
	- Mediated by gluons (quarks) and, at the nucleon level, by mesons (pions).
	- Short range; vanishes beyond $\sim 2\text{--}3\text{ fm}$.
Electromagnetic Force	- Repulsive between protons (Coulomb repulsion).
	- Long range; counteracts the strong force, especially in heavy nuclei.
Weak Interaction	- Responsible for beta decay ($n \rightarrow p + e^- + \bar{\nu}_e$, etc.).
	- Changes quark flavor, altering proton $\leftrightarrow$ neutron.
Gravity	Negligible at nuclear scales ($\sim 10^{-38}$ times weaker than the strong force).

4. Nuclear Stability

1. Valley of Stability

- Plot of N vs. Z shows a narrow band where nuclei are stable.
- Light nuclei: $N \approx Z$.
- Heavy nuclei: $N > Z$ (extra neutrons offset proton repulsion).

2. Decay Modes

- Alpha (α) decay:** Emission of ${}^4\text{He}$ nucleus; common in heavy nuclei ($Z > 82$).
- Beta (β^-) decay:** Neutron $\rightarrow$ proton + electron + antineutrino.
- Beta-plus (β^+) decay / Electron capture:** Proton $\rightarrow$ neutron + positron + neutrino (or captures an inner electron).
- Gamma (γ) emission:** De-excitation of nucleus; photon