Module 6 – Atoms, Ions, and Periodicity

Prerequisites: None. This module may be started at any point.

Each lesson in this module has a pretest. If you pass the pretest, you may skip the lesson. Module 6 covers fundamentals. Depending on your background, you may be able to skip several lessons or complete them very quickly.

To do this module, you will need an alphabetical list of the elements (at the end of these lessons) and a periodic table of the elements that closely resembles the type of table you will be allowed to consult during quizzes and tests in your course.

Lesson 6A: Atoms

Pretest: Using a list of elements or a periodic table, try problem 4 at the end of this lesson. If you find problem 4 easy, you may skip to Lesson 6B.

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Terms and Definitions

The following definitions are general and highly simplified, but they will provide us with a starting point for discussing atoms.

1. **Matter**. Chemistry is primarily concerned with the measurement and description of the properties of matter and energy. Matter is anything that has mass and volume. All matter is composed of extremely small particles. A substance's identity depends on the particles that make up the substance.

2. When substances undergo **physical changes**, they do not change their identity. Melting ice to water is a physical change, because both ice and liquid water are composed of the same basic particles.

   When substances undergo **chemical reactions**, they change their identity. The basic particles change, and the formulas for the substances also change.

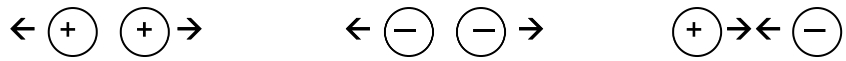
3. **Atoms** are the fundamental building blocks of matter**.** There are 91 different kinds of atoms that are naturally occuring in the Earth's crust. More than 20 additional atoms have been synthesized by scientists using nuclear reactions. All of the many different types of matter on earth are composed of these *limited* different types of atoms.

   Chemical reactions cannot create, destroy, nor change an atom from one type of atom to another.

   A list of the atoms, each corresponding to specific element, is found at the end of these lessons. Each atom is represented by a one- or two-letter **symbol**. The first letter of the symbol is always capitalized. The second letter, if any, is always lower case.

4. **Electrical charges.** Some particles have a property known as electric charge.

   - There are two types of charges, positive and negative. Particles with like electrical charges repel. Unlike charges attract.



5. **Atomic structure:** Atoms can be described as combinations of three **subatomic particles.** The subatomic particles that make up all atoms are:

   a. **Protons**

   ➢ Each proton has a **+1** electrical charge (1 unit of positive charge).

   o Protons have a mass of about 1.0 amu (**atomic mass units**).

   o Protons are found in the center of the atom, called the nucleus. The nucleus is extremely small and occupies very little volume in the atom.

   ➢ The number of protons in an atom is defined as the **atomic number** (symbol Z) of the atom.

   ➢ The number of protons determines the ***name*** (and thus the symbol) of the atom.

   ➢ The number of protons in an atom is never changed by *chemical* reactions.

   b. **Neutrons**

   o A neutron has an electrical charge of zero.

   o A neutron has about the same mass as a proton, 1.0 amu.

   o Neutrons are located in the nucleus of an atom, along with the protons.

   o Neutrons are thought to act as the glue of the nucleus: the particles that keep the repelling protons from flying apart.

   o Neutrons, like protons, are never gained or lost in chemical reactions.

   o The neutrons in an atom have very little influence on the chemical behavior of the atom.

   c. **Electrons**

   ➢ Each electron has a **–1** electrical charge (1 unit of negative charge).

   o Electrons have very little mass, weighing about 1/1837th as much as protons and neutrons.

   o Electrons are found outside the nucleus of an atom, in regions of space called **orbitals**.

   o Nearly all of the *volume* of an atom is due to the space occupied by the electrons in motion around the nucleus.

   ➢ Electrons are the *only* subatomic particles that can be gained or lost during chemical reactions.

Each of the above points will be addressed at various times in your course. For this lesson, the items above identified by the ➢ symbol must be *memorized*.

6. Atoms of elements, by definition, always contain an equal number of protons and electrons. This balance between positive and negative charges gives an atom a *net* charge of zero. The charges are said to "cancel" to produce an overall electrically **neutral** particle.

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Practice A

Memorize the points in Section 5 above labeled with a ➢ .

For the problems below, use either the alphabetical list of elements at the end of these lessons or a table inside the cover of in your chemistry text. Apply the rules listed above from memory. Check answers at the end of the lesson frequently.

1. Write the symbols for these atoms.

   a. Carbon   b. Oxygen   c. Osmium   d. Tungsten

2. Name the atoms represented by these symbols.

   a. N   b. F   c. Fe   d. Pb

3. Assume each particle below is a neutral atom. Fill in the blanks.

Atom Name	Symbol	Protons	Electrons	Atomic Number
Sodium				
	N			
		6		
			82	
				9

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More Terms and Definitions

7. Ions. During chemical reactions, the number of protons and neutrons in an atom never changes, but atoms can gain or lose one or more electrons. Any particle that does not have the same number of protons and electrons is termed an **ion**, which is a particle with a net electrical charge.

- Neutral particles that *lose electrons* become **positive ions**.
- Neutral particles that *gain electrons* become **negative ions.**

The symbol or chemical formula for a particle that is not electrically neutral places the value of the net charge as a superscript to the right of the symbol.

It is important to remember that an ion is *not* the same as the neutral particle from which it was formed.

Examples of atoms and ions

a. All particles with a single nucleus containing 16 protons are examples of **sulfur** (symbol **S**).

A sulfur *atom* has 16 protons and 16 electrons. The positive and negative charges balance to give a net charge of zero. The symbol for the neutral sulfur atom is written as **S**. The symbol $\mathbf{S^0}$ may also be written to emphasize that the sulfur atom has a neutral charge.

Often, a sulfur particle is found to contain 16 protons and 18 electrons. This particle is a sulfur *ion*. Although the 16 protons cancel the charge of 16 electrons, the two un-cancelled electrons leave the ion with an overall charge of **–2**. The symbol for this particle is S^{2-}, and it is called a **sulfide ion**.

b. All particles with **19** protons are named **potassium** (symbol **K**).

In nature, potassium is always found with 18 electrons. The 18 electrons balance the charge of 18 protons. This leaves one positive charge un-cancelled, and the ion has a net charge of **+1**. This ion form of potassium is symbolized as $\mathbf{K^+}$. In a charge, if no number is given, a **1** is understood.

c. Any particle with 88 protons is named **radium** (symbol **Ra**).

Ra^{2+} ions must have 2 more positive protons than negative electrons. Because all radium atoms must have 88 protons, an Ra^{2+} ion must have 86 electrons.

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Practice B

For the problems below, use the alphabetical list of elements at the end of these lessons or a table inside the cover of your chemistry text.

1. Calcium has atomic number 20.
   a. A neutral Ca atom has how many protons? How many electrons?
   b. How many protons and electrons are found in a Ca^{2+} ion?

2. In their nucleus, during chemical reactions, atoms always keep a constant number of ______________s, which have a positive charge. Atoms take on a charge and become ions by gaining or losing ______________s, which have a ______________charge.

3. In terms of subatomic particles, an atom that is a positive ion will always have more ________________ than __________________.

4. For the particles below, fill in the blanks.

Symbol	Protons	Electrons	Name of Element
O			
O^{2-}			
Mg^{2+}			
I^{-}			
	79	79	
	1	0	
	35	36	
		36	selenium
		10	aluminum

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ANSWERS

Part A

1. a. **C** b. **O** c. **Os** d. **W**
2. a. **Nitrogen** b. **Fluorine** c. **Iron** d. **Lead**
3.

Atom Name	Symbol	Protons	Electrons	Atomic Number
sodium	**Na**	**11**	**11**	**11**
nitrogen	N	**7**	**7**	**7**
carbon	**C**	6	**6**	**6**
lead	**Pb**	**82**	82	**82**
fluorine	**F**	**9**	**9**	9

Part B

1. a. **20 protons, 20 electrons.** b. **20 protons, 18 electrons**
2. In their nucleus, during chemical reactions, atoms always keep a constant number of **PROTONS** , which have a positive charge. Atoms take on a charge, to become ions , by gaining or losing **ELECTRONS** , which have a **NEGATIVE** charge.
3. In terms of sub-atomic particles, an atom that is a positive ion will always have more **PROTONS** than **ELECTRONS** .

4.

Symbol	Protons	Electrons	Name of Element
O	**8**	**8**	**oxygen**
O^{2-}	**8**	**10**	**oxygen**
Mg^{2+}	**12**	**10**	**magnesium**
I^{-}	**53**	**54**	**iodine**
Au	79	79	**gold**
H^{+}	1	0	**hydrogen**
Br^{-}	35	36	**bromine**
Se^{2-}	**34**	36	selenium
Al^{3+}	**13**	10	aluminum

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Lesson 6B: The Nucleus, Isotopes, and Atomic Mass

Pretest: If you can fill in the blanks below, you may skip this lesson. Answers are at the end of the lesson.

Atom Name	Atom Symbol	Protons	Neutrons	Electrons	Nuclide Symbol	Ion Symbol
		85	125	86		
					^{27}Al	Al^{3+}

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The Nucleus

At the center of an atom is the nucleus. The nucleus contains all of the protons and neutrons in the atom.

The nucleus is very small, with a diameter that is roughly 100,000 times smaller than the diameter of most atoms, yet the nucleus contains all of the atom's positive charge, and nearly all of its mass.

Because the nucleus contains nearly all of the atom's mass in a tiny volume, it is extremely dense. Outside of the nucleus, nearly all of the volume of an atom is occupied by its electrons. Because electrons have low mass but occupy a large volume compared to the nucleus, the region occupied by the electrons has a very low density. In terms of mass, an atom is mostly empty space.

However, the electron has a charge that is equal in magnitude (though opposite) to that of the more massive proton. It is the charges of the particles inside an atom, rather than their masses, that play the major role in determining an atom's size and chemical reactions.

Types of Nuclei

For a nucleus with a given number of protons, only certain numbers of neutrons can exist with the protons and form a nucleus that is stable. If a combination of protons and neutrons is formed in a nuclear reaction (such as by radioactive decay, or in a nuclear reactor) that is unstable, that nucleus will decay.

The possible combinations of protons and neutrons found in nuclei can be divided into three types.

- **Stable:** Stable nuclei combinations of protons and neutrons do not change in a planetary environment such as Earth even over many billions of years.
- **Radioactive:** Radioactive nuclei are *somewhat* stable. Once formed, they can exist for a time on Earth (from a few seconds to several billion years), but they fall apart (**decay**) at a constant, characteristic rate.
- **Unstable:** If combinations of protons and neutrons that are unstable are formed in nuclear reactions on earth, they decay within a few seconds.

Nuclei that exist in the earth's crust include all of the stable nuclei plus some radioactive nuclei.

All atoms that have between one and 82 protons (except technetium with 43 protons) have at least one stable nucleus. Atoms with 83 to 92 protons can be found in the earth's crust, but all are radioactive. Atoms with 93 or more protons exist on earth only when they are created in nuclear reactions (in nuclear reactors or nuclear weapons).

Radioactive elements comprise a very small percentage of the matter found on earth. Over 99.99% of the earth's atoms have nuclei that are stable. The nuclei in those stable atoms have not changed since the atoms came together to form the earth billions of years ago.

Terminology

Protons and neutrons together are called the **nucleons**. A given combination of protons and neutrons is called a **nuclide**. A group of nuclides that have the same number of protons but differing numbers of neutrons are called the **isotopes** of an element.

Stable Nuclei

Some elements have only one stable nuclide; other elements have as many as 10 stable isotopes.

Example: All atoms with 17 protons are called chlorine. Only two chlorine nuclei are stable: those with

- 17 protons and **18** neutrons; and
- 17 protons and **20** neutrons.

Nuclei that have 17 protons and *other* numbers of neutrons can be made in nuclear reactors, but in all of those combinations, either protons or neutrons leave the nucleus or decay within a few seconds.

Nuclide Symbols

Each nuclide can be assigned a **mass number** (symbol A), which is simply the *sum* of its protons and neutrons.

Mass Number of a nucleus **= A = Protons + Neutrons**

A nuclide can be identified in two ways,

- either by its number of protons and number of neutrons,
- or by its **nuclide symbol** (or **isotope symbol**).

A nuclide symbol has two parts. The number of protons is identified by the *element symbol*. The *mass number* is written as a superscript in front of the atom symbol.

For example, the two stable isotopes of chlorine can be represented as

- 17 protons + 18 neutrons *or as* $^{35}\mathbf{Cl}$ (a nuclide called "chlorine-35"); and
- 17 protons + 20 neutrons *or as* $^{37}\mathbf{Cl}$ (called chlorine-37).

$^{37}_{17}\mathrm{Cl}$

Nuclide symbols may also be written with the number of protons before and below the mass number. This is called **A-Z notation**, illustrated at the right. Including the Z values is helpful when balancing nuclear reactions (a future topic), but the Z values are not needed to *identify* a nuclide, since the Z value repeats what the atom symbol also identifies: the number of protons in the nucleus.

Knowing one representation for the composition of a nucleus, either the nuclide symbol or its number of protons and neutrons, you need to be able to write the other.

Using a table of elements, atom symbols, and atomic numbers that can be found at the end of these lessons or inside the cover of most chemistry texts, try these two examples.

Q1. A nuclide with 6 protons and 8 neutrons would have what nuclide symbol?

Q2. How many protons and neutrons would be found in $^{20}\mathbf{Ne}$?

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A1. Atoms with 6 protons are always named carbon, symbol C. The mass number of this nuclide is 6 protons + 8 neutrons = **14** . This isotope of carbon, used in "radiocarbon dating," is carbon-14, written $^{14}\mathbf{C}$ **.**

A2. All atoms called neon contain 10 protons. The mass number 20 is the total number of protons *plus* neutrons, so neon-20 contains **10 protons and 10 neutrons.**

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Practice A: Use a table of elements to fill in the blanks below.

1.

Atom Name	Atom Symbol	Protons	Neutrons	Atomic Number	Mass Number	Nuclide Symbol
	C		6			
		7	7			
Iodine			78			
						^{235}U

2. Which nuclides in Problem 1 must be radioactive? Why?

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The Mass of Nuclides

The mass of a single nuclide is usually measured in **atomic mass units**, abbreviated **amu**. By definition, one amu = 1.66×10^{-24} grams.

Protons and neutrons have essentially the same mass, and both are much heavier than electrons. The mass of

- a proton is **1.0** amu,
- a neutron is **1.0** amu, and
- an electron is 1/1837th amu.

Based on those masses, you might expect that the mass of a ^{35}**Cl** atom would be just over 35.0 amu, since it is composed of 17 protons, 18 neutrons, and 18 electrons. In fact, for neutral atoms of ^{35}**Cl**, the actual mass is 34.97 amu, slightly *lighter* than the combined mass of its protons, neutrons, and electrons.

Why do the masses of the three subatomic particles *not* add exactly to the mass of the atom? When nuclei form, a small amount of mass is converted to, or created from, energy. This change is the relationship discovered by Einstein:

Energy = mass times the speed of light squared ($E = mc^2$).

In nuclear reactions, small changes in mass equal very large changes in energy.

However, when calculating the mass for a nuclide or atom, its mass in amu's will be *close* to its mass number.

The sum of the mass numbers of a nuclide ≈ its mass in amu

The Average Mass of Atoms (Atomic Mass)

In chemical reactions, isotopes of an atom behave the same. In addition, for *most* atoms (those not formed by radioactive decay), one kind of atom may have several stable isotopes, but the percentage of each isotope in samples of that atom found on earth will always be the same.

For these reasons, when dealing with visible amounts of most atoms, the atoms of a element that are not formed by radioactive decay (nearly all matter on earth) will have the same *average mass* in any sample of matter found on earth.

The average mass of an element, called its **atomic mass,** can be calculated from the *weighted average* of the mass of its isotopes. The equation for this weighted average is

∑ (isotope fraction)(isotope mass) = average mass = **atomic mass** of the element

An example will help to explain this equation. All samples of chlorine atoms collected on earth contain

- **75.78%** atoms with a mass of 34.97 amu that have **^{35}Cl** nuclei; and
- **24.22%** atoms with a mass of 36.97 amu that have **^{37}Cl** nuclei.

This means that the average mass of chlorine atoms is

(0.7578)(34.97 amu) + (0.2422)(36.97 amu) = __________ amu

(The percentages for the isotopes must add to 100%, and the fractions must add to 1.00.)

Complete the calculation above, fill in the blank, then check your answer by looking up the atomic mass of chlorine in the table of elements inside the covers of your chemistry text.

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= $26.5\underline{0}0$ amu + $8.9\underline{4}6$ amu = $35.4\underline{5}4$ = 35.45 amu = average mass for a chlorine atom

(Sig figs: carry extra sf until the final step; when adding round to highest *place* with doubt.)

This answer should be consistent with the atomic mass for chlorine given in your text.

No single atoms of chlorine will have this average mass, but in visible amounts of substances containing chlorine, the *average* chlorine atom has this mass. Use of the average mass (atomic mass) will simplify chemistry calculations involving mass.

The numeric value for the atomic mass in amu that is found in tables is also the mass of the element in "grams per mole." The number 6.022×10^{23}, called one mole, is defined so that that one mole of atoms that contain the nuclide carbon-12 have a mass of exactly 12 grams.

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Practice B

1. Silver has two stable isotopes: ^{107}Ag (106.91 amu) and ^{109}Ag (108.90 amu). Assuming that for both isotopes, the value for the mass in amu is equal to the mass number, and that 51.8% of naturally occurring silver is silver-107,
   a. calculate the atomic mass of Ag.
   b. Compare your answer to the value listed for iron in your textbook or in the table at the end of these lessons.
   c. What would be the atomic mass of Ag in grams per mole?

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Isotopes and Chemistry

The rules and the reactions for standard chemistry are very different from those of nuclear chemistry. For example,

- chemical reactions can release substantial amounts of energy, such as seen in the burning of fuels or in conventional explosives. Nuclear reactions, however, often involve *much* larger amounts of energy, as in the burning of stars or in nuclear weapons.
- An important rule in chemical processes is that atoms can neither be created nor destroyed. In nuclear reactions, atoms are often created and destroyed.

Because the rules are so different, a clear distinction must be made between *chemistry* and *nuclear chemistry*. By convention, it is assumed that the rules that are cited as part of "chemistry" refer to processes that do *not* involve changes in nuclei (unless *nuclear* chemistry or physics is specified). Changes in atoms that affect the nucleus are *defined* as *nuclear* reactions, which are *not chemical* reactions.

The good news is that because all isotopes of an element have the same chemical behavior, and because the atoms in visible amounts of an element can be considered in chemical reactions to have the same average mass, we can ignore the fact that elements have isotopes as we investigate most *chemical* reactions and processes.

We will return to the differences among isotopes when we consider *nuclear* chemistry and reactions such as radioactive decay, fission, and fusion.

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Practice C

Fill in the blanks below.

Atom Name	Atom Symbol	Protons	Neutrons	Electrons	Nuclide Symbol	Ion Symbol
		90	144	88		
			148			Pu^{2+}
				78	^{206}Pb	
Hydrogen			0	0		
					^{3}H	H^{-}
	Ra		138	86		
		19	19	18		
Nitrogen			7	10		

* * * * *

ANSWERS

Pretest

Atom Name	Atom Symbol	Protons	Neutrons	Electrons	Nuclide Symbol	Ion Symbol
Astatine	**At**	85	125	86	**^{210}At**	**At^{-}**
Aluminum	**Al**	**13**	**14**	**10**	^{27}Al	Al^{3+}

Practice A

1.

Atom Name	Atom Symbol	Protons	Neutrons	Atomic Number	Mass Number	Nuclide Symbol
Carbon	C	**6**	6	**6**	**12**	**^{12}C**
Nitrogen	**N**	7	7	**7**	**14**	**^{14}N**
Iodine	**I**	**53**	78	**53**	**131**	**^{131}I**
Uranium	**U**	**92**	**143**	**92**	**235**	^{235}U

2. Uranium must be radioactive, because no nuclei with more than 82 protons are stable.

Practice B

1a. Since there are only two Ag isotopes, ^{109}Ag must be 48.2%.

(0.518)(106.91 amu) + (0.482)(108.90 amu) = (55.3̲8 + 52.4̲9) amu = 107.8̲7 = **107.9 amu**

1b. It should match. 1c. **107.9 g/mole** (value for amu = value for g/mole)

Practice C

Atom Name	Atom Symbol	Protons	Neutrons	Electrons	Nuclide Symbol	Ion Symbol
Thorium	**Th**	90	144	88	**^{234}Th**	**Th^{2+}**
Plutonium	**Pu**	**94**	148	**92**	**^{242}Pu**	Pu^{2+}
Lead	**Pb**	**82**	**124**	78	^{206}Pb	**Pb^{4+}**
Hydrogen	**H**	**1**	0	0	**^{1}H**	**H^{+}**
Hydrogen	**H**	**1**	**2**	**2**	^{3}H	H^{-}
Radium	Ra	**88**	138	86	**^{226}Ra**	**Ra^{2+}**
Potassium	**K**	19	19	18	**^{38}K**	**K^{+}**
Nitrogen	**N**	**7**	7	10	**^{14}N**	**N^{3-}**

Lesson 6C: Elements, Compounds, and Formulas

Prerequisites: Lesson 6A.

Pretest: Use the list of elements on the last page of these lessons or in a textbook. If you get a perfect score on this pretest, you may skip to Lesson 6C. Answers are at the end of the lesson.

1. In this list:

   A. H_2O B. Cl_2 C. Au D. S_8 E. CO_2 F. Co G. H_2SO_4

   a. Which formulas represent elements?

   b. Which formulas represent a substance without ionic or covalent bonds?

   c. Which formulas represent substances that are diatomic?

2. Write the number of oxygen atoms present in each of these compounds.

   a. $Co(OH)_2$ b. CH_3COOH c. $Al_2(SO_4)_3$

3. Write the total number of atoms in each of the compounds in question 2.

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Bonded Atoms: Some Vocabulary

The definitions below are general and highly simplified, but they will give us a starting point for discussing how atoms may combine to yield different substances.

1. A pure **substance** (also known as a **chemical**) is composed of particles whose neutral units have the same number and kind of atoms, chemically bonded in the same way. **Chemical formulas** can be used to represent a substance. A **mixture** is a combination of two or more substances.

2. **Elements** are electrically neutral substances that contain only one kind of atom. A sample of an element exists as a collection of electrically neutral atoms or molecules. Ne, Cl_2, and S_8 are formulas for elements because they are electrically neutral and all contain only one kind of atom.

   The basic particles for some elements, termed the **monatomic elements,** are individual atoms. The chemical formulas for monatomic elements are written as one instance of the atom's formula, reflecting the fact that the basic unit is a single atom.

   For example, the basic particles of the **noble gases** (helium, neon, argon, krypton, xenon, and radon) are single atoms. Therefore, the formulas for these elements are written as **He** for helium, **Ne** for neon, etc.

   Other elements are found in our environment as **molecules**: neutral particles consisting of two or more atoms chemically bonded to form a new larger unit.

   Bonds are forces that hold particles together. Molecules of the **diatomic elements** consist of two atoms (*di-* means two), and their chemical formulas reflect the fact that each unit contains 2 atoms. In chemical formulas, a **subscript** written after a symbol represents the number of that kind of atom or ion present.

For example, the elemental forms of oxygen, nitrogen, and chlorine are all diatomic. The chemical formula for chlorine is Cl_2, nitrogen is N_2, and oxygen is O_2.

Polyatomic elements are neutral molecules that contain 2 or more atoms, but only one kind of atom.

For example, the elemental formula for sulfur is S_8, indicating that it exists as eight atoms bonded together.

Over 70% of the elements found in the earth's crust are metals. Metals have a more complex nature than simple monatomic or polyatomic elements, but metal formulas are represented by single atoms, such as **Ag** for silver, and **Al** for aluminum.

Some elements have multiple forms that are stable at room temperature. The elemental forms of carbon, for example, include graphite, diamond, and fullerenes (carbon molecules shaped like soccer balls). Each of these has very different bonding and properties, but all are composed entirely of carbon atoms. As an element, carbon is usually represented by simplified monatomic formula: **C**.

3. A **compound** is a substance that consists of two or more different elements chemically bonded together as a new substance. While there are just over 100 elements, there are countless known compounds. In a given compound, the ratio of the elements is always the same, which is reflected in their formulas. H_2O, NaCl, and H_2SO_4 are all formulas for compounds, because they contain two or more different elements. Compounds can be classified as either ionic or covalent, depending on the type of bonding present.
4. The basic particles for **covalent compounds** (also known as molecular compounds) are molecules. The molecules are held together by **covalent bonds**. In a covalent bond, electrons are shared between two neighboring atoms. Covalent bonds can be single bonds (involving 2 shared electrons), double bonds (4 shared electrons), or triple bonds (6 shared electrons). Covalent bonds hold atoms at predictable angles within the molecule.
5. **Molecular formulas** use atomic symbols and subscripts to represent the number and kind of atoms covalently bonded together in a single molecule.
   - Water is composed of molecules that each consist of two hydrogen atoms and one oxygen atom, represented by the molecular formula $\mathbf{H_2O}$.

     In chemical formulas, when there is no subscript is written after a symbol, the subscript is understood to be *one*.
   - Carbon dioxide is composed of molecules that each consist of two oxygen atoms and one carbon atom. The molecular formula is $\mathbf{CO_2}$.

6. **Structural formulas** can be used to represent chemical particles that are held together by covalent bonds. These formulas show each of the atoms present along with information about their positions within the particle**.**

   ```
      O — H
     /
    H
   ```

   At the left is a structural formula for water. It shows that the oxygen atom is found in the middle of the molecule, and that water has two directional covalent bonds and a *bent* shape.

   The structural formula for carbon dioxide, CO_2 , is **O=C=O** . Carbon dioxide has two double bonds, and the molecule is linear in shape with the carbon atom in the middle.

7. Often, chemical formulas are written as a mixture of different types of formulas. For example,

   - ethyl alcohol can be written as CH_3CH_2OH or as C_2H_6O. The shorter formula, however, is also the molecular formula of dimethyl ether, which is usually written CH_3OCH_3 to show that the O is found in the middle in the ether, rather than toward one end as in the alcohol.

     Ethyl alcohol and dimethyl ether have the same number and kind of atoms, but the differing atomic arrangements give the molecules very different properties. To predict chemical behavior, we often need to know a formula with structural information.

8. **Ionic compounds** are substances consisting of a collection of positive and negative **ions** (particles with a net electrical charge). Ions can be **monatomic** (single "atoms" that have gained or lost one or more electrons) or **polyatomic** (a group of covalently bonded atoms that have gained or lost one or more electrons). An **ionic bond** is the electrostatic attraction between the oppositely charged ions.

9. **Ionic formulas** use atomic symbols and numbers to represent the ratio and kind of ions present in an ionic compound. The ions in an ionic compound are *always* present in a ratio that guarantees overall electrical neutrality.

   A **formula unit** is defined as the smallest combination of ions for which the sum of the electrical charges is zero. Parentheses are used to indicate more than 1 polyatomic ion. Chemical formulas for ionic compounds show the atom ratios in a single neutral formula unit.

   - Table salt consists of a 1:1 ratio of positively charged sodium ions (formula Na^+) and negatively charged chloride ions (Cl^-). The formal name of table salt is sodium chloride, and its ionic formula is written as **NaCl**. The formula unit for NaCl represents 2 ions.

   - Calcium phosphate is an ionic compound composed of three monatomic Ca^{+2} ions for every two polyatomic PO_4^{-3} ions. The ionic formula is $\mathbf{Ca_3(PO_4)_2}$, and 1 formula unit represents a total of 5 ions.

- Copper(II) nitrate is an ionic compound composed of one monatomic Cu^{+2} ion for every two polyatomic NO_3^- ions. The ionic formula is written as $\mathbf{Cu(NO_3)_2}$. Writing the formula as CuN_2O_6 shows the atom ratios, but indicating that the compound contains two NO_3^- groups better conveys the true nature of this compound.

10. To summarize, although molecules of covalent substances and formula units of ionic compounds have different types of bonds, all compound formulas refer to a single, overall electrically neutral unit of a substance.

Be careful to *write* formulas so that you can distinguish between upper- and lower-case letter combinations such as CS and Cs, Co and CO, NO and No.

- $Co(OH)_2$ has 1 cobalt atom, 2 oxygen atoms, and 2 hydrogen atoms.
- CH_3COOH has 2 carbon, 4 hydrogen, and 2 oxygen atoms.

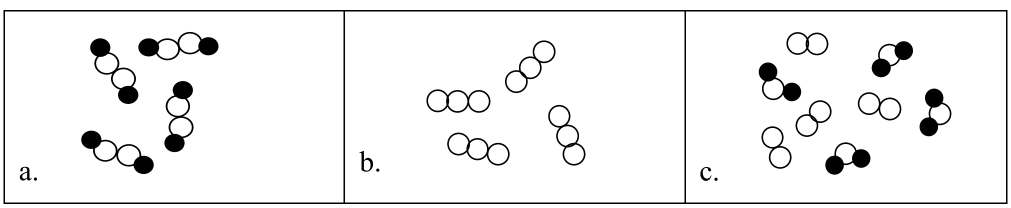
* * * * *

Practice

Use the elements table at the end of these lessons or in a textbook to answer these questions. Answers are on the next page.

If you need additional practice, redo the pretest at the beginning of Lesson 6C.

1. Identify each sample sketched below as an *element*, *compound*, or *mixture*. Different elements are indicated by different shades, and individual particles are separated for clarity.



a. ________________ b.__________________ c. _______________

2. Label the following formulas as elements or compounds.

   a. C b. H_2O c. NaCl d. S_8 e. $C_6H_{12}O_6$

3. Which of these formulas contain chemical bonds?

   a. H_2 b. CO c. Co d. NH_3 e. He

4. In problems 2 and 3, which formula represents a diatomic element?
5. In problems 2 and 3, which formulas represents monatomic elements?
6. In problems 2 and 3, which formula has 4 atoms?

7. Write the number of oxygen atoms in each of these compounds.

   a. $Al(OH)_3$ b. C_2H_5COOH c. $Co_3(PO_4)_2$

8. Write the total number of atoms for each of the compounds in question 7.

9. Try every third one of these, then check your answers. If you need more practice, do a few more.

   Name each atom, and write the total number of those atoms, in each of the following chemical formulas.

   a. $HCOOH$ b. $CoSO_4$ c. $No(NO_3)_2$

   d. $Ca_3(PO_4)_2$ e. $(NH_4)_3PO_4$ f. $Pb(C_2H_5)_4$

* * * * *

ANSWERS

Pretest

1a. B, C, D, F   1b. C, F   1c. B   2a. 2   2b. 2   2c. 12   3a. 5   3b. 8   3c. 17

Practice

1. a. Compound   b. Element   c. Mixture
2. 2a and 2d are elements because they have one kind of atom. The rest are compounds because they have more than one kind of atom.
3. 3a, 3b, and 3d have bonds, because they have more than one atom. It takes bonds to hold two or more atoms together in particles.
4. 3a, H_2, is the only diatomic element.   5. 2a, 3c, and 3e are the only monatomic elements.
6. 3d, NH_3, is the only formula with 4 atoms.   7a. 3 oxygen atoms   7b. 2   7c. 8
8. a. 7 total atoms   b. 11   c. 13
9. a. 2 hydrogen
1 carbon
2 oxygen   b. 1 cobalt
1 sulfur
4 oxygen   c. 1 nobelium
2 nitrogen
6 oxygen

   d. 3 calcium
2 phosphorous
8 oxygen   e. 3 nitrogen
12 hydrogen
1 phosphorous
4 oxygen   f. 1 lead
8 carbon
20 hydrogen

* * * * *

Lesson 6D: The Periodic Table

Pretest: If you think you know this topic, try the last letter of each numbered question at the end of this lesson. If you get those right, you may skip this lesson.

* * * * *

Patterns of Chemical Behavior

Learning the behavior of over 100 different elements would be a formidable task. Fortunately, the elements can be organized into **families**. The behavior of one atom in a family predicts the chemical behavior other elements in the family.

The grouping of elements into families results in the **periodic table.** To build the table, the atoms are arranged in *rows* across (also called **periods**) in order of number of protons in each atom. This order usually, but not always, matches the order of the increasing average mass of the atoms.

At certain points, the chemical properties of the elements begin to repeat, somewhat like the octaves on a musical scale.

In the periodic table, under most graphic designs, when a noble gas atom is reached, it marks the end of a horizontal row. The next element, with one more proton, starts a new row of the table. This convention places the elements into vertical **columns** (called *families* or **groups**) with the noble gases in the last column on the right.

Within each *column,* the elements have similar chemical behavior.

Some Families in the Periodic Table

The noble gases (He, Ne, Ar, Kr, Xe, Rn) are monatomic elements (composed of single atoms).

These atoms are termed noble because they are chemically "content" with their status as single atoms. These atoms rarely bond with other atoms or each other.

Although the noble gases take part in very few chemical reactions, they are important in predicting chemical behavior. Other atoms tend to react in ways that give them the same electron configuration as the nearest noble gas. The outer electrons of atoms tend to react to attain the "cloak of nobility."

The alkali metals (Li, Na, K, Rb, Cs) are in **column one** (also called group 1A) of the periodic table, at the far left. As elements, all are soft, shiny metals that tend to react with many substances, including the water vapor present in air.

In chemical reactions, alkali metal atoms tend to *lose* an electron to become a *+1 ion*. This ion has the same number of electrons as the noble gas that has one fewer protons. Once an alkali metal atom forms a +1 ion, it becomes quite stable. Most chemical reactions do not change its +1 charge.

The halogens (F, Cl, Br, I, and At) are in **column 7** (group 7A) just to the left of the noble gas column. As neutral elements at room temperature, halogen atoms are stable only when they are found in the diatomic molecules F_2, Cl_2, Br_2, I_2, and At_2.

Like alkali metals, the halogens are very reactive. In reactions, neutral halogen atoms tend to *gain* one electron to become a **halide ion** with a —1 charge. This ion has the same number of electrons as the noble gas just to the right in the periodic table.

Halogen atoms can also share electrons with neutral nonmetal atoms. Shared electrons result in a covalent bond. Including the shared electrons, each neutral halogen atom will tend to be surrounded by the same number of electrons as the nearest noble gas.

Hydrogen is often placed in column one of the table, and the reactions of hydrogen are often like those of the alkali metals. However, other hydrogen reactions are like those of the halogens. Hydrogen is probably best portrayed as a unique family of one that can have characteristics of both alkali metals and halogens.

The main group elements are those found in the *tall* columns, termed either groups 1, 2, and 13 to 18, or groups 1A, 2A, and 3A-8A, depending on the version of the periodic table that you are using.

The transition metals are in the "middle dip" of the periodic table, in groups 3-12 or the "B" groups. There are 10 elements in each row of the transition metals.

The inner transition elements (also called the **lanthanides** and **actinides**, or **rare earth metals)**, appear beginning in the 6th row. These elements are usually listed below the rest of the periodic table.

* * * * *

Predicting Behavior

The following table summarizes the *general characteristics* of the elements in the columns of the periodic table. The positions of the column numbers, family names, and likely ion charges should be memorized.

Group	1A	2A		3A	4A	5A	6A	7A	8A
Family Name	Alkali Metals		Transition Metals					Halogens	Noble Gases
Likely monatomic ion	1+	2+		3+ (or 1+)		3—	2—	1—	None

Example

The atom Cesium (Cs) is in column *one* of the periodic table. Based on this placement, it can be predicted to

- behave like other alkali metals; and
- form a Cs^{+} ion in compounds.

* * * * *

Metals, Metalloids, and Nonmetals

The elements in the periodic table can be divided into metals, metalloids (also called semimetals), and nonmetals.

Metalloids

Many periodic tables include a thick line, like a staircase, as shown in the section of the periodic table below. This line separates the metal and nonmetal elements.

The six elements bordering the line in **bold** below are the **metalloids**. They have chemical behavior that is *in-between* that of the metals and the nonmetals.

Unless you are allowed to use a periodic table that has the staircase and identifies the metalloids on tests, you should memorize the location of the staircase and the 6 metalloids.

If you memorize how the staircase looks at boron (**B**), the rest of the staircase is easy. Remembering "11220" will help with the number of metalloids per row going down the table. (Some textbooks include polonium (Po) as a metalloid, others do not.)

					(H)	He
	B	C	N	O	F	Ne
		Si	P	S	Cl	Ar
		Ge	**As**	Se	Br	Kr
			Sb	**Te**	I	Xe
				(Po)	At	Rn

Nonmetals

At the right are the 18 nonmetals. The nonmetals must be *memorized*.

Note the shape of their positions in the table. They are all to the right of the staircase and to the right of the metalloids. All elements in the last two columns (all halogens and all noble gases) are nonmetals.

			(H)	He
C	N	O	F	Ne
	P	S	Cl	Ar
		Se	Br	Kr
			I	Xe
			At	Rn

Note also that hydrogen, despite the fact that it is often placed in column one in periodic tables, is considered to be a *non*metal. Hydrogen has unique properties, but it most often behaves as a nonmetal.

Metals

The metals are all of the elements to the left of the thick line and the six metalloids in the above chart. The metals include all of the transition metals, as well as all of the inner transition (rare earth) elements usually listed below the rest of the chart.

Of the over 100 elements, over 75 percent are metals. To memorize the atoms that are metals, memorize the 6 metalloids and 18 nonmetals. The metals are all of the remaining elements.

* * * * *

Practice

Use a copy of the periodic table and your memorized knowledge about the columns of the table to answer these.

1. Describe the location in the periodic table of the
   a. noble gases
   b. alkali metals
   c. halogens
   d. transition metals

2. Add a charge to these symbols to show the ion that a single atom of these elements tends to form.

   a. Br (35)   b. Ra (88)   c. Cs (55)   d. In (49)   e. Te (52)

3. How many elements are non-metals?

4. Without consulting a periodic table, add the metal/nonmetal dividing line to the portion of the periodic table below, then circle the metalloid elements.

					(H)	He
	B	C	N	O	F	Ne
	Al	Si	P	S	Cl	Ar
Zn	Ga	Ge	As	Se	Br	Kr
Cd	In	Sn	Sb	Te	I	Xe
Hg	Tl	Pb	Bi	Po	At	Rn

* * * * *

ANSWERS

1. a. Noble gases -- last column   b. Alkali metals – column one
   c. Halogens – Group 7A (tall column 7), just before the noble gases.
   d. Transition metals – the 10 columns in the middle dip.

2 a. Br^{-} b. Ra^{2+} c. Cs^{+} d. In^{3+} e. Te^{2-}

3. 18   4. See table in lesson.

* * * * *

Lesson 6E: A Flashcard Review System

Previous Flashcards

At this point, you may have a sizeable stack of flashcards, and we will soon add more. Before going further, let's organize the current cards. Try this system.

A. Separate your existing flashcards into 4 stacks.

1-Daily: Those you have done until correct for 3 days or less;

2-End of Chapter/Quiz: Those you have done for *more* than 3 days, run again before each session doing end of chapter textbook problems *and/or* before your next quiz or test on this material.

3-Test: those you have done 5 or more times, run again before starting practice problems for your next major test ; and

4-Final Exam Review: Those you have retired until the final.

B. Add cards with those 4 *labels* to the top of each stack. Rubber-band each stack.

You may want to carry the *daily* pack with you for use during down time.

Module 6 Flashcards

If you have had a previous course in chemistry, you may recall much of the material in Module 6 with ease after the above review. However, the material in Module 6 will need to be *firmly* in memory for the remainder of the course.

Identify and write any *needed* flashcards below. Use the method in Lesson 2D: cover the answers, check those which you can answer correctly and quickly. Make the flashcard if the answer is not automatic.

Run your new cards for several days in a row. Be sure to run the two-way cards in both directions. Run the new cards again before the next quiz, next test, and final exam.

For Lesson 6A

One-way cards (with notch at top right): Back Side -- Answers

One-way cards (with notch at top right)	Back Side -- Answers
Like charges	Repel
Unlike Charges	Attract
The particles in a nucleus =	protons and neutrons
Subatomic particle with lowest mass	electron
Subatomic particles with charge	protons and electrons
Mass of a proton in amu	1.0 amu
Mass of a proton in grams/mole	1.0 grams/mole
Protons minus electrons	Charge on particle
Atomic Number	Number of protons
Determines atom symbol	Number of protons

Particles gained and lost in chemical reactions	electrons
Zero charge on an atom means	# protons = # electrons
Negative ions have	More electrons than protons
Subatomic particles with mass of 1.0 amu	protons and neutrons

Two-way cards (with*out* notch):

ion	A particle with electrical charge
Protons plus Neutrons =	Mass Number
Z	Symbol meaning atomic number
A	Symbol meaning mass number

For Lesson 6B

One-way cards (with notch) Back Side -- Answers

To calculate the average atomic mass of an element	∑ (isotope fraction)(isotope mass)
Same # of p^+, different #'s of n^0	isotopes
Different nuclides with same chemical behavior =	isotopes

Two-way cards (with*out* notch):

1 proton and 1 neutron = ? nuclide symbol	^2H = contains what particles?
1 proton and 0 neutron = ? nuclide symbol	^1H = what particles?
1 proton and 2 neutrons = ? nuclide symbol	^3H = what particles?
Protons plus neutrons approximately equals	Mass of nuclide in amu approx. equals

For Lesson 6C

Two-way cards (with*out* notch):

Define a Substance	All particles have same chemical formula
A Mixture	2 or more substances
Molecule	Neutral, independent particles with one or more atoms
Molecular Formula	Shows neutral atoms inside a neutral particle
Structural Formula	Shows atoms and positions in a particle
Elements	Stable neutral molecules with one kind of atom
Compounds	Stable neutral particles with more than one kind of atom
Bonds	Forces holding atoms together

For Lesson 6D

One-way cards (with notch) — Back Side -- Answers

Family that rarely bonds to other atoms	noble gases
Lightest non-metal	Hydrogen (H)
Lightest metalloid	Boron (B)
Number of non-metal elements	18

Two-way cards (with*out* notch):

Position of *alkali metals*	First column below hydrogen
Position of *halogens*	Next-to-last column
Position of *noble gases*	Last column
Position of *rare earths*	Two rows below body of table
Position of *transition metals*	In dip between tall columns 2 and 3
Tend to form —1 ions	Ions formed by *halogens*
Family forms +1 ions	Ions formed by *alkali metals*
Family forms +2 ions	Ions formed by *Column 2 atoms*
Name for halogen atoms with a —1 charge	Halide ions

Metals that were known in ancient times often have symbols based on their latin names, rather than their modern names. Though you will usually be able to consult a periodic table during tests, learning the name to symbol relationships for the following frequently encountered metals that have symbols based on their latin names will speed your work and help you to "keep your train of thought."

If any of these are not firmly in your memory in both directions, add them to your cards.

Two-way cards (with*out* notch):

copper	Cu
tin	Sn
mercury	Hg
gold	Au
potassium	K

Two-way cards (with*out* notch):

iron	Fe
lead	Pb
silver	Ag
sodium	Na

If you are in a course that goes at a fast pace, it would be a good idea to put onto flashcards the names and symbols for all of the elements in the first 3 periods (rows) of the table, as well as names and symbols for other elements that are frequently encountered in your course.

# # # # #