Basics 3: Bonding & Naming

Bonding

As noted earlier, there are three kinds of chemical bonds:

ionic–these bonds form between ions, and usually bond a metallic element to a nonmetallic one;
covalent--these bonds form between atoms which have not become ions and usually occur between nonmetals
metallic---these form between atoms of metals

In an ionic bond, a metal atom completely transfers an electron (or 2, or 3) to another atom or group of atoms. The metal atom then becomes a positive ion. The atom (or group of atoms) to which the electron is transferred becomes negatively charged. The positive and negative ions then attract each other, forming an ionic compound. We showed a simplified version of this a few pages back in the context of a discussion of sodium chloride:

You can look upon this as sort of like a whale being harpooned...the sodium shoots out an electron to the chlorine atom, and then the harpooned whale (the chloride ion), is reeled in due to the electronic attraction between the two ions.

In a covalent bond, electrons are shared as opposed to transferred...they are handed back and forth between the atoms that are sharing them, and this causes the atoms to attract each other and form a molecule. I realize that this doesn't sound too convincing just yet...but be patient...covalent bonding is a little tougher to understand than ionic bonding and we are only giving you some of the facts so far.

In metallic bonding, the electrons act like a kind of oatmeal, in which the nuclei (the raisins) float. This kind of bonding is the reason that metals conduct electricity so readily, but it will not concern us after this.

Ions

We have mentioned ions in passing on several occasions and should now try to address in detail of what precisely we are talking about. Ions are--we have said this before--atoms or groups of atoms that have an imbalance between the number of protons they contain, and the number of electrons they contain. If there are more electrons than protons, the ions are negatively charge. If there are more protons than electrons, the ions are positively charged.

Positive and negative ions attract each other, and form ionic compounds. We refer to this electronic attraction as the ionic bond.

The basis for the formation of ionic compounds is the principle of charge neutrality. Let us examine this principle in light of a few examples.

sodium chloride
calcium chloride
potassium oxide
iron (II) chloride
iron (III) chloride

The sodium ion has a charge of +1 and the chloride ion has a charge of -1. When a sodium and chloride combine, there is a net charge of zero and so the correct formula for this compound is:

$$NaCl$$

On the other hand, calcium has a charge of +2 and chloride (still) has a -1 charge. So you need two chloride ions to balance out the charge in one calcium ion. So the correct formula for calcium chloride is:

$$CaCl_2$$

No law requires the positive ion to have the bigger charge. In potassium oxide, the potassium has a charge of +1 and the oxide ion a charge of −2. Therefore you need two potassiums for each oxygen and the compound formula is:

$$K_2O$$

Likewise the formulas for iron (II) chloride and iron (III) chloride are, respectively:

$$FeCl_2 \text{ and } FeCl_3$$

Remember that the roman numerals in the parentheses simply tell us the charge on the metal ion. Try out your technique with the following compounds:

Iron (II) phosphate

barium sulfate

sodium sulfate

ammonium carbonate

rubidium iodide

Important note: To perform the above problems you will also need to review the idea of polyatomic ions. Remember that we said that ions can consist of charged atoms or charged groups of atoms. A charged group of atoms is called a polyatomic ion. In a compound, a polyatomic ion acts like a single entity. This means that we count the charge in the same way we count the charge on a monatomic ion. Some important polyatomic ions are shown below:

1) Anions

Acetate	CH_3COO^-	-1
Carbonate	CO_3^{2-}	-2
Halide (chloride, bromide, etc.)	Cl^-, Br^-, etc.	-1
Hydroxide	OH^-	-1
Nitrate	NO_3^-	-1
Phosphate	PO_4^{3-}	-3
Sulfate	SO_4^{2-}	-2

2) Cations

Ammonium	NH_4^+	+1
Alkali metals	Na^+, K^+, etc.	+1
Alkaline earth metals	Mg^{2+}, Ca^{2+}, etc.	+2
Aluminum	Al^{3+}	+3

Answers

Here are the answers. I included the table from the previous page to help you figure out why they are right.

Iron (II) phosphate	$Fe_3(PO_4)_2$
barium sulfate	$BaSO_4$
sodium sulfate	Na_2SO_4
ammonium carbonate	$(NH_4)_2CO_3$
rubidium iodide	RbI

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Covalent

Covalent compounds consist of atoms bonded together with covalent bonds. Covalent compounds can exist as conventional molecules, as polymers, or as covalently bonded network solids. Some elements occur naturally in the form of covalently bonded compounds.

In an ionic bond there is a transfer of one or more electrons between the entities that form that bond. Ionic compounds almost always occur either between metals and nonmetals, or between metals and polyatomic ions. One important exception to this is the positive ammonium ion, which, because of its positive charge, acts just as if it were a positive ion.

Covalent bonds are more complicated. They only occur between nonmetal atoms. The bonds are formed (as is the case with all bonds) by electrons. But the electrons don't jump from atom to atom. Instead they leave their parent atoms part of the time, and hang out between them. While they are "hanging out" the parents are each left with a positive charge. Each parent atom is pulled towards the electrons in between them (still another case of positives and negatives attracting each other). This is the covalent bond. You have probably heard it said that, in an ionic bond, there is a complete transfer of electrons, but in a covalent bond the electrons are shared. Hopefully, this explanation explains what is meant by sharing.

Let's examine some covalently bonded molecules. What you will see in each case is that these are compounds consisting of nonmetals.

Elemental fluorine does not come as separate atoms but as a diatomic fluorine molecule.

$$F_2$$

Water is a famous covalently bonded molecule. If you have never heard of its formula, then what planet are you from?

$$H_2O$$

Methane is street gas (the gas we get from the gas company). We've seen it before:

$$CH_4$$

Sulfur dioxide is a major air pollutant...like most sulfur compounds it smells bad.

$$SO_2$$

Silicon dioxide is a network solid. It is the formula for quarts, a very pure and crystalline kind of glass.

$$SiO_2$$

Elemental carbon comes in a variety of forms. One of them is graphite and one of them is carbon. Both are very different beasts, having very distinct structures and very different properties. But both are network solids. When the same element is encountered in different forms, it is said that these forms are **allotropes.** Another example of allotropes are diatomic oxygen (often simply referred to as oxygen) and ozone:

oxygen -- O_2

ozone -- O_3

Covalent: How Many Bonds?

The question that probably is in your mind after looking at the last page is "How do you figure out how many atoms go together?" The ionic bond seems pretty straightforward, but there doesn't seem to be any rules for covalent compounds.

Well in fact there are, but they are a bit more complicate. One starting point that covers most situations is to simply memorize the characteristic number of bonds for a few important atoms. You still won't be right in every case, but you will in most cases, and the exceptions you will learn as you continue your study of chemistry.

Number of Bonds

Carbon	4
Nitrogen	3
Oxygen	2
Sulfur	2
Halogens	1
Hydrogen	1

Considering this table, if I tell you that ammonia is a compound consisting of nitrogen and hydrogen, you might reason as follows: since hydrogen forms only one bond but nitrogen forms three, a compound with one nitrogen atom bonded to three hydrogen atoms should fit. And indeed that is the answer:

$$NH_3$$

If I asked you to predict a compound between carbon and oxygen, you would, I hope, see that, since carbon can form four bonds, and oxygen 2, then a compound in which carbon was doubly bonded to each of two oxygens should work. It does, and this compound is called carbon dioxide.

$$CO_2$$

Now the fact that there is also a compound called carbon monoxide, which does not follow these rules , should not disturb you. This is the 20% I told you not to fret about.

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Try these out:

What is the formula of the compound formed from fluorine and hydrogen?

Formaldehyde has one carbon atom, one oxygen atom and the rest hydrogen atoms. What is its formula?

There is a kind of cleaning fluid (its so toxic they don't use it anymore) that contains a single carbon atom and some chlorine atoms. What is its chemical formula?

See the next section for answers

Covalent Answers

Here are the answers. I left the table here too for your convenience.

Number of Bonds	
Carbon	4
Nitrogen	3
Oxygen	2
Sulfur	2
Halogens	1
Hydrogen	1

What is the formula of the compound formed from fluorine and hydrogen?

$$HF$$

Formaldehyde has one carbon atom, one oxygen atom, and the rest hydrogen atoms. What is its formula?

$$CH_2O$$

There is a kind of cleaning fluid (its so toxic they don't use it anymore) that contains a single carbon atom and some chlorine atoms. What is its chemical formula?

$$CCl_4$$

Summing Up

Let's go all the way back to the basics. I am talking about the idea of there being two kinds of pure substances, elements and compounds.

As you can see now, the concept of atoms and molecules clears up a lot of the confusion associated with these ideas. The idea is that elements only have one kind of atom, each kind of atom being defined by its atomic number (but not its mass number). Compounds are composed of combinations of elements called molecules.

But be careful..don't be careless or imprecise in your thinking...we have seen, for example, that some kind of compounds have no definable molecules...we get around this by referring to them as "macromolecular compounds".

But be careful too on the other end. Just because you have a molecule, does not mean that you have a compound. The molecule must consist of at least 2 elements if it is to be called a compound. This implies that elements can form molecules all by themselves, and this in fact happens as we have seen.

So let's close with some questions:

Can an element form molecules all by itself? The answer is yes. Many molecules, particularly gaseous ones, are diatomic. Hydrogen, oxygen, nitrogen and all the halogens prefer this configuration. Some gaseous elements are monatomic (1 atom)--these are the inert gases, helium, neon, argon, krypton, xenon and radon.

There are also examples of elements which come in polyatomic form with 3, 4, 8, or even 60 atoms covalently bonded to one another.

Can an element form network solids? Again the answer is yes. Graphite and diamond, as well as elemental silicon are answers that we have seen.

Can an element form ionic compounds with itself? Here the answer is an absolute and unequivocal no. For there to be an ionic compound, an electron must be transferred from one atom to another. There has to be some reason for this transfer, usually because one of the elements has a higher affinity for electrons than does the other. Since all the atoms of an element are similar, there is no conceivable reason for such a transfer to take place and so we never see ionic bonding between atoms of the same element.

Ionic or covalent

Before you name a compound, you should decide if it is ionic or covalent. This is comparatively easy. If a compound contains ionic bonds, it is ionic. A compound will usually contain ionic bonds if it contains a metal and a nonmetal. Compounds containing the positively charge ammonium ions are also ionic. The ionic bond can occur between a metal ion and one or more monatomic negative ions, or with one or more polyatomic ions. The polyatomic ion contains covalent bonds within the ion between the various nonmetal atoms that make it up, but the ionic bond between it and a metal ion is what makes the compound ionic.

When the compound contains solely nonmetals (including the metalloids), all the bonds are covalent and the compound is said to be covalent.

Iron (II) phosphate	$Fe_3(PO_4)_2$
ammonia	NH_3
hydrogen sulfide	H_2S
barium sulfate	BaSO4
sodium sulfate	Na_2SO_4
ammonium carbonate	$(NH_4)_2CO_3$
diborane	B_2H_6
rubidium iodide	RbI
sulfuric acid	H_2SO_4
ammonium nitrate	NH_4NO_3
sodium hydroxide	NaOH

See the next section for answers to the practice questions.

Ionic or covalent Answers

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When the compound contains solely nonmetals (including the metalloids), all the bonds are covalent and the compound is said to be covalent.

The table below gives answers and reasons for the questions in the previous section.

Iron (II) phosphate	$Fe_3(PO_4)_2$	ionic	transition metal + polyatomic ion
ammonia	NH_3	covalent	all non metals--do not confuse with ammonium ion
hydrogen sulfide	H_2S	covalent	all non metals, similar to water
barium sulfate	BaSO4	ionic	metal + polyatomic ion
sodium sulfate	Na_2SO_4	ionic	metal + polyatomic ion
ammonium carbonate	$(NH_4)_2CO_3$	ionic	ammonium ion + polyatomic ion
diborane	B_2H_6	covalent	metalloid + nonmetal
rubidium iodide	RbI	ionic	metal + nonmetal
sulfuric acid	H_2SO_4	covalent	sulfate is a polyatomic ion, but the compound is still all nonmetals
ammonium nitrate	NH_4NO_3	ionic	Both the ammonium ion and the nitrate ion are polyatomic ions
sodium hydroxide	NaOH	ionic	metal plus polyatomic ion

Predicting Ionic Compounds

The Rules:

(A) Memorize a few important polyatomic ions.

(B) Use a periodic table to guess the charges on positive ions.
e.g. Na+ because sodium is in column 1.

Then scrupulously enforce charge balance.

For Positive ions, column 1 elements always have a +1 charge, column 2 have +2, and aluminum has +3.

For negative ions, start from the right hand column and move left. The inert gases do not ionize (charge 0), the halogens have -1 charge, and the oxygen group has a -2 charge (generally only S and O form negative ions. Nitrogen forms -3 ions, and occasionally phosphorous does so too.

Remember to always treat polyatomic ions as a group. The sulfate ion, SO_4^{2-}, always has a charge of -2. Don't go trying to reinvent the wheel by adding up charges of oxygen and sulfur--you will get it wrong. Those rules only work for monatomic ions, and not for polyatomic ions.

Examples:

Give the chemical formula and name for the ionic compounds formed from:

(1) aluminum and chlorine

(2) barium and the phosphate ion

(3) sodium and oxygen

(4) magnesium and sulfur

Please proceed to the next section for the solutions.

Predicting Ionic Compounds

Answers

(1) aluminum and chlorine $AlCl_3$

Aluminum has a charge of +3 and chlorine, a halogen, +1. The +3 charge of the aluminum ion must be balanced by three chloride ions, each with a charge of −1.

(2) barium and the phosphate ion $Ba_3(PO_4)_2$

Barium is in column 2 (it is an alkaline earth metal). This means it has a +2 ionic charge. The phosphate ion always has a charge of −3. Three barium ions bring a total of +6 charge to the compound. This is balanced by 2 phosphate ions , each with a −3 charge, bringing a total charge of −6, and exactly balancing the positive charge of the barium ions.

(3) sodium and oxygen Na_2O

The oxide ion has a −2 charge, and each sodium (column 1, alkali metal) has a +1 charge. The 2 sodium ions together contribute a total charge of +2 balancing the −2 of the oxide ion.

(4) magnesium and sulfur MgS

Sulfur resembles oxygen: the sulfide ion has a −2 charge. Magnesium (column 2) has a +2 charge. A 1:1 ratio balances the charge perfectly.

Identifying Ionic Compounds

Name to formula

This is a pretty easy, similar to what you did a page back. In this case, you can also figure out the formulas for transition metal compounds. This is because the name contains the charge of the metal ion. It is given as a roman numeral in parentheses in the name. The roman numerals are not included for alkali metals, alkaline earth metals, or aluminum, because it is assumed that everyone can figure these out from their location in the periodic table. In addition, transition metals don't always have the same charge in different compounds. For example, iron sometimes has a +2 charge, and other times has a +3 charge. The person who writes down the formula has to give you this information (via the roman numeral).

iron (III) sulfate $Fe_2(SO_4)_3$

strontium fluoride SrF_2

aluminum nitrate $Al(NO_3)_3$

Now you try!

1.) copper (II) oxide

2.) cesium chloride

3.) magnesium perchlorate

See the next section for the solutions.

Identifying Ionic Compounds

Name to Formula Answers

copper (II) oxide CuO

cesium chloride $CsCl$

magnesium perchlorate $Mg(ClO_4)_2$

Identifying Ionic Compounds

Formula to Name

Just use the name of the metal ion and the non metal ion.

For Transition Metals: You must state the charge as a roman numeral!

$FeCl_3$ Iron (III) Chloride

Cu_2O Copper (I) Oxide

$PbCl_2$ Lead (II) Chloride

You try it!

$AgCl$

$SnCl_4$

$FeSO_4$

See the next section for the answers.

Identifying Ionic Compounds

Formula to Name Answers

$AgCl$	Silver Chloride
$SnCl_4$	Tin (IV) Chloride
$FeSO_4$	Iron (II) Sulfate

Why not silver (I) chloride?

Beats me...everyone knows that silver only forms a +1 ion and so everyone writes it this way, even thought it contradicts the "rules".

Naming Covalent Compounds

Basically you use Greek prefixes to denote the number of atoms.

di	2
tri	3
tetra	4
penta	5
hexa	6

Etc.

CS_2 carbon disulfide

CF_4 carbon tetrafluoride

HCl hydrogen chloride

Now you try!

1. P_2O_5
2. CO
3. CCl_4
4. H_2O

See the next section for the solutions.

Naming Covalent Compounds: Answers

P_2O_5	Diphosphorous pentoxide (you will usually see it written as phosphorous pentoxide).
CO	carbon monoxide
CCl_4	carbon tetrachloride
H_2O	Dihydrogen monoxide? Nobody ever calls it that...it is just plain old water. Water is an example of a "trivial name" and there are some you just must know.

More examples of compounds with trivial names

NH_3	ammonia
CH_4	methane