Chapter 6

Chemical Bonding

This mother and child are shown bonding in this picture taken like a million years ago.

6.1: Ionic Bonds

In isolation, atoms just sort of loaf around. However, if you put a couple of atoms near one another, they'll usually react. The reason for this is something called the **octet rule**, which states that *all elements want to have the same number of outer electrons as the nearest noble gas*. To figure out what this means, let's take a look back at part of the periodic table:

1 **H** 1.01																	2 **He** 4.00
3 **Li** 6.94	4 **Be** 9.01											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.87	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.63	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80

In this figure, you can see the noble gases in the right column, with various other elements stuck in other places on the table.

Now, if you'll recall, the noble gases are really, really stable and don't react with much. The reason for this is that they have filled shells of outer electrons. This makes them very stable, and makes all other elements want to have the same number of outer electrons. Chemists call these outer electrons **valence electrons**.

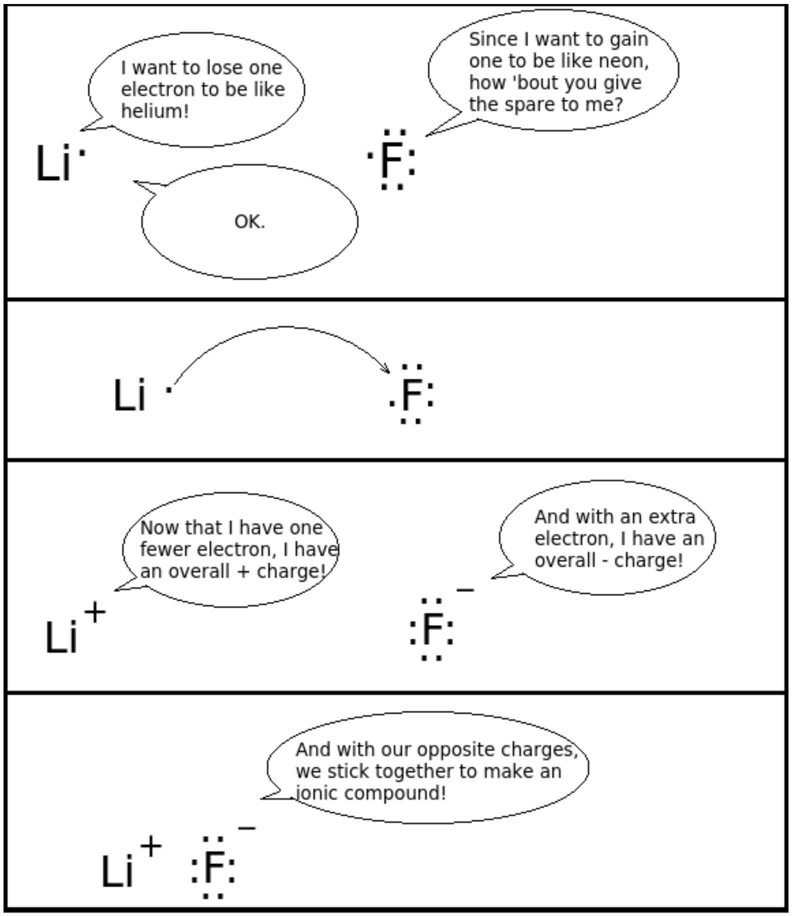
To see how this works, let's consider the case of lithium (Li). Lithium has one more electron than helium and seven less than neon. As a result, it can either lose one electron to have the same number of valence electrons as helium or gain seven to have the same number as neon. If you guessed that it will lose one electron to be like helium, give yourself a gold star!

Likewise, nitrogen has five more electrons than helium and three less than neon. If you guessed that nitrogen would rather gain three valence electrons than lose five, give yourself another gold star!

Chemical bonding occurs when the outer electrons of the elements arrange themselves such that all elements have the right number of electrons. There are a number of ways this happens, which is why we have a whole chapter devoted to it.

How Does Ionic Bonding Work?

Ionic bonding occurs when an element that wants to give up electrons hands them over to an element that wants to gain electrons. For example, let's consider the case of lithium and fluorine. Lithium, as you can see in the table above, can either lose one electron or gain seven, so it loses one. Fluorine can either gain one electron or lose seven, so it gains one. Since lithium wants to lose one electron and fluorine wants an electron, lithium gives fluorine its spare electron, as seen in the awesome diagram on the next page.



You'd be surprised at how much time I spent making this cartoon.

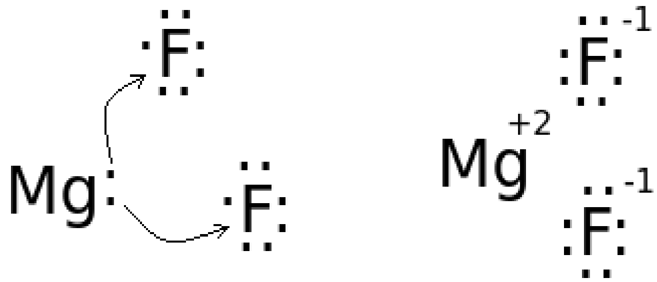
This can be summed up by saying that *ionic bonding is when an electron*[1] *transfers from one atom to another, giving both of them charges and allowing them to stick together.*

Some handy things you should probably know:

- **Ions** are atoms or groups of atoms with either positive or negative charge. **Cations** are ions with positive charge, and **anions** are ions with negative charge.
- The attraction between the ions in an ionic bond comes from the fact that opposite charges attract one another. The same principle explains why the + pole of one magnet is attracted to the – pole of another.[2]
- Every ion needs a **counterion** (i.e. an ion with another charge) somewhere nearby to be stable. You can't just put a bunch of positive ions together in a bottle because they'll all repel each other.

1 *It can actually be more than one electron, as we'll see in a second.*
2 *It's more precise to call this attraction an electrostatic force. This is different from the attraction you see in magnets because ions don't have both a + and – pole, instead having only one charge.*

The similar principle works in the formation of all ionic compounds. For example, magnesium (Mg) wants to either lose two electrons to be like neon or gain six electrons to be like argon – not surprisingly, losing two electrons is preferred. Now, let's say that a bunch of fluorine atoms wander by. As we mentioned in the earlier example, they want to either gain one electron or lose seven, and gaining one is vastly preferred. Because magnesium wants to lose two electrons and fluorine wants to gain one electron, then magnesium will give one electron to one fluorine atom and the second electron to another fluorine atom. This causes magnesium to have an overall charge of +2 and each fluorine ion to have a charge of -1. Since one +2 ion and two -1 ions result in neutral charge, everything is cool.



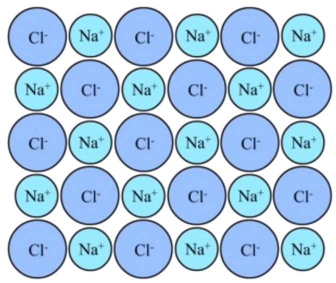
What Are The Properties Of Ionic Compounds?

To understand the properties of ionic compounds, let's imagine sticking a bunch of magnets in a box. If you've ever done this, you know that they'll clump together in a big difficult-to-separate hunk of magnets. If you've never done this, I'd recommend you give it a shot.

Though I'd recommend the magnets not be so terrifyingly huge.

Understanding that the ions in an ionic compound are all strongly attracted to their neighboring counterions is key to understanding their properties. Let's have a look at some of them:

- **Ionic compounds form crystals**: The idea here is simple: If you have positive and negative charges crammed together into a small space, the positive charges will all want to be surrounded by negative charges and the negative charges will all want to be surrounded by positive charges. As a result, we get a structure that looks like this:



Sodium chloride (NaCl), is an ionic compound. Note how every positive cation is separated by negative anions, and vice-versa.

On a large scale, this structure (called a **crystal lattice**) looks like what we normally think of when we think “crystal”:

Note that the sides of the crystals are all cubic, just as you'd expect from the picture with the blue ions above.

- **Ionic compounds are hard**: This one is easy to understand if you think about the alternating + and – structure we discussed. Imagine smacking somebody in the head with a big crystal. Either the ions will move and the crystal will effortlessly turn into powder, or the person getting whacked in the head will scream “ouch” as it fractures their skull. Clearly, the “ouch” outcome will be the one that actually occurs, because the + and – ions are so happy being surrounded by their buddies that they won't want to move away from each other. Which, among other reasons, is why you shouldn't hit people with a block of salt.[3]

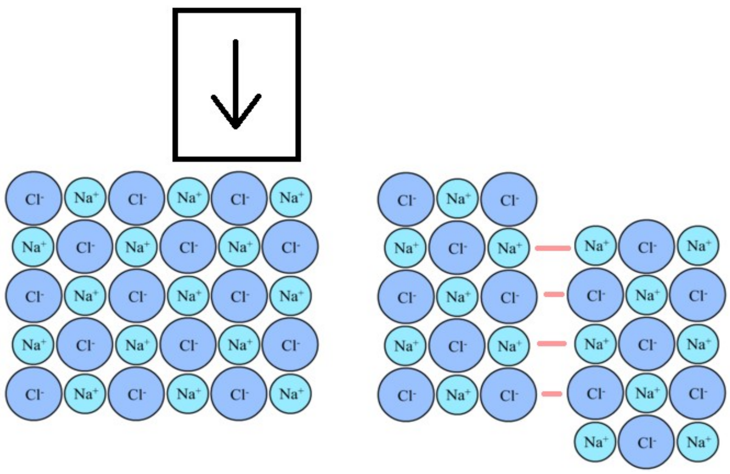
3 *This sentence fulfills my court-mandated community service for a salt-related crime I may or may have not committed in 2014.*

The Magic of Himalayan Salt Lamps

Some people believe that lamps made from salt originating in the Himalayas can produce beneficial ions that benefit the user. In fact, there are no actual ions generated from the use of these lamps (because cations and anions don't separate like that) and even if they did, there wouldn't be any particular health benefit. As a result, people who believe in the healing power of these lamps are morons.

Think of it as a stupid person detector.

- **Ionic compounds are brittle**: Remember how that diagram from the last page shows the cations and anions all nicely aligned with each other? Well, let's imagine that you are able to put enough energy into the crystal that they shift a little bit. Our nice +/- alignment now looks like this:



Since positively-charged sodium cations are now next to other positively-charged sodium atoms and negatively-charged chloride ions are now next to other negatively-charged chloride ions, the crystal is now highly unstable and shatters. Which is pretty much the definition of something brittle.

- **Ionic compounds have high melting and boiling points**: To explain this, we again go back to the strong attractions between anions and cations. In order for these ions to start moving around as a liquid or gas, all of the +/- interactions they experience would have to be overcome by adding energy to the ionic compound in the form of heat. This takes a lot of heat, so ionic compounds have melting and boiling points in the hundreds or thousands of degrees Celsius.

What's A Salt?

The term "salt" doesn't just refer to sodium chloride (NaCl). In fact, it's another way to refer to ionic compounds in general. To a chemist, we'd call sodium chloride "table salt" and just refer to other ionic compounds as "salts." In this way "Epsom salts" is a sodium sulfate compound and contains no sodium or chloride at all.[4]

This is a salt. But I wouldn't put it on my food if I were you.[5]

6.2: Covalent Compounds

Ionic compounds are formed when one element that wants to lose electrons gives electrons to something that wants to gain electrons. That makes sense, at least if you understood section 6.1. However, what happens when two elements that each want to gain electrons bump into each other?

The answer, as the subject of section 6.2 would suggest, is a covalent bond.

How Covalent Bonds Are Formed

Let's go back to the idea of the octet rule and figure out what would happen if two atoms of fluorine came into contact with each other. Each wants to gain one electron to be like neon, and since neither wants to lose electrons, this isn't going to happen.

Before moving on, let's take a quick step back and look at the word "octet." What number does it bring to mind? If you said "eight", you've probably heard the words "octopus" and "octagon."

As it turns out, all elements want to be like the nearest noble gas *because* noble gases all have stable numbers of outer electrons (which we chemists like to call **valence electrons**). And what's the magic number for stable valence electrons? Eight! As a result, if everything can get a filled outer shell by either gaining or losing electrons, there will be a total of eight outer electrons.

4 *It's actually slightly more complicated than that. "Salts", in strict terminology, are ionic compounds formed through the neutralization reaction between an acid and base. Even so, most ionic compounds can be formed by doing this, and the terms "salt" and "ionic compound" are often used interchangeably, if not technically correct.*

5 *Copper(II) sulfate, to be exact. It's used to kill bacteria and fungi, and isn't that good for people, either.*

If we look at the periodic table, we can very quickly figure out how many valence electrons each element has:

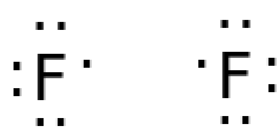
1	2	3	4	5	6	7	8
1 **H** 1.01							2 **He** 4.00
3 **Li** 6.94	4 **Be** 9.01	5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.31	13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.95

That's right: All you need to do is count across the periodic table and you're in good shape.[6]

To write the number of valence electrons of each element in pictorial form, we do so by drawing all of the valence electrons around the atom. For example, carbon has four valence electrons and fluorine has seven valence electrons, as seen here:

For reasons having to do with quantum mechanics[7], we like to make sure that we fill all of the spaces for electrons with one electron before we start pairing them up, which is why carbon looks the way it did in the diagram above and not like this:

In any case, let's say that we have two atoms of fluorine, as in the example I mentioned above:

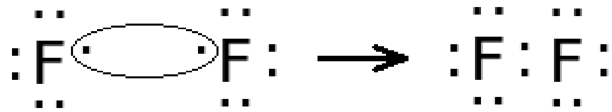


Again, one fluorine atom isn't going to gain one electron from the other, because the other would have fewer than it wanted in the first place. Transferring electrons just isn't going to happen.

6 *The exception to this is helium, which has only two electrons. Since both of them are in the outer shell, it has two valence electrons, too.*

7 *It's called Hund's rule, and does, indeed, have to do with quantum mechanics.*

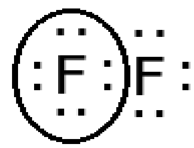
But what would happen if each fluorine atom decided to *share* electrons instead of transferring them? Because we scientists like making diagrams, let's make a diagram to see what it would look like:



In this diagram, we can see that the unpaired electrons on each fluorine pair up with one another so that the shared electrons are between both of the atoms.

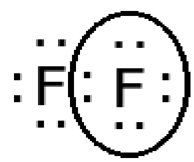
Now for the big question: Why would they want to pair up in the first place? I mean, sure, we *can* get them to be shared between the two atoms, but what benefit does this provide?

I'm glad you asked! When atoms look at how many valence electrons they have (and remember, the magic number is 8), they look at all of the electrons that are immediately adjacent to it. If you were to ask the fluorine on the left, it would look at all of the electrons immediately adjacent to it (including the shared electrons) and say "I've got eight!"



It believes that it owns the shared electrons, giving it a full octet.

Likewise, the fluorine atom on the right thinks it has eight valence electrons for exactly the same reason, which also gives it a full set of valence electrons:

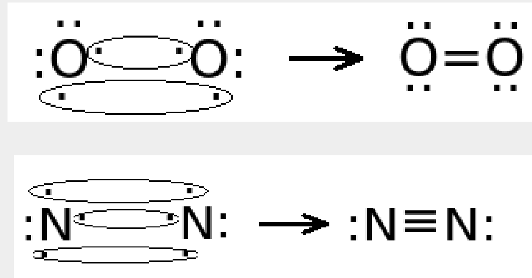


Covalent bonds occur when two electrons are shared between two atoms, both of which would rather gain than lose electrons:

This notation, where the two shared electrons are shown as a line rather than as two dots, is standard when writing the structures of covalent compounds, as it shows exactly which electrons are being shared.

The Magic Of Multiple Bonding

Sometimes we find that elements have more than one unpaired electron that needs to be shared. When this happens, we can get multiple covalent bonds, where several pairs of electrons are shared between the two atoms. One common example of this is in oxygen (O_2), in which two unpaired electrons on each atom pair up with each other to form a ***double bond****. Similarly, nitrogen (N_2) has a* ***triple bond*** *because three unpaired electrons on each atom pair up.*



Two oxygen atoms share two electrons each to form a double bond, and each nitrogen atom shares three electrons to make a triple bond.

Unequally-Shared Electrons and Polarity

So far, we've been pretending that every atom loves having electrons equally. And, in some cases, this is true. If we have two fluorine atoms bonding to each other, they'll both want the electrons equally and will share electrons equally. However, this is not always the case.

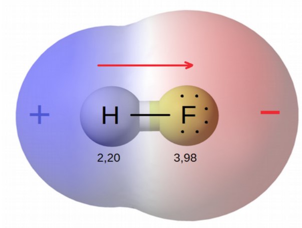
Let's say that you and your sister are both on a long car trip with your parents. During the last stop you used the bathroom, but your sister was asleep and stayed in the car. Now, imagine that you've driven a couple of hours since then and it's time for another gas stop. Both you and your sister have to use the bathroom enough that you demand to go first, but your sister has to use the bathroom bad enough that she gets to the bathroom before you. As a result, you'll both get what you want (i.e. to use the bathroom) but she'll use the toilet while you're stuck peeing in the sink.[8]

This example assumes that you are female and sharing a restroom with your sister. If you're male, imagine you have a brother, and you end up peeing in the trash can.

In the case of atoms, it turns out that elements that are closer to the right edge of the periodic tables want to grab electrons more than atoms that are further from the center of the periodic table. This "grabbiness" of electrons from other atoms is referred to as **electronegativity**. As a result, if you were to combine hydrogen with fluorine, you'd find that, while electrons are shared between the two atoms, the fluorine tends to pull on them more tightly. As a result, the fluorine atom has a little more of the bonding electrons, which causes it to have a little bit of negative charge. Likewise, the hydrogen atom has a little less of the bonding electrons, with

8 *Let's see if the mainstream textbook companies are awesome enough to use this example.*

gives it a slightly positive charge:

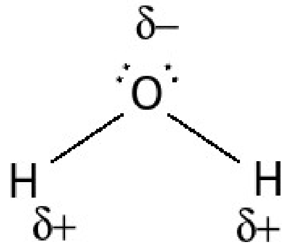


This diagram shows how the electrons are pulled toward fluorine, giving it a partial negative charge. Overall, you can see that the entire molecule looks a bit like a magnet as a result.

Polarity occurs when electrons are unequally shared. This can take two different forms:

- **Polar bonds** occur when two atoms with different electron "pulling power" have bonded to one another. This case is exactly the same as the one above, where one atom grabs electrons more than the other, giving it a partial negative charge and the other atom a partial positive charge.

- **Polar molecules** occur when one part of a molecule has collected more electrons than the other. For example, you already know that water contains two hydrogen atoms and one oxygen atom. Additionally, a quick glance at a periodic table can tell you that oxygen wants to grab electrons from hydrogen, which will give oxygen a partially negative charge and each hydrogen a partially-positive charge. This means that the side of the molecule with the oxygen atom on it will have a net partial-negative charge, while the side with the hydrogen atoms will have a net partially-positive charge:



The bottom of the water molecule is partially-positive due to the presence of partially-positive hydrogen atoms, while the bottom is partially-negative because oxygen has a partial negative charge.

Not surprisingly, if either a bond or a molecule don't have this unequal sharing of electrons, it's not polar. And if it's not polar, we just refer to it as either a **nonpolar bond** or **nonpolar molecule**, depending on whether it's a bond or a molecule.

Properties of Covalent Compounds

Remember how we said how the properties of ionic compounds are based mostly on how the ions all stack together into great big stable stacks? Well, the properties of covalent compounds are totally different than that.

The reason is that covalent compounds exist as **molecules**, or groups of atoms that have chemically-bonded to one another in order to become stable.[9] While the atoms in a molecule are very tightly-bound to one another via covalent bonding, atoms in adjacent molecules aren't particularly attracted to one another because they already have a filled valence shell.

To help us visualize the properties of covalent compounds, let's imagine that a chunk of covalent compound is like a bean bag chair full of those little Styrofoam spheres. In this example, the molecules in the bean bag chair aren't attracted to one another, but are just kind of wandering around in the same neighborhood.

- **Covalent compounds have low melting and boiling points**: In ionic compounds, the ions are all stuck together in a great big block and it takes lots of energy to break the covalent bonds and make them move apart. In covalent compounds, the only thing required to make the compound melt is to pull the molecules away from each other. Because no covalent bonds are broken when a covalent compound is melted, very little energy is required in this process.[10] The range of melting points for covalent compounds is varied, but tops out at about 250 °C, while the boiling points may be a hundred or so degrees higher than that.

- **Covalent compounds aren't hard or brittle**: Recall from a few pages back that ionic compounds are hard and brittle because the ions are all held tightly together. In covalent compounds, even solid ones, the molecules aren't held together this tightly, making them much easier to pull apart. Because of this, the hardnesses of covalent compounds is measured using entirely different methods than are used for the hardness of minerals.

I wouldn't, however, recommend you stab anybody with an icicle. They're not that *soft.*

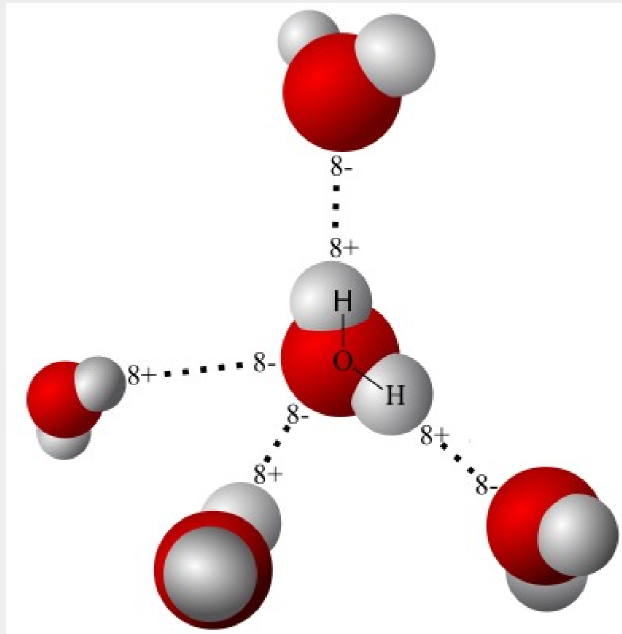
9 *Covalent compounds are sometimes referred to as "molecular compounds" for this reason.*

10 *By far the most common misconception that students have is that covalent compounds melt at lower temperatures than ionic compounds because covalent bonds are weaker than ionic bonds. This is not, in fact, the case. The reason this happens is that the process of melting is fundamentally different: Melting an ionic compound requires breaking bonds, while melting a covalent compound requires only that molecules be moved away from each other.*

- **Covalent compounds are frequently flammable**: The reason for this is simple – hydrogen and carbon are needed for things to burn, and hydrogen and carbon form only covalent bonds with one another. Though I'm not going to say that all covalent compounds are flammable, **organic compounds** (compounds that contain both carbon and hydrogen) usually are.

But What About All That Polar Stuff From Earlier?

If you think back to a couple of pages back, you'll recall that polar covalent compounds have molecules that behave like little magnets. You may be asking yourself, "Don't these stack up like the ions in ionic compounds and give polar covalent compounds different properties than other covalent compounds?"[11] Actually, they do. However, because covalent compounds contain only partial *positive and negative charges, the attraction between these polar molecules is nowhere near as strong as that between actual ions in ionic compounds. Consequently, polar covalent compounds tend to have higher melting and boiling points and be harder and more brittle than nonpolar covalent compounds, but still behave a lot more like nonpolar covalent compounds than ionic compounds.*



Water molecules arrange themselves so the partial positive and negative sides are aligned. This results in weak attractions (called intermolecular forces) between them.

6.3: Naming Chemical Compounds

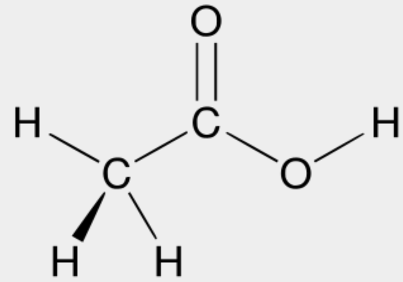
I'm going to be totally honest with you here: It's very boring to name chemical compounds. There's no little game you can play and no way you can memorize them all. If you want to name compounds and get a good grade in anything involving chemistry, you've just got to get over the pain and figure out how to do it.

This isn't to say that naming compounds is hard. It's not. It may not be an entertaining activity, but with a few minutes of study you can figure it out and move on to something more interesting.

11 *I'd actually be really surprised if you were wondering that right now.*

Who Comes Up With The Rules For Naming Compounds?

In 1919, the International Union of Pure and Applied Chemistry (IUPAC) was established to come up with standard methods of naming chemical elements and compounds. If you don't like naming things, blame them.



IUPAC calls this "ethanoic acid", but most of the cool kids still call it "acetic acid."

Naming Ionic Compounds

All ionic compounds have two word names. The first word is the name of the cation (the positively-charged ion) and the second is the name of the anion (the negatively-charged ion). As long as you remember that there are only two words, you should be in good shape.

Even better, the cation in the chemical compound is always the first thing in the formula, and except for NH_4^+, it's always a metal.[12] The anion is, you guessed it, the second thing in the formula, and always contains nonmetals. Pretty cool, huh?

So, let's try this out: Name the compound NaBr.

- Na is the element sodium, so the first word is "sodium."
- Br is the element bromine, so we call it the "bromide" ion. We use the -ide ending indicating it's an anion.
- Put 'em together, and you've got "sodium bromide."

Another example: What's the name of CaF_2?

- Ca is "calcium."
- F is "fluoride" (fluorine with the -ide ending).
- The compound, then, is "calcium fluoride."

Insane Scary Untrue Pseudoscience Fact

Sodium fluoride, a compound used to fluoridate water to improve dental health, is responsible for lulling you into a false sense of security so the government can oppress you. You see, the Nazis tried it first, and when it started showing up in drinking water as chemical waste, the government decided that this was the perfect time to start their evil plan. I read it here, so it must be true.

I'm back, I'm wearing a tinfoil hat, and I approve of this message.

12 *For our purposes anyway. By the time you see more complicated cations, you'll be much further along in your chemistry career and won't remember you ever read this book, so don't sweat it.*

Some compounds are slightly more complicated. For example, if you were to try and name the compound $NaNO_3$, you wouldn't be out of line to think that it's "sodium nitrogen oxide" or something like that. You'd be wrong, but if you said that, you're at least in the right ballpark.

However, there are three words in "sodium nitrogen oxide", so that doesn't really work according to the "two word name" rule at the top of the page. Anytime something violates this rule, it means we have a polyatomic ion.

Polyatomic ions are ions that contain more than one element. Almost all polyatomic ions are anions, with the exception of the NH_4^+ ion I mentioned above. Because you simply have to memorize their names, here's a list of the common polyatomic ions:

Ion Name	Ion Formula
acetate	CH_3COO^- or $C_2H_3O_2^-$
ammonium	NH_4^+
bicarbonate[13]	HCO_3^-
carbonate	CO_3^{-2}
cyanide	CN^-
hydroxide	OH^-
nitrate	NO_3^{-1}
phosphate	PO_4^{-3}
sulfate	SO_4^{-2}

Using this way of thinking, let's name Na_2CO_3:

- The Na part means the first word is "sodium."
- The CO_3 part looks like "carbon oxide", which isn't a thing. If an ion name is made up, look at the table and just write down whatever it says, which in this case is "carbonate."
- Put the names together and you've got "sodium carbonate."

Likewise, ZnO is "zinc oxide" (no need to use the chart above) and $Mg(CN)_2$ is "magnesium cyanide" (which does require the chart).

Writing Ionic Compound Formulas When Given The Name

It may be that somebody will one day ask you to write the formula for magnesium chloride. It's not likely, but you never know. If this happens, you'll want to give the person asking you a reasonable answer so they don't think you're a moron.

13 *This is sometimes referred to as the "hydrogen carbonate" ion. Which nobody actually does in the real world, so don't do it either.*

To do this, we need to go back to our friend, the periodic table. To be precise, this small version of it:

+1	+2	+3	N/A	-3	-2	-1	N/A
1 **H** 1.01							2 **He** 4.00
3 **Li** 6.94	4 **Be** 9.01	5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
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This periodic table will help you a lot if people want you to write ionic formulas. Let's find out what the formula of magnesium chloride is through its use:

- Magnesium has a charge of +2, as you can see by looking at the label on its family.

- Chloride has a charge of -1, as you can see by looking at its family's label.

- To find the formula, figure out what combination of +2 and -1 will equal zero. I'm going to go ahead and guess that you know that two things with a charge of -1 will cancel out one thing with a charge of +2. This means you've got two chlorides and one magnesium, with an overall formula of $MgCl_2$.

By this same reasoning, you can figure out the following examples:

- Aluminum nitride has a formula of AlN (Al has a charge of +3, N has a charge of -3, and one of each cancel each other out).

- Potassium oxide has a formula of K_2O (K has a charge of +1, O has a charge of -2, so it takes two K^+ ions to cancel out one O^{-2} ion).

- Lithium sulfate has a formula of Li_2SO_4. This one is only slightly more complicated than the rest, due to the presence of the sulfate ion. In this example, lithium has a charge of +1 (which is what the table tells you), and since sulfate isn't an element, you just look up the formula and charge on the table of ions from before SO_4^{-2}. Because Li has a charge of +1 and sulfate has a charge of -2, it takes two lithium ions to cancel out one sulfate ion).

But What About The Other Elements?

You may have noticed that the periodic table I reproduced on the last page only has the first three periods of elements on it. This is because once you get to the transition metals (the ones in the middle), things get a little weird. If your teacher gives you something like "Ca" to work with, just look at what column it would be in if I had included it on the table.

This astoundingly stupid cartoon character is the FDA's way of telling you whether there is calcium in your food.[14]

Formulas and Naming For Covalent Compounds

Covalent compounds have a lot less to remember when it comes to naming and formulas. There are no polyatomic ions and no tables of ions. In fact, the only thing you really have to remember is this chart (and you probably already know most of it):

Number	Prefix
1	mono-
2	di-
3	tri-
4	tetra-
5	penta-
6	hexa-

These prefixes are here to tell you how many atoms of each element are in a compound. I'll just jump into some examples to show you how to do this:

- P_2O_5 is called "diphosphorus pentoxide", which literally means "two phosphorus, five oxygen."
- N_2O_3 is "dinitrogen trioxide", which means "two nitrogen, three oxygen."

14 *There's actually a multimedia presentation starring Label Man at the FDA site (http://www.accessdata.fda.gov/videos/CFSAN/HWM/hwmintro.cfm). I'm not sure whether he's supposed to be a superhero or not, but he certainly isn't very dynamic for somebody who's saving the world.*

About the only thing you need to remember is that you only use the prefix “mono-” for oxygen, and even then *only* when it's the second element in the compound. For example:

- CO is “carbon monoxide”. Carbon doesn't have a prefix because it's not oxygen. Oxygen has a prefix because there's only one of them, *and* it's the second element in the compound.

- OF_2 is “oxygen difluoride.” Oxygen doesn't have a prefix because it's the first element in the formula, and “difluoride” simply refers to the two fluorine atoms.

Working backwards, if I told you to write the formula for “phosphorus pentafluoride”, you should know that there's only one phosphorus atom (there's no prefix) and there are five fluorine atoms (penta = 5) – this give us PF_5.

How Do I Know Whether To Name Something As An Ionic Or Covalent Compound?

If a compound contains a metal ion or the NH_4^+ ion, it's an ionic compound. If it doesn't, it's covalent. For example, CaI_2 is an ionic compound (Ca is a metal) so is named “calcium iodide.” If you had erroneously used the covalent method for naming, you would have called it “calcium diiodide”, which will make your teacher deeply, deeply disappointed.

6.4: Metals

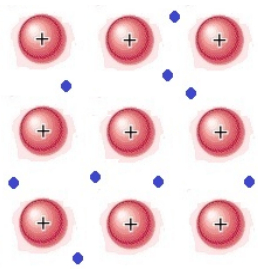
We haven't yet talked about metallic bonding. **Metallic bonds** are bonds formed when metal atoms bond with each other. That seems simple enough.

Both osmium and Iron Maiden (shown here) are considered heavy metal.

The big difference between a metallic bond and ionic or covalent bonding is that metallic bonds are *delocalized*. To understand what this means, it's best to explain what *localized* means in terms of ionic and covalent bonding.

When a bond is localized, this means that the electrons are either transferred or shared between two atoms. In an ionic compound, one atom gives electrons to another atom and the two stick together. In a covalent compound, two atoms share electrons with another to make a covalent bond. In both cases, only these two atoms are involved. Since “local” means “within a short distance”, both covalent and ionic bonding are very short-distance forces between two atoms.

Metals, on the other hand, have *delocalized* bonding. In this sort of bonding the atoms still want to be like the nearest noble gas (every atom wants to do this) but simple sharing or transferring of electrons between two atoms can't make this happen. As a result, all of the valence electrons are shared between all of the atoms. Metallic bonding is usually described using the **electron sea theory**, which says that all of the atomic nuclei are islands of positive charge, held together by an ocean of shared electrons.



The diagram above shows how the positively charged metal nuclei (red) are arranged in a regular, crystalline pattern, while the negatively-charged valence electrons (blue) move freely around them and help bind them all together. Because these electrons collectively hold all of the ions together, rather than holding together only two nuclei at a time, these bonds are said to be delocalized.

As with ionic and covalent compounds, the type of bonding helps us greatly in understanding the properties of metals. Because the electron sea theory isn't exactly something that brings familiar things to mind, we'll need to get creative.

Getting Creative With Metallic Bonding

Imagine this: For some reason or another, you've decided to unroll a giant ball of yarn and put the whole clumpy mess into a cardboard box. Now, throw a bunch of kittens into the box of yarn and stir it up. When you're done, the kittens will all be held in place by the Velcro (and their claws).

Now, imagine the kittens are positively-charged nuclei and the yarn represents the delocalized electrons that hold them together. What you'll find is that, while the kittens can move around, they're still really tightly stuck into the yarn. We'll see why we care about this in a moment.

Anything to get away from this monkey.

Keeping this incredibly odd image in mind, let's talk about the properties of metals:

- **Metals are malleable (bendy) and ductile (can be stretched)**: Consider a box full of kittens and yarn. If you push on one side of the box, the kittens will be pushed to the other side of the box because the yarn gives them the flexibility to move while still staying secure. Likewise, if you hit some metal with a hammer, the delocalized bonding will allow the nuclei to shift position without actually knocking them apart.

- **Metals have high melting and boiling points**: Imagine trying to pull the kittens out of the yarn box. Though you can wiggle the kittens around, they're still put tightly enough in place that it takes considerable energy to pull them out. This is similar to metals in that, if you want to move the metal atoms away from each other, you need to put a lot of energy into the metal to do it.

- **Metals form alloys**: **Alloys** are homogeneous mixtures / solutions in one or more elements are mixed together to make a metallic mixture. This is done for various reasons, the primary of which is that by adding small amounts of other elements into a metal the properties of the metal can be vastly improved. I'm not sure how this is related to kittens, but I'm sure you'll think of something.

Name	Composition	Use
[x] carat gold	Au, varying amounts of Ag, Cu, etc.[15]	The chains that rappers wear.
steel	Fe, small amounts of C.	To make iron more durable and more rust-resistant.
sterling silver	92.5% Ag, 7.5% Cu	To make those tarnished forks your grandma eats with.
brass/bronze	Cu (brass has Zn, bronze has Sn).	That statue in the park your dog barks at.
pewter	Sn, small amounts of Cu, Sn, Bi.	Those weird Warhammer gaming figurines.
dental amalgam	Ag and Hg	Freak out hippies who think mercury poisoning is coming for them.

Some important alloys

15 *The percent of gold is found by dividing the number of carats by 24 and multiplying by 100. As a result, 18 kt gold is (18/24) x 100 = 75% gold.*

The Main Ideas In Chapter 6:

- Chemical bonds are strong forces that hold atoms together.

- Ionic bonds consist of strong electrostatic forces between positively-charged cations and negatively-charged anions. The properties of ionic compounds reflects this very tight, very localized bonding.

- Covalent bonds consist of shared pairs of electrons between nonmetallic atoms. The properties of covalent compounds reflects the fact that covalent compounds exist as molecules rather than as large arrays of ions.

- Metallic bonds occur when many metal nuclei are held together by an ocean of delocalized valence electrons. The properties of metals can be compared to a bunch of cats in a yarn-filled box.[16]

16 *It's actually surprising how many things can be compared to a bunch of cats in a yarn-filled box, if you think about it.*

Image credits:

- Huge electromagnet: Deutsche Fotothek [CC BY-SA 3.0 de (http://creativecommons.org/licenses/by-sa/3.0/de/deed.en)], via Wikimedia Commons. For the record, electromagnets and permanent magnets, while both being magnetic, are different than one another in that permanent magnets are, well, permanent, while electromagnets have a temporary magnetic field that's induced by the movement of electricity.
- NaCl lattice: By Eyal Bairey (user: Eyal Bairey) (Own work) [Public domain], via Wikimedia Commons.
- Salt crystal: By SlashSlash (Own work) [CC BY-SA 4.0 (http://creativecommons.org/licenses/by-sa/4.0)], via Wikimedia Commons.
- Lamp for stupid people: By KorbinD (http://www.saltlamps.pl) [GFDL (http://www.gnu.org/copyleft/fdl.html) or CC BY-SA 4.0-3.0-2.5-2.0-1.0 (http://creativecommons.org/licenses/by-sa/4.0-3.0-2.5-2.0-1.0)], via Wikimedia Commons.
- Copper(II) sulfate: By Ra'ike (see also: de:Benutzer:Ra'ike) (Own work) [GFDL (http://www.gnu.org/copyleft/fdl.html) or CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons.
- Gas station: Adapted from an image by S Lukens (Own work) [CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons. Studies have found that school desks are 100 times dirtier than public toilets. I'd still rather lick a desk, though.
- H-F diagram: By Riccardo Rovinetti (Own work) [CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons. Note: The numbers shown below each atom refer to the Pauling electronegativity values for each, which is a measure of their electron pulling power. You don't need to worry about that at this point, but you'll be seeing it later!
- Icicles: By Shahidalibmw (Own work) [CC BY-SA 4.0 (http://creativecommons.org/licenses/by-sa/4.0)], via Wikimedia Commons. Cropped by me, though. There's some debate as to whether people have ever been stabbed to death with an icicle, but since I saw it in *Die Hard 2*, I'll just assume it happens all the time.
- Water: By User Qwerter at Czech wikipedia: Qwerter. Transferred from cs.wikipedia; Transfer was stated to be made by User:sevela.p. Translated to english by by Michal Maňas (User:snek01). Vectorized by Magasjukur2 (File:3D model hydrogen bonds in water.jpg) [CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons. Incidentally, I have no idea what the “1” is doing in the diagram.
- Ethanoic/acetic acid: By Vuo at English Wikipedia [Public domain], via Wikimedia Commons. Complex compounds are surprisingly difficult to name because, in many cases, there are several different ways that a compound can be systematically-named, as well as one or more common names that people use. The CAS method is the one that the American Chemical Society uses, and is considered the final word.
- Tin foil hat guy: By Drvec (talk)Drvec at en.wikipedia [Public domain], from Wikimedia Commons. I just thought he needed to make another appearance.
- Label Man: By The U.S. Food and Drug Administration (Ad for Nutritional Label (FDA 147)) [Public domain], via Wikimedia Commons. From the amount of stuff about him on the FDA website, it would be safe to assume that the FDA isn't a big fan of “Label Man.” Personally, I'd like to see Label Man's adventures – maybe he could tell a fat guy about the amount of saturated fat in Cheez-Its or something.[17]
- Iron Maiden and Eddie: By _Iron_Maiden_in_Bercy_1.jpg: Metalheart derivative work: Swicher (_Iron_Maiden_in_Bercy_1.jpg) [CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0) or GFDL (http://www.gnu.org/copyleft/fdl.html)], via Wikimedia Commons. An excellent example of heavy metal is Megadeth's *Killing Is My Business... And Business Is Good* album (1985).
- Metal structure: By Spirit469 (Own work) [CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons. I have edited this image for this specific purpose. Because I'm awesome.
- Unhappy cat with monkey: By Salim Virji (Monkey with cat) [CC BY-SA 2.0 (http://creativecommons.org/licenses/by-sa/2.0)], via Wikimedia Commons. Though the monkey in this picture is just some dumb boring monkey, the gorilla Koko was not only taught sign language but also kept a kitten named “All Ball” for nearly a year in 1984. Unfortunately, Koko took a bite out of the kitten's head.[18]

17 *Two grams per serving. Plus no trans-fats, which is pretty good. I guess.*
18 *Actually, it was hit by a car. I just thought it would make the story more interesting.*