# Mahopac High School

## Chemistry

Mahopac CSD

## Mass Defect of Nuclear Binding Energy

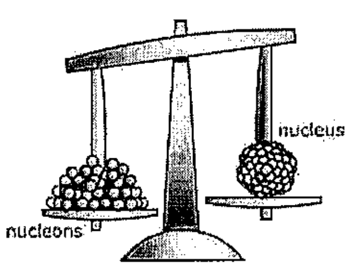
Uranium's radiation isn't just a brief spurt of energy. A sample of uranium metal will continue to radiate indefinitely at an apparently constant rate, and this was a serious problem. By the law of conservation of energy, it would seem that energy could not be created out of nothing, and yet energy seemed to be created out of nothing in connection with radioactivity.

In 1903, Rutherford suggested that all atoms possessed large volumes of energy within their structure. Ordinarily, this energy was never tapped, so that people remained unaware of its existence. Radioactivity was, however, a spontaneous outpouring of a little of this energy.

And yet Rutherford's suggestion might have seemed to be a case of pulling a rabbit out of a hat. Just saying that the atom contained energy explained nothing. But then in 1905, Einstein showed, convincingly, that mass a very concentrated form of energy. If radioactive substances were to turn even a small fraction of their mass to energy, then all of the energy liberated in radioactivity could easily be accounted for.

Mass Defect

Careful measurements have shown that the mass of a particular atomic nuclei is always slightly less than the sum of the masses of the individual neutrons and protons. The difference between the mass of the nucleus and the sum of the masses of its parts is called the *mass defect*. So, the mass of any nucleus is less than the sum of the separate masses of its protons and neutrons. In other words, sticking protons and neutrons together somehow causes some of their mass to vanish into thin air. The "vanishing" mass of the protons and neutrons is simply converted to energy. This energy is called the binding energy.



An example that illustrates nuclear binding energy is the nucleus of $^{12}C$ (Carbon 12), which contains 6 protons and 6 neutrons. The protons are all positively charged and repel each other, but the nuclear force overcomes the repulsion and causes them to stick together. The nuclear force is a close-range force (it is very strongly inversely proportionate to distance), and virtually no effect of this force is observed outside the nucleus. The nuclear force also pulls neutrons together, or neutrons and protons.[

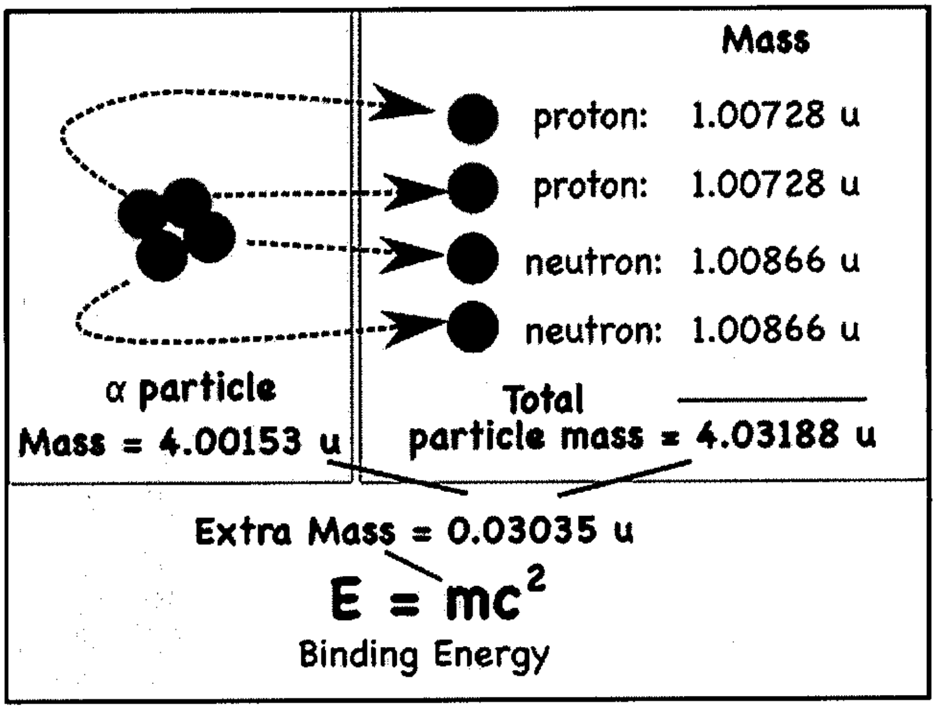



TABLE 21.6 Mass Defects and Binding Energies for Three Nuclei

| Nucleus | Mass of Nucleus (amu) | Mass of Individual Nucleons (amu) | Mass Defect (amu) | Binding Energy (J) | Binding Energy per Nucleon (J) |
|---|---|---|---|---|---|
| $^{4}_{2}He$ | 4.00150 | 4.03190 | 0.03040 | $4.54 \times 10^{-12}$ | $1.14 \times 10^{-12}$ |
| $^{56}_{26}Fe$ | 55.92066 | 56.44938 | 0.52872 | $7.90 \times 10^{-11}$ | $1.41 \times 10^{-12}$ |
| $^{238}_{92}U$ | 238.0003 | 239.9356 | 1.9353 | $2.89 \times 10^{-10}$ | $1.22 \times 10^{-12}$ |

# CALCULATIONS Tutorial

## Determining the Mass Defect

The difference between the mass of a nucleus and the sum of the masses of the nucleons of which it is composed is called the *mass defect.* Three things need to be known in order to calculate the mass defect:

- the actual mass of the nucleus,
- the composition of the nucleus (number of protons and of neutrons),
- the masses of a proton and of a neutron.

To calculate the mass defect:

- add up the masses of each proton and of each neutron that make up the nucleus,
- subtract the actual mass of the nucleus from the combined mass of the components to obtain the mass defect.

**Example:** Find the mass defect of a copper-63 nucleus if the actual mass of a copper-63 nucleus is 62.91367 amu.

- Find the composition of the copper-63 nucleus and determine the combined mass of its components.

  Copper has 29 protons and copper-63 also has (63 - 29) 34 neutrons.
  The mass of a proton is 1.00728 amu and a neutron is 1.00867 amu.
  The combined mass is calculated:

$$29 \text{ protons}(1.00728 \text{ amu/proton}) + 34 \text{ neutrons}(1.00867 \text{ amu/neutron})$$

or

$$63.50590 \text{ amu}$$

- Calculate the mass defect.

$$\Delta m = 63.50590 \text{ amu} - 62.91367 \text{ amu} = 0.59223 \text{ amu}$$

## Conversion of Mass Defect into Energy

To convert the mass defect into energy:

- Convert the mass defect into kilograms (1 amu = $1.6606 \times 10^{-27}$ kg)
- Convert the mass defect into its energy equivalent using Einstein's equation.

**Example:** Determine the binding energy of the copper-63 atom.

- Convert the mass defect (calculated in the previous example) into kg.

  $(0.59223 \text{ amu/nucleus})(1.6606 \times 10^{-27} \text{ kg/amu}) = 9.8346 \times 10^{-28} \text{ kg/nucleus}$

- Convert this mass into energy using $\Delta E = \Delta mc^2$, where $c = 2.9979 \times 10^8$ m/s.

$$E = (9.8346 \times 10^{-28} \text{ kg/nucleus})(2.9979 \times 10^8 \text{ m/s})^2 = 8.8387 \times 10^{-11} \text{ J/nucleus}$$

**YOUTUBE Tutorial https://www.youtube.com/watch?v=4N3Srx0xRQc**

| Tier one words | Tier two words | Tier three words |
|---|---|---|
| mass | proton | Binding energy |
| energy | neutron | Nuclear forces |
| volume | Inversely proportional | amu |
| defect | particle | Mass defect |
| vanishing/missing | nucleus | |
| measurements | | |

## Sample problems:

1) For the following examples calculate the mass defect in terms of the atomic mass unit.

A) $^{6}Li_{3}$ Mass = 6.0151u, 3 protons and 3 neutrons.

B) $^{14}C_{6}$ Mass = 13.0034 u, 6 protons and 8 neutrons.

C) $^{56}Fe_{26}$ Mass = 55.9349 u, 26 protons and 30 neutrons.

D) $^{238}U_{92}$ = 238.0508 u, 92 protons and 146 neutrons.

2) During a decay process energy is released from the decaying nuclei. This energy comes from the mass of the starting parent nuclei which is lost as it transmutates into a daughter nuclei, an emitted particle and radiation. Calculate the difference between the mass of the reactants and the products and reactants. This missing mass is converted to energy via $E=mc^2$.

A) ${}^{222}Rn_{86} \rightarrow {}^{4}He_{2} + {}^{218}Po_{84}$ + Energy

| Mass of particles |
|---|
| Rn-222 = 222.0175 u |
| He-4 = 4.0026 u |
| Po-218 = 218.0090 u |

B) ${}^{19}Ne_{10} \rightarrow {}^{0}e_{+1} + {}^{19}F_{9}$ + Energy

| Mass of particles |
|---|
| Ne-19 = 19.0019 u |
| Positron = 0.0005 u |
| F-19 = 18.9984 u |

C) ${}^{42}K_{19} \rightarrow {}^{0}e_{-1} + {}^{42}Ca_{20}$ + Energy

| Mass of particles |
|---|
| K-42 = 41.9624 u |
| Beta = 0.0005 u |
| Ca-42 = 41.9586 u |

**Reflection:**

Describe where the energy released during radioactive decay comes from.

**Questions:**

1) What is the name of the force which holds the nucleus of an atom together?

2) Why do a positron and a beta particle have the same mass?

3) If 1 u = $1.6605 \times 10^{-27}$ kg determine the amount of kilograms found in the energy from question *2A*. The missing mass from the alpha decay of Rn-222.

4) Convert the mass from energy of the alpha decay of Rn-222 in to energy by using $E=mc^2$. Where $c = 3.00 \times 10^8$ m/s.

**Sources:** Hofstra University Web and labs, Perdue University Web, Wikipedia