Stability in Bonding

Compounds

- Some of the matter around you is in the form of uncombined elements such as copper, sulfur, and oxygen.
- Like many other sets of elements, these three elements unite chemically to form a compound when the conditions are right.

Stability in Bonding

Compounds

- The green coating on the Statue of Liberty and some old pennies is a result of this chemical change.
- The compound formed when elements combine often has properties that aren't anything like those of the individual elements.
- Sodium chloride, for example, is a compound made from the elements sodium and chlorine.

Stability in Bonding

Formulas

- A **chemical formula** tells what elements a compound contains and the exact number of the atoms of each element in a unit of that compound.
- The compound that you are probably most familiar with is H_2O, more commonly known as water.

Stability in Bonding

Formulas

- This formula contains the symbols H for the element hydrogen and O for the element oxygen.
- Notice the subscript number 2 written after the H for hydrogen.

Stability in Bonding

Formulas

- A subscript written after a symbol tells how many atoms of that element are in a unit of the compound.

Table 1 Some Familiar Compounds

Common Name	Chemical Name	Chemical Formula
Sand	silicon dioxide	SiO_2
Milk of magnesia	magnesium hydroxide	$Mg(OH)_2$
Cane sugar	sucrose	$C_{12}H_{22}O_{11}$
Lime	calcium oxide	CaO
Vinegar	acetic acid	CH_3COOH
Laughing gas	dinitrogen oxide	N_2O
Grain alcohol	ethanol	$C_{2H5}OH$
Battery acid	sulfuric acid	H_2SO_4
Stomach acid	hydrochloric acid	HCl

Stability in Bonding

Formulas

- If a symbol has no subscript, the unit contains only one atom of that element. A unit of H_2O contains two hydrogen atoms and one oxygen atom.

Table 1 Some Familiar Compounds

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Stomach acid	hydrochloric acid	HCl

Stability in Bonding

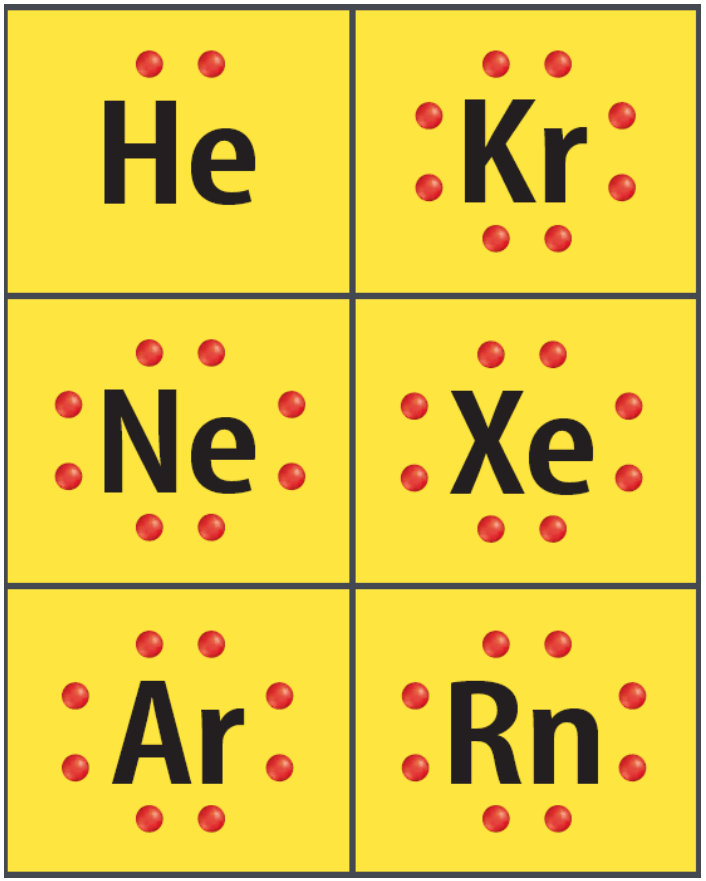
Atomic Stability

- The electric forces between oppositely charged electrons and protons hold atoms and molecules together, and thus are the forces that cause compounds to form.
- Atoms of noble gases are unusually stable.
- Compounds of these atoms rarely form because they are almost always less stable than the original atoms.

Stability in Bonding

The Unique Noble Gases

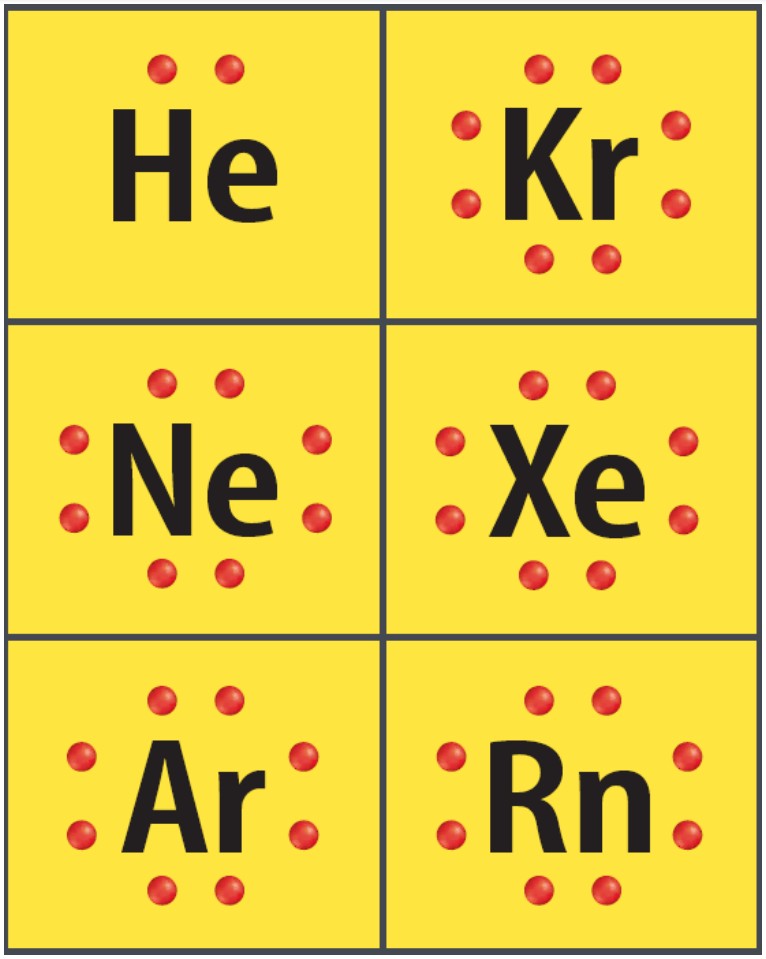
- To understand the stability of the noble gases, it is helpful to look at electron dot diagrams.
- Electron dot diagrams show only the electrons in the outer energy level of an atom.



Stability in Bonding

Chemical Stability

- The noble gases are stable because they each have a complete outer energy level.
- Notice that eight dots surround Kr, Ne, Xe, Ar, and Rn, and two dots surround He.



Stability in Bonding

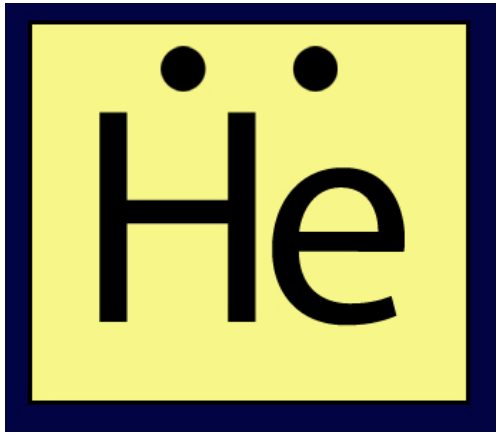
Energy Levels and Other Elements

- Hydrogen contains one electron in its lone energy level.
- A dot diagram for hydrogen has a single dot next to its symbol. This means that hydrogen's outer energy level is not full.
- It is more stable when it is part of a compound.

Stability in Bonding

Energy Levels and Other Elements

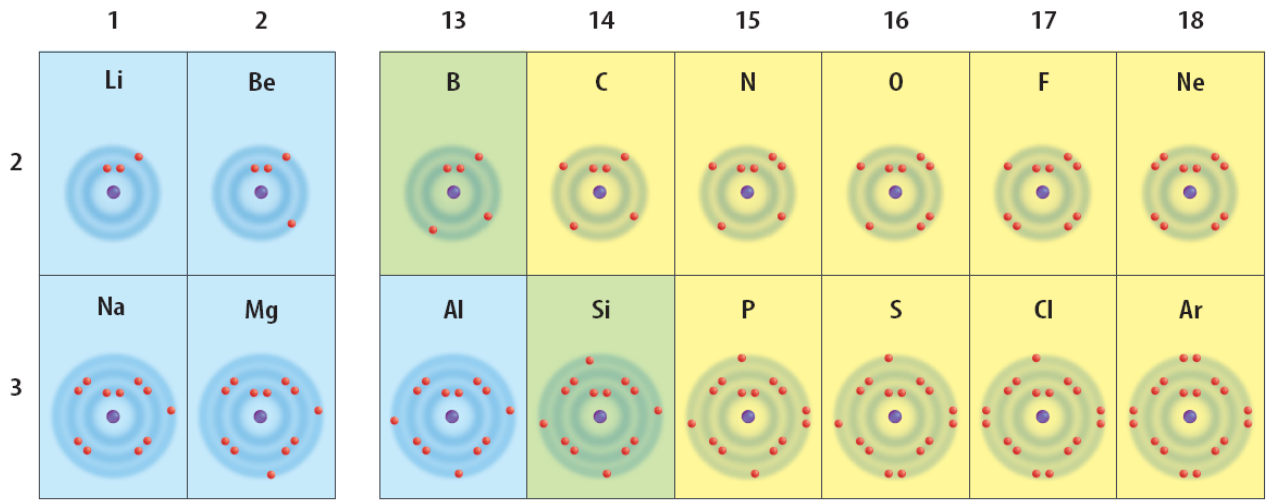
- In contrast, helium's outer energy level contains two electrons.
- Helium already has a full outer energy level by itself and is chemically stable.
- Helium rarely forms compounds but, by itself, the element is a commonly used gas.



Stability in Bonding

Energy Levels and Other Elements

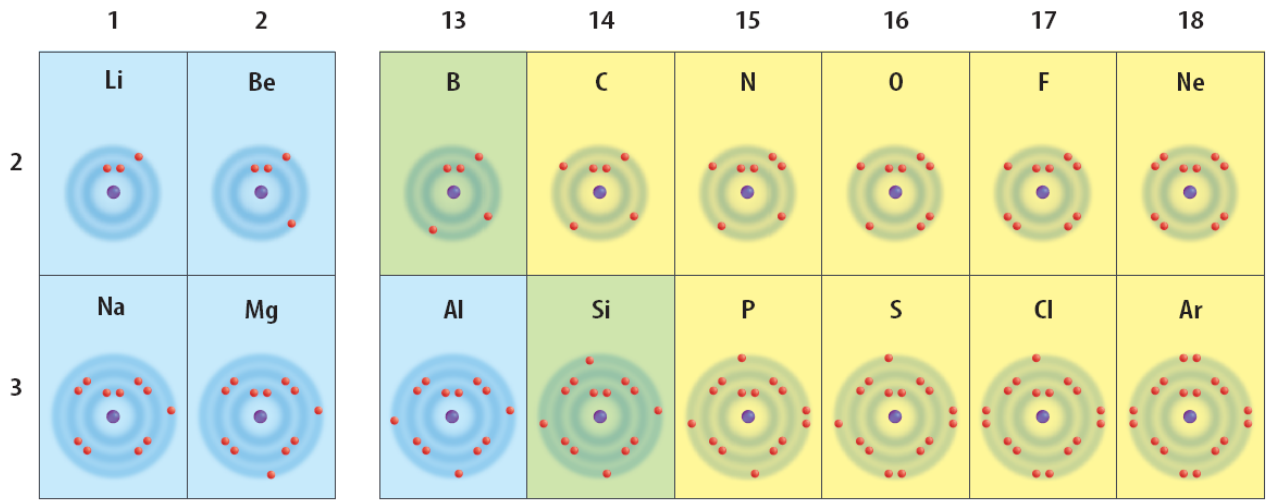
- When you look at the elements in groups 13 through 17, you see that each of them falls short of having a stable energy level.



Stability in Bonding

Energy Levels and Other Elements

- Each group contains too few electrons for a stable level of eight electrons.



Stability in Bonding

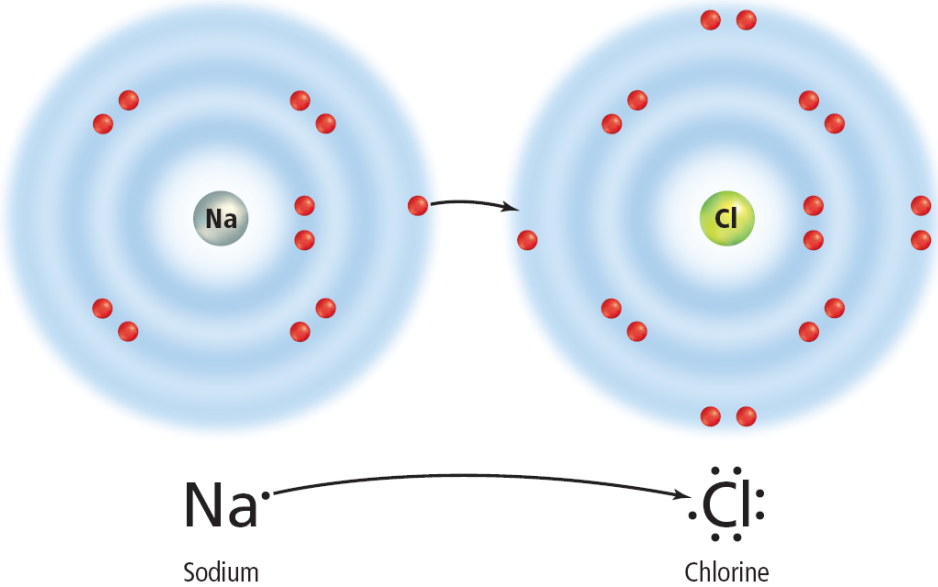
Outer Levels —Getting Their Fill

- How does hydrogen, or any other element, trying to become stable, gain or lose its outer electrons?
- They do this by combining with other atoms that also have partially complete outer energy levels.
- As a result, each achieves stability.

Stability in Bonding

Outer Levels —Getting Their Fill

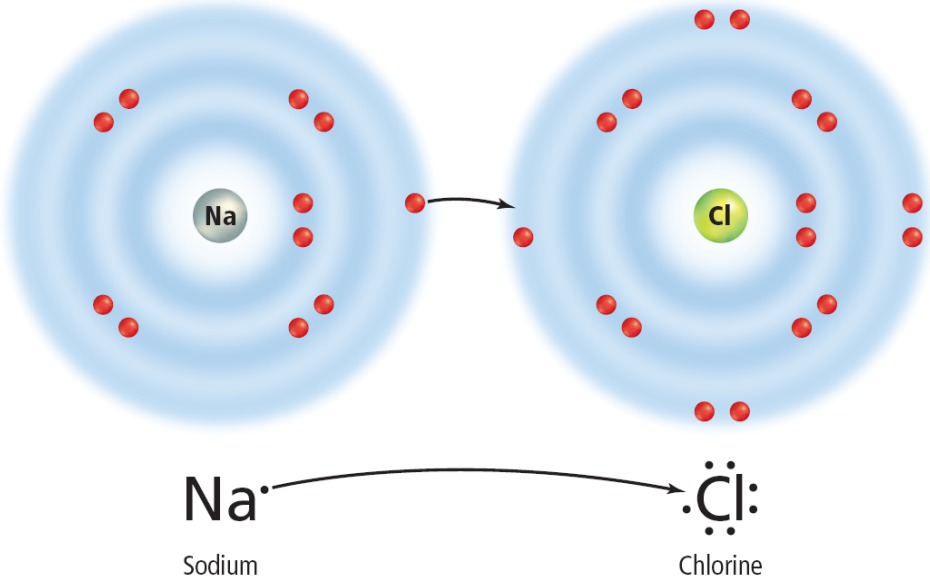
- This illustration shows electron dot diagrams for sodium and chlorine.
- When they combine, sodium loses one electron and chlorine gains one electron.



Stability in Bonding

Outer Levels —Getting Their Fill

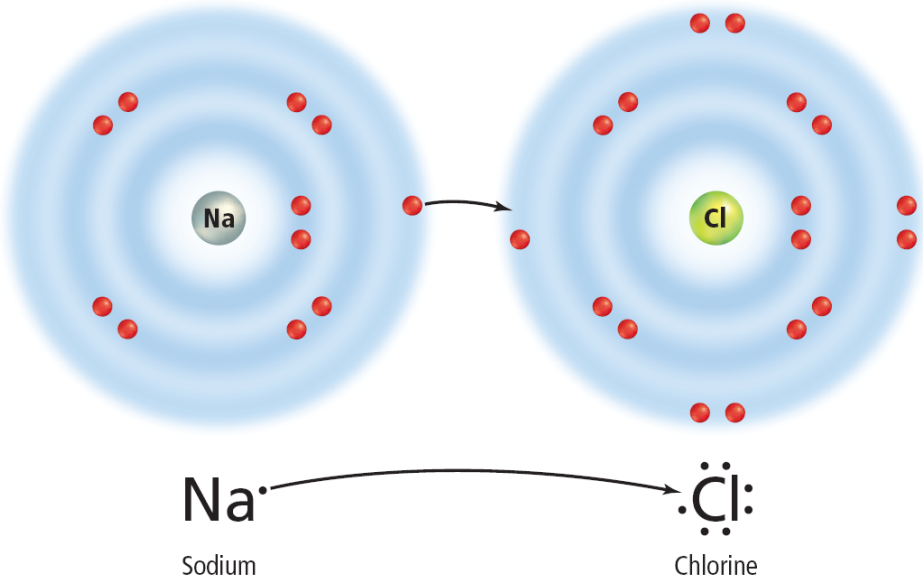
- You can see from the electron dot diagram that chlorine now has a stable outer energy level.
- Sodium had only one electron in its outer energy level, which it lost to combine with chlorine in sodium chloride.



Stability in Bonding

Stability Is Reached

- Look back to the next, outermost energy level of sodium.
- This is now the new outer energy level, and it is stable with eight electrons.



Stability in Bonding

Stability Is Reached

- When atoms gain, lose, or share electrons, an attraction forms between the atoms, pulling them together to form a compound.
- This attraction is called a chemical bond. A **chemical bond** is the force that holds atoms together in a compound.

Types of Bonds

Gain or Loss of Electrons

- Atoms lose or gain electrons to meet a standard—a stable energy level.
- An atom that has lost or gained electrons is called an ion. An **ion** is a charged particle because it now has either more or fewer electrons than protons.

Types of Bonds

Gain or Loss of Electrons

- The positive and negative charges are not balanced.
- It is the electric forces between oppositely charged particles, such as ions, that hold compounds together.

Types of Bonds

Gain or Loss of Electrons

- Some of the most common compounds are made by the loss and gain of just one electron.
- Some examples are sodium chloride, commonly known as table salt; sodium fluoride, an anticavity ingredient in some toothpastes; and potassium iodide, an ingredient in iodized salt.

Types of Bonds

A Bond Forms

- A neutral atom of potassium has one electron in its outer level. This is not a stable outer energy level.
- When potassium forms a compound with iodine, potassium loses one electron from its fourth level, and the third level becomes a complete outer level.

Types of Bonds

A Bond Forms

- The potassium atom has become an ion.
- When a potassium atom loses an electron, the atom becomes positively charged because there is one electron less in the atom than there are protons in the nucleus
- The 1+ charge is shown as a superscript written after the element's symbol, K^+ , to indicate its charge.

Types of Bonds

A Bond Forms

- The iodine atom in this reaction undergoes a change.
- An iodine atom has seven electrons in its outer energy level.
- During the reaction with potassium, the iodide atom gains an electron, leaving its outer energy level with eight electrons.

Types of Bonds

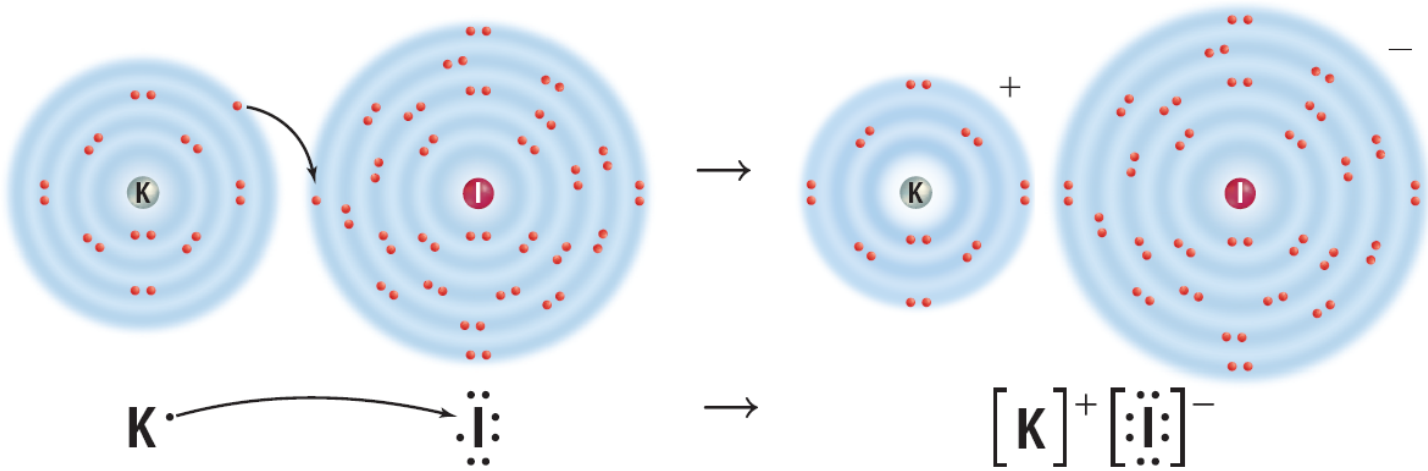
A Bond Forms

- This atom is no longer neutral because it gained an extra negative particle.
- It now has a charge of 1− and is called an iodide ion, written as I^-.

Types of Bonds

A Bond Forms

- Notice that the resulting compound has a neutral charge because the positive and negative charges of the ions cancel each other.



Types of Bonds

The Ionic Bond

- An **ionic bond** is the force of attraction between the opposite charges of the ions in an ionic compound.
- In an ionic bond, a transfer of electrons takes place.
- If an element loses electrons, one or more elements must gain an equal number of electrons to maintain the neutral charge of the compound.

Types of Bonds

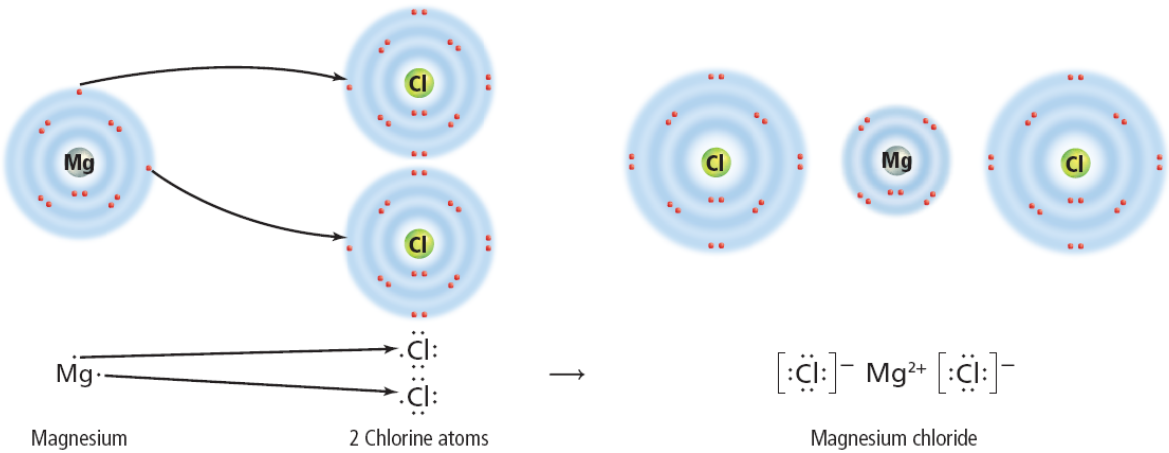
The Ionic Bond

- The formation of magnesium chloride, $MgCl_2$, is another example of ionic bonding.
- When magnesium reacts with chlorine, a magnesium atom loses two electrons and becomes a positively charged ion, Mg^{2+}.

Types of Bonds

The Ionic Bond

- At the same time, two chlorine atoms gain one electron each and become negatively charged chloride ions, Cl^-.



Types of Bonds

Zero Net Charge

- The result of this bond is a neutral compound.
- The compound as a whole is neutral because the sum of the charges on the ions is zero.

Types of Bonds

Zero Net Charge

- When atoms form an ionic compound, their electrons are shifted to the other atoms, but the overall number of protons and electrons of the combined atoms remains equal and unchanged. Therefore, the compound is neutral.
- Ionic bonds usually are formed by bonding between metals and nonmetals.

Types of Bonds

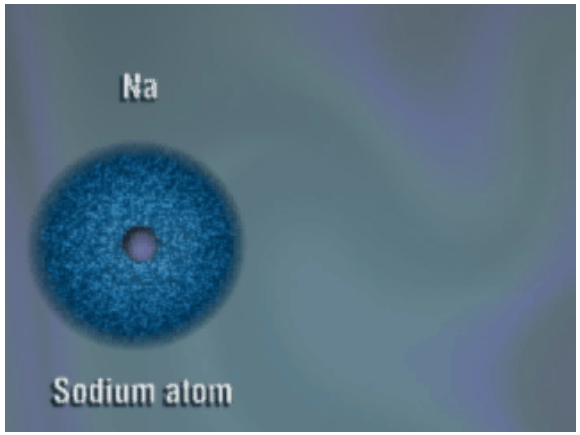
Sharing Electrons

- Some atoms of nonmetals are unlikely to lose or gain electrons.
- For example, the elements in Group 4 of the periodic table have four electrons in their outer levels.
- They would have to either gain or lose four electrons in order to have a stable outer level.

Types of Bonds

Sharing Electrons

- The loss of this many electrons takes a great deal of energy.
- Therefore, these atoms become more chemically stable by sharing electrons, rather than by losing or gaining electrons.



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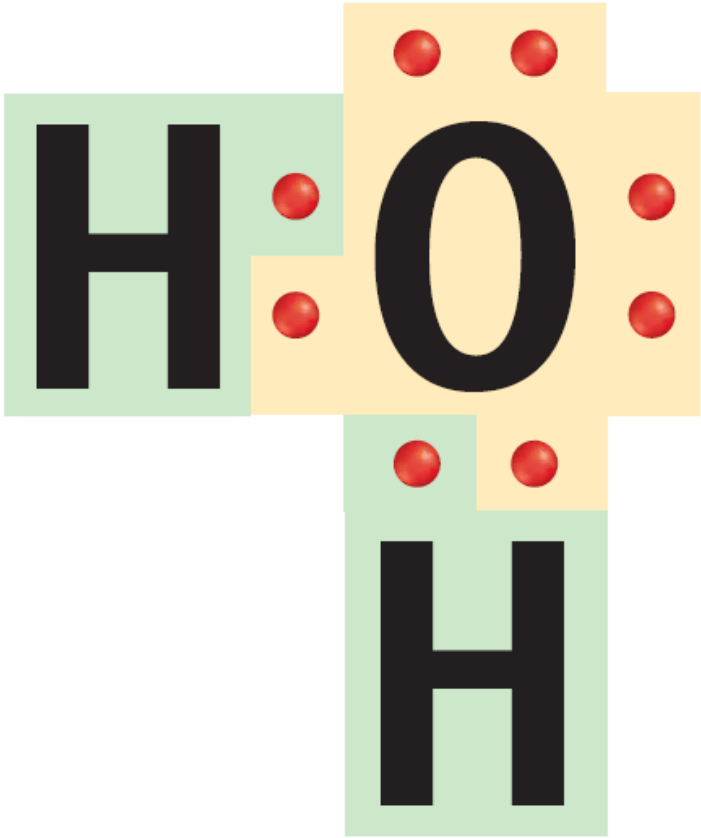
Types of Bonds

Sharing Electrons

- The attraction that forms between atoms when they share electrons is known as a **covalent bond**.
- A neutral particle that forms as a result of electron sharing is called a **molecule**.



Types of Bonds

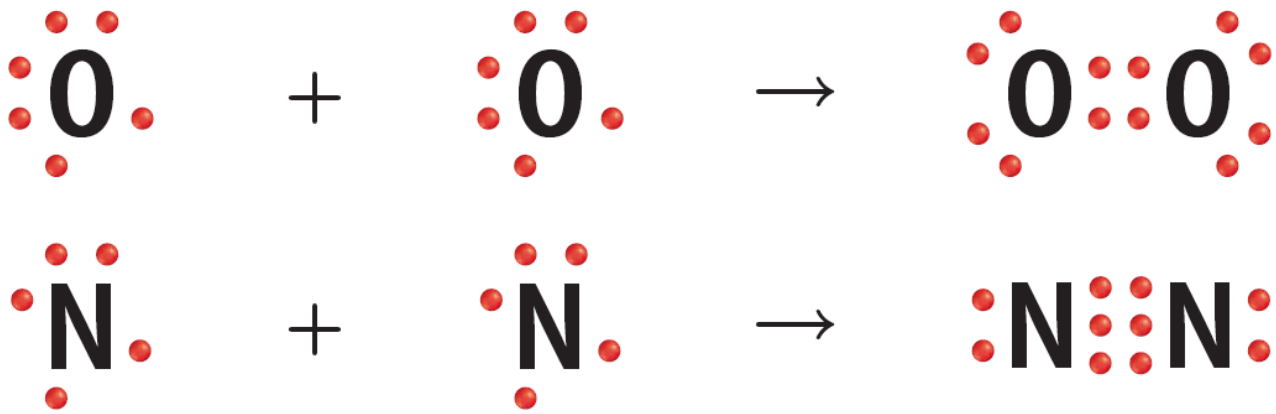
Single Covalent Bonds

- A single covalent bond is made up of two shared electrons.
- A water molecule contains two single bonds. In each bond, a hydrogen atom contributes one electron to the bond and the oxygen atom contributes the other.
- The result of this type of bonding is a stable outer energy level for each atom in the molecule.

Types of Bonds

Multiple Bonds

- A covalent bond also can contain more than one pair of electrons.
- An example of this is the bond in oxygen (O_2) or nitrogen (N_2).



Types of Bonds

Multiple Bonds

- A nitrogen atom has five electrons in its outer energy level and needs to gain three electrons to become stable.
- It does this by sharing its three electrons with another nitrogen atom.

Types of Bonds

Multiple Bonds

- When each atom contributes three electrons to the bond, the bond contains six electrons, or three pairs of electrons.
- Each pair of electrons represents a bond.
- Therefore, three pairs of electrons represent three bonds, or a triple bond.

Types of Bonds

Unequal Sharing

- Electrons are not always shared equally between atoms in a covalent bond.
- These elements are close together in the upper right-hand corner of the periodic table. The strength of the attraction of each atom to its electrons is related to the size of the atom, the charge of the nucleus, and the total number of electrons the atom contains.

Types of Bonds

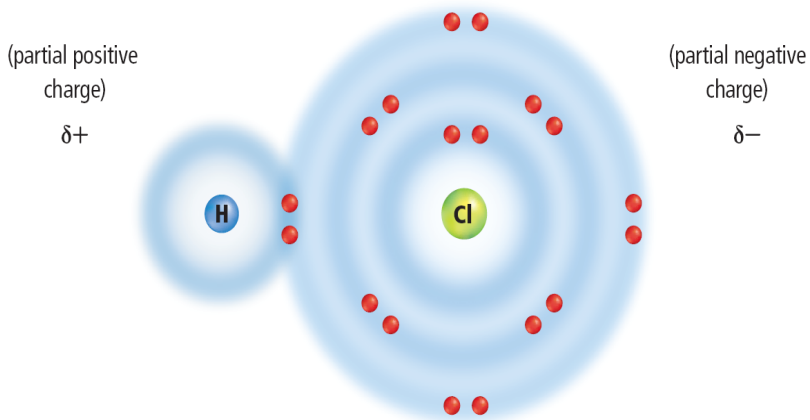
Unequal Sharing

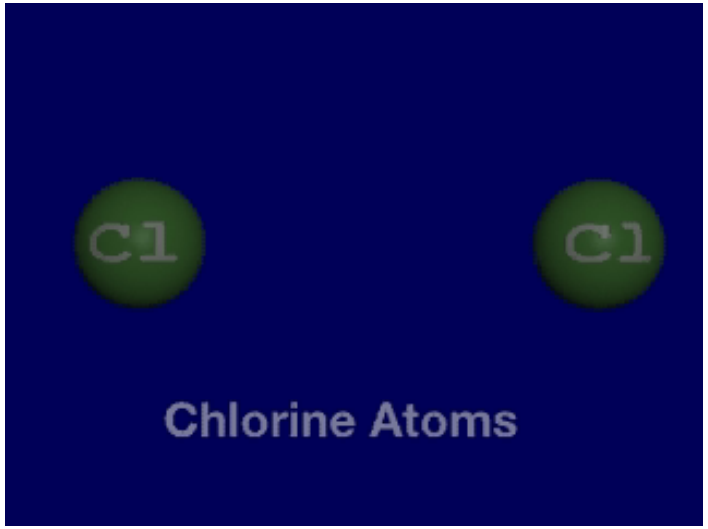
- Part of the strength of attraction has to do with how far away from the nucleus the electron being shared is.
- The other part of the strength of attraction has to do with the size of the positive charge in the nucleus.

Types of Bonds

Unequal Sharing

- One example of this unequal sharing is found in a molecule of hydrogen chloride, HCl.





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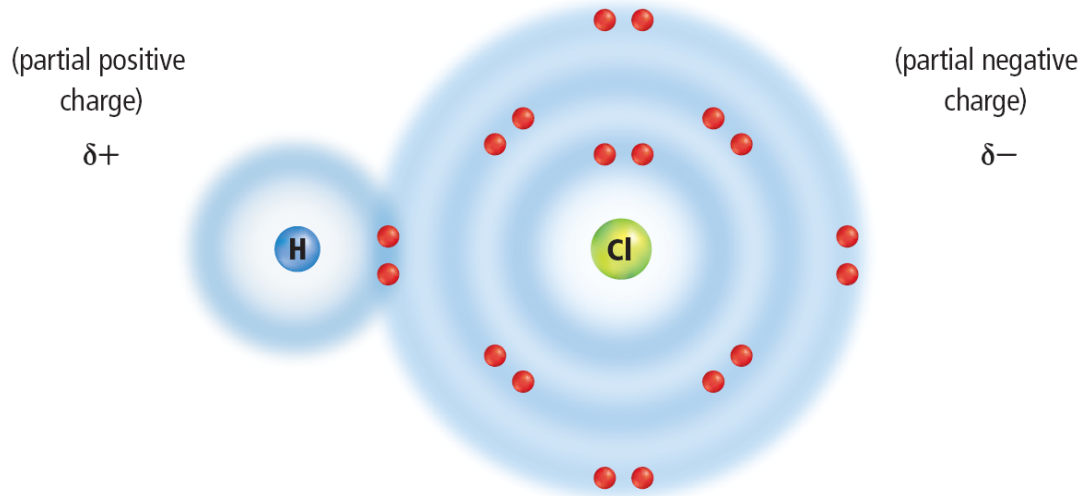
- Chlorine atoms have a stronger attraction for electrons than hydrogen atoms do.

Types of Bonds

Unequal Sharing

- As a result, the electrons shared in hydrogen chloride will spend more time near the chlorine atom than near the hydrogen atom.



Types of Bonds

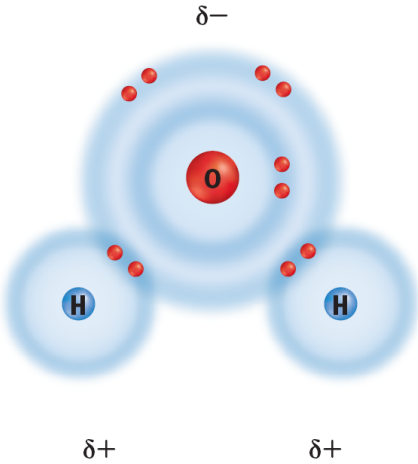
Tug-of-War

- You might think of the bond as the rope in a tug-of-war and the shared electrons as the knot in the center of the rope.
- Each atom in the molecule attracts the electrons that they share. However, sometimes the atoms aren't the same size.

Types of Bonds

Polar or Nonpolar?

- The charge is balanced but not equally distributed. This type of molecule is called **polar bond**.
- A **polar molecule** is one that has a slightly positive end and a slightly negative end although the overall molecule is neutral. Water is an example of a polar molecule.



H_2O
Water

Types of Bonds

Polar or Nonpolar?

- A **nonpolar molecule** is one in which electrons are shared equally in bonds.
- Such a molecule does not have oppositely charged ends.
- This is true of molecules made from two identical atoms or molecules that are symmetric, such as CCl_4.

Writing Formulas and Naming Compounds

Binary Ionic Compounds

- The first formulas of compounds you will write are for binary ionic compounds.
- A **binary compound** is one that is composed of two elements.
- Before you can write a formula, you must have all the needed information at your fingertips.

Binary Ionic Compounds

- You need to know which elements are involved and what number of electrons they lose, gain, or share in order to become stable.
- The relationship between an element's position on the periodic table and the number of electrons it gains or loses is called the **oxidation number** of an element.

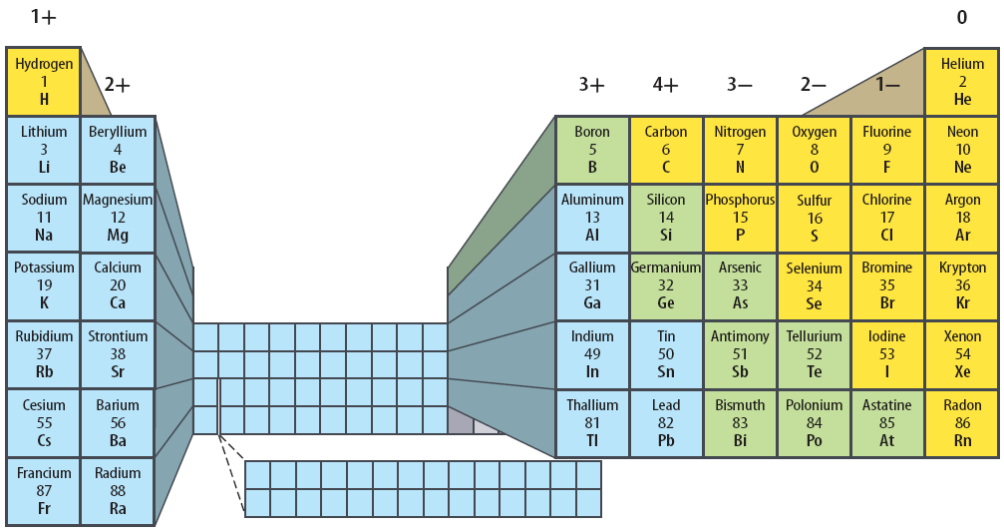
Binary Ionic Compounds

- An oxidation number tells you how many electrons an atom has gained, or shared, to become stable.
- For ionic compounds, the oxidation number is the same as the charge on the ion.
- For example, a sodium ion has a charge of 1+ and an oxidation number of 1+.

Writing Formulas and Naming Compounds

Oxidation Numbers

- The number at the top of each column is the most common oxidation number of elements in that group.



Writing Formulas and Naming Compounds

Oxidation Numbers

- The elements in this table can have more than one oxidation number.
- When naming these compounds, the oxidation number is expressed in the name with a roman numeral. For example, the oxidation number of iron in iron (III) oxide is 3+.

Table 2 Special Ions

Ion Name	Oxidation Number
Copper(I)	1+
Copper(II)	2+
Iron(II)	2+
Iron(III)	3+
Chromium(II)	2+
Chromium(III)	3+
Lead(II)	2+
Lead(IV)	4+

Compounds Are Neutral

- When writing formulas, it is important to remember that although the individual ions in a compound carry charges, the compound itself is neutral.
- A formula must have the right number of positive ions and the right number of negative ions so the charges balance.

Compounds Are Neutral

- What if you have a compound like calcium fluoride?
- A calcium ion has a charge of 2+ and a fluoride ion has a charge of 1 −.
- In this case you need to have two fluoride ions for every calcium ion in order for the charges to cancel and the compound to be neutral with the formula CaF_2.

Writing Formulas

- You can write formulas for ionic compounds by using the following rules in this order.
  1. Write the symbol of the element or polyatomic ion (ions containing more than one atom) that has the positive oxidation number or charge.

Writing Formulas

2. Write the symbol of the element or polyatomic ion with the negative oxidation number.
3. The charge (without the sign) of one ion becomes the subscript of the other ion. Reduce the subscripts to the smallest whole numbers that retain the ratio of ions.

Writing Names

- You can name a binary ionic compound from its formula by using these rules.

  1. Write the name of the positive ion.

Writing Formulas and Naming Compounds

Writing Names

2. Check to see if the positive ion is capable of forming more than one oxidation number. If it is, determine the oxidation number of the ion from the formula of the compound.

Table 2 Special Ions

Ion Name	Oxidation Number
Copper(I)	1+
Copper(II)	2+
Iron(II)	2+
Iron(III)	3+
Chromium(II)	2+
Chromium(III)	3+
Lead(II)	2+
Lead(IV)	4+

Writing Formulas and Naming Compounds

Writing Names

2. (continued) Write the charge of the positive ion using roman numerals in parentheses after the ion's name. If the ion has only one possible oxidation number, proceed to step 3.

Table 2 Special Ions

Ion Name	Oxidation Number
Copper(I)	1+
Copper(II)	2+
Iron(II)	2+
Iron(III)	3+
Chromium(II)	2+
Chromium(III)	3+
Lead(II)	2+
Lead(IV)	4+

Writing Formulas and Naming Compounds

Writing Names

3. Write the root name of the negative ion. The root is the first part of the element's name.
4. Add the ending -*ide* to the root. The table lists several elements and their -*ide* counterparts.

Table 3 Elements in Binary Compounds

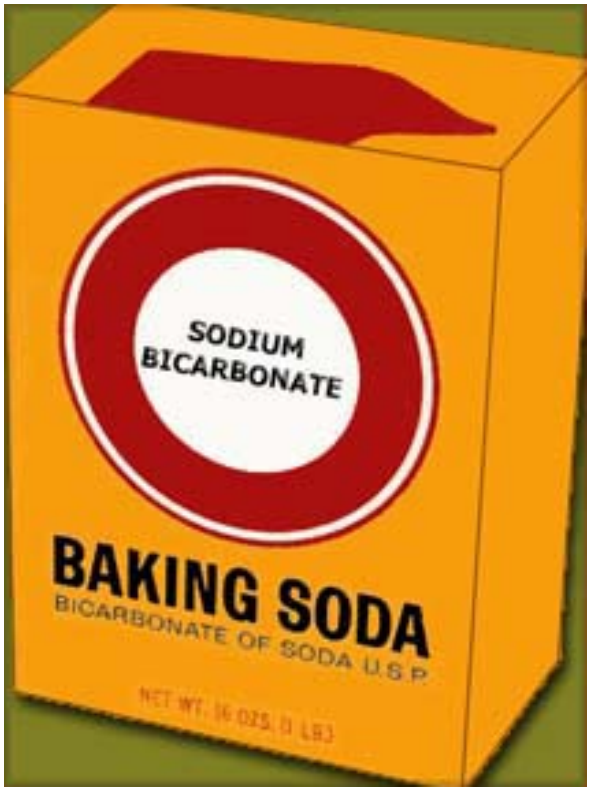
Element	–*ide* Name
Oxygen	oxide
Phosphorus	phosphide
Nitrogen	nitride
Sulfur	sulfide

Writing Names

- Subscripts do not become part of the name for ionic compounds.
- However, subscripts can be used to help determine the charges of those metals that have more than one positive charge

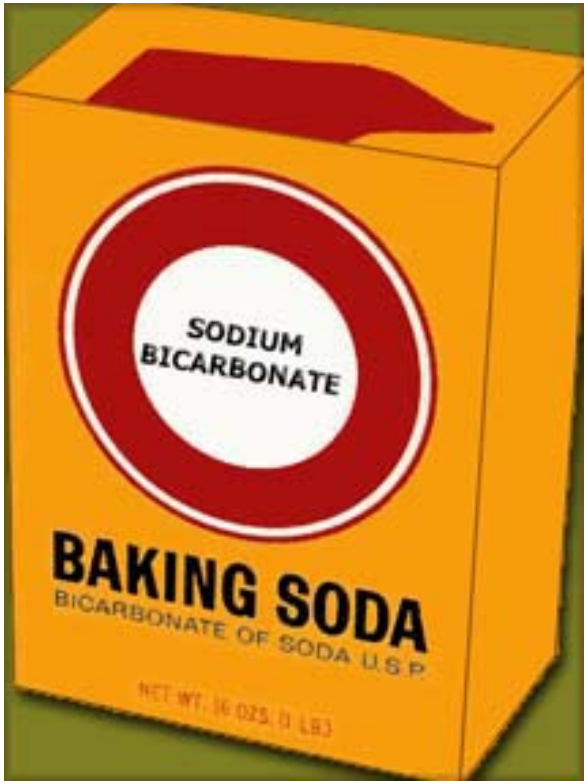
Compounds with Complex Ions

- Not all ionic compounds are binary.
- Baking soda has the formula $NaHCO_3$.
- This is an example of an ionic compound that is not binary.



Compounds with Complex Ions

- Some ionic compounds, including baking soda, are composed of more than two elements. They contain polyatomic ions.



Compounds with Complex Ions

- A **polyatomic ion** is a positively or negatively charged, covalently bonded group of atoms.
- So the polyatomic ions as a whole contain two or more elements.

Writing Formulas and Naming Compounds

Writing Names

- The table lists several polyatomic ions.
- To name a compound that contains one of these ions, first write the name of the positive ion.
- Then write the name of the negative ion.

Table 4 Polyatomic Ions

Charge	Name	Formula
1+	ammonium	NH_4^-
1–	acetate chlorate hydroxide nitrate	$C_2H_3O_2^-$ ClO_3^- OH^- NO_3^-
2–	carbonate sulfate	CO_3^{2-} SO_4^{2-}
3–	phosphate	PO_4^{3-}

Writing Formulas

- To write formulas for these compounds, follow the rules for binary compounds, with one addition.
- When more than one polyatomic ion is needed, write parentheses around the polyatomic ion before adding the subscript.

Writing Formulas and Naming Compounds

Writing Formulas

- Here is one example of naming a complex compound.

Table 5 Naming Complex Compounds

To write the chemical formula for ammonium phosphate, answer these questions:
1. What is the positive ion and its charge? The positive ion is NH_4^+, and its charge is 1+.
2. What is the negative ion, and what is its charge? The negative ion is PO_4^{3-}, and its charge is 3–.
3. How can the charges be balanced in order to make the compound neutral? Three NH_4^+ ions (3+) balances one PO_4^{3-} (3–) ion. Add parentheses for subscripts greater than one. The chemical formula for ammonium nitrate is $(NH_4)_3PO_4$.

Compounds with Added Water

- Some ionic compounds have water molecules as part of their structure. These compounds are called hydrates.
- A **hydrate** is a compound that has water chemically attached to its ions and written into its chemical formula.

Common Hydrates

- When a solution of cobalt chloride evaporates, pink crystals that contain six water molecules for each unit of cobalt chloride are formed.
- The formula for this compound is $CoCl_2 \cdot 6\ H_2O$.

Common Hydrates

- Plaster of paris also forms a hydrate when water is added.
- It becomes calcium sulfate dihydrate, which is also known as gypsum.

Common Hydrates

- When writing a formula that contains a hydrate, the number of water molecules is shown after a "·". Following the number 2 is the formula for water as shown.

$$CaSO_4 \cdot 2\ H_2O$$

Naming Binary Covalent Compounds

- Covalent compounds are those formed between elements that are nonmetals.
- Some pairs of nonmetals can form more than one compound with each other.
- In the system you have learned so far, N_2O, NO, NO_2, and N_2O_5 would be called nitrogen oxide. You would not know from that name what the composition of the compound is.

Using Prefixes

- Scientists use Greek prefixes to indicate how many atoms of each element are in a binary covalent compound.
- Notice that the last vowel of the prefix is dropped when the second element begins with a vowel as in pentoxide.

Table 6 Prefixes for Covalent Compounds

Number of Atoms	Prefix	Example
1	mono-	carbon monoxide
2	di-	sulfur dioxide
3	tri-	phosphorous trichloride
4	tetra-	carbon tetrachloride
5	penta-	dinitrogen pentoxide
6	hexa-	uranium hexafluoride
7	hepta-	dichlorine heptoxide
8	octa-	xenon octaflouride

Using Prefixes

- Often the prefix *mono-* is omitted, although it is used for emphasis in some cases.

Table 6 Prefixes for Covalent Compounds

Number of Atoms	Prefix	Example
1	mono-	carbon monoxide
2	di-	sulfur dioxide
3	tri-	phosphorous trichloride
4	tetra-	carbon tetrachloride
5	penta-	dinitrogen pentoxide
6	hexa-	uranium hexafluoride
7	hepta-	dichlorine heptoxide
8	octa-	xenon octaflouride

Using Prefixes

- These same prefixes are used when naming the hydrates previously discussed.
- The main ionic compound is named the regular way, but the number of water molecules in the hydrate is indicated by the Greek prefix.