# Mass Defect & Binding Energy

**Unit:** Atomic and Nuclear Physics

**NGSS Standards/MA Curriculum Frameworks (2016):** HS-PS1-8

**AP® Physics 2 Learning Objectives/Essential Knowledge (2024):** 1.4.C.1, 5.B.11.1

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

- Calculate the binding energy of an atom.
- Calculate the energy given off by a radioactive decay based on the binding energies before and after.

**Success Criteria:**

- Variables are correctly identified and substituted correctly into the correct equation.
- Algebra is correct and rounding to appropriate number of significant figures is reasonable.

**Language Objectives:**

- Explain where the energy behind the strong force (which holds the nucleus together) comes from.

**Tier 2 Vocabulary:** defect

## Notes:

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. The mass defect is the amount of "missing" mass that was turned into binding energy.

- A proton has a mass of $1.6726\times10^{-27}$ kg = 1.0073 amu
- A neutron has a mass of $1.6749\times10^{-27}$ kg = 1.0087 amu
- An electron has a mass of $9.1094\times10^{-31}$ 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.

<u>binding energy</u>: 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 released as energy when the nucleus was formed, 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 ($3\times10^8\ \frac{\text{m}}{\text{s}}$), which means $c^2$ is $9\times10^{16}\ \frac{\text{m}^2}{\text{s}^2}$ (a very large number)!

You can figure out how much energy is produced by spontaneous radioactive decay by calculating the difference in the sum of the binding energies of the atoms before and after the decay.

## Sample problem:

Q: Calculate 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 of one atom of $^{238}_{92}\text{U}$ 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, or 0.001 9867 kg.

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

$$0.001\,9867\ \text{kg}\times(3.00\times10^8)^2 = 1.79\times10^{14}\ \text{J}$$

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!