

Nuclear and Particle Physics

1 Binding Energy and Nuclear Fission of Uranium-238

1.1 Part 1: Binding Energy Calculation Using the Semi-Empirical Mass Formula

The semi-empirical mass formula is given by:

$$B(Z, A) = a_v A - a_s A^{2/3} - a_c \frac{Z^2}{A^{1/3}} - a_a \frac{(A - 2Z)^2}{A} + \delta(A, Z)$$

Where $B(Z, A)$ is the total binding energy, A is the mass number (total number of nucleons), Z is the atomic number (number of protons), a_v, a_s, a_c, a_a are constants for the volume, surface, Coulomb, and asymmetry terms respectively, $\delta(A, Z)$ is the pairing term.

Typical values of the constants are:

- $a_v = 15.8 \text{ MeV}$,
- $a_s = 18.3 \text{ MeV}$,
- $a_c = 0.714 \text{ MeV}$,
- $a_a = 23.2 \text{ MeV}$.

The pairing term $\delta(A, Z)$ is given by:

$$\delta(A, Z) = \begin{cases} +11.2/\sqrt{A} \text{ MeV}, & \text{for even-even nuclei,} \\ 0, & \text{for odd A,} \\ -11.2/\sqrt{A} \text{ MeV}, & \text{for odd-even nuclei.} \end{cases}$$

Tasks

1. Calculate the binding energy per nucleon for Uranium-235 and Uranium-238.
2. Plot the binding energy per nucleon for Uranium isotopes, including Uranium-235 and Uranium-238. Analyze which isotope among these two exhibits greater stability.

1.2 Part 2: Fission of Uranium-238

In nuclear fission, a large nucleus (like Uranium-238) splits into two smaller nuclei (fission fragments). The stability of the fragments can be compared to that of the parent nucleus to determine if fission is energetically favorable.

Tasks

1. Calculate the total binding energy for the following:
 - Uranium-238,
 - Krypton-92,
 - Barium-141.
2. Explain whether the fission process of Uranium-238 is energetically favorable.
3. If so;
 - a) calculate and display the energy released during fission,
 - b) explain why heavy nuclei such as Uranium-238 tend to undergo fission.
4. Plot a bar graph comparing the total binding energy of Uranium-238, Krypton-92, Barium-141, and the combined energy of the fission fragments.

Additional Questions for Analysis

How does the energy released during fission compare to the binding energy of Uranium-238? Relate this to the concept of nuclear energy production in reactors or atomic bombs.

1.3 Submission Requirements

- A Python script implementing the calculation of binding energies and fission analysis (50%).
- A plot of the binding energy per nucleon for Uranium isotopes (10%).
- A bar chart comparing the binding energies of Uranium-238 and the fission fragments (10%).
- Written answers to the analysis questions (30%).