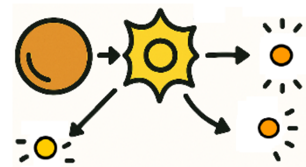
Nuclear Bombardment Reactions

Read from **Lesson 3: Nuclear Bombardment Reactions** in the **Chemistry Tutorial** Section**, Chapter 19** of **The Physics Classroom**:

Part a: Transmutation by Bombardment Part b: Binding Energy

Part c: Nuclear Fission and Fusion

Part 1. Transmutation by Bombardment



- **Transmutation** is the conversion of one element into another by changing the number of protons in the nucleus.
- Two pathways:
  - **Radioactive decay** (spontaneous)
  - **Bombardment reactions** (non-spontaneous; require high-energy particles)

A. Historical Milestones

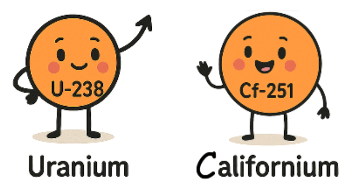
- **1919 – Rutherford** bombards nitrogen-14 with alpha particles → forms oxygen-17.
- **1931 – Chadwick** bombards Be-9 with alpha particles → discovers the neutron.
- **1932 – Cockcroft & Walton** split Li-7 using protons → first artificial fission.
- **1933 – Joliot-Curie** create first artificial radioisotope (P-30).

B. How Bombardment Works

- A **target nucleus** is struck by a **bombarding particle** (n, p, α, deuteron, or heavier ions).
- Charged particles require **particle accelerators** to overcome electrostatic repulsion.
- Products may include:
  - A new nucleus (transmuted element)
  - Additional particles (n, p, α)
  - Energy release

C. Transuranium Elements

- Elements **Z > 92** are synthetic and produced via bombardment.
- First: **Np-239** and **Pu-239** formed by neutron capture in U-238.



D. Balancing Bombardment Equations

- Conserve **mass number (A)** and **atomic number (Z)**.
- Identify unknown particles by solving for missing A and Z.

Questions

1. What makes neutron-induced nuclear transmutations easier to achieve compared to transmutations involving protons?

2. Compare natural and artificial nuclear transmutation, using specific historical events or discoveries to illustrate both processes.

Nuclear Chemistry and Radiation

3. Why must transuranium elements be synthesized through bombardment reactions rather than found in nature?

4. Write complete nuclear equations for the following:
   a. An unknown nucleus is bombarded with a proton to produce magnesium-23 and a gamma photon.

   b. Lead-206 absorbs an unknown particle and emits a neutron to form polonium -210.

   c. Chlorine-37 reacts with a neutron to form an unknown particle and an alpha particle.

   d. Uranium-235 is bombarded with a neutron to form molybdenum-95, an unknown particle, and two neutrons.

   e. Plutonium-239 absorbs two neutrons and emits a beta particle to form an unknown particle.

Nuclear Chemistry and Radiation

Part 2. Binding Energy & Mass Defect

A. Mass Defect (Δm)

- The mass of a nucleus is **less** than the sum of its individual nucleons.
- Δm = (mass of nucleus) – (mass of protons + mass of neutrons)
- Always **negative**, indicating mass is "lost" when the nucleus forms.

B. Einstein's Mass–Energy Equivalence

- $\Delta E_{system} = \Delta m_{system} \bullet c^2$
- Lost mass becomes **binding energy**, released to surroundings.

C. Binding Energy (BE)

- Energy required to **separate** a nucleus into its nucleons.
- A measure of **nuclear stability**.

D. Binding Energy per Nucleon

- Best indicator of stability.
- Peaks around **Fe-56**, **Co-59**, **Ni-62** → most stable nuclei.
- Drives nuclear processes:
  - Heavy nuclei → split to reach higher BE/nucleon (fission)
  - Light nuclei → fuse to reach higher BE/nucleon (fusion)

E. Why Nuclear Reactions Release So Much Energy

- Nuclear Δm values are ~10^6 times larger than chemical Δm.
- Even small mass changes correspond to enormous energy changes.

Questions

1. The mass of a carbon-12 atom (nucleus plus electrons) is 11.996708 amu. (1 amu•c^2 is equivalent to 931.49410242 MeV.) Use this information to determine:
   a. the mass of the nucleus (in amu)

   b. the mass of all protons and neutrons that are in the nucleus (in amu)

   c. the mass defect (in amu)

d. the binding energy (in MeV)

e. the binding energy/nucleon (in MeV/nucleon) to 4 significant digits

2. The mass of a mercury-201 atom (nucleus plus electrons) is 200.970277 amu. (1 amu•c^2 is equivalent to 931.49410242 MeV.) Use this information to determine:
a. the mass of the nucleus (in amu)

b. the mass of all protons and neutrons that are in the nucleus (in amu)

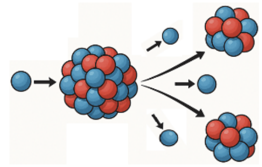
c. the mass defect (in amu)

d. the binding energy (in MeV)

e. the binding energy/nucleon (in MeV/nucleon) to 4 significant digits

Part 3. Nuclear Fission & Fusion

A. Nuclear Fission

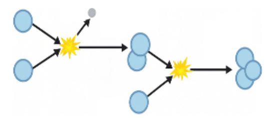


- A heavy nucleus (e.g., **U-235**) absorbs a neutron and splits into:
  - Two lighter nuclei (e.g., Ba-141, Kr-92)
  - 2–3 neutrons
  - Gamma radiation
- **Chain reaction** occurs if at least one emitted neutron induces another fission.
- Controlled using:
  - **Moderators** (slow neutrons)
  - **Control rods** (absorb neutrons)
  - **Critical mass** (ensures steady reaction)

B. Energy Comparison

- Fission of U-235 releases ~10^{13} J/mol—**millions of times** more than combustion of methane.

C. Nuclear Fusion



- Light nuclei (e.g., H-1, H-2, H-3) combine to form heavier nuclei (e.g., He-4).
- Occurs naturally in stars; it requires **extreme temperature and pressure**.
- Fusion of hydrogen isotopes yields enormous energy with minimal long-lived waste.

D. D-T Fusion

- Deuterium + Tritium → Helium-4 + neutron + energy
- Current focus of fusion power research.

Questions

1. Compare and contrast the conditions required for fission vs. fusion.

2. Describe at least one technological hurdle that currently limits fusion power plants.