Why is the Atomic Mass of Iron not 56 but 55.847?

•INTRODUCTION

We have talked in class about **isotopes**: atoms of the same element that have different numbers of neutrons in their nucleus. For example, there are actually three different kinds of hydrogen atoms. The most common atom (or isotope) of the element hydrogen is called protium. It has one proton and zero neutrons in its nucleus. 99.9855 % of all hydrogen atoms are protiums. Another isotope of hydrogen, one which has one proton and one neutron in its nucleus, is called deuterium. Only 0.0145% of all hydrogen atoms are deuterium atoms. Deuterium is also called "heavy hydrogen" and forms a compound with oxygen called "heavy" water, D_2O. Tritium, the third isotope of the element hydrogen, has one proton and two neutrons in its nucleus. It is produced by cosmic ray bombardment of water in our atmosphere, radioactive, and is found only once in every quintillion (10^{18}) atoms of hydrogen. Other isotopes of common atoms are listed below.

isotope	protons	electrons	neutrons	significance
protium	1	1	0	"normal" hydrogen
deuterium	1	1	1	"heavy hydrogen"
tritium	1	1	2	radioactive hydrogen
carbon-12	6	6	6	"normal" carbon
carbon-14	6	6	8	carbon-14 dating
uranium-233	92	92	141	radioactive
uranium-235	92	92	143	nuclear fuel/bombs
uranium-238	92	92	146	radioactive

Carbon-12 atoms have a mass of about 12 amu and carbon-14 atoms have a mass of about 14 amu. Because there are both carbon-12 atoms and carbon-14 atoms, the average mass of a carbon atom will not be either 12 or 14 but somewhere in between. The average mass of a carbon atom is 12.011, since 99% of all carbon atoms are carbon-12 isotopes.

• HERE'S WHAT WE'RE DOING

If atoms were as large as beans they could be sorted, counted, and weighed. In this experiment we will sort, count, and mass three different kinds of beans and imagine that we are observing three different isotopes of the same element (let's call it the **bean element**). Finally we will calculate the isotopic mass, the isotopic abundance, and the atomic mass of the bean element.

• DEFINITIONS

isotopic mass: the average mass of a specific isotope of an element.
isotopic abundance: what percent of the element's atoms are a specific isotope
atomic mass: the average mass of an element's atoms.

The isotopic mass of deuterium is 2.014102 amu. The isotopic mass of protium is 1.007825 amu. The isotopic abundance of deuterium is 0.0145%. The isotopic abundance of protium is 99.9855%. The atomic mass of the element hydrogen is 1.00797 amu.

• OBJECTIVE

Show the relationship between isotopic mass, isotopic abundance, and atomic mass. Explain why the atomic mass of iron is not 56 but 55.847.

• EQUIPMENT

triple-beam balance
large beakers
lima beans
pinto beans
blackeyed beans

• PROCEDURE

1. Obtain a gallon milk jug which contains many atoms (beans) of the bean element.
2. Sort the atoms (beans) into a group of each isotope: lima, pinto, and blackeyed. Record the total number of atoms and the number of each type of isotope (lima, pinto, blackeyed) in a data table.
3. Sketch a picture of each isotope. Show clearly the difference between each isotope.
4. Determine the isotopic mass:
   a) find the total mass of each of the three isotope groups
   b) find the average mass of a single atom of each isotope (the isotopic mass)
   EXAMPLE: I counted 340 lima beans. They have a mass of 80 grams. The average mass of one lima bean is 80 / 340 = 0.235
5. Find the isotopic abundance for each isotope by dividing the number of atoms of one isotope by the total number of atoms (lima, pinto, and blackeyed) and multiplying by 100%.
   EXAMPLE: There are a total of 500 atoms. 340 are lima atoms. 340 / 500 • 100% = 68% are lima atoms.
6. Determine the atomic mass for your element based on the isotopic abundances and the isotopic masses.

atomic mass = lima atom%•mass of one lima atom + pinto atom%•mass of one pinto atom + blackeyed atom%•mass of one blackeyed atom

• SAMPLE DATA TABLE

Total number of bean element atoms in container: ____________

Isotope information:

isotope	# of beans (atoms)	mass of beans (atoms)
lima	______	______
pinto	______	______
blackeyed	______	______

• QUESTIONS

1. How many atoms do you have of each isotope?
2. What is the isotopic mass of each isotope?

3. What is the percent abundance of each isotope?
4. What is the atomic mass of the bean element?
5. Why is the atomic mass of iron 55.847 and not 56?

MORE QUESTIONS

High energy radiation poses a health hazard because of the damage it does to cells. Healthy cells are either destroyed or damaged by radiation, leading to physiological disorders. However, radiation can also destroy *unhealthy* cells, including cancer cells. All cancers are characterized by the runaway growth of abnormal cells. This growth can produce masses of abnormal tissue called *malignant tumors*. Malignant tumors can be caused by the exposure of healthy cells to high-energy radiation. However, somewhat ironically, malignant tumors can be destroyed by exposing them to the same radiation. In fact, cancerous cells are more susceptible to destruction by radiation than are healthy ones, allowing radiation to be used effectively in the treatment of cancer. As early as 1904, physicians attempted to use the radiation emitted by radioactive substances to treat tumors by destroying the mass of unhealthy tissue. The treatment of disease by high-energy radiation is called *radiation therapy*.

The chemical used in radiation therapy may be inside or outside the body. Radioactive iridium-192 "seeds" coated with 0.1 mm of platinum metal can be surgically implanted in a tumor. In other cases, human physiology allows the chemical to be swallowed. For example, most of the iodine in the human body ends up in the thyroid gland, a fact that allows thyroid cancer to be treated by using large doses of radioactive iodine-131. Radiation therapy on deep organs, where a surgical implant is impractical, often uses a cobalt-60 "gun" outside the body to shoot a beam of radiation at the tumor.

Because radiation is so strong, it is nearly impossible to avoid damaging healthy cells during radiation therapy. Most cancer patients undergoing radiation treatments experience unpleasant and dangerous side effects such as fatigue, nausea, hair loss, a weakened immune system, and even death. Thus, in many cases, radiation therapy is used only if other cancer treatments such as *chemotherapy* (treatment using powerful drugs) are unsuccessful. Nevertheless, radiation therapy is one of the major weapons we have in the fight against cancer.

1. Cobalt-59 and cobalt-60 are two isotopes of the element cobalt. How many protons, electrons, and neutrons does cobalt-59 have? How many protons, electrons, and neutrons does cobalt-60 have? What makes them different? Which is used in radiation therapy?

2. How many protons and neutrons are there in an atom of iodine-125? How many protons and neutrons are there in another isotope of iodine, iodine-131? How is iodine-131 used in cancer treatment?

3. Plutonium-239 is used to fuel nuclear reactors. The periodic table in your textbook says the atomic mass of Pu is 244. What is similar between plutonium-239 and plutonium-244? What makes them different?

4. How many protons and neutrons does magnesium-24 have? How many protons and neutrons does sodium-23 have? Why is a magnesium-24 atom magnesium and why is a sodium-23 atom sodium?

5. Boron has two common isotopes. An atom of boron-10 has an average mass of 10.012939 amu. An atom of boron-11 has an average mass of 11.009305 amu. 19.91% of all boron atoms are boron-10 and 80.09% of all boron atoms are boron-11. What is the atomic mass of boron? Why is it not 11?