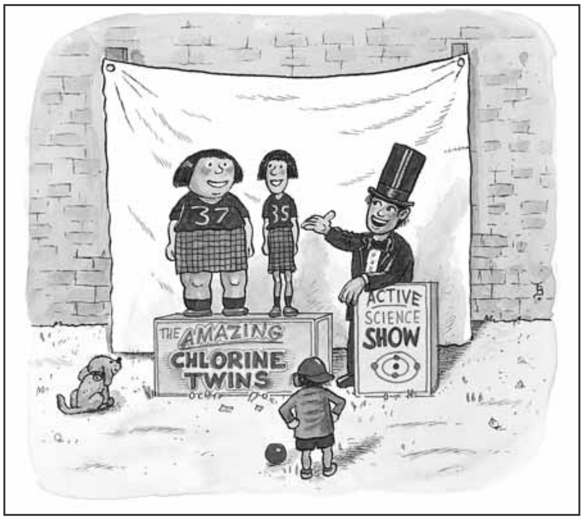
Activity 9 What Determines and Limits an Atom's Mass?



GOALS

In this activity you will:

- Investigate the composition of the atom's nucleus.
- Explain why the atomic masses of some elements are not whole numbers.
- Use symbols to represent different isotopes of an element.
- Determine the composition of the nucleus of an atom from its isotope symbol.
- Calculate the average atomic mass of an element from the percent abundance of its isotopes.

What Do You Think?

In **Activity 4** you learned that the structure of an atom includes a nucleus surrounded by electrons. Most of the mass of an atom is concentrated in the small nucleus that has a positive electric charge equal in magnitude to the negative charge of all the electrons surrounding the nucleus.

- What do you think makes up the nucleus of the atom?

Record your ideas about this question in your *Active Chemistry* log. Be prepared to discuss your responses with your small group and the class.

Investigate

Part A: What's in the Nucleus?

1. Atomic mass is the average mass of atoms of each element. Atomic number indicates the number of electrons in the atom and the number of protons located in the nucleus needed to produce an electrically neutral atom. Refer to the periodic table to answer the following questions:

What Do You Think?

Many students will be aware that protons and neutrons make up the nucleus of all atoms. They may have an understanding of what makes up the mass of an atom as well. A few students may assume that the mass is the sum of the protons and electrons. As they work through the activity they will learn that the mass of an electron is extremely small and that the neutron is the part that they were missing initially.

Student Conceptions

This activity asks students to explain concepts of conservation of nuclear particles and binding energy. These concepts are typically difficult for students because they are intangible. In order for students to develop mental pictures of the innards of atoms, and how those particles rearrange in nuclear processes, they must solidly understand the conservation of matter. Students often memorize the patterns involved in determining the composition of the nucleus of an isotope from its symbolic representation, and vice versa, rather than reason out the answers to these questions from sufficient information. In balancing nuclear equations, difficulties arise when students are unable to sum and take differences easily. Understanding the forces and energy involved in holding atoms together requires students to visualize a balance between attractive and repulsive forces. However, when two forces balance each other, students often do not understand that those forces may be quite large. Analogies can be useful in developing students' mental images, such as two large buildings that have the same mass balancing each other.

Active Chemistry The Periodic Table

a) How many protons are there in a hydrogen atom?

b) To the nearest whole number, what is the atomic mass of a hydrogen atom?

c) How many protons are there in a helium atom?

d) Since the mass of an electron is negligible, compared to the nucleus, what would you expect the atomic mass of a helium atom to be? Explain your answer.

e) To the nearest whole number, what is the atomic mass of a helium atom?

2. In **Step 1**, you found that the helium atom has a mass that is four times the mass of a hydrogen atom, while the electric charge on the helium nucleus is only twice that of the hydrogen atom. This suggests the presence of another particle in the nucleus, with about the same mass as the proton but no electric charge. This particle is called a neutron.

   Sample:

   Boron has atomic number 5. This informs you that there are 5 electrons and that the nucleus contains 5 protons. The average atomic mass of boron is 10.811 atomic mass units. Most boron has 11 atomic mass units and some has 10 atom mass units. Since the mass is the sum of the protons and the neutrons (electrons have very, very little mass) then you can conclude that most boron nuclides have 5 protons and 6 neutrons in the nucleus.

   Refer to your table of atomic numbers and atomic masses to answer the following questions:

   a) How many protons would you expect to find in the nucleus of a helium atom? (Recall that the number of protons needs to balance the number of electrons.)

   b) How many neutrons would you expect to find? (The atomic mass is a combination of the mass of the protons and the mass of the neutrons.)

   c) How many protons and neutrons would you expect to find in the nucleus of an atom of each of the following elements:

   - lithium
   - beryllium
   - boron
   - carbon
   - nitrogen
   - oxygen
   - fluorine
   - neon

3. Refer again to the periodic table.

   a) What are the atomic masses of magnesium and chlorine? What are the atomic masses of sodium and fluorine? Which set is closer to whole numbers?

   b) We expect protons and neutrons to exist in whole numbers. You cannot have part of a proton in the nucleus. What would you expect the atomic masses of most magnesium, chlorine, sodium, and fluorine atoms to be? Explain your answer.

4. The fact that some atomic masses are not close to whole number multiples of the atomic mass of hydrogen is now explained by the fact that the number of neutrons is not the same in all atoms of a given element. Only the number of protons, the atomic number, is the same in all atoms of a

Investigate

Teaching Suggestions and Sample Answers

Part A: What's in the Nucleus?

1. a) A hydrogen atom contains 1 proton.

b) If students look at the periodic table, they will note that the mass of the hydrogen atom is 1.008 amu. They will accept the atomic mass of hydrogen to be 1.

c) The atomic number of helium is 2 and this means that it contains 2 protons.

d) Students may think that since hydrogen had an atomic number of 1 and a mass of 1 amu, then helium must have a mass of 2 amu since it has atomic number of 2.

e) The atomic mass of helium is 4 amu.

2. a) Helium has atomic number of 2 and it implies that helium has 2 protons.

b) Since the atomic mass of helium is 4, then we would have to assume that the nucleus must contain 2 neutrons as well. Atomic mass is the sum of protons and neutrons. 2 protons + 2 neutrons = 4 amu.

c)

• Lithium:	3 protons	+	4 neutrons	=	7 amu
• Beryllium:	4 protons	+	5 neutrons	=	9 amu
• Boron:	5 protons	+	6 neutrons	=	11 amu
• Carbon:	6 protons	+	6 neutrons	=	12 amu
• Nitrogen:	7 protons	+	7 neutrons	=	14 amu
• Oxygen:	8 protons	+	8 neutrons	=	16 amu
• Fluorine:	9 protons	+	10 neutrons	=	19 amu
• Neon:	10 protons	+	10 neutrons	=	20 amu

3. a) Magnesium (24.305 amu); chlorine (35.4527 amu); sodium (22.98977); and fluorine (18.99840). Sodium and fluorine are closer to whole numbers than magnesium and chlorine are.

b) Magnesium (24 amu); chlorine (35 amu); sodium (23 amu); and fluorine (19 amu). Rounding the values to whole numbers. The students will eventually understand that the atomic mass units are average values.

Chem Tip:
1 atom ^{12}C = 12 u, where u is the symbol used in the SI system and means the atomic mass unit (amu). Also 1 u = 1 dalton.

given element. Atoms of the same element with different number of neutrons in the nucleus are known as isotopes (meaning "same number of protons"). Isotopes are identified by their mass number, the sum of the number of neutrons plus protons.

Sample:

Lithium has an atomic number of 3 and an average atomic mass of 6.941. All lithium atoms have 3 protons in the nucleus. A neutral atom of lithium always has 3 electrons to balance the charge of the three protons. The average atomic mass of a lithium atom is 6.941 atomic mass units, indicating that some lithium atoms have 3 neutrons, to make a total atomic mass of 6 and other lithium atoms have 4 neutrons, to make a total atomic mass of 7. These 2 isotopes are designated lithium-6 and lithium-7. Since there are so many more lithium-7 atoms, the average of all of the atoms is very close to 7.

Refer to your list of atomic masses to answer the following questions:

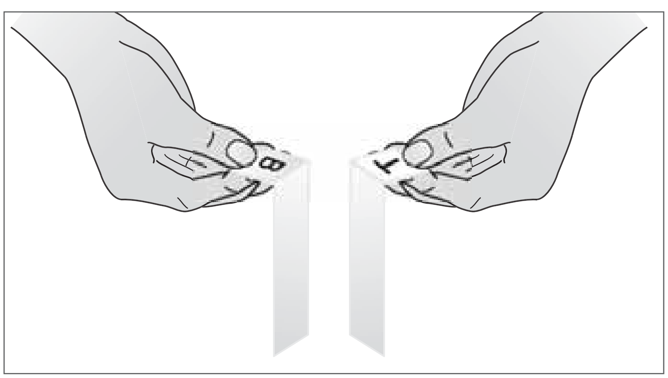
a) What isotopes (as indicated by their mass numbers) do you expect to account for the known atomic masses of the following elements?
   - carbon (carbon-12 atoms with 6 neutrons and carbon-13 atoms with 7 neutrons; more carbon-12 atoms)
   - hydrogen
   - beryllium
   - boron
   - sodium
   - magnesium

b) In the notation below, the mass number is written at the upper left of the chemical symbol of the element. The atomic number is written at the lower left of the chemical symbol of the element. How many neutrons and protons are present in the following isotopes?
   i) $^{3}_{2}\mathrm{He}$ and $^{4}_{2}\mathrm{He}$
   ii) $^{6}_{3}\mathrm{Li}$ and $^{7}_{3}\mathrm{Li}$
   iii) $^{12}_{6}\mathrm{C}$ and $^{13}_{6}\mathrm{C}$
   iv) $^{14}_{7}\mathrm{N}$ and $^{15}_{7}\mathrm{N}$

Part B: Forces within the Atom

1. There are two very different forces acting on the electrons, protons, and neutrons in the atom. In order to better understand the atom, you must first understand these forces.

   Cut two strips of transparent tape about 12 cm long. Bend one end of each strip under to form a tab. Place one strip sticky-side down on a table and label the tab "B," for "bottom." Place the other strip sticky-side down



4. **a)**

- Carbon: 6 protons + 6 neutrons = 12 amu, and 6 protons + 7 neutrons = 13 amu. The average amu is 12.011, carbon-12 is the major isotope.
- Hydrogen: 1 proton + 0 neutrons = 1 amu, and 1 proton + 1 neutron = 2 amu. The average amu is 1.00794, hydrogen-1 is the major isotope.
- Beryllium: 4 protons + 5 neutrons = 9 amu, and 4 protons + 6 neutrons = 10 amu. The average amu is 9.01218, beryllium-9 is the major isotope.
- Boron: 5 protons + 5 neutrons = 10 amu, and 5 protons + 6 neutrons = 11 amu. The average amu is 10.811, boron-11 is the major isotope.
- Sodium: 11 protons + 11 neutrons = 22 amu, and 11 protons + 12 neutrons = 23 amu. The average amu is 22.98977, sodium-23 is the major isotope.
- Magnesium: 12 protons + 12 neutrons = 24 amu, 12 protons + 13 neutrons = 25 amu. The average amu is 24.305, magnesium-24 is the major isotope.

b) **i)** $^{3}_{2}He$ contains 2 protons and 1 neutron to give 3 amu.

$^{4}_{2}He$ contains 2 protons and 2 neutrons to give 4 amu.

ii) $^{6}_{3}Li$ contains 3 protons and 3 neutrons to give 6 amu.

$^{7}_{3}Li$ contains 3 protons and 4 neutrons to give 7 amu.

iii) $^{12}_{6}C$ contains 6 protons and 6 neutrons to give 12 amu.

$^{13}_{6}C$ contains 6 protons and 7 neutrons to give 13 amu.

iv) $^{14}_{7}N$ contains 7 protons and 7 neutrons to give 14 amu.

$^{15}_{7}N$ contains 7 protons and 8 neutrons to give 15 amu.

on top of the first strip and label the tab "T," for "top."

Peel off the top strip, using the tab, with one hand and then pick up the bottom strip with the other hand. Hold both strips apart, allowing them to hang down.

Slowly bring the hanging strips toward each other, but do not let them touch.

a) Record your observations.

b) If the strips accelerated toward or away from each other, Newton's Second Law tells you that there must be a force. Is the force between the two strips of tape attractive or repulsive?

2. Make a second set of strips as in **Step 1**.

a) Predict what you think will happen if the two top strips are picked up, one from each set and brought toward each other. Record your prediction in your *Active Chemistry* log.

Pick up the two top strips by the tabs, allowing both strips to hang down. Slowly bring them toward each other.

b) Record your observations.

c) Was the force attractive or repulsive? Explain.

d) Predict what you think will happen if the two bottom strips of tape are picked up and brought toward each other. Record your prediction.

Pick up the two bottom strips by the tabs, allowing both strips to hang down. Slowly bring them toward each other.

e) Record your observations.

f) Was the force attractive or repulsive? Explain.

3. The two different strips of tape have different charges. The top strips have a positive electric charge. They have lost some of their electrons. Since the number of protons has remained the same, the strips are positive. The bottom strips have a negative charge. The bottom strips have gained some electrons. Since the number of protons has remained the same, the strips are negative. The force between the strips is called the electric force.

a) Is the force between two positive strips repulsive or attractive? Use evidence to justify your answer.

b) Is the force between two negative strips repulsive or attractive? Use evidence to justify your answer.

c) When a positive and a negative strip come near each other, is the force attractive or repulsive? Justify your answer.

4. The nucleus has a positive charge due to all of the protons there. The electrons surrounding the nucleus have negative charges.

a) What kind of electric force (attractive or repulsive) exists between the nucleus of an atom and any one of the atom's electrons?

b) What kind of electric force (attraction or repulsion) exists between pairs of protons in the nucleus?

Part B: Forces within the Atom

1. a) They are attracted to each other.

   b) Attractive force.

2. a) The two strips should repel each other since they have like charges.

   b) The top strips repel each other.

   c) The force was a repulsive force since the strips have like charges.

   d) The bottom strips also have a like charge and so when the strips are brought close to each other they will repel each other.

   e) The strips do repel each other.

   f) The force is a repulsive. The charges on the bottom strips are opposite to the charge that was on the top strips. Again we find that like charges will repel each other.

3. a) Like charges will repel each other as noted when the two top strips were brought near each other.

   b) The bottom strips have negative charges and they will repel each other since like charges repel and as was noted when the two bottom strips were brought near each other.

   c) When a top and bottom strip are brought near each other we find that the strips are attracted to each other. Unlike charges attract each other.

4. a) The electron has a negative charge and the proton has a positive charge. Unlike charges will attract each other.

   b) The protons have like charges and will repel each other.

5. The nucleus is a very crowded place. The protons in the nucleus are very close to one another. If these protons are repelling each other by an electrostatic force (and they are!), there must be another force, an attractive force, that keeps them there. The attractive force is the nuclear force, also called the strong force. This force is much stronger than the electric force. It acts between pairs of protons, pairs of neutrons, and protons and neutrons. The electron is not affected by the nuclear force.

   a) Copy and complete the table below in your *Active Chemistry* log. The first row has been completed for you.

6. If the nucleus were too large, the protons on one side of the nucleus are too far away to attract the protons on the other side of the nucleus. The protons can still repel one another since the coulomb electrostatic force is long-range. The repulsive electrostatic force wins and the nucleus won't form.

   A large nucleus will break apart when the electrostatic repulsion between the protons is too great. The repulsion pushes the fragments of the nucleus apart, releasing a great amount of energy. This process of splitting an atom into smaller atoms is called fission. It occurs in uranium when an additional neutron is added and causes instability.

   One example of the fission process can be represented as follows:

   $$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{94}_{36}\text{Kr} + ^{139}_{56}\text{Ba} + 3\ ^{1}_{0}\text{n} + \text{energy}$$

   a) Is the mass number conserved on both sides of the reaction? What is the total mass number on each side?

   b) Is the atomic number conserved on both sides of the reaction? What is the total atomic number on each side?

   c) Why does the neutron have a mass number of 1?

   d) Why is the atomic number of a neutron equal to 0?

   Small nuclei can also combine to form a larger nucleus and release energy. This process is called fusion.

Particles	Coulomb electrostatic force	Strong, nuclear force
electron-proton	*attractive*	*none*
electron-neutron		
proton-proton		
proton-neutron		
neutron-neutron		

5.

Particles	Coulomb electrostatic force	Strong, nuclear force
electron-proton	attractive	none
electron-neutron	none	none
proton-proton	repel	strong
proton-neutron	none	strong
neutron-neutron	none	strong

6. **a)** The mass number is conserved on both sides. The total mass is 236 amu.

   b) The atomic number is conserved on both sides. The total atomic number is 92.

   c) A neutron has almost the same mass numerical value as a proton.

   d) The neutron is neutral and the atomic number is associated with the positive charge of a proton or the negative charge of an electron. Therefore, the neutron will have an atomic number of zero.

Active Chemistry The Periodic Table

Chem Talk

THE NUCLEUS OF AN ATOM

Discovery of the Neutron

The average atomic masses of some elements were known in Mendeleev's time, even though scientists didn't know much about the actual structure of an atom. In **Part A** of this activity you explored the idea of how the atomic mass relates to the atomic number. Mendeleev began organizing his periodic table by listing all the known elements in order of atomic mass. However, he found that organizing the elements in this way did not always make sense in terms of the behavior of the elements. He concluded that his measurements of atomic mass were incorrect and in those situations used the properties of the elements to place them in the table.

As it turned out, Mendeleev's measurements were not necessarily flawed. Although early models of the nucleus included the **proton**, the proton alone could not account for the fact that the mass of a helium atom is four times the mass of a hydrogen atom while the electric charge on the helium nucleus is only twice that of the hydrogen atom. Lord Rutherford (after discovering that atoms had a nucleus) addressed this problem when he suggested that another particle was present in the nucleus, with about the same mass as the proton but no electric charge. He named this particle the **neutron**.

Chem Words

proton: a positively charged subatomic particle contained in the nucleus of an atom. The mass of a proton is 1.673×10^{-24}g and has a charge of +1

neutron: neutral subatomic particle with a mass of 1.675×10^{-24}g located in the nuclei of the atom

The neutron was actually discovered in 1932 (by Chadwick, a British physicist), adding a great deal to the understanding of the nucleus of the atom. This discovery did not solve all of the mysteries concerning the atomic masses of some elements. Scientists today refer to protons and neutrons as nucleons since they reside in the nucleus and are almost identical in mass. The mass number tells us the number of nucleons.

Isotopes

In **Part A** of this activity you also investigated why the atomic mass of an element is not a whole number. Not all atoms of a given element have the same number of neutrons in the nucleus. Only the number of protons, the atomic number, is the same in all atoms of a given element. Atoms of the same element with different number of

ChemTalk

Chem Tip:
Nuclear stability depends on several factors but one that we can look at is the neutron to proton ratio. We should note that those elements that have atomic number less than 26 and have a neutron to proton ratio that is close to 1:1 are quite stable. The elements that have atomic numbers greater than 26, we find that the neutron to proton ratio favors more neutrons than protons. It should also be noted that all of the elements that have an atomic number of 84 or greater are radioactive. Then let us look at three different types of radioactive decay that could take place in order for the element to gain stability.

(I) The elements that have too many neutrons to proton ratio will try to achieve stability through beta emission. Examples of beta emission are:

Carbon-14 has 8 neutrons to 6 protons: ${}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$

Iodine-131 has 78 neutrons to 53 protons: ${}^{131}_{53}I \rightarrow {}^{131}_{54}Xe + {}^{0}_{-1}e$

(II) The elements that have a rich proton nuclei can have positron emission. Examples of positron emission are:

Xenon-118 has 64 neutrons to 54 protons: ${}^{118}_{54}Xe \rightarrow {}^{131}_{53}I + {}^{0}_{1}e$

Oxygen-15 has 7 neutrons to 8 protons: ${}^{15}_{8}O \rightarrow {}^{15}_{7}N + {}^{0}_{1}e$

(III) Those elements that have atomic number of 84 or greater have a tendency to undergo alpha emission. Examples of alpha emission are:

Radon-222 has 136 neutrons and 86 protons: ${}^{222}_{86}Rn \rightarrow {}^{218}_{84}Po + {}^{4}_{2}He$

Uranium-238 has 146 neutrons and 92 protons: ${}^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$

We see that uranium-238 will undergo radioactive decay (alpha emission) but it does participate in nuclear fission. Uranium-235 has a stable nuclei (neutron to proton ratio) and apparently does decay spontaneously like the previous examples illustrated, but will allow the nuclei to be split into smaller elements and achieve greater stability (nuclear fission).

Nuclear fusion is the hope of the future in that it uses light isotopes and because in this process the products are not considered to be radioactive. The largest problem that we must overcome is the large amount energy needed to overcome the repulsion of the nuclei. In the fusion process of fusing deuterium and tritium requires temperatures of around 4×10^7K. So, you can see that we have much research needed to be done in order to resolve this problem.

neutrons in the nucleus are known as **isotopes** (meaning "same number of protons"). Isotopes are identified by their mass number, the sum of the number of neutrons plus protons.

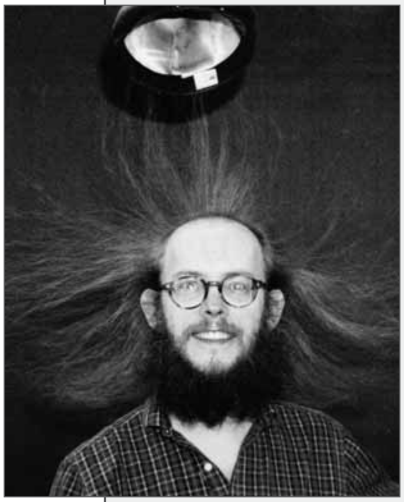
You can refer to an element by its name (chlorine), by its atomic symbol (Cl), or by its atomic number (17). All three identifications are equivalent and used interchangeably in chemistry. The same element can have a different number of neutrons in the nucleus. Chlorine, which must have 17 protons in the nucleus, can have 18 or 20 neutrons. Chlorine with 20 neutrons and chlorine with 18 neutrons are the isotopes of chlorine (^{35}Cl and ^{37}Cl).

Chem Words

isotope: atoms of the same element but different atomic masses due to different number of neutrons

Electrostatic and Nuclear Forces

In **Part B** of this activity, when you brought the two positive strips near each other, they experienced a repulsive force. This was true for two negative strips as well. When a positive and a negative strip were brought close together, the force was attractive. As you have heard, "opposites attract!"



Inside the nucleus, the protons are repelling one another. Every pair of protons has a repulsive force between them. The force is very large because the distances within the nucleus are very small. The nucleus is between 10,000 and 100,000 times smaller than the atom. The electrical force can be described mathematically.

$$F = \frac{kq_1q_2}{d^2}$$

where F is the force,

k is Coulomb's constant (a number $= 9 \times 10^9$ N m^2/C^2),

q_1 and q_2 are the charges, and
d is the distance between the charges.

As the distance between the charges increases the force weakens. Since the distance in the denominator is squared, if the distance triples the electrical force is 9 times (3^2) weaker or one-ninth as strong.

We will recap the fission and fusion reactions with the two basic reactions:

Fission: $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{142}_{56}Ba + ^{91}_{36}Kr + 3\ ^{1}_{0}n$
(This is just one example of how uranium-235 can split.)

Fusion: $^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$

The question then becomes, what holds the protons together in the nucleus? The protons do have an electrical force pushing them apart but they have the larger nuclear force holding them together. The nuclear force is strong at short range. Anywhere beyond a distance of approximately 10^{-14} m (that's less than one 10 millionth of one 10 millionth of a meter), the nuclear force is zero. Neutrons in the nucleus are also attracted to each other and to protons with the nuclear force. Electrons are not affected by the nuclear force. Electrons belong to a different class of particles than protons and neutrons and do not interact with the strong nuclear force.

The nucleus is held together by a new force—the strong nuclear force. The nuclear force:

- is very, very strong at small distances;
- acts only between nucleons (proton-proton, proton-neutron, neutron-neutron);
- is always attractive;
- is very short range (if nucleons are more than 10^{-14} m apart, the nuclear force is zero).

The atom is held together by the electrostatic coulomb force. The electrostatic force:

- is strong at small distances, weak at large distances;
- acts only between charged particles (proton-proton, electron-electron, proton-electron);
- is attractive or repulsive;
- is long range (the force gets weaker at large distances).

All the nucleons are attracted by the nuclear force. The electrostatic force repelling protons in the nucleus is overwhelmed by the attractive nuclear force between these protons.

Unstable Atoms

You might expect to find nuclei of atoms with all sorts of combinations of neutrons and protons. Yet the quantity of isotopes for each element is rather small, and the number of elements is also limited. Moreover, elements do not occur in nature with atomic number greater than 92, and the highest atomic number for an atom created in the laboratory is 117.

NOTES

There are two stable masses of chlorine, chlorine-35 and chlorine-37. The key word in this statement is "stable." There are other isotopes of chlorine, both heavier and lighter than chlorine-35 and chlorine-37, but they are not stable. The unstable isotopes can convert to a more stable combination of neutrons and protons, and they do so according to a systematic pattern in time. These other isotopes of chlorine are said to be **radioactive**. Understanding why certain elements are radioactive requires a deeper understanding of the structure of the nucleus. Scientists are still trying to fully understand stability of the elements.

If the nucleus of an atom is too large, the protons on one side of the nucleus are too far away to attract the protons on the other side of the nucleus. The protons can still repel one another since the coulomb electrostatic force is long-range. The interaction between the repulsive electrostatic force and the attractive nuclear force is one determining factor on the maximum size of a nucleus.

The stability of an atom varies with the elements. Light elements become more stable as the atomic mass (the number of nucleons) increases. The most stable element is iron (atomic number 26) with an atomic mass of 56. Elements with larger atomic masses become less stable.

In general, elements with nuclear mass much, much less than 56 can combine to gain mass, become more stable, and give off energy. This process is called **fusion**. Elements with nuclear mass much, much greater than 56 can break apart to lose mass, become more stable, and give off energy. This process is called **fission**.

Fusion is the process of small nuclei combining to increase their mass. The best example of fusion processes is what occurs in the Sun and other stars. The fusion process is ideal for supplying safe energy because it releases very large amounts of energy without leaving much dangerous radioactive residue. However, it is very difficult to accomplish this on an industrial level at the present time. In the future we hope scientists will figure out how to harness the energy of nuclear fusion, because it would be an excellent source of energy for society.

The process of splitting an atom into smaller atoms is called fission. This is the process that is used to produce nuclear energy. It is used to power nuclear submarines and to produce electrical energy in nuclear power plants all over the world.

Chem Words

radioactive: an atom that has an unstable nuclei and will emit alpha, positron, or beta particles in order to achieve more stable nuclei

fusion: nuclei of lighter atoms combining to form nuclei with greater mass and release of a large amount of energy

fission: the process of breaking apart nuclei into smaller nuclei and with the release of a large amount of energy

NOTES

Active Chemistry The Periodic Table

The use of nuclear energy for the production of electricity is quite apparent as you look at the numerous states that depend on nuclear energy. For example, over 40% of Illinois' electricity is produced by nuclear energy. Nuclear fission does create some major problems: (1) Security, (2) Radiation, (3) Removal of spent rods, and (4) Disposal of waste. With these problems, there is a need for continued research. Numerous universities and government facilities are trying to improve the efficiency of nuclear fission and at the same time, trying to develop nuclear fusion for commercial use.

This ongoing research is expensive and depends on the government, industry, and other organizations to continue supporting this research. If we can learn how to harness nuclear fusion we can alleviate our nation's electrical problems while decreasing pollution. The field of nuclear science is going to continue to grow and the future will provide great opportunities for a young scientist like you to get involved.

Checking Up

1. Explain the difference between atomic mass and atomic number.
2. What two forces are at work in the nucleus of an atom? Explain how each works.
3. What is an isotope?
4. Why are some isotopes unstable?
5. Construct a table or diagram to compare and contrast the nuclear processes of fission and fusion.

ChemTalk

Checking Up

1. The atomic mass is the sum of the number of protons and neutrons that an atom contains. The mass contributed by the electron is so small that it is insignificant. The atomic number is the number of protons or the number of electrons that an atom contains.

2. The electrostatic coulomb force and the strong nuclear force operate in the nucleus of an atom. The electrostatic force can be a repulsion force (proton-proton) and is strong at close range but becomes weaker as the distance between the protons becomes greater. The strong nuclear force is very strong at close distances but becomes insignificant as the particles become farther apart. These forces are attractive and can act on: proton-proton, proton-neutron, and neutron-neutron.

3. Elements can have atoms with different masses. The difference in mass is due to the number of neutrons, as they all have the same number of protons. These conditions are called isotopes.

4. The binding stability of an atom is dependent on the ratio of neutron to proton in the nucleus. Low atomic number elements favor a ratio that is close to 1:1 and elements that have high atomic numbers favor more neutrons to protons. Atoms that do not have favorable ratios will undergo radioactive decay.

5. Fission: ${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{142}_{56}Ba + {}^{91}_{36}Kr + 3\,{}^{1}_{0}n$

   Fusion: ${}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + {}^{1}_{0}n$

Reflecting on the Activity and the Challenge

In **Part A** of this activity you learned that the mass of an atom, concentrated in the nucleus, is due to two types of particles, the proton and the neutron. Elements are identified by their atomic number, the number of protons in the nucleus. The atomic mass, the average mass of an atom of a given element, listed on the periodic table is a reflection of the variety of isotopes of a given element that exist. How will you incorporate your expanded understanding of the contents of an atom's nucleus, average atomic masses and isotopes into your game about the periodic table?

In **Part B** of this activity you also learned that only some combinations of neutrons and protons in a nucleus are stable, depending on the balance between the strong force holding the nuclear particles together and the electric force pushing them apart. The nuclear force is a short-range force. Beyond a distance of approximately 10^{-14} m, the nuclear force has no strength. Within that distance, this force between protons and protons, protons and neutrons, and neutrons and neutrons is quite strong. Recognizing the interplay between the electric force in the nucleus and the strong, attractive nuclear force provides an insight into the size of nuclei and the maximum size of a nucleus. These insights can be incorporated into your periodic table game in a creative way.

Chemistry to Go

1. If lithium loses an electron to become Li+, what is the average atomic mass of the lithium ion? Explain how you arrived at your answer.
2. Hydrogen has 3 isotopes with mass numbers of 1, 2, and 3. Write the complete chemical symbol for each isotope.
3. Give the complete chemical symbol for the element that contains 16 protons, 16 electrons, and 17 neutrons.
4. Complete the table below: (Use the periodic table.)

Chemical symbol	$^{39}_{19}K$			
Atomic number		9		
Number of protons			15	
Number of electrons				53
Number of neutrons		10	16	
Atomic mass				127

5. Neutrons can be used to bombard the nucleus of an atom like uranium. Why would it be more difficult to inject the nucleus of uranium with a proton?

Chemistry to Go

1. Lithium average mass is 6.941 amu. If the lithium is ionized and becomes an Li^+ it will still have the same average mass since the loss of the mass of an electron is insignificant.

2. $^{1}_{1}H$, $^{2}_{1}H$, and $^{3}_{1}H$ (Also note that tritium is radioactive.)

3. $^{33}_{16}S$

4.

Chemical symbol	$^{39}_{19}K$	$^{19}_{9}F$	$^{31}_{15}P$	$^{127}_{53}I$
Atomic number	19	9	15	53
Number of protons	19	9	15	53
Number of electrons	19	9	15	53
Number of neutrons	20	10	16	74
Atomic mass	39	19	31	127

5. The neutrons are neutral and would not cause noticeable repulsion until they enter the nucleus, whereas, a proton would have difficulty in approaching the nucleus since it would be repelled by the positive nucleus.

Active Chemistry The Periodic Table

6. Complete the following reaction: $^{215}_{92}\mathrm{U} + ^{1}_{0}\mathrm{n} \rightarrow ^{94}_{38}\mathrm{Sr} +$ _____ $+ 2\,^{1}_{0}\mathrm{n}$
7. Radon is a threat to the well-being of people in their homes because it emits radioactive particles at a significant rate. Complete the following radioactive decay equation:

   $^{222}_{86}\mathrm{Rn} \rightarrow ^{218}_{84}\mathrm{Po} +$ _____
8. Explain why a helium atom is able to exist. What keeps the 2 electrons, 2 protons, and 2 neutrons together?

Inquiring Further

Calculating average atomic mass

If you know the percentages of abundance for the isotopes of a chemical element and the known masses of those isotopes, you can calculate the average atomic mass of that element. The process is similar to calculating the average age of students in your class — add up each person's age and divide by the number of students in your class. However, if you had to average the age of all of the students in your high school, you might choose another route. It would be easier to find out how many students are fourteen, how many are fifteen, and so on. Then you could multiply the number of students in each age group by that age. Then you would add these subsets together and divide by the total number of students.

A similar process is used to average the masses of different isotopes of an element. Consider the element chlorine. There are two stable isotopes of chlorine, chlorine-35 and chlorine-37. Of all the chlorine atoms on Earth, 75.77% of them are the isotope chlorine-35, each having a mass of 34.96885. The other 24.23% of stable chlorine atoms are the isotope chlorine-37, each having a mass of 36.96590. This means that 75.77 out of 100 chlorine atoms have a mass of 34.96885 and 24.23 have a mass of 36.96590. To find the average mass, the number of each isotope is multiplied by that isotope's mass. Then the products are added together. The sum is divided by 100, since the information pertained to 100 chlorine atoms. The result is an average atomic mass of 35.45 for chlorine, the same value stated in the periodic table. The math is shown below:

Chlorine-35 $34.96885 \times 75.77 = 2649.6$

Chlorine-37 $36.96590 \times 24.23 = 895.7$

$3545.3 \div 100 = 35.453$

Magnesium, another isotope you investigated, has three stable isotopes as follows:

mass number	isotopic mass	% abundance
24	23.98504	78.99
25	24.98594	10.00
26	25.98259	11.01

Calculate the average atomic mass for magnesium. Describe how you arrived at your answer. You may use the process described above or challenge yourself to develop your own process.

6. $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{94}_{38}Sr + ^{140}_{54}Xe + 2\ ^{1}_{0}n$

7. $^{222}_{86}Rn \rightarrow ^{218}_{84}Po + ^{4}_{2}He$ (alpha decay)

8. The nucleus is held together by the strong nuclear force and the electrostatic coulomb attractive force between the electrons and protons hold the atom together.

Inquiring Further

mass number	isotopic mass		% abundance		
24	23.98504	×	78.99	=	1895.
25	24.98594	×	10.00	=	249.9
26	25.98259	×	11.01	=	286.1
					2431.0 ÷ 100 = 24.31

Note: Using significant digits, the mass contributed by the isotope magnesium-24 is 1895 amu. Then the sum of the isotopes would be 2431 amu and the average would be 24.31 amu.

The Periodic Table Assessment

Your Chapter Challenge is to develop a game related to Mendeleev's Periodic Table of the Elements. The game should be interesting, entertaining and informative. It should demonstrate your understanding of the periodic table while it helps other students learn about the periodic table. When people begin your game, they may have no knowledge of chemistry or the periodic table. After they complete the game, they should be able to report on chemistry principles which are reflected in the periodic table.

You can begin work on the **Chapter Challenge** by reviewing the important features of the periodic table that you want to include in your game. Choose a small section of the periodic table and list what you know about each element including its atomic number, atomic mass, chemical properties, electron configuration, nuclear structure and where and why it is placed where it is in the periodic table. Next to each of these items, you may wish to describe how we know some of these details (e.g., describe the Rutherford scattering experiment for evidence of the nucleus; Law of Definite Proportions for evidence of atoms). You should review the nine activities in the chapter to add to your list. You should pay particular attention to the section **Reflecting on the Activity and the Challenge**. You should also compare your list with that given in the **Chemistry You Learned** summary.

You now have to create the game which will highlight the chemistry principles that you have investigated in the past few weeks. There are a wide variety of games. There are traditional board games like Monopoly, Parcheesi, Clue and Risk. There are card games like gin rummy, hearts, solitaire, poker and bridge. There are TV games like *Jeopardy*, *Wheel of Fortune* and *The Price is Right*. There are video games like SimCity, PacMan and Space Invaders. There are also word games like crossword puzzles and anagrams. You have lots of experience with many different kinds of games. The first hurdle for your team will be to decide on the type of game that you will use as the format for communicating your knowledge of the periodic table. Your game should not merely be a periodic table test. It should be an entertaining approach to learning about the periodic table as well as displaying knowledge.

Once you decide and agree upon a game format, you will have to generate a set of rules. These rules will include whether people work individually or in groups, how one earns points or wins, how to get help during the game and suggested strategies for the game.

After the rules of the game are set, you must integrate your expert knowledge of the periodic table into the game. How will people playing the game learn that the atomic number corresponds to the number of protons and electrons in the neutral atom? How will players learn that isotopes of chlorine affect the stated mass? How will players get credit for

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remembering that the electron configurations are responsible for chemical behavior. The list of chemistry principles that you first completed can now be expanded so that each principle becomes the basis for a part of the game.

After the game structure is completed, you may have to design a board or some computer application so that the game can be played. Some careful preparation here can make a big difference in how well your game is accepted by others.

You should now practice the game as if you and your team members are playing it for the first time. Carefully critique your own game and edit the rules, approaches and chemistry principles so that the game is truly entertaining and educational. Review all of the criteria listed at the beginning of the chapter and the grading criteria agreed to by your teacher and class. Create a checklist and perform a final review of your checklist. Grade yourself before the presentation of your game to ensure that your team is heading for a great grade.

Chemistry You Learned

Elements' chemical and physical properties	**Protons**	**The spectral lines classified as Balmer series, Lyman series, and Paschen series**	**Group chemical behavior**
Atoms	**Line spectrums produced by different elements**	**Ionization potential of atom's electron**	**Noble gas electron configuration and stability**
Single-displacement reactions	**Energy, frequency, and wavelength produced by the excitation of electrons**	**Periodicity of the elements**	**Valence electrons**
Double-displacement reactions	**Electromagnetic spectrum**	**Atom's energy level and the sublevel energy of the outermost electron**	**Ionic compounds and ionic bonding**
Atomic mass	**Bohr's Atomic Theory**	**Electron configuration**	**Covalent compounds and covalent bonds**
Compound	**Orbits of electrons**	**Family or chemical groups on the periodic table**	**Chemical formula**
Law of Definite Proportions			**Neutrons**
Avogadro's number and a mole			**Nuclear stability**
Electrons			**Isotopes**
Nucleus			**Fission**
			Fusion
			Electrostatic force
			Strong, nuclear force

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