Mass Defect & Binding Energy

Unit: Nuclear Chemistry

NGSS Standards/MA Curriculum Frameworks (2016): N/A (HS-PS1-8 in physics frameworks)

Mastery Objective(s): (Students will be able to…)

- Explain where the energy that powers the strong force comes from.
- Calculate the "missing" mass and convert it to energy.

Success Criteria:

- Theoretical mass accounts for mass of all protons, neutrons and electrons.
- Mass defect is calculated correctly.
- Einstein's equation ($E = mc^2$) is properly applied to the mass defect to calculate energy.

Tier 2 Vocabulary: defect

Language Objectives:

- Explain the concept of "missing" mass and how it converts to energy.

Notes:

binding energy: the energy that holds the nucleus of an atom together through the strong nuclear force

The binding energy comes from the small amount of mass (the mass defect) that was turned into a large amount of energy, given by the equation:

$$E = mc^2$$

where E is the binding energy, m is the mass defect, and c is the speed of light ($3\times10^8\ \frac{m}{s}$, which means c^2 is a very large number).

mass defect: the difference between the actual mass of an atom, and the sum of the masses of the protons, neutrons, and electrons that it contains.

- A proton has a mass of 1.6726×10^{-27} kg = 1.0073 amu
- A neutron has a mass of 1.6749×10^{-27} kg = 1.0087 amu
- An electron has a mass of 9.1094×10^{-31} kg = 0.0005486 amu

To calculate the mass defect, total up the masses of each of the protons, neutrons, and electrons in an atom. The actual (observed) atomic mass of the atom is always *less* than this number. The "missing mass" is called the mass defect.

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Sample problem:

Q: Find the mass defect of 1 mole of uranium-238.

A: ${}^{238}_{92}\text{U}$ has 92 protons, 146 neutrons, and 92 electrons. This means the total mass of one atom of ${}^{238}_{92}\text{U}$ should theoretically be:

92 protons × 1.0073 amu = 92.6704 amu

146 neutrons × 1.0087 amu = 147.2661 amu

92 electrons × 0.000 5486 amu = 0.0505 amu

92.6704 + 147.2661 + 0.0505 = 239.9870 amu

The actual observed mass of one atom of ${}^{238}_{92}\text{U}$ is 238.0003 amu.

The mass defect is therefore 239.9870 – 238.0003 = 1.9867 amu.

One mole of ${}^{238}_{92}\text{U}$ would have a mass of 238.0003 g, and therefore a total mass defect of 1.9867 g (which is 0.001 9867 kg).

Because $E = mc^2$, that means the binding energy of one mole of ${}^{238}_{92}\text{U}$ is:

$$0.001\,9867\,\text{kg} \times (3.00 \times 10^{8})^{2} = 1.79 \times 10^{14}\ \text{J}$$

In case you don't realize just how large that number is, the binding energy of just 238 g (1 mole) of ${}^{238}_{92}\text{U}$ would be enough energy to heat every house on Earth for an entire winter!

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