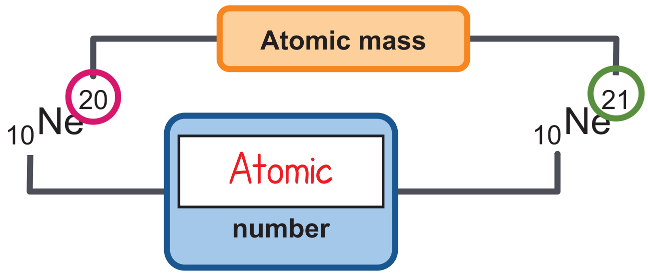
Warm-Up | The Nucleus

Isotopes and Nuclides

Isotopes are atoms of the same element that have different numbers of neutrons.

A nuclide is the nucleus of a specific isotope of an element.

Chemical symbols:



Lesson Objectives

By the end of this lesson, you should be able to:

- Explain how protons and neutrons in the nucleus are held together by nuclear forces.
- Differentiate chemical and nuclear reactions in terms of energy released.
- Explain why Einstein's equation $E = mc^2$ is used to determine the nuclear binding energy.
- Identify some naturally occurring isotopes of elements that are radioactive.

Science Practice: Analyze a sequence (i.e., radioactive decay) that is characteristic of natural phenomena.

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W2K

Words to Know

Write the letter of the definition next to the matching word as you work through the lesson. You may use the glossary to help you.

D	radioactive decay	A. the sum of the masses of the nucleons minus the mass of the atom
C	nuclear binding energy	B. a particle that, along with other particles, makes up the nucleus (protons and neutrons)
E	strong nuclear force	C. the energy required to split the nucleus of an atom into separate protons and neutrons
A	mass defect	D. the spontaneous release of energy and particles from the nucleus of an unstable atom
B	nucleon	E. the force responsible for binding protons and neutrons together in the nucleus

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Lesson Question

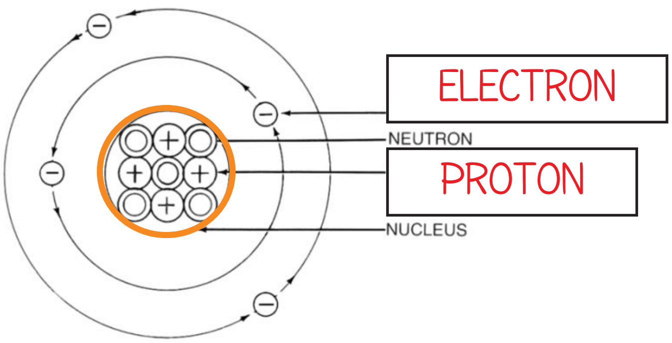
What causes radioactivity?

Slide 2

Strong Nuclear Force

The **strong nuclear force** is the force responsible for binding protons and neutrons together in the nucleus.

Nuclear reactions produce thousands of times more energy than chemical reactions.



Isotopes and Stability

- Strong nuclear force can hold the nucleus together when there are "enough" neutrons present to counteract repulsive forces.
- Too few neutrons relative to protons can lead to instability.
- As the atomic number increases, the neutron-to-proton ratio needed for a stable nucleus increases. Relatively more neutrons are needed as the number of protons increases.

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Instability and Radioactivity

Radioactive decay is the spontaneous release of energy and particles from the nucleus of an unstable atom.

- Isotopes of an element have different stabilities.
- For example, 16 of 19 neon isotopes are unstable and will undergo radioactive decay.

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Carbon's Useful Isotopes

- Carbon has 15 known isotopes.
- Its two stable isotopes are:
  - carbon-12 (C-12).
  - carbon-13 (C-13).
- Most unstable isotopes decay quickly.
- Carbon-14 decays very slowly. It is used for radiocarbon dating.

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Chemical Reactions Versus Nuclear Reactions

Chemical reactions:

- involve interactions between electrons with no change in mass.

Nuclear reactions:

- involve the splitting apart or coming apart of nuclei.
- seemingly violate the law of conservation of mass.
- release more energy than in chemical reactions.

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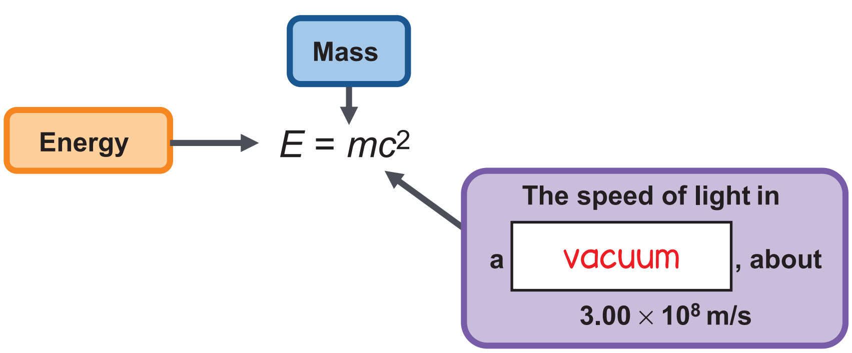
Mass-Energy Equivalence

- The law of conservation of mass states that matter can neither be created nor destroyed.
- The law of conservation of energy states that energy can neither be created nor destroyed.
- Einstein showed mass and energy equivalence: $E = mc^2$.

Einstein's Equation

- The laws of conservation of mass and energy needed modification.
- Matter can be converted into energy.



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Slide 7

Calculating Energy Equivalent

How much energy is released if 3.00 kg is converted into energy?

$$\begin{aligned} E &= mc^2 \\ &= 3.00\ \text{kg}(3.00 \times 10^8\ \text{m/s})^2 \\ &= 2.7 \times 10^{17}\ \text{J} \end{aligned}$$

- Nuclear reactions yield thousands of times more energy per gram compared to chemical reactions.

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Nuclear Force and Nuclear Binding Energy

Nuclear binding energy is the energy required to split the nucleus of an atom into separate protons and neutrons.

- Strong nuclear force binds protons and neutrons together in the nucleus.

The mass of an atom's nucleus is less than the sum of the masses of nucleons.

Mass Defect

$$29 + 34 < 63$$

The **mass defect** is the sum of the masses of the nucleons minus the mass of the atom.

- The mass defect is always positive.
- Mass defects can be expressed in amu or kilograms.

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Calculating Mass Defects

Calculate the mass defect of copper-63.

- Copper-63 has 29 protons and 34 neutrons.
- The atomic mass of copper-63 is 62.91367 amu.
- The mass of a proton is 1.00728 amu.
- The mass of a neutron is 1.00866 amu.

Mass defect of copper-63 =
$(29)(1.00728) + (34)(1.00866) - 62.91367 =$ 0.59189 amu

Slide 13

Converting Mass Defect into Nuclear Binding Energy

- The nucleus of an atom has lower potential than its individual components.
- Energy is released when an atom is formed, reducing the mass.
- To separate the nucleus, restore the energy.
- The energy released is equal to the energy of the mass defect.
- To calculate the nuclear binding energy:
  - convert the mass defect into kilograms.
  - use Einstein's equation.

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Calculating Nuclear Binding Energy

Copper-63 has a mass defect of 0.59189 amu.

$$0.59189 \text{ amu}\left(\frac{1.6606 \times 10^{-27} \text{ kg}}{\text{amu}}\right) = 9.8289 \times 10^{-28} \text{ kg}$$

The binding energy is the mass defect converted into energy using Einstein's equation.

$$E = mc^2$$

$$= (9.8289 \times 10^{-28} \text{ kg})(3.00 \times 10^{8} \text{ m/s})^2$$

$$= 8.85 \times 10^{-11} \text{ J}$$

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Lesson Question

What causes radioactivity?

Answer

(Sample answer) Radioactivity occurs when unstable isotopes undergo radioactive decay, the nuclear binding energy is released. Nuclear reactions involve the nuclei of atoms and require consideration of both mass and energy.

Slide 2

The Chemistry of the Nucleus

- Some isotopes are unstable and exhibit radioactive decay.
- The strong nuclear force holds the nucleus together.
- Nuclear binding energy is the energy to split a nucleus completely.
- Chemical and nuclear reactions differ.
- $E = mc^2$ explains the mass-energy equivalence of nuclei.
- Mass defect is why atoms have a smaller mass than their nucleons.
- Nuclear binding energy is the energy of the mass defect.
- Nuclear binding energy can be calculated using Einstein's equation.

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Use this space to write any questions or thoughts about this lesson.