Naming Compunds BASICS
Objectives for: Ions, Ionic Compounds & Molecular Compounds

1. periodic table layout and the properties of metals, non-metals, and metalloids
2. mono-atomic ions
3. polyatomic ions (table E)
4. ionic bonding
5. Naming ionic compounds, writing ionic compound formulas, writing formula from names
6. Transitional metal with multiple cations: the Roman Numeral or STOCK naming
7. Molecular compounds
8. naming molecular compounds using the prefix methods, DIATOMIC ELEMENTS
9. oxidation numbers, using to make sensible molecular compound ratios
10. Naming of acids and bases (tables K and L).

Periodic Table layout (revisited)

The periodic table was designed to list the elements in a way to group them by similarity, and to also order them with regular "periodic" repetitions of chemical properties. It has a oddly shaped outer border, but to keep the elements in groups that make sense, this is the shape it must have.

The vertical columns are the GROUPS. Elements in GROUPS have similar chemical properties. Group 1 has each element having just one electron in its outermost orbital. Outermost orbitals are called VALENCE ORBITALS. Group 1 elements all have 1 VALENCE ELECTRON in their VALENCE ORBITALS.

Group 2 has two valence electrons in their valence orbitals.
This gives every atom in group 2 similar bonding abilities and ion formation.

Group 18 has eight valence electrons in its valence orbital (except for He, it is too small an atom to have even a second orbital). All group 18 elements are NOBLE GASES, and all have complete outer orbitals, the PERFECT ARRANGEMENT of ELECTRONS. Because of this they do not make any compounds, they do not “mix with the peasant elements”.

Group 17 has 7 valence electrons in its valence orbital. LOOK at the electron configurations for each group and see that this is the case and that you actually can recognize this fact. It's very important.

Going left to right, the horizontal rows on the periodic table are called PERIODS. The periods (1 to 7) are equal to the number of ORBITALS that are in that PERIOD. Period 2 elements all have 2 orbitals. Period 5 elements all have 5 orbitals.

Metals are on the left side of the periodic table. All elements on the left side of the DARK STAIRCASE LINE are the metals.

Non-metals are all on the right side of this STAIRCASE line (except hydrogen).

There are nine elements TOUCHING THE STAIRCASE, and seven of them are called the Metalloids, or the semi-metals. They are metals that have some non-metallic properties, or non-metals with some metallic properties.

Two elements that touch the line, aluminum & polonium (Al-Po), but they both are actually metals and have only metallic characteristics.

Sometimes the nice order of the table is slightly less than perfect, but it's the best anyone has yet devised to keep properties ordered, atomic numbers ordered, and periodicity intact. A few asterisks are good for the soul.

MONO-ATOMIC IONS

All atoms are neutral because all atoms have the same number of positive protons as they do negative electrons. When the positives equal the negatives, you have a neutral. **Atoms like to be neutral.**

Atoms would, given a good chance, give up their neutrality for a chance at an electron configuration that matches a Noble Gas. Metals, because of their electron configurations will lose electrons rather than gain them to make this noble gas configuration come about.

When an atom gains that perfect NOBLE GAS electron configuration it is said to be ISOELECTRIC to that noble gas.

Isoelectric means… having the same e^- configuration as…

The sodium cation has a 2-8 e^- configuration by losing $1e^-$
Na^{+1} is isoelectric to Neon (Ne has a 2-8 e^- configuration)

The sulfur anion has a 2-8-8 e^- configuration by gaining $2e^-$
S^{-2} is isoelectric to Argon (Ar has a 2-8-8 e^- configuration)

So, group 1 metals all have one valence electron, which each would give up to obtain a noble gas electron configuration. Na at 2-8-1 would become the sodium ion (Na^{+1})with a 2-8 configuration. Since the number of protons is constant, the ion becomes a net +1 charge. All **group 1 ALKALI METALS** make +1 cations.

A positive ion is called a CATION.

Group 2, the ALKALINE EARTH METALS, have two valence electrons, so in fact, each of those can lose these two valence electrons, leaving them then with full outer orbitals, but they all end up +2 cations. For example, Mg becomes the Mg^{+2} cation when it loses its 2 outer, valence electrons.

Aluminum has a 2-8-3 electron configuration, and readily gives up THREE electrons for that coveted complete outer orbital, making the aluminum cation +3!

METALS MAKE CATIONS, all metals tend to lose electrons in the quest for a complete outer orbital. This is because they all have just a few electrons in their valence orbitals, and it's easier to lose a few electrons than to gain a bunch.

Aluminum has an electron configuration of 2-8-3. It will lose 3 electrons to become like the noble gas neon, becoming a +3 ion, Al^{+3}.

On the other side of the table are the non-metals. Due to their electron arrangements, they all have more valence electrons than the metals do, it makes more sense for them to gain electrons to make for a complete outer orbital.

Group 17 atoms (the HALOGENS) all have 7 valence electrons. It makes sense that they'd each like to gain one electron to get a complete outer orbital. Hence they form negative one (-1) **ANIONS.** (the gain of one negative electron by the neutral atoms yields a -1 charge extra)

Group 16 atoms all have outer, valence electron orbitals that end with 6 electrons. In order to gain the perfectly full orbital like the noble gases they need to gain 2 electrons (that’s two negative electrons extra) they form negative 2 ions like O^{-2}, and S^{-2}.

Group 15 atoms all have outer, valence electron orbitals that end with 5 electrons. In order to gain the perfectly full orbital like the noble gases they need to gain 3 electrons (that’s three negative electrons extra) they form negative 3 ions like N^{-3}, and P^{-3}.

Noble gases do not make any ions at all.

POLYATOMIC IONS

Ions of both kinds, cations and anions, are possible for nearly all atoms (not the noble gases). There are many cases where 2 or more atoms bond together and act as an individual ion with one total charge. The only poly-atomic ions that you need to be familiar with are listed in Table E.

The poly atomic ions come in cation form and in anion form. They "work" the same as mono-atomic ions as far as determining the ratio of cations to anions (use the ionic charges to get to NET ZERO).

Their names DO NOT CHANGE like the mono-atomic anions names change to the -ide endings. They have particular names that they always keep, and the names are on Table E as well.

Be careful with these as there are many similar but different polyatomic ions (sulfite and sulfate, carbonate and hydrogen carbonate, chromate and dichromate, for example).
USE THE CORRECT IONS, with the correct ionic charge.

ION RATIOS for ionic compounds

John Dalton said that molecules formed in simple whole number ratios. There are a limited number of possible ions from the periodic table, cations and anions. For our class they are +1, +2, +3, -1, -2, and -3. A neutral ionic compound can only be made from a balanced ratio of positive cations and negative anions. The only possible ratios of ions from these are as follows:

cation charge	anion charge	ratio of **cations : anions** in the neutral ionic compound
+1	-1	1:1
+2	-1	1:2
+3	-1	1:3
+1	-2	2:1
+2	-2	1:1
+3	-2	2:3
+1	-3	3:1
+2	-3	3:2
+3	-3	1:1

MOLECULAR COMPOUNDS

Are formed from 2 or more non-metals combining together. There are NO METALS, there are NO IONS, and the compounds formed are still neutral, but because they form from neutral ATOMS. The electrons are NOT transferred from one atom/ion to another. Here the electrons are shared, they remain with their original atoms.

The smallest part of a molecular compound is called the molecule. There are specific ratios of atoms that can make real molecules. To determine how these atoms fit together (or do not fit together), we use the selected oxidation states listed in our periodic tables.

Selected oxidation states ARE NOT IONS, nor ionic charges that need to be neutral. They are a set of numbers that allow you to determine which atom ratios are possible or impossible for molecules to form into.

The numbers are listed and come in positive or negative values. These numbers ARE NOT ionic forms, and many atoms have many different oxidation states. Many more selected oxidation states exist, not all of them are listed.

We use these numbers to see how the atoms can combine into particular ratios and make compounds that can exist. The atoms need to combine so that these oxidation numbers end up to a net zero, similar of course to ionic compounds needing to balance the + cation charges against equal but opposite - anion charges.

BUT, the oxidation numbers are more of a pattern set of numbers, or, a ratio set of numbers. There are NO CHARGES for molecular compounds.

EXAMPLE: nitrogen and oxygen have their own oxidation numbers. (see periodic table)
Oxygen has only one: (-2).
Nitrogen has many (-3, -2, -1, +1, +2, +3, +4, and +5).

The ratios must net to zero, so when ever there are negative oxidation numbers that must combine to other negative oxidation numbers, they are omitted. (same for 2 positive oxidation numbers.) we over look those because they can’t add to net zero.

The only possible combinations for nitrogen with oxygen are the 5 different positive nitrogen oxidation numbers combining to the single -2 oxidation number that oxygen has. The oxidation numbers SUM to zero in combination, not just 1:1 ratios.

THESE ARE NOT IONS, even though there are +/- numbers involved. They’re Not Ionic!

Nitrogen	Oxygen	
~~-3~~	-2	X will not sum to zero - do not use for N-O compounds
~~-2~~		X will not sum to zero - do not use for N-O compounds
~~-1~~		X will not sum to zero - do not use for N-O compounds
+1		N^{+1} combines to O^{-2} in a 2:1 ratio: N_2O dinitrogen monoxide
+2		N^{+2} combines to O^{-2} in a 1:1 ratio: NO nitrogen monoxide
+3		N^{+3} combines to O^{-2} in a 2:3 ratio: N_2O_3 dinitrogen trioxide
+4		N^{+4} combines to O^{-2} in a 1:2 ratio: NO_2 nitrogen dioxide
+5		N^{+5} combines to O^{-2} in a 2:5 ratio: N_2O_5 dinitrogen pentoxide

Carbon trioxide CO_3 is NOT POSSIBLE. Oxygen with its -2 oxidation number would require carbon then to have a +6 oxidation number to balance the three -2's.

Carbon DOES NOT have a +6, and thus, **carbon trioxide is not a real molecular compound**.

The CARBONATE ANION on Table E is CO_3^{-2}, but it's NOT a compound, it is an ion made up of 4 atoms plus 2 extra electrons.

Molecular compounds ARE compounds, not ions.

Check to see that carbon dioxide and carbon monoxide are both possible according to the selected oxidation states. Both do exist.

The oxidation numbers for carbon are −4, +2, and +4; and for oxygen it is just −2

When the oxidation numbers are the same sign (both negative, or both positive) we disregard them since they cannot combine in any way that would give us a net zero.

Example Carbon's −4 cannot combine with oxygen's −2, so those oxidation numbers are not part of the carbon to oxygen molecular bonding ratios.

Carbon +2 and oxygen at −2 shows us that these atoms can combine in a 1:1 ratio. The molecule CO is possible to form. It's called carbon monoxide.

Carbon with the +4 oxidation number can also combine in a different ratio with oxygen with the −2 oxidation number. That would require a 1:2 ratio of carbon to oxygen, or CO_2, carbon dioxide, which of course also exists.

The DIATOMIC ELEMENTS

There are 7 elements that do not exist in the pure form as individual atoms.

Their existence is in pairs, or twins if you will. They are H, O, N, Cl, Br, I, and F (the HONClBrIF twins).

These seven elements exist in the pure form as H_2, O_2, N_2, Cl_2, Br_2, I_2, and F_2 , as diatomic molecules. These seven are not found as individual atoms in nature. They are technically molecules, as they are made up of 2 or more non-metals sharing electrons in their bond together.

This is why we have both atoms and molecules making up non-metals.

IONIC COMPOUNDS

Cations + anions = neutral compounds

Only metals form cations.
Only non-metals form anions

Ionic compounds are all neutral, so you have to be sure that the ratio of cations to anions is proper. Use the ion charges to decide.

The compounds only come about because the **electrons from cations quite literally are transferred to the anions**.

This leaves cations with 1, 2, 3 less negative electrons (cations form +1, +2, & +3)

Non-metals must be present to be able to accept these electrons.
Non-metals can accept 1 or 2 or 3 electrons, depending upon their
specific electron configurations.
(anions come in 3 forms: -1, -2, and -3).

The smallest part of an ionic compound is called a FORMULA UNIT. They don't really exist alone, rather the ionic compounds exist in vast crystal structures, made up of 100's to millions of formula units all stuck together.

NAMING IONIC COMPOUNDS

Cation or metal always goes first.

The name of the metal atom is the first name of the ionic compound

If the anion is MONO-ATOMIC, change the anion atomic name to end in -ide.

If the ion is POLY-ATOMIC, don't change the polyatomic ion name from Table E

If the cation is polyatomic, don’t change the name of that ion from Table E.

If transitional metal is involved: use a Roman Numeral to distinguish which possible cation is being used.

MOLECULAR COMPOUNDS

Make no ions, do not combine as ions.
No metals form into molecular compounds.

Only combinations of Non-Metal plus Non-Metal form molecules.

Atoms combine together to form neutral compounds

They are neutral because they form from neutral atoms.

The ratios are also very particular, and we use the selected oxidation numbers to determine what these ratios are.

The electrons have to be shared by the atoms bonded into molecules, but **there is no transfer of electrons from one atom to another.**

The smallest part of a molecular compound is called a molecule.

NAMING MOLECULAR COMPOUNDS

The first name rule: Single atoms get called by their name, multiple atoms get a prefix first.

The second name rule is that you always use a prefix. Always.

These two rules are clear if you understand the names and formulas of these three simple compounds: CO, CO_2, H_2O.

The prefixes from one to ten are: mono, di, tri, tetra, penta, hexa, hepta, octa, nona, and deca.

Properties of Metals, non-metals, metalloids, ionic & molecular compounds

property	**metals**	**non-metals**	**metalloids**	**ionic compounds**	**molecular compounds**
luster	yes	no	some are, such as Si	no	not usually
malleable, ductile	yes, yes	no, no	no	no, no	no
conduct heat	yes	no	no	no	no
conduct electricity	yes	no	some, such as Si	no	no
form cations or anions?	cations only	anions only	follows metal non-metal rules	formed from ions but are neutral	none
smallest particle	atoms	atoms or molecules	atoms	formula units	molecules
density	fairly high	low	varies, check table S	medium high	varies
melting point	relatively high	relatively lower	varies	extremely high	low compared to metals or ionic compounds
phases at room temp	solid	solid, liquid, or gas	solid	solid	solid

Transitional metal cations

As previously stated, the transitional metals often can and do some strange things as compared to their more “logical” group 1 and 2 metals. As metals they form cations, but some can form more than one kind of cation.

Even though the oxidation numbers shown on the periodic table are PRIMARILY for making molecular compounds, with JUST the non-metals bonding together, these selected oxidation numbers do show the possible ionic forms for the metals.

All of group 1 metals have a +1 selected oxidation state. They also only make +1 cations.

All of group 2 metals have a +2 selected oxidation state. They also only make +2 cations.

Many transitional metals, such as scandium, zinc, yttrium, zirconium, silver, cadmium, indium, tantalum, tungsten, etc. make ONLY ONE type of cation. That would be the same charged cation as the selected oxidation state on our periodic table.

Some transitional metal cations: Sc^{+3}, Zn^{+2}, Y^{+3}, Zr^{+4}, Ag^{+1}, Cd^{+2}, In^{+3}, Ta^{+5}, W^{+6}, etc.

The order to these is all mixed up, but it is clearly printed onto our periodic tables. These cations work just like the group one and two cations, but they give up the amount of electrons as their + charges indicate.

The strange transitional metals make more than one stable type of cation, indicated by MORE THAN ONE POSITIVE oxidation state.

Titanium is number 22. It can make a +2, +3 or a +4 cation. Copper, number 29, can make a +1 or +2 cation. **The cations that are possible are the positive selected oxidation states listed on the periodic table.**

Lead, number 82 can make a +2 or +4 cation.
Vandium, number 23 forms +2, +3, +4, and +5 cations.

It’s possible and they do. Each different ion will form different ionic compounds, compounds with different ratios or amounts of anions. Since the transfer of electrons is balanced, if we combine lead with oxygen for example, it can combine in a 1:1 ratio or a 1:2 ratio.

$Pb^{+2} + O^{-2}$ —–> PbO (1:1 ratio)

$Pb^{+4} + O^{-2}$ —–> PbO_2 (1:2 ratio)

Both of these compounds cannot be called lead oxide.

They need another way to be named, to keep them separate.

Of course there is…

cation	anion	formula	name
Pb^{+2}	O^{-2}	PbO	Lead (II) oxide lead Roman Numeral 2 oxide
Pb^{+4}	O^{-2}	PbO_2	LEAD (IV) oxide lead Roman Numeral 4 oxide

+4 cation leads to using a IV Roman Numeral here

We add a Roman Numeral that corresponds to the cation charge into the compound name.

Both types of lead oxide are different. Now we know how to say their names differently. If we used just formulas in speech ("Give me some PbO please!", or maybe, "I really like the color of PbO_2", then this Roman Numeral naming system would be unnecessary. Since we usually speak in words and not formula, we need this system of naming.

Try looking at the 3 possible cations for chromium (number 24)
They all can't be chromium chloride since they are all different.
The Roman Numeral always corresponds to the cation charge of the particular transitional metal cation.

cation	anion	formula	name
Cr^{+2}	Cl^{-1}	$CrCl_2$	chromium (II) chloride chromium Roman Numeral 2 chloride
Cr^{+3}	Cl^{-1}	$CrCl_3$	chromium (III) chloride chromium Roman Numeral 3 chloride
Cr^{+6}	Cl^{-1}	$CrCl_6$	chromium (VI) chloride chromium Roman Numeral 6 chloride

This naming system is called the Roman Numeral
naming system, or the
STOCK naming system
for transitional metal ionic compounds.