Name: ____

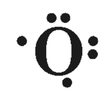
Skill Sheet 19-A Dot Diagrams

You have learned that atoms are composed of protons, neutrons, and electrons. The electrons occupy energy levels that surround the nucleus in the form of an "electron cloud". The electrons that are involved in forming chemical bonds are called valence electrons. Atoms can have up to eight valence electrons. These electrons exist in the outermost region of the electron cloud often called the "valence shell".

The most stable atoms have eight valence electrons. When an atom has eight valence electrons, it is said to have a complete octet. Atoms will gain or lose electrons in order to complete their octet. In the process of gaining or losing electrons, atoms will form chemical bonds with other atoms. The method we use to visually represent an atom's valence state is called a *dot diagram,* and you will practice drawing these in the following exercise.

1. What is a Dot Diagram?

Dot diagrams are composed of two parts—the chemical symbol for the element and dots surrounding the chemical symbol. Each dot represents one valence electron. If an element, such as oxygen, has six valence electrons, then six dots will surround the chemical symbol as shown to the right.



Boron has three valence electrons, so three dots surround the chemical symbol for boron as shown to the right.

There can be up to eight dots around a symbol, depending on the number of valence electrons the atom has. The first four dots are single, and then as more dots are added, they fill in as pairs.

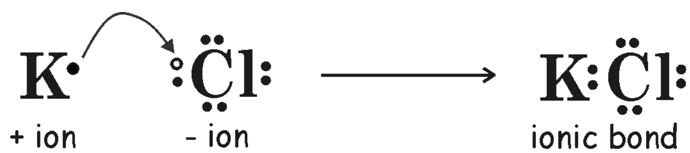
2. Drawing Dot Diagrams

Using a periodic table, complete the following chart. With this information, draw a dot diagram for each element in the chart. Remember, only the valence electrons are represented in the diagram, not the total number of electrons.

Element	Chemical Symbol	Total Number of Electrons	Number of Valence Electrons	Dot Diagram
Potassium	K			
Nitrogen	N			
Carbon	C			
Beryllium	Be			
Neon	Ne			
Sulfur	S			

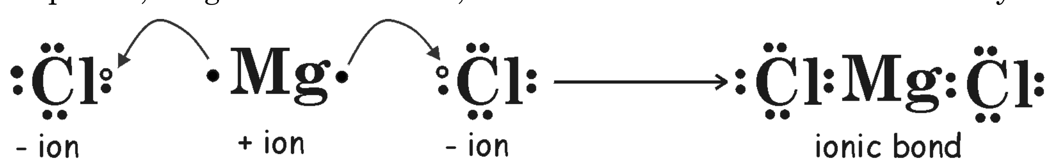
3. Using Dot Diagrams to Represent Chemical Reactivity

Once you have a dot diagram for an element, you can predict how an atom will achieve a full valence shell. For instance, it is easy to see that chlorine has one empty space in its valence shell. It is likely that chlorine will try to gain one electron to fill this empty space rather than lose the remaining seven. However, potassium has a single dot or electron in its dot diagram. This diagram shows how much easier it is to lose this lone electron than to find seven to fill the seven empty spaces. When the potassium loses its electron, it becomes *positively* charged. When chlorine gains the electron, it becomes *negatively* charged. Opposite charges attract, and this attraction draws the atoms together to form what is termed an **ionic bond**, a bond between two charged atoms or ions.



Because chlorine needs one electron, and potassium needs to lose one electron, these two elements can achieve a complete set of eight valence electrons by forming a chemical bond. We can use dot diagrams to represent the chemical bond between chlorine and potassium as shown above.

For magnesium and chlorine, however, the situation is a bit different. By examining the electron or Lewis dot diagrams for these atoms, we see why magnesium requires two atoms of chlorine to produce the compound, magnesium chloride, when these two elements chemically combine.



Magnesium can easily donate one of its valence electrons to the chlorine to fill chlorine's valence shell, but this still leaves magnesium unstable; it still has one lone electron in its valence shell. However, if it donates that electron to another chlorine atom, the second chlorine atom has a full shell, and now so does the magnesium.

The chemical formula for potassium chloride is KCl. This means that one unit of the compound is made of one potassium atom and one chlorine atom.

The formula for magnesium chloride is $MgCl_2$. This means that a one unit of the compound is made of one magnesium atom and two chlorine atoms.

Now try using dot diagrams to predict chemical formulas. Fill in the table below:

Elements	Dot Diagram for Each Element	Dot Diagram for Compound Formed	Chemical Formula
Na and F			
Br and Br			
Mg and O			

Name: ______________________________

Skill Sheet 19-B Chemical Formulas

Compounds have unique names that identify them for us when we study chemical properties and changes. Chemists have devised a shorthand way of representing chemical names that provides important information about the substance. This shorthand representation for a compound's name is called a chemical formula. You will practice writing chemical formulas in the following activity.

1. What is a chemical formula?

Chemical formulas have two important parts: **chemical symbols** for the elements in the compound and **subscripts** that tell how many atoms of each element are needed to form the compound. The chemical formula for water, H_2O, tells us that a water molecule is made of the elements hydrogen (H) and oxygen (O) and that it takes 2 atoms of hydrogen and one atom of oxygen to build the molecule. For sodium nitrate, $NaNO_3$, the chemical formula tells us there are three elements in the compound: sodium (Na), nitrogen (N), and oxygen (O).To make a molecule of this compound, you need one atom of sodium, one atom of nitrogen, and 3 atoms of oxygen.

2. How to write chemical formulas

How do chemists know how many atoms of each element are needed to build a molecule? For ionic compounds, oxidation numbers are the key. An element's oxidation number is the number of electrons it will gain or lose in a chemical reaction. We can use the periodic table to find the oxidation number for an element. When we add up the oxidation numbers of the elements in an ionic compound, the sum must be zero. Therefore, we need to find a balance of negative and positive ions in the compound for the molecule to form.

Example 1:

A compound is formed by the reaction between magnesium and chlorine. What is the chemical formula for this compound?

- From the periodic table, we find that the oxidation number of magnesium is 2+. Magnesium loses 2 electrons in chemical reactions. The oxidation number for chlorine is 1-. Chlorine tends to gain one electron in a chemical reaction.
- Remember that the sum of the oxidation numbers of the elements in a molecule will equal zero. This compound requires one atom of magnesium with an oxidation number of 2+ to combine with two atoms of chlorine, each with an oxidation number of 1-, for the sum of the oxidation numbers to be zero.

$$(2+) + 2(1-) = 0$$

To write the chemical formula for this compound, first write the chemical symbol for the positive ion (Mg) and then the chemical symbol for the negative ion (Cl). Next, use subscripts to show how many atoms of each element are required to form the molecule. When one atom of an element is required, no subscript is used. Therefore, the correct chemical formula for magnesium chloride is $MgCl_2$.

Example 2:

Aluminum and bromine combine to form a compound. What is the chemical formula for the compound they form?

From the periodic table, we find that the oxidation number for aluminum (Al) is 3+. The oxidation number for bromine (Br) is 1-. In order for the oxidation numbers of this compound add up to zero, one atom of aluminum must combine with three atoms of bromine:

$$(3+) + 3(1-) = 0$$

The correct chemical formula for this compound, aluminum bromide, is $AlBr_3$.

3. Practice writing chemical formulas for ionic compounds

Use the periodic table to find the oxidation numbers of each element. Then write the correct chemical formula for the compound formed by the following elements:

Element	Oxidation Number	Element	Oxidation Number	Chemical Formula for Compound
Potassium (K)		**Chlorine (Cl)**		
Calcium (Ca)		**Chlorine (Cl)**		
Sodium (Na)		**Oxygen (O)**		
Boron (B)		**Phosphorus (P)**		
Lithium (Li)		**Sulfur (S)**		
Aluminum (Al)		**Oxygen (O)**		
Beryllium (Be)		**Iodine (I)**		
Calcium (Ca)		**Nitrogen (N)**		
Sodium (Na)		**Bromine (Br)**		

4. Polyatomic ions

Have you ever heard of sodium nitrate? It's a preservative used in foods like hot dogs. The chemical formula for sodium nitrate is $NaNO_3$. How many types of atoms does this compound contain? You are right if you said three: sodium, nitrogen, and oxygen. The nitrogen and oxygen atoms have a shared-electron bond. They act as one unit (called nitrate) with an oxidation number of 1-. Ions that have more than one type of atom (like nitrate) are called *polyatomic ions*.

To write the chemical formula for a compound containing one or more polyatomic ions, consult a reference table or guide to determine the ion's oxidation number. Then, use the same procedure for writing chemical formulas that you practiced in section 3. The oxidation numbers for the polyatomic ions you will need for the problems in the skill sheet are shown in the following table:

Polyatomic Ion	Oxidation Number	Polyatomic Ion	Oxidation Number
Phosphate (PO_4)	3-	Nitrate (NO_3)	1-
Carbonate (CO_3)	2-	Sulfate (SO_4)	2-
Ammonium (NH_4)	1+	Acetate ($C_2H_3O_2$)	1-
Hydroxide (OH)	1-	Hydronium (H_3O)	1+

Example 3:

Calcium and the hydroxide ion (-OH) combine to form a compound. Write the chemical formula for this compound.

From the periodic table, we see that the oxidation number for calcium is 2+. From the table above, you will see that the oxidation number for the hydroxide ion is 1-. To make a molecule of calcium hydroxide, therefore, we need one calcium atom and two hydroxide ions:

$$(2+) + 2(1-) = 0$$

The correct chemical formula for this compound would be $Ca(OH)_2$. Note that we enclose the members of the polyatomic ion in parentheses. The subscript for this ion is placed outside of the parentheses. This shows that we need two complete polyatomic hydroxide ions to form the compound.

5. Writing chemical formulas for compound containing polyatomic ions

Use the table on the previous page and the periodic table to find the oxidation numbers of each ion. Then write the correct chemical formula for the compounds formed by these ions.

Element	Oxidation Number	Polyatomic Ion	Oxidation Number	Chemical Formula for Compound
Sodium (Na)		**Phosphate (PO_4)**		
Calcium (Ca)		**Nitrate (NO_3)**		
Fluorine (F)		**Ammonium (NH_4)**		
Boron (B)		**Sulfate (SO_4)**		
Lithium (Li)		**Hydroxide (OH)**		
Beryllium (Be)		**Carbonate (CO_3)**		
Nitrogen (N)		**Hydronium (H_3O)**		

Name: ______________________________

Skill Sheet 19-C Naming Chemical Compounds

Compounds have unique names that identify them for us when we study chemical properties and changes. Predicting the name of a compound is fairly easy provided certain rules are kept in mind. In this skill sheet, you will practice naming a variety of chemical compounds.

1. Chemical formulas and compound names

Chemical formulas tell a great deal of information about a compound—the types of elements forming the compound, the numbers of atoms of each element in one molecule, and even some indication, perhaps, of the arrangement of the atoms when they form the molecule.

In addition to having a unique chemical formula, each compound has a unique name. These names provide scientists with valuable information. Just like chemical formulas, chemical names tell which elements form the compound. However, the names may also identify a "family" or group to which the compound belongs. It is useful for scientists, therefore, to recognize and understand both a compound's formula and its name.

2. Naming compounds

Naming ionic compounds is relatively simple, especially if the compound is formed only from monoatomic ions. Follow these steps:

1. Write the name of the first element or the positive ion of the compound.
2. Write the root of the second element or negative ion of the compound.
   For example, write *fluor-* to represent fluorine, *chlor-* to represent chlorine.
3. Replace the ending of the negative ion's name with the suffix *-ide*.
   Fluorine → Fluoride; Chlorine → Chloride

Examples:

A compound containing potassium (K^{1+}) and iodine (I^{1-}) would be named potassium iodide. Lithium (Li^{1+}) combined with sulfur (S^{2-}) would be named lithium sulfide.

Naming compounds that contain polyatomic ions is even easier. Just follow these two steps:

1. Write the name of the positive ion first. Use the periodic table or an ion chart to find the name.
2. Write the name of the negative ion second. Again, use the periodic table or an ion chart to find the name.

Examples:

A compound containing aluminum (Al^{1+}) and sulfate (SO_4^{2-}) would be called aluminum sulfate.

A compound containing magnesium (Mg^{2+}) and carbonate (CO_3^{2-}) would be called magnesium carbonate.

3. Practice writing compound names

Predict the name of the compound formed from the reaction between the following elements and/or polyatomic ions. Use the periodic table and the polyatomic ion chart in section 19.2 of your student text to help you name the ions.

Combination	Compound Name
Al + Br	
Be + O	
K + N	
Ba + CrO_4^{2-}	
Cs + F	
NH_3^{1+} + S	
Mg + Cl	
B + I	
Na + SO_4^{2-}	
Si + $C_2H_3O_2^{1-}$	

4. Extension: Families of chemical compounds

Certain compounds have common characteristics, so we place them into groups or families. The The group called "enzymes" contains thousands of representative chemicals, but all share certain critical features that allow them to be placed into this group. Often, the name of a compound identifies the family of chemical to which it belongs. The clue is usually found in the suffix for the compound's name. The table below lists suffixes for some common chemical families.

Chemical Family	Suffix
Sugars	*-ose*
Alcohols	*-ol*
Enzymes	*-ase*
Ketones	*-one*
Organic acids	*-oic* or *-ic* acid
Alkanes	*-ane*

Glucose, the compound used by your brain as its primary fuel, is a sugar. The suffix *-ose* indicates its membership in the sugar family. Propane, the compound used to operate your gas barbecue grill, is an alkane, a compound formed from carbon and hydrogen atoms that are covalently bonded with single pairs of electrons. We know this from the suffix *-ane*.

Knowing such information about a compound can be very useful when you are reading the labels of consumer products. Compound names can be found in the ingredients list on the label. If you are purchasing a hand lotion to alleviate dry skin, you should avoid one that lists a compound with an *-ol* suffix early in the ingredients list.

The ingredients are listed from largest amount to smallest amount. The earlier a compound is listed, the greater the amount of that compound in the product. A compound with an *-ol* suffix is an alcohol. Hand lotions with high percentages of alcohols are less effective since alcohols tend to dry out rather than moisturize the skin!

In later chemistry courses, you will learn more about the names and characteristics of "families" of compounds. This knowledge will provide you with a powerful tool for making informed consumer decisions.

5. Practice predicting family identities of compounds

Using the information in the table on the previous page to predict the chemical family to which the following compounds are members:

Compound Name	Chemical Family
Lipase	
Methanol	
Formic Acid	
Butane	
Sucrose	
Acetone	
Acetic Acid	

Name: ______________________________

Skill Sheet 19-D The Mole and Avogadro's Number

Atoms are so small that you could fit millions of them on the head of a pin. As you have learned, the masses of atoms and molecules are measured in atomic mass units. Working with atomic mass units in the laboratory is very difficult because each atomic mass unit has a mass of 1/12th the mass of one carbon atom. In order to make atomic mass units more useful to work with, it would be convenient to set the value of one atomic mass unit to one gram. One gram is an amount of matter we can actually see. For example, the mass of one paper clip is about 2.5 grams. Avogadro's number, 6.02×10^{23} allows us to convert atomic mass units to grams.

1. What is a mole?

In chemistry, the term "mole" does not refer to a furry animal that lives underground. In chemistry, a mole is *quantity* of something and is used just like we use the term "dozen". One dozen is equal to 12. One mole is equal to 6.02×10^{23}, or Avogadro's number. If you have a *dozen* oranges, you have 12. If you have a *mole* of oranges, you have 6.02×10^{23}. This would be enough oranges to cover the entire surface of the Earth, seven feet deep in oranges!

Could you work with only a dozen atoms in the laboratory? You cannot see 12 atoms without the aid of a very powerful microscope. A mole of atoms would be much easier to work with in the laboratory because the mass of one mole of atoms can be measured in grams. Moles allow us to convert atomic mass units to grams. This relationship is illustrated below:

$$1 \text{ carbon atom} = 12.0 \text{ amu}$$

$$1 \text{ mole of carbon atoms} = 6.02 \times 10^{23} \text{atoms} = 12.0 \text{ grams}$$

To calculate the mass of one mole of any substance (the **molar mass**), you use the periodic table to find the atomic mass (not the mass number) for the element or for the elements that create the compound. You then express this value in grams.

Example:

Substance	Elements in substance	Atomic mass of element (amu)	No. of atoms of each element	Formula mass (amu)	Molar mass (g)
Na	Na	22.99	1	22.99	22.99
U	U	238.03	1	238.03	238.03
H_2O	H O	1.01 16.00	2 1	18.01	18.01
$CaCO_3$	Ca C O	40.08 12.01 16.00	1 1 3	100.09	100.09
$Al(NO_3)_3$	Al N O	26.98 14.01 16.00	1 3 9	313.1	313.1

2. Calculating molar mass

For the following elements and compounds, complete the following table to calculate the mass of one mole of the substance:

Substance	Elements in substance	Atomic mass of element (amu)	No. of atoms of each element	Formula mass (amu)	Molar mass (g)
Sr					
Ne					
$Ca(OH)_2$					
NaCl					
O_3					
$C_6H_{12}O$					

The molar mass of a substance can be used to calculate the number of particles (atoms or molecules) present in any given mass of a substance. You can determine the number of particles present by using Avogadro's number. This will be practiced in the next exercise.

3. Avogadro's number

Avogadro's number states that for one mole of any substance, whether element or compound, there are 6.02×10^{23} particles present in the sample. Those particles are atoms if the substance is an element and molecules if the substance is a compound. If we look again at our previous examples we see that every substance has a different molar mass:

Substance	Elements in substance	Atomic mass of element (amu)	No. of atoms of each element	Formula mass (amu)	Molar mass (g)
Na	Na	22.99	1	22.99	22.99
U	U	238.03	1	238.03	238.03
H_2O	H	1.01	1	1.01	1.01
CaCO3	Ca C O	40.08 12.01 16.00	1 1 3	100.09	100.09
$Al(NO_3)_3$	Al N O	26.98 14.01 16.00	1 3 9	313.1	313.1

However, one mole of each of these substances contains exactly the same number of fundamental particles, 6.02×10^{23}. The difference is that each of these fundamental particles, atoms, and molecules, has a different mass based on its composition (number of protons and neutrons, numbers and types of atoms). Therefore, the number of particles in one mole of any substance is identical; however, the mass of one mole of substances varies based on the formula mass for that substance.

When a substance's mass is reported in grams and you need to find the number of particles present in the sample, you must first convert the mass in grams to the mass in moles. By using proportions and rations, you can easily calculate the molar mass of any given amount of substance.

Example:

How many molecules are in a sample of NaCl that has a mass of 38.9 grams?

First, determine the molar mass of NaCl:

Element	Atomic mass (amu)	No. of atoms	Molar mass (g)
Sodium (Na)	22.99	1	22.99
Chlorine (Cl)	35.45	1	35.45
Molar mass of NaCl			**58.44 g**

Next, determine how many particles are in 38.9 g of NaCl:

We know that 58.44 g of NaCl contains 6.02×10^{23} molecules of NaCl. Therefore, we can set up a proportion to determine the number of molecules in 38.9 g of NaCl:

$$\frac{58.44 \text{ g NaCl}}{6.02 \times 10^{23}} = \frac{38.9 \text{ g NaCl}}{x}$$

Solving for x using cross-multiplication gives us a value of 4.0×10^{23} molecules of NaCl.

4. How many particles are in a sample of matter?

Complete the following table by determining the molar mass of each listed substance and either providing the number of particles in the given mass of sample or the mass of the sample that contains the given number of particles.

Substance	Molar Mass (g)	Mass of Sample (g)	Number of Particles Present
$MgCO_3$		12.75	
H_2O			296×10^{50}
N_2			7.1×10^{8}
Yb		0.00038	
$Al_2(SO_3)_3$		4657	
K_2CrO_4			0.23×10^{19}

Name: ____________________

Skill Sheet 19-E Calculating Formula Mass

A chemical formula gives you useful information about a compound. First, it tells you which types of atoms and how many of each are present in a compound. Second, it lets you know which types of ions are present in a compound. Finally, it allows you to determine the mass of one molecule of a compound, relative to the mass of other compounds. We call this the formula mass. This skill sheet will show you how to calculate the formula mass of a compound.

1. Calculating formula mass: a step-by-step approach

A common ingredient in most toothpastes is a compound called sodium phosphate. If you examine a tube of toothpaste, you will find that it is usually listed as trisodium phosphate.
What is the formula mass of sodium phosphate?

Step 1: Determine the formulas and oxidation numbers of the ions in the compound.

Sodium phosphate is made up of the *sodium ion* and the *phosphate ion*. The oxidation number for the sodium ion can be determined from the periodic table. Since sodium, Na, is located in group 1 of the periodic table, it has an oxidation number of 1+ like all of the elements in group 1.

The chemical formula and oxidation number for sodium is: Na^+

To find the formula and oxidation number for the phosphate ion, use the ion chart in chapter 19 of your textbook.

The chemical formula and oxidation number for the phosphate ion is: PO_4^{3-}

Step 2: Write the chemical formula of the compound.

Remember that compounds must be neutral that is, the oxidation numbers of the elements and ions must be equal to zero. Since sodium = $\mathbf{Na^+}$ and phosphate = $\mathbf{PO_4^{3-}}$ how many of each do you need to make a neutral compound? You need three sodium ions for each phosphate ion to make a neutral compound.

The chemical formula of sodium phosphate is: Na_3PO_4.

Step 3: List the atoms, number of each atom, atomic mass of each atom, and total mass of each atom.

Atom	number	atomic mass (from the periodic table)	total mass (number × atomic mass)
Na	3	22.99 amu	3 × 22.99 = 68.97 amu
P	1	30.97 amu	1 × 30.97 = 30.97 amu
O	4	16.00 amu	4 × 16.00 = 64.00 amu

Step 4: Add up the values and calculate the formula mass of the compound.

68.97 amu + 30.97 amu + 64.00 amu = 163.94 amu

The formula mass of sodium phosphate is 163.94 amu

2. Practice

Now try one on your own:

Eggshells are made mostly of a brittle compound called calcium phosphate. What is the formula mass of this compound?

1. Write the chemical formula and oxidation number of each ion in the compound:

   First ion: Second ion:

2. Write the chemical formula of the compound:

3. List the atoms, number of each atom, atomic mass of each atom, and total mass of each atom.

Atom	number	atomic mass (from the periodic table)	total mass (number × atomic mass)

4. Add up the values to calculate the formula mass of the compound.

3. More practice on your own

Write the chemical formula and the formula mass for each of the compounds below. Use separate paper and show all of your work.

1. barium chloride
2. sodium hydrogen carbonate
3. magnesium hydroxide
4. ammonium nitrate
5. strontium phosphate
6. **Challenge!**
   What is the formula mass of $CoCl_2 \cdot 6H_2O$?
   Hint: Read about hydrates in chapter 19 of your textbook.

Name:

Skill Sheet 20-A Chemical Equations

Chemical symbols provide us with a shorthand method of writing the name of an element. Chemical formulas do the same for compounds. But what about chemical reactions? To write out, in words, the process of a chemical change would be long and tedious. Is there a shorthand method of writing a chemical reaction so that the all the information is presented correctly and is understood by all scientists? Yes! This is the function of chemical equations. You will practice writing and balancing chemical equations in this skill sheet.

1. What are chemical equations?

Chemical equations show what is happening in a chemical reaction. They provide you with the identities of the reactants (substances entering the reaction) and the products (substances formed by the reaction). They also tell you how much of each substance is involved in the reaction. Chemical equations use symbols for elements and formulas for compounds. The reactants are written to the left of the arrow. Products go on the right side of the arrow.

$$H_2 + O_2 \rightarrow H_2O$$

The arrow should be read as "yields" or "produces." This equation, therefore, says that hydrogen gas (H_2) plus oxygen gas (O_2) yields or produces the compound water (H_2O).

2. Practice writing chemical equations

Write chemical equations for the following reactions:

Reactants	Products	Chemical Equation
Hydrochloric acid **HCl** and Sodium hydroxide **NaOH**	Water **H_2O** and Sodium chloride **NaCl**	
Calcium carbonate **$CaCO_3$** and Potassium iodide **KI**	Potassium carbonate **K_2CO_3** and Calcium iodide **CaI_2**	
Aluminum fluoride **AlF_3** and Magnesium nitrate **$Mg(NO_3)_2$**	Aluminum nitrate **$Al(NO_3)_3$** and Magnesium fluoride **MgF_2**	

3. Conservation of atoms

Take another look at the chemical equation for making water:

$$2H_2 + O_2 \rightarrow 2H_2O$$

Did you notice that something has been added?

The large number in front of H_2 tells how many atoms of H_2 are required for the reaction to proceed. The large number in front of H_20 tells how many molecules are formed by the reaction. These numbers are called *coefficients*. Using coefficients, we can balance chemical equations so that the equation demonstrates conservation of atoms. The law of conservation of atoms says that no atoms are lost or gained in a chemical reaction. The same types and numbers of atoms must be found in the reactants and the products of a chemical reaction.

Coefficients are placed before the chemical symbol for single elements and before the chemical formula of compounds to show how many atoms or molecules of each substance are participating in the chemical reaction. When counting atoms to balance an equation, remember that the coefficient applies to all atoms within the chemical formula for a compound. For example, $5CH_4$ means that 5 atoms of carbon and 20 atoms of hydrogen are contributed to the chemical reaction by the compound methane.

4. Balancing chemical equations

To write a chemical equation correctly, first write the equation using the correct chemical symbols or formulas for the reactants and products.

If a reaction is to occur between sodium chloride and iodine to form sodium iodide and chlorine gas, we would write:

$$NaCl + I_2 \rightarrow NaI + Cl_2$$

Remember that certain elements, when found alone, are diatomic; iodine and chlorine are two examples.

- Next, count the number of atoms of each element present on the reactant and product side of the chemical equation:

Reactant Side of Equation	Element	Product Side of Equation
1	Na	1
1	Cl	2
2	I	1

- For the chemical equation to be balanced, the numbers of atoms of each element must be the same on either side of the reaction. This is clearly not the case with the equation above. We need coefficients to balance the equation.

- First, choose one element to balance. Let's start by balancing chlorine. Since there are two atoms of chlorine on the product side and only one on the reactant side, we need to place a "2" in front of the substance containing the chlorine, the NaCl.

$$2NaCl + I_2 \rightarrow NaI + Cl_2$$

  This now gives us two atoms of chlorine on both the reactant and product sides of the equation. However, it also give us two atoms of sodium on the reactant side! This is fine—often balancing one element will temporarily unbalance another. By the end of the process, however, all elements will be balanced.

  We now have the choice of balancing either the iodine or the sodium. Let's balance the iodine. (It doesn't matter which element we choose.)

- There are two atoms of iodine on the reactant side of the equation and only one on the product side. Placing a coefficient of "2" in front of the substance containing iodine on the product side:

$$2NaCl + I_2 \rightarrow 2NaI + Cl_2$$

  There are now two atoms of iodine on either side of the equation, and at the same time we balanced the number of sodium atoms!

  In this chemical reaction, two molecules of sodium chloride react with one diatomic molecule of iodine to produce two molecules of sodium iodide and one diatomic molecule of chlorine. Our equation is balanced!

5. Polyatomic ions and balancing equations

Some compounds contain multiple numbers of polyatomic ions. For example, $Mg(OH)_2$ is formed when two complete hydroxide (-OH) groups attach to the element magnesium. Therefore, in a chemical equation:

$$3Mg(OH)_2$$

represents 3 atoms of magnesium, 6 atoms of oxygen, and 6 atoms of hydrogen. Each hydroxide group contributes 2 oxygen atoms and 2 hydrogen atoms to the compound. There are 3 molecules of the compound in the reaction, so there are 6 total atoms of oxygen and hydrogen in the reaction. Be aware of this as you balance equations.

If your equation contains a polyatomic ion with a subscript, like SO_4, you really have to watch your math! For example, if you have 3 molecules of aluminum sulfate, $3Al_2(SO_4)_3$, you actually have nine atoms of sulfur and thirty-six atoms of oxygen! Can you figure out why?

6. Practice balancing equations

Balance the equations on the next page using the appropriate coefficients. Remember that balancing one element may temporarily unbalance another. You will have to correct the imbalance in the final equation. Check your work by counting the total number of atoms of each element—the numbers should be equal on the reactant and product sides of the equation.

1. $Al + O_2 \rightarrow Al_2O_3$

2. $CO + H_2 \rightarrow H_2O + CH_4$

3. $HgO \rightarrow Hg + O_2$

4. $CaCO_3 \rightarrow CaO + CO_2$

5. $C + Fe_2O_3 \rightarrow Fe + CO_2$

6. $N_2 + H_2 \rightarrow NH_3$

7. $K + H_2O \rightarrow KOH + H_2$

8. $P + O_2 \rightarrow P_2O_5$

9. $Ba(OH)_2 + H_2SO_4 \rightarrow H_2O + BaSO_4$

10. $CaF_2 + H_2SO_4 \rightarrow CaSO_4 + HF$

11. $KClO_3 \rightarrow KClO_4 + KCl$

Name: ______________________________

Skill Sheet 20-B Predicting Product in a Reaction

A balanced chemical equation tells you the *proportional* relationship between the reactants and the products in a reaction. This means that you can use the information provided in a balanced chemical equation to predict how much product will be formed in a reaction, given the mass of the *limiting reactant* (the one that reacts completely).

1. Proportional relationships in balanced, chemical equations

In the Investigations, you discovered an important mathematical relationship that allows you to predict the amount of a product produced in a reaction.

$$\frac{\text{mass of limiting reactant (LR)}}{\text{coefficient of LR} \times \text{formula mass of LR}} = \frac{\text{mass of product (P)}}{\text{coefficient of P} \times \text{formula mass of P}}$$

You can use this relationship to predict the amount of one of the products produced in a reaction, when you know the amount of the limiting reactant that was used up in the reaction.

2. Predicting the amount of product formed: a step-by-step approach

Coal gasification is a process that converts coal into methane gas, the substance that is often used to heat homes and cook food. This process involves a reaction between the carbon found in coal, and water to produce methane gas (CH_4), and carbon dioxide. *If 50.0 g of carbon react completely with water, how many grams of methane gas will be produced*?

Step 1: Write and balance the equation.

Word equation: carbon + water → methane + carbon dioxide.

Unbalanced equation: $C(s) + H_2O(l) \rightarrow CH_4(g) + CO_2(g)$

Balanced equation: $2C(s) + 2H_2O(l) \rightarrow CH_4(g) + CO_2(g)$

Step 2: What do you know? What do you need to find out?

Look at the equation in part 1. Which variables in the equation do you know? Which variable are you solving for?

limiting reactant	product
mass (from problem) = 50.0 g	**mass = need to find out (X)**
coefficient (from bal. equation) = 2	**coefficient = 1**
formula mass of C = 12.0 amu	**formula mass of CH_4 = 16.0 amu**

Step 3: Set up the proportional relationship and solve.

$$\left(\frac{50.0\ g}{2 \times 12.0\ \text{amu}} = \frac{X}{1 \times 16.0\ \text{amu}}\right) = \left(\frac{50.0\ g}{24.0\ \text{amu}} = \frac{X}{16.0\ \text{amu}}\right)$$

$$X = \left(\frac{50.0\ g \times 16.0\ amu}{24.0\ amu}\right) = 33.3\ g \text{ of methane gas will be produced}$$

3. Practice

Now try one on your own:

Oxygen gas can be produced by the decomposition of potassium chlorate ($KClO_3$). Another product in this reaction is potassium chloride. How many grams of oxygen gas can be produced by decomposing 150.0 grams of potassium chlorate?

1. Write the balanced equation for the reaction:

____

____

____

2. What do you know? What do you need to find out? Fill out the table below:

limiting reactant	product
mass:	**mass:**
coefficient:	**coefficient:**
formula mass:	**formula mass:**

3. Set up the proportional relationship and solve.

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4. More practice on your own

1. When methane gas burns in oxygen gas, carbon dioxide and water are produced. If 85.0 grams of methane burn completely in oxygen gas, how many grams of carbon dioxide will be produced?

2. In the space shuttle, the carbon dioxide that the astronauts exhale is removed from the air by a reaction that occurs inside canisters of lithium hydroxide. The products of the reaction are lithium carbonate and water. If the crew on the space shuttle exhales 3,000 grams of carbon dioxide in one day, and all of it reacts with the lithium hydroxide, how many grams of water will be produced?

Use the space below to show your work for the practice problems:

Name:

Skill Sheet 21 Predicting Chemical Equations

Chemical reactions are the mechanism of chemical change. Elements and compounds enter into a reaction, and new substances are formed as a result. Often, we know the types of substances that entered the reaction and, with chemical analysis, determine what types of substance(s) were formed. Sometimes, though, it might be helpful if we could predict the products of the chemical reaction—know in advance what would be formed and how much of it would be produced. For certain chemical reactions, this is possible, using our knowledge of oxidation numbers, mechanics of chemical reactions, and balancing equations. In this skill sheet, you will practice writing a complete balanced equation for chemical reactions when only the identities of the reactants are known.

1. Chemical equations

Recall that chemical equations document, in shorthand form, the process of a chemical change or chemical reaction. The equation reads from left to right with the reactants, substances entering the reaction, separated from the products, substances formed from the reaction, by an arrow that indicates "yields" or "produces."

In the chemical equation:

$$2Li + BaCl_2 \rightarrow 2LiCl + Ba$$

two atoms of lithium combine with one molecule of barium chloride to yield or produce two molecules of lithium chloride and one atom of barium. The equation fully describes the nature of the chemical change that we are generating with the reaction.

For reactions such as the one above, a single-displacement reaction, and double-displacement reactions, we are generally capable of predicting the nature of the products in advance and write a completely balanced equation for the chemical change. To do this we must:

1. Predict the products for the reaction.
2. Determine the chemical formulas for the products of the reaction.
3. Balance the equation.

2. Predicting the products of single- and double-displacement reactions

In displacement reactions, one member of a compound is replaced by some other substance, usually an element or polyatomic ion. The pattern for this replacement is easily predictable: if the substance doing the replacing forms a positive ion, it replaces the member of the compound that also forms a positive ion. If the substance doing the replacing forms a negative ion, it replaces the member of the compound that also forms a negative ion. The balance of negative and positive charges must be maintained in the new compound that will be formed. For the reaction described above:

$$2Li + BaCl_2 \rightarrow 2LiCl + Ba$$

we could predict that the lithium would replace the barium in the compound barium chloride since both lithium and barium have positive oxidation numbers. The resulting product would pair lithium (1+) and chlorine (1-): the positive/negative combination required for ionic compounds.

For double-replacement reactions, the substance with the positive oxidation number of one compound replaces the substance with the positive oxidation number of the second compound, with the same holding true for the negative members:

$$HCl + NaOH \rightarrow NaCl + H_2O$$

$$H^{1+}Cl^{1-} + Na^{1+}OH^{1-} \rightarrow Na^{1+}Cl^{1-} + H_2^{1+}O^{2-}$$

3. Predicting replacements

1. If calcium were to combine with the compound barium nitrate, which member of barium nitrate would calcium replace?

2. If LiCl and $MgBr_2$ were to enter into a chemical reaction, which member of $MgBr_2$ will chlorine replace?

3. If Fe^{2+} were to combine with K_2Br, what component of K_2Br would be replaced by the Fe^{2+}?

4. Predicting chemical formulas for reaction products

In 19.2, you examined the method by which we can predict the chemical formula for ionic compounds. Using oxidation numbers and the fact that the sum of the oxidation numbers for an ionic compound must equal zero, we were able to determine the chemical formula for compounds formed from ionic bonding.

You will follow this same procedure when writing the chemical formula for the products of single- and double-replacement reactions. Once you have determined which elements or ions will be swapped to form the new compounds, the products of the reaction, use the oxidation numbers of the elements/ions to be combined to generate the chemical formulas for the new compounds.

Example

If beryllium (Be) combines with potassium iodide (KI) in a chemical reaction, what will be the identities of the products?

First, we decide which member of KI will be replaced by the beryllium. Since beryllium has an oxidation number of 2+, it replaces the element in KI that also has a positive oxidation number—the potassium (K^{1+}). It will therefore combine with the iodine to form a new compound.

Because beryllium has an oxidation number of 2+ and iodine's oxidation number is 1-, it is necessary for two atoms of iodine to combine with one atom of beryllium to form an electrically neutral compound:

$$(2+) + 2(1-) = 0$$

The resulting chemical formula for beryllium iodide is BeI_2.

In single-replacement reactions, the component of the compound that has been replaced by the uncombined reactant now stands alone and uncombined. The resulting products of this chemical reaction, therefore, are BeI_2 and K.

For polyatomic ions, the process is identical to that used when replacing monoatomic ions. Find the oxidation number of the polyatomic ion from a reference table and use that value in your calculations.

5. Predicting product formulas for single- and double-replacement reactions

For the following combinations of reactants, predict the chemical symbols or formulas of the products:

Reactants	Products
$Li + AlCl_3$	
$BeO + Na_2SO_4$	
$CaCO_3 + KF$	
$K + CaO$	
$AlPO_4 + NH_4Cl$	
$KBr + Cs_2O$	

6. Predicting chemical equations for single- and double-replacement reactions

Once you have determined the nature and formulas/symbols of the products for a chemical reaction, the final step is to write a balanced equation for the reaction. Using the skills you practiced in 20.2, write complete balanced equations for the following combinations of reactants.

1. $NaCl$ and $Mg(OH)_2$

2. Ca and K_2S

3. LiF and BI_3

4. $BeCrO_4$ and KNO_3

5. Mg and Fe_2O_3