Chemistry Fundamentals

Lecture 7: Isotopes

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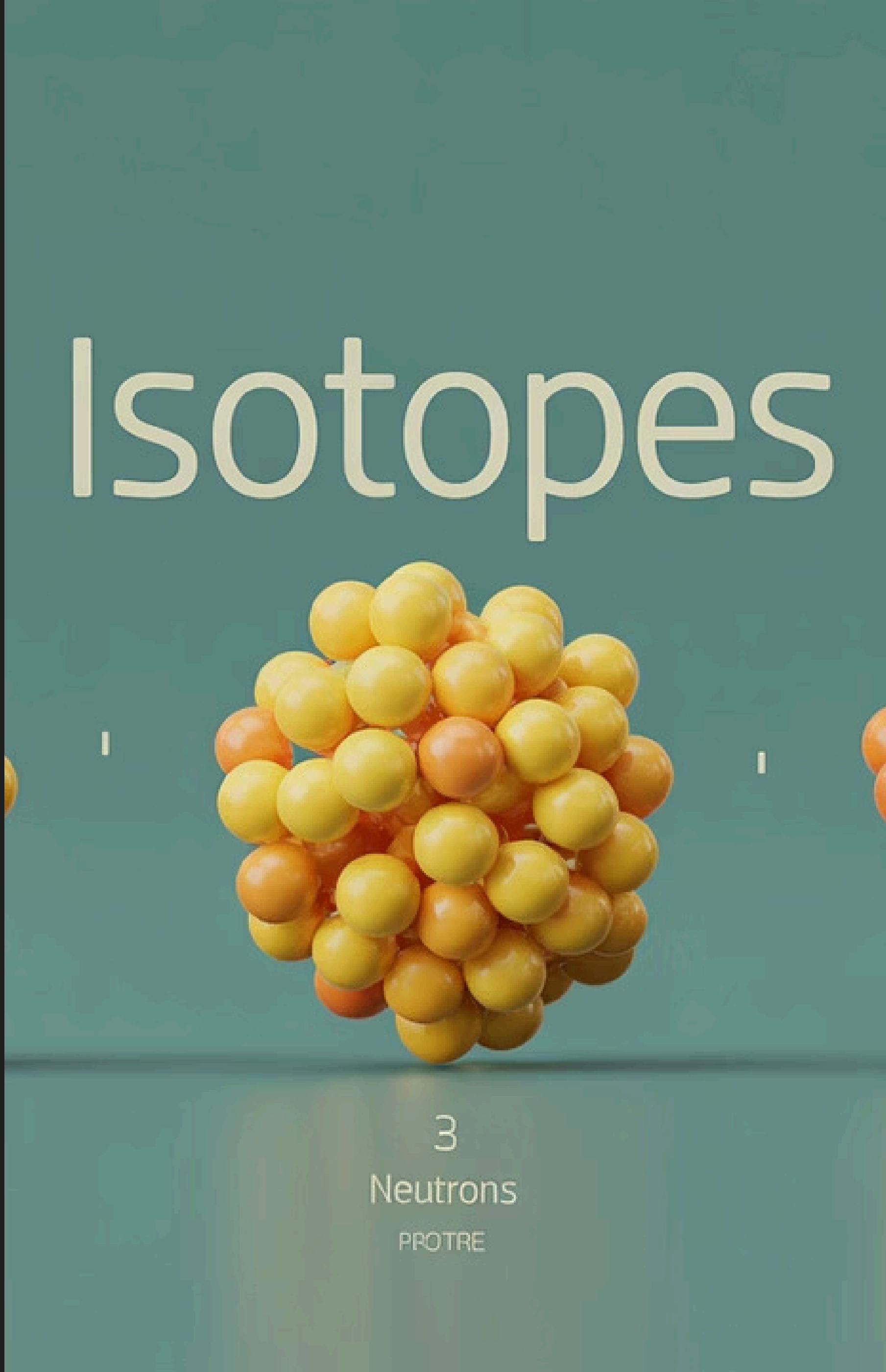


Isotopes - Same Element, Different Mass

Definition

Atoms of the same element with different numbers of neutrons

Key Characteristics

Same Z (protons), different A (mass number), different N (neutrons)

Properties

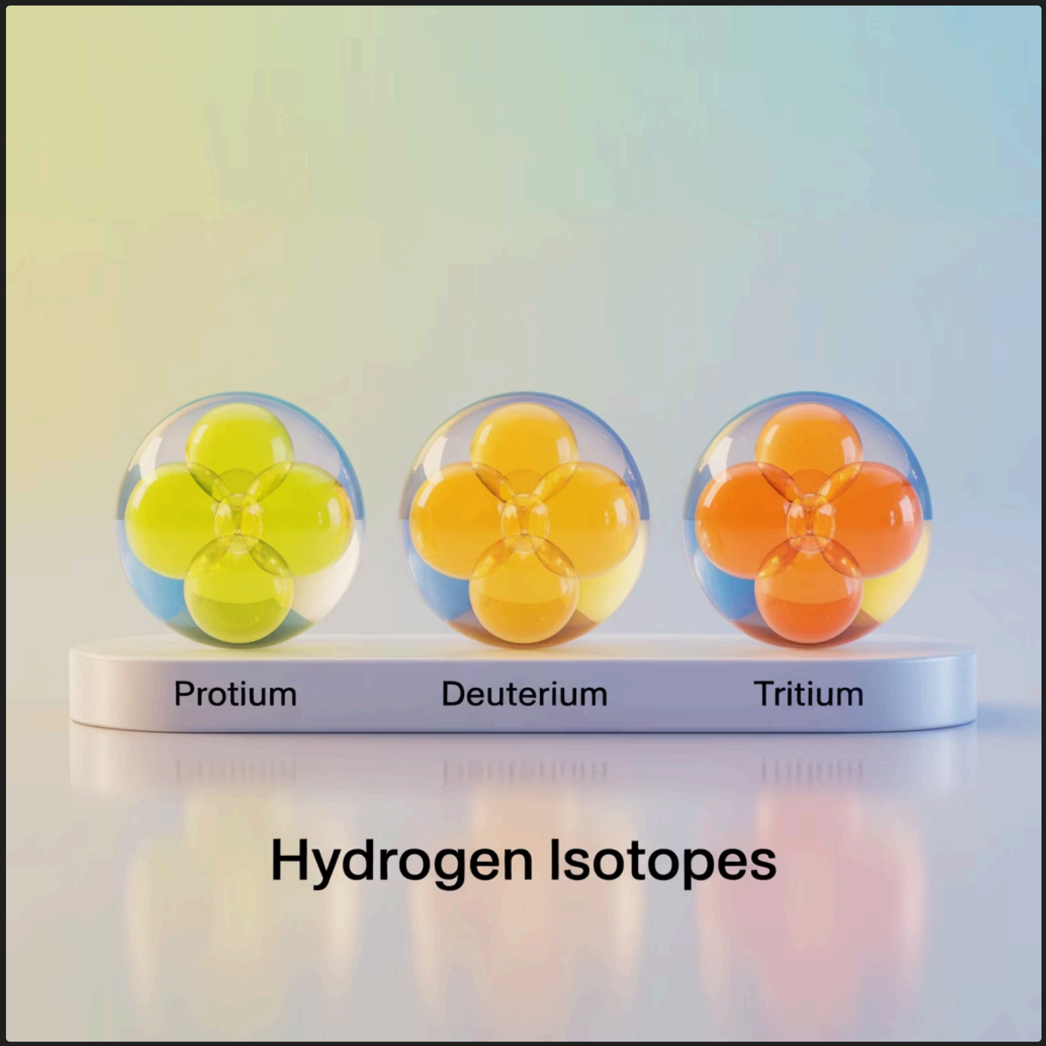
Chemical: Nearly identical due to same electron configuration

Physical: Different mass, density, nuclear stability

Most elements exist as mixtures of isotopes in nature. Notation examples: ^{1}H, ^{2}H, ^{3}H are all hydrogen isotopes.

Common Misconception: Isotopes are different elements (they're not!)

Hydrogen Isotopes - The Classic Example



1

Protium (^1H)

1 proton, 0 neutrons, 1 electron

Abundance: 99.985%

Most common isotope in universe

2

Deuterium (^2H or D)

1 proton, 1 neutron, 1 electron

Abundance: 0.015%

Used in heavy water (D_2O)

3

Tritium (^3H or T)

1 proton, 2 neutrons, 1 electron

Radioactive with 12.3-year half-life

Used in nuclear weapons and luminous watch dials

All form similar compounds (H_2O, D_2O, T_2O) despite mass differences (D is 2× heavier than H, T is 3× heavier)

Carbon Isotopes and Radioactive Dating

1	**Carbon-12 (^{12}C)** 6 protons, 6 neutrons 98.89% abundance Stable isotope, reference standard for atomic mass
2	**Carbon-13 (^{13}C)** 6 protons, 7 neutrons 1.11% abundance Stable, used in NMR spectroscopy
3	**Carbon-14 (^{14}C)** 6 protons, 8 neutrons Radioactive, 5,730-year half-life Formed by cosmic ray bombardment in atmosphere

Carbon Dating: Living organisms maintain constant $^{14}C/^{12}C$ ratio. After death, ^{14}C decays and ratio decreases predictably. Effective for samples up to ~50,000 years old.

Uranium Isotopes and Nuclear Applications

99.28%

^{238}U Abundance

92 protons, 146 neutrons

Half-life: 4.47 billion years

0.72%

^{235}U Abundance

92 protons, 143 neutrons

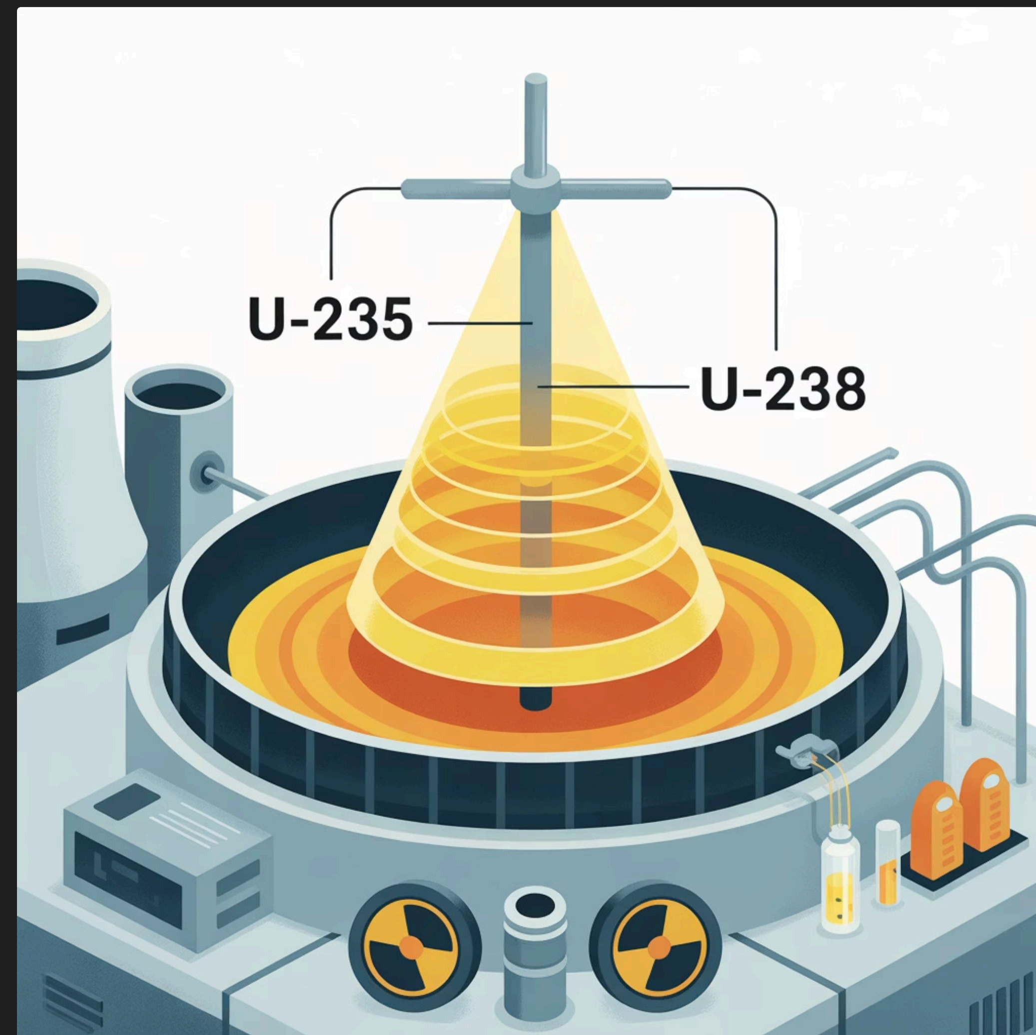
Half-life: 704 million years

0.0055%

^{234}U Abundance

92 protons, 142 neutrons

Decay product of ^{238}U



^{235}U is fissile and can sustain nuclear chain reactions, while ^{238}U cannot sustain chain reactions alone.

Enrichment increases ^{235}U concentration for nuclear fuel used in power plants, weapons, and medical isotopes.

Isotope Abundance and Mass Spectrometry

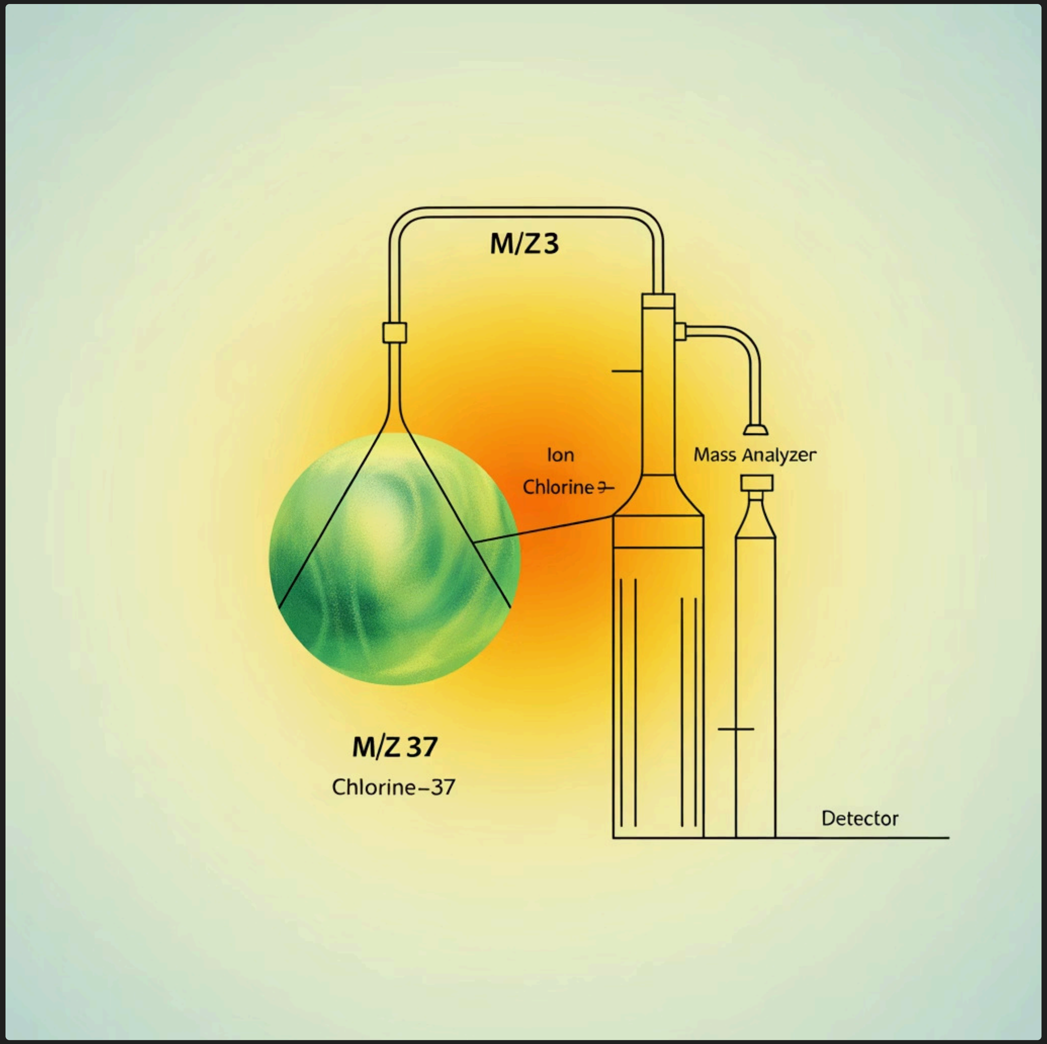
Mass spectrometry separates and identifies isotopes by:

1. Ionizing the sample
2. Accelerating through magnetic field
3. Separating by mass/charge ratio

Each element has a characteristic isotope pattern or "fingerprint".

Example: Chlorine MS Pattern

- Peak at m/z 35: ^{35}Cl (75.77%)
- Peak at m/z 37: ^{37}Cl (24.23%)
- Peak height ratio reflects abundance



Applications include forensics, environmental monitoring, and pharmaceutical analysis. Can distinguish isotopes differing by just 1 amu with high precision.

Calculating Isotope Problems

Problem Type 1: Finding Average Atomic Mass

Example: Bromine isotopes

- ^{79}Br: 78.92 amu (50.69%)
- ^{81}Br: 80.92 amu (49.31%)

Average mass = (78.92 × 0.5069) + (80.92 × 0.4931) = 79.90 amu

Problem Type 2: Finding Isotope Abundance

Given average mass and one isotope, find other isotope abundance

Strategy: Set up algebraic equation using $x + y = 1$ and weighted average formula

Important Tips: Always use decimal form for abundance in calculations. Match significant figures to the precision of given data.

Stable vs. Radioactive Isotopes

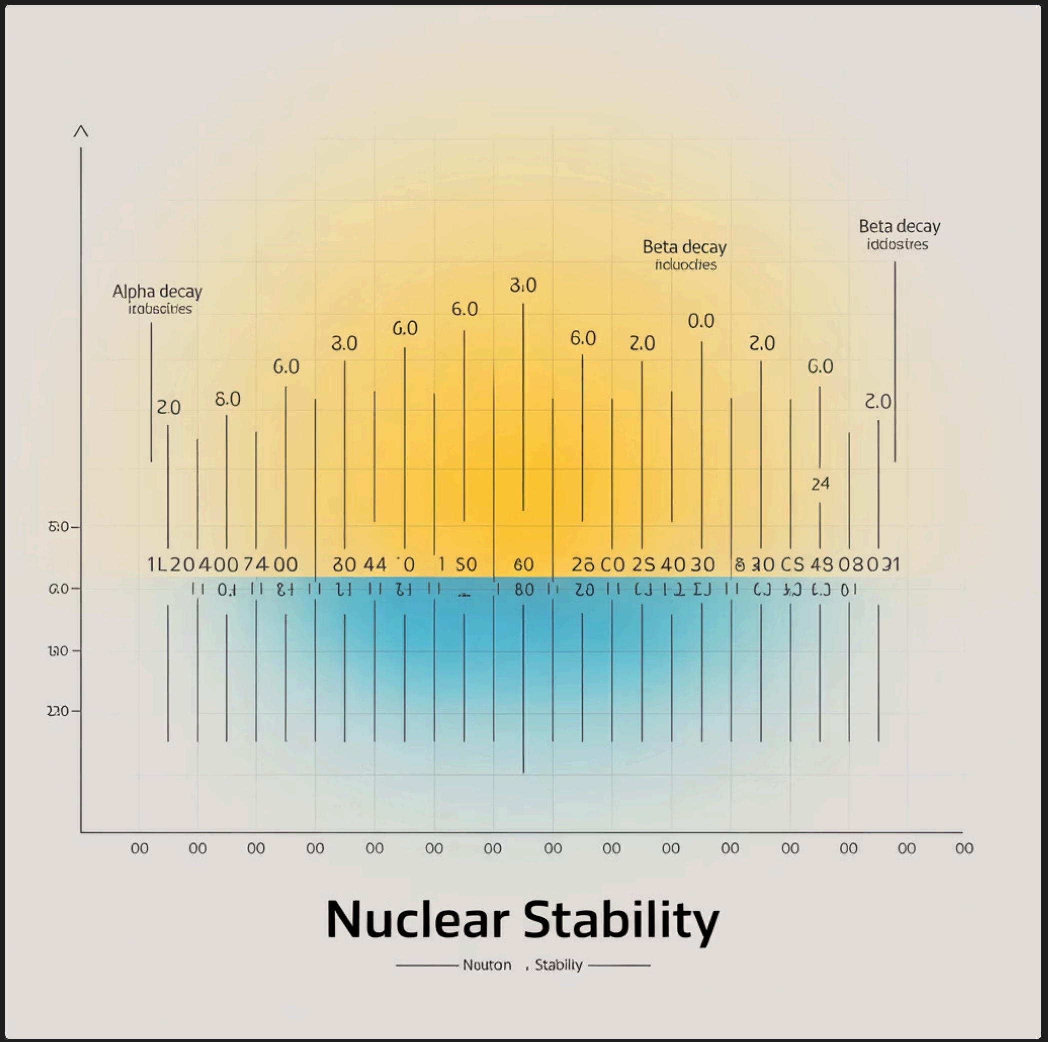
Nuclear Stability Factors

- Depends on neutron-to-proton ratio
- Light Elements: N/P ratio ≈ 1 for stability
- Heavy Elements: N/P ratio >1 for stability (need more neutrons)

Decay Types

Radioactive isotopes emit alpha, beta, or gamma radiation during decay

Half-Life: Time for half of radioactive sample to decay



The "Band of Stability" graph shows where stable isotopes exist. Isotopes outside this band undergo radioactive decay to achieve stability.

Medical applications use radioisotopes for both diagnosis and treatment.

Isotope Applications in Science and Technology

Medical

^{99m}Tc for bone scans, ^{201}Tl for heart imaging, ^{131}I for thyroid cancer treatment, ^{60}Co for radiation therapy

Dating

^{14}C for organic materials (archaeology), K-Ar for rocks (geology)

Energy

^{235}U fission provides clean nuclear power

Research

Tracers for following chemical pathways in biological systems, isotope labeling in biochemistry

Food

Gamma irradiation for food preservation by killing bacteria

Next Lecture: Atomic Mass of Elements

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