Radioactivity: Stable and Unstable Isotopes

The Periodic Table of the Elements lists all of the chemical elements that have been identified so far. On the table you will see one listing per element. However, many elements have variations called isotopes. They have the same number of protons, but a different number of neutrons.

Isotopes are identified by their atomic mass. An atom's atomic number represents the number of protons in the element. When you subtract the atomic number from the atomic mass you find the number of neutrons in the element or isotope.

Unstable isotopes want to be stable. Atoms undergo a variety of different processes to change the proton/neutron ratio in the nucleus as it becomes stable. Atoms with 83 or more protons in the nucleus can emit alpha particles, which reduce the size of the nucleus. Atoms can also decay by losing a beta particle, which converts a neutron into a proton. Other methods for becoming stable include positron emission where a proton is converted to an electron, or electron capture where protons are converted to neutrons. Gamma radiation, a very short wavelength of pure energy, can also be released during radioactive decay.

There are multiple decay paths for isotopes, and some isotopes decay faster than others. Below is a table showing one decay path for Uranium-238.

Isotope	Half-Life	Decay Mode
Uranium-238	4.5 billion years	alpha
Thorium-234	24.1 days	beta
Protactinium-234	1 minute	beta
Uranium-234	245,000 years	alpha
Thorium-230	76,000 years	alpha
Radium-226	1,600 years	alpha
Radon-222	3.8 days	alpha
Polonium-218	3.0 minutes	alpha
Lead-214	27 minutes	beta
Bismuth-214	20 minutes	beta
Polonium-214	<1 second	alpha
Lead-210	22.3 years	beta
Bismuth-210	5 days	beta
Polonium-210	138.4 days	beta
Lead-206	stable	

Directions

1. Complete the tables on the following page. Use the Periodic Table of the Elements to find the atomic number and number of protons.
2. On a separate piece of graph paper, draw a vertical Y-axis and label it "Neutrons" with a scale from 0-150.
3. Draw a horizontal X-axis and label it "Protons" with a scale from 0-100.
4. Plot the points of the stable isotopes. When all isotopes have been plotted, draw a bold curve through the points. Make the curve as smooth as possible. This is the "band of stability."
5. Next, plot the unstable points on the graph. Use a key so you can identify the different isotopes.
6. Where do the unstable isotopes fall relative to the band of stability?

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Stable Isotope	Atomic Number	Protons (X axis)	Neutrons (Y axis)
Helium-4			
Carbon-12			
Silicon-28			
Scandium-45			
Iron-56			
Silver-109			
Xenon-131			
Gadolinium-160			
Tungsten-184			
Lead-206			

Unstable Isotope	Atomic Number	Protons (X axis)	Neutrons (Y axis)
Carbon-14			
Silicon-32			
Iron-52			
Xenon-135			
Lead-214			
Radium-226			

There are currently 243 isotopes identified as stable, and 70 naturally occuring unstable isotopes, and many more that are unstable as a result of processes such as nuclear fission. These charts are only a small representation of the stable and unstable isotopes.

Radiation Dose Chart

We are exposed to radiation from the natural environment and some everyday activities. Complete the information below to find out how many millirems of radiation you are exposed to each year.

mrems dose

Where You Live

1. Cosmic radiation (from outer space) at sea level 26
2. Select the number of millirems for your elevation (in feet above sea level) .... ____
   - up to 1000 = 2 | 1000-2000 = 5
   - 2000-3000 = 9 | 3000-4000 = 9
   - 4000-5000 = 21 | 5000-6000 = 29
   - 6000-7000 = 40 | 7000-8000 = 53
   - 8000-9000 = 70
3. Terrestrial (from the ground):
   - If you live in states that border the Gulf of Mexico or Atlantic Coast, add 23 .... ____
   - If you live in the Colorado Plateau area (around Denver), add 90 .... ____
   - If you live in the rest of the U.S., add 46 .... ____
4. House Construction
   - If you live in a stone, brick, or concrete building, add 7 .... ____

What You Eat and Drink

5. Internal radiation (in your body)*
   - From food and water 40
   - From air (radon) 200

Other Sources

6. Weapons test fallout**: 1
7. Jet plane travel: For each 1,000 miles you travel, add 1 .... ____
8. If you wear a luminous (LCD) wristwatch, add 0.006 .... ____
9. If you use luggage inspection at airports (using a typical x-ray machine), add 0.002 .... ____
10. For each smoke detector you have add 0.008 .... ____
11. If you wear a plutonium-powered cardiac pacemaker, add 100 .... ____
12. If you have had medical exposures:*
    - Diagnostic x-rays (e.g., upper and lower gastrointestinal, chest, dental), add 40 .... ____
    - If you have had nuclear medical procedures (e.g., thyroid scans), add 14 .... ____
13. If you live within 50 miles of a nuclear power plant (pressurized water reactor), add 0.0009 .... ____
14. If you live within 50 miles of a coal-fired power plant, add 0.03 .... ____

My total annual mrems dose: ____________

Some of the radiation sources listed in this chart result in an exposure to only part of the body. For example, false teeth result in radiation close to the mouth. The annual dose numbers given here represent the "effective dose" to the whole body.

* These are yearly average doses.

** The value is actually less than 1.

In the United States the average person is exposed to 360mrem of whole body radiation each year from all sources.

Activity from www.nrc.gov.

Average Atomic Weight

In this activity you will assemble two stable isotopes of boron, boron-10, and boron-11, and calculate the average weight of boron.

Materials

- M&M's® (two colors)
- Digital balance

✔ Procedure

1. Choose one color to represent protons and the other color will represent neutrons.
2. Make one atom of boron-10 with five protons and five neutrons.
3. Make four atoms of boron-11, each boron-11 atom has five protons and six neutrons.
4. Measure the weight of boron-10.
5. Measure the weight of boron-11.
6. Calculate the average weight of boron by dividing the total weight by the number of atoms (five).

Data

Draw a diagram of each boron atom. Label the protons and neutrons.

Boron-10

Boron-11

Mass of boron-10 atom ____________________

Percentage of Isotope ____________________

Mass of boron-11 atom ____________________

Percentage of Isotope ____________________

Average Weight of Boron ____________________

Examining Nuclear Energy

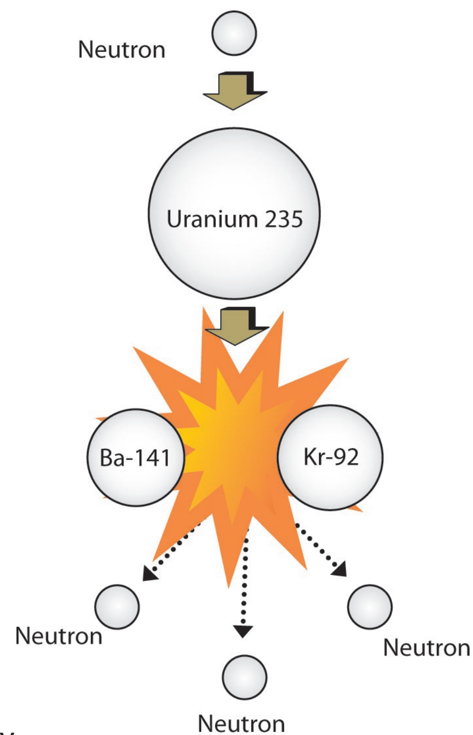
Uranium is the source used to generate heat in a nuclear reactor, but how does this work and what happens to the uranium? Let's take a closer look.

Here is a common decomposition of uranium where "n" stands for neutron:

$$^{235}U + n \longrightarrow {}^{92}Kr + {}^{141}Ba + 3\,{}^{1}n + \text{energy}$$

Use the following masses given in amu (atomic mass units) to solve the nuclear equation.

Mass of U-235 = 235.044
Mass of Kr-92 = 91.926
Mass of Ba-141 = 140.914
Mass of one neutron = 1.00866



Next, add the masses on both sides of the equation:

Left Side →		Right Side	
U-235	____________	Kr-92	____________
+ n	____________	+ Ba-141	____________
		+ n	____________
		+ n	____________
		+ n	____________
Total =	____________	Total =	____________

Albert Einstein presented the theory, $E=mc^2$ as part of his Theory of Relativity. "E" stands for energy, "m" stands for mass, and "c" is the speed of light (in a vacuum), used as a constant in this equation. This equation says that energy equals mass and mass equals energy. They are somehow related, or can be converted back and forth.

This means that during nuclear fission, mass is not lost, it is released as energy! Energy is measured as megaelectron volts, or MeV. One MeV equals one million electron volts. The average energy released by U-235 fission is about 200 MeV, in this scenario the energy is 170 MeV.

Uranium-235 does not always fission the same way. Some other products of fission include:

$$^{235}U + {}^{1}n \longrightarrow {}^{144}Ba + {}^{90}Kr + 2\,{}^{1}n + \text{energy}$$

$$^{235}U + {}^{1}n \longrightarrow {}^{94}Zr + {}^{139}Te + 3\,{}^{1}n + \text{energy}$$

$$^{235}U + {}^{1}n \longrightarrow {}^{94}Zr + {}^{139}La + 3\,{}^{1}n + \text{energy}$$