ChemQuest 23

Forming Ions

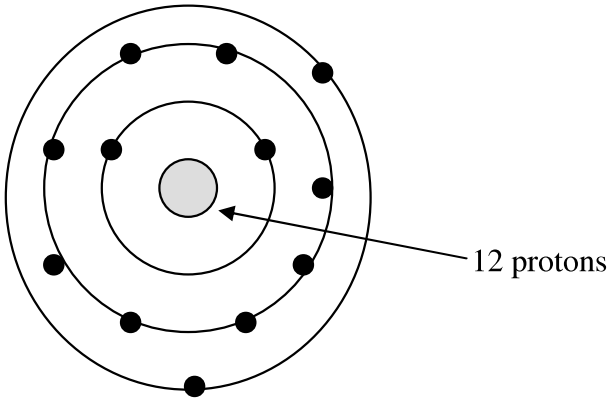
Name: _____

Date: _____

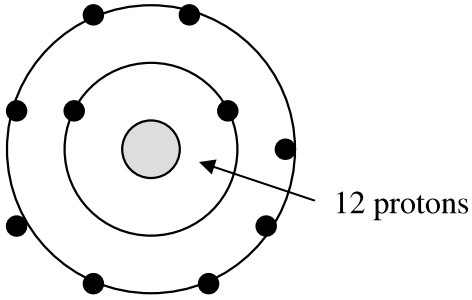
Hour: _____

Information: Ions

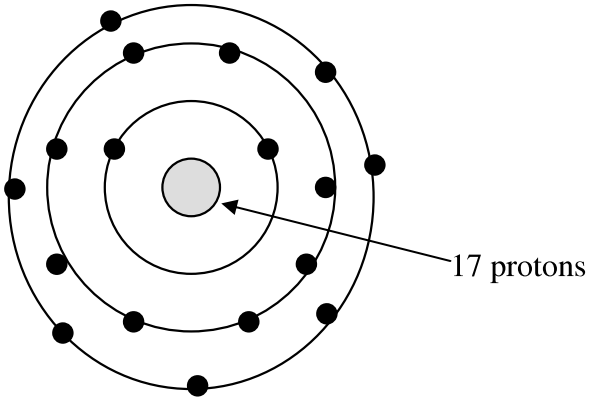
Figure 1: Below are four Bohr diagrams of atoms and ions. The two diagrams on the left are atoms; the two on the right are ions.



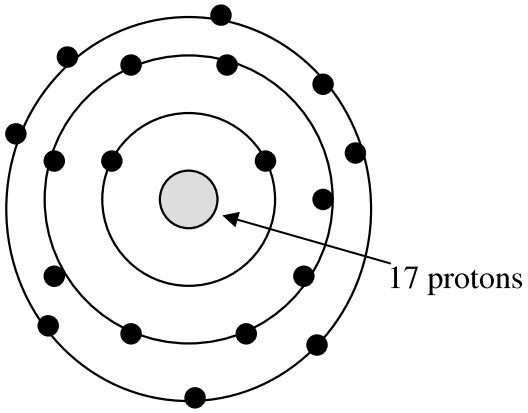
Atom A



Ion of Atom A



Atom B



Ion of Atom B

Critical Thinking Questions

1. Prove that both Atom A and Atom B are neutral (have a charge of zero).
   Both atoms have an equal number of protons and electrons.

2. What is the identity of Atom A and of Atom B?
   The atom with 12 protons and 12 electrons is magnesium.

3. Given the above diagrams, how does an atom become an ion?
   An atom can become an ion by either gaining or losing electrons.

4. Before answering this question, note that an ion's charge must have a sign (+ or -) and a number.

   a) What is the charge on Ion A?
   Ion A = 12 protons and 10 electrons = +2 charge

   b) What is the charge on Ion B?
   Ion B = 17 protons and 18 electrons = -1 charge

5. a) How many electrons does Ion A have? 10

   b) What atom has the same number of electrons as Ion A? Neon

6. a) How many electrons does Ion B have? 18

   b) What atom has the same number of electrons as Ion B? Argon

7. Bromine atoms always gain one electron when they become an ion. Which atom has the same number of electrons as a bromine ion?
   Krypton

8. Cesium atoms always lose one electron to become an ion. Which atom has the same number of electrons as a cesium ion?
   Xenon

9. Consider your answers to questions 5-8. What do all of the atoms you named have in common?
   They are all noble gases with eight outer-level electrons.

10. Knowing what you know about the atoms that you named in questions 5-8, why do you think atoms want to form ions the way they do?
    The noble gases have very stable electron configurations and so atoms want to gain or lose electrons so that their electron configuration is the same as a noble gas and more stable.

Information: Ions

As you know, all of the noble gases are very stable. Ions form in such a way so that the ion will have the same number of electrons as a noble gas. Take oxygen, for example. Oxygen has 8 electrons. To become like a noble gas it could either gain two to become like neon or it could lose six to become like helium. So what will oxygen do—gain two or lose six? **As a general rule, atoms will gain or lose the fewest number of electrons possible.**

Critical Thinking Questions

11. What does an oxygen atom do when becoming an ion? (Does it gain or lose electrons and how many?)
    It will gain 2 electrons rather than losing 6.

12. An oxygen atom has an overall neutral charge because it has an even number of protons and electrons. What is the overall charge on an oxygen ion? After gaining 2 negative electrons the charge will be -2.

13. Consider an aluminum atom.
    a) To become like argon, would aluminum have to gain or lose electrons? How many?
       Aluminum would have to gain 5 electrons.

    b) To become like neon, would aluminum have to gain or lose electrons? How many?
       Aluminum would have to lose 3 electrons.

    c) Considering your answers to parts a and b, what does an aluminum atom do to become an ion?
       Since aluminum wants to gain or lose the fewest number of electrons possible, aluminum will lose 3 electrons.
    d) What is the charge on an aluminum ion?
       After losing 3 electrons, the charge will be a net +3.

14. When each of the following atoms becomes an ion, what will the charge be?

a) Ca	b) Cl	c) N	d) K	e) S	f) B	g) P
+2	-1	-3	+1	-2	+3	-3

ChemQuest 24

Ionic Bonding

Name: _____

Date: _____

Hour: _____

Information: Naming Ions

To write an ion, you write the symbol of the atom and put the charge in the upper right corner. Consider the following examples: Al^{3+}, O^{2-}, Mg^{2+}. You should verify that each of the charges is correct.

Positive and negative ions are named differently. Positive ions retain the same name as the parent atom. For example, Al^{3+} is called the "aluminum ion" and Mg^{2+} is called the "magnesium ion." Negative ions are named a little differently. For negative ions, you change the ending of the name to "-ide". Therefore, O^{2-} is named oxide and P^{3-} is named phosphide.

Critical Thinking Questions

1. Sulfur forms a negatively charge ion. Is the name of the ion sulfur or sulfide? Explain why.

   "Sulfide," because negative ions end in "-ide" (with some exceptions to learn later).

2. Sodium forms a positive ion. Is the name of the ion sodium or sodide? Explain why.

   "Sodium," because the names of positive ions are the same as the name of the atom.

3. Write the symbol (including the charge) AND the name for each of the ions for each of the following. The first is done for you.

a) Cl	b) Ca	c) N	d) K	e) S	f) B	g) P
	Ca^{2+}	N^{3-}	K^{+}	S^{2-}	B^{3+}	P^{3-}
	calcium ion	nitride	potassium ion	sulfide	boron ion	phosphide

Cl^{-1}

chloride

Information: Ionic Bonding and Formulas

There are two ways in which atoms can "bond" to each other and form a compound. The means of bonding that we will consider now is called ionic bonding.

Ionic bonding occurs between a **metal** and a **nonmetal**. As you know, opposite charges attract. Ionic bonding is when two ions of opposite charge attract and bond to each other forming an ionic compound.

Consider the following examples of formulas for ionic compounds:

- One Na^{+} (sodium ion) and one Cl^{-} (chloride ion) bond to make NaCl, "sodium chloride."
- One Mg^{2+} (magnesium ion) and two F^{-} (fluoride ion) bond to make MgF_2, "magnesium fluoride."
- Three Ca^{2+} (calcium ion) and two N^{3-} (nitride ion) bond to make Ca_3N_2, "calcium nitride."
- One Al^{3+} (aluminum ion) and one N^{3-} (nitride ion) bond to make AlN, "aluminum nitride."

The small numbers at the bottom right of each symbol in a formula are called "subscripts". Subscripts tell us how many of each type of atom are present. For example in the formula Mg_3N_2 there are three magnesium ions and two nitride ions.

Critical Thinking Questions

4. Consider the formula NaCl in the above example. It tells us that one Na^{+} ion is bonded to one Cl^{-} ion. What is the overall charge for NaCl? Is it positive, negative, or neutral?
   neutral

5. Consider MgF_2.
   a) What is the charge on a magnesium ion? +2

   b) What is the charge on a fluoride ion? -1

   c) What is the overall charge on MgF_2? Note: The formula "MgF_2" tells us that one Mg^{2+} ion bonds with two F^{-} ions.
   neutral

6. Given your answer to question 4 and 5c, what do you think is the overall charge on any ionic compound?
   neutral

7. Calcium nitride is written like this: Ca_3N_2.

   a) What is the charge on one calcium ion? +2

   b) What is the charge on one nitride ion? -3

   c) In the formula, Ca_3N_2, there are 3 calcium ions. What is the total charge on 3 calcium ions? (Hint: multiply 3 times your answer to part a.)
   +6

   d) In the formula, Ca_3N_2, there are 2 nitride ions. What is the total charge on 2 nitride ions? (Hint: multiply 2 times your answer to part b.)
   -6

   e) Why do you think it MUST be written like Ca_3N_2 and not something like CaN_2 or Ca_2N_3? In other words why do exactly three calcium ions bond with exactly two nitride ions? (Hint: think about what your answers to part c and d equal when added together.)
   so that the compound will be neutral

8. Why do you think sodium nitride is written Na_3N instead of Na_2N?
   Na_3N has a charge of zero

9. The formula Ca_3N_2 can never be written as N_2Ca_3. To find out why, take note of each of the four example formulas given above.
   a) What do the first ions named all have in common?
      They are positive.

   b) What do the second ions named all have in common?
      They are negative.

   c) Now, why can't Ca_3N_2 ever be written like N_2Ca_3?
      Positive ions must come first.

10. There are two rules to follow when writing formulas for ionic compounds. One has to do with charges (see questions 4 ad 5) and the other has to do with which atom to write first and which one to write second (see question 6). What are these two rules?
    1) Positive ions come first
    2) The overall charge on the compound must be zero.

11. What is wrong with the following formulas?

a) Al_2S	b) PNa_3	c) MgS_2
This compound is not neutral. Two Al^{3+} ions will combine with three S^{2-} ions to give the correctly written, neutral compound: Al_2S_3.	Although this compound is neutral, the positive ion (Na^+) is not written first. The correct way to write it would be Na_3P.	This compound is not neutral. The correct formula should be MgS.

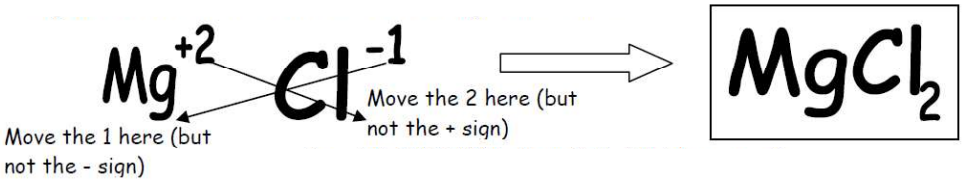
Information: Writing Formulas

Let's say you needed to write the formula for the compound formed by magnesium and chlorine. Follow the two steps below to write the formulas:

Step 1: Write the charges for each of the ions. The positive ions should be written first.
Mg^{+2} and Cl^{-1}

Step 2: Write the positive one first and make sure the charges equal zero. We will need TWO chloride ions to cancel out one magnesium ion.
$MgCl_2$

Note: many times you can use the "crisscross" method. Write the ions next to each other and like in step one above and then crisscross the charges like below:



12. Write the formula and name for the compound that forms when the following atoms form ionic compounds. The first is done for you.

a) lithium and chlorine

LiCl
lithium chloride

b) barium and sulfur

BaS
barium sulfide

c) magnesium and iodine

MgI_2
magnesium iodide

d) oxygen and aluminum

Al_2O_3
aluminum oxide

e) calcium and phosphorus

Ca_3P_2
calcium phosphide

f) sodium and sulfur

Na_2S
sodium sulfide

13. Given the following compounds, determine the charge on the unknown ion "X". The first one is done for you.

a) X_2S

Answer: +1. Here's why: Remember that S has a negative 2 charge. There are two "X" ions to balance out the negative 2 charge of S. Therefore, the charge on each X is +1.

b) MgX

-2

c) X_3P_2

+2

d) X_3N

+1

ChemQuest 25

Advanced Ionic Bonding

Name: _____

Date: _____

Hour: _____

Information: Polyatomic Ions

The word, "polyatomic" means "many atoms". A polyatomic ion, therefore, is an ion that is made of more than one atom. An example of a polyatomic ion is the sulfate ion, SO_4^{2-}. Sulfate is composed of one sulfur atom and four oxygen atoms and overall sulfate has a negative two charge.
Some polyatomic ions are listed below.

Many polyatomic ions end in "-ate":

Acetate: $C_2H_3O_2^{-1}$
Carbonate: CO_3^{2-}
Chlorate: ClO_3^{-1}
Nitrate: NO_3^{-1}
Phosphate: PO_4^{3-}
Sulfate: SO_4^{2-}

Some other polyatomic ions:

Ammonium: NH_4^{+1}
Cyanide: CN^{-1}
Hydroxide: OH^{-1}

Critical Thinking Questions

1. What do all of the polyatomic ions that have the suffix "-ate" have in common? (ie, What atom exists in all of the polyatomic ions that end in "-ate"?)

   They all contain oxygen.

2. Which two atoms do you think compose the polyatomic ion called "silicate"?

   Silicon and oxygen

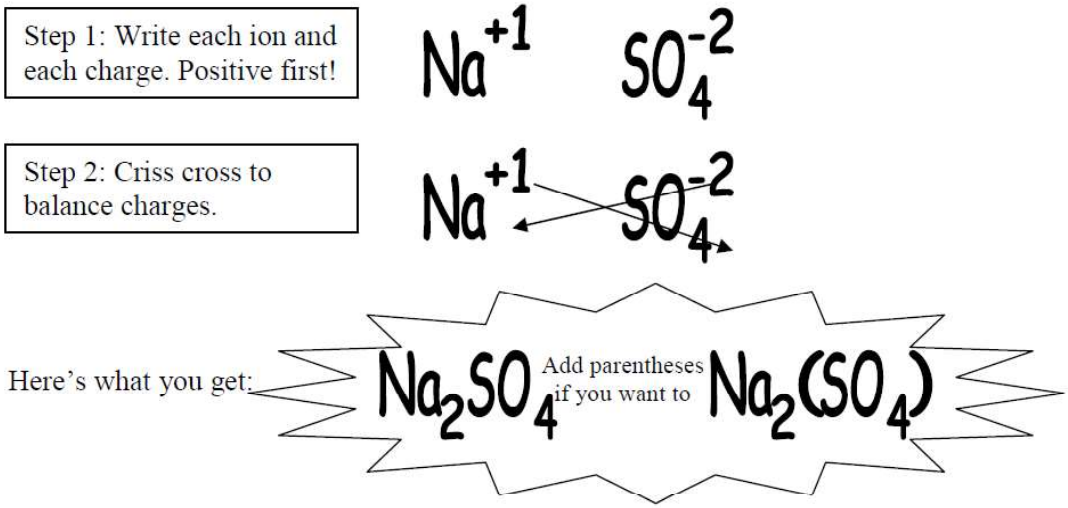
3. What is the difference between calcium nitride and calcium nitrate?

   Calcium nitrate has oxygen, but calcium nitride does not.

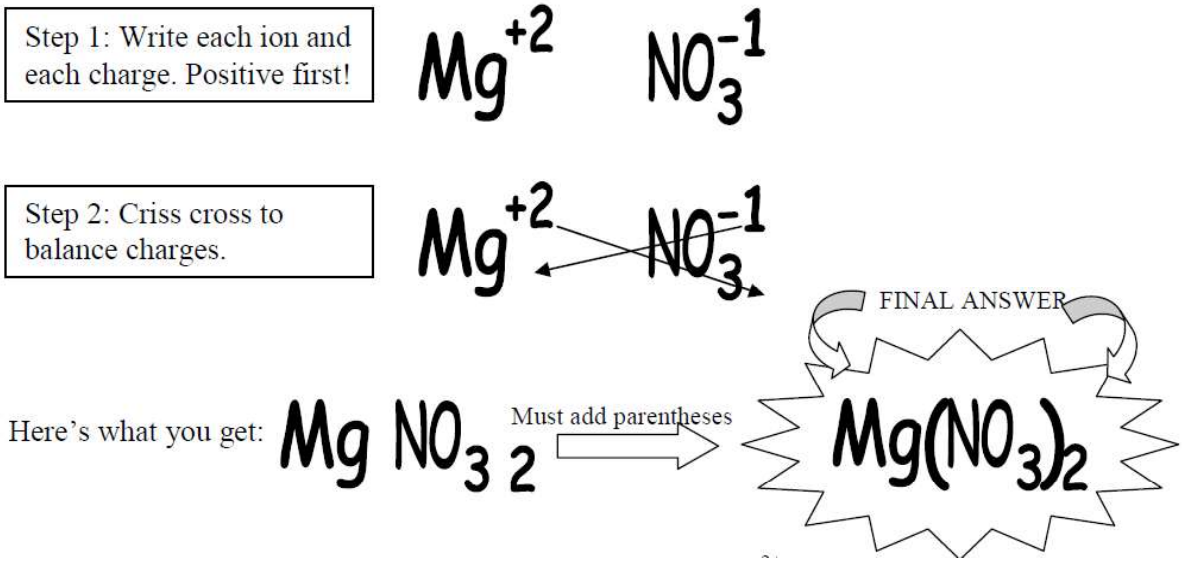
Information: Writing Formulas With Polyatomic Ions

First of all, you must remember that you can never change the formula for a polyatomic ion. Sulfate is always SO_4^{2-} and never $S_2O_8^{4-}$ or something else. Following are some examples of chemical formulas that contain polyatomic ions.

Sodium sulfate, Na_2SO_4:



Magnesium nitrate, $Mg(NO_3)_2$:



Consider calcium hydroxide. Calcium has a positive two charge (Ca^{2+}) and hydroxide has a negative one charge (OH^-). We need two hydroxide ions to combine with one calcium ion so that the overall charge ends up being zero. We write calcium hydroxide like $Ca(OH)_2$.

Following are some more examples:

potassium acetate: $KC_2H_3O_2$ magnesium nitrate: $Mg(NO_3)_2$
barium phosphate: $Ba_3(PO_4)_2$ calcium carbonate: $CaCO_3$

Critical Thinking Questions

4. In the expression $Mg(CN)_2$, there is one magnesium atom, two carbon atoms, and 2 (how many?) nitrogen atoms.

5. In the expression $MgCN_2$, there is 1 (how many?) magnesium atom, 1 (how many?) carbon atom, and 2 (how many?) nitrogen atoms?

6. As mentioned above, calcium hydroxide is written like $Ca(OH)_2$. Why can't it be written like $CaOH_2$?
   There needs to be two hydroxide ions (OH^-) and not merely two hydrogens.

7. As mentioned above, magnesium nitrate is written as $Mg(NO_3)_2$. Why can't it be written like $MgNO_{32}$?
   $MgNO_{32}$ looks like 32 oxygens rather than 2 nitrates.

8. Name the following compounds. Each includes at least one polyatomic ion.
   a) Na_3PO_4 — sodium phosphate
   b) $(NH_4)_2SO_4$ — ammonium sulfate
   c) $Mg(C_2H_3O_2)_2$ — magnesium acetate
   d) $(NH_4)_2S$ — ammonium sulfide
   e) $CaCO_3$ — calcium carbonate
   f) $Ba(NO_3)_2$ — barium nitrate

9. Write formulas for the following ionic compounds. Note that each includes a polyatomic ion.
   a) lithium phosphate — Li_3PO_4
   b) ammonium oxide — $(NH_4)_2O$
   c) barium hydroxide — $Ba(OH)_2$
   d) calcium cyanide — $Ca(CN)_2$
   e) sodium chlorate — $NaClO_3$
   f) potassium sulfate — K_2SO_4

10. In question 3, you were asked the difference between calcium nitride and calcium nitrate. Now write the formula for each of them.
    calcium nitride: Ca_3N_2 calcium nitrate: $Ca(NO_3)_2$

Information: Formulas for Acids

Acids are compounds that contain positive hydrogen ions (H^+) bonded to a negative ion. For example, carbonic acid is formed when the carbonate ion (CO_3^{2-}) bonds with two hydrogen ions (H^+) to give H_2CO_3. Other common acids are listed below:

Hydrochloric acid: HCl
Sulfuric acid: H_2SO_4
Nitric Acid: HNO_3
Acetic Acid: $HC_2H_3O_2$

Critical Thinking Questions

11. Why do carbonic and sulfuric acid require two H^+ ions to bond, but HCl and HNO_3 only have one H^+?

    Carbonate and sulfate both have a -2 charge and therefore require two H^+ ions (each having a +1 charge) so that overall the formulas will be neutral.

12. Phosphoric acid is made from the phosphate ion and H^+ ions. Write the formula for phosphoric acid.

    H_3PO_4 Three H^+ ions are needed because phosphate has a -3 charge.

ChemQuest 26

Transition Metals

Name: _____

Date: _____

Hour: _____

Information: Charges of Some Transition Elements

So far you have learned that you can predict the charge that an ion will have based on its location on the periodic table. However, the transition elements are not easy to predict. A few common transition elements are listed below. You should memorize their charges.

Silver: Ag^{+} Zinc: Zn^{2+} Cadmium: Cd^{2+}

Critical Thinking Questions

1. Write the formulas for the following compounds:

a) silver nitrate — $AgNO_3$

b) zinc phosphate — $Zn_3(PO_4)_2$

c) cadmium chloride — $CdCl_2$

Information: More Than One Possible Charge

Many transition elements can have more than one charge when they become an ion. Copper ions, for example, can be Cu^{+} or Cu^{2+}. As another example, iron ions are sometimes Fe^{2+} and sometimes Fe^{3+}.

Critical Thinking Questions

2. Copper and iron are in the "d block" and so you need to calculate their charge by comparing what bonds to them. Find the charge on copper and iron in each of the following compounds.

a) $CuCl_2$ — +2

b) $CuCl$ — +1

c) $FeSO_4$ — +2

d) $Fe_2(SO_4)_3$ — +3

(This is similar to what you did in question 10 for ChemQuest 16)

3. Give your best attempt at naming the compounds from question 2. (They are rewritten below.)

a) $CuCl_2$ — copper chloride

b) $CuCl$ — copper chloride

c) $FeSO_4$ — iron sulfate

d) $Fe_2(SO_4)_3$ — iron sulfate

Information: Formulas Containing Roman Numerals

You probably put the same name for the compounds in question 3a and 3b. You may also have put the same name for the compounds in 3c and 3d. BUT these are not the same compound! You cannot have the same name for two different compounds. Here are the correct names for the compounds in questions 2 and 3:

a) $CuCl_2$	b) CuCl	c) $FeSO_4$	d) $Fe_2(SO_4)_3$
copper(II) chloride	copper(I) chloride	iron(II) sulfate	iron(III) sulfate

Critical Thinking Questions

4. Compare your answers for questions 2 & 3 with the names of the compounds given in the information section. What do the Roman numerals stand for?
   The Roman numerals stand for the charge on the transition metal ion.

5. Why is MnO_2 called manganese(IV) oxide?
   Manganese has a charge of +4 indicated by the Roman numeral IV.

6. Name the following compounds. *Note: assume that anytime you have a transition element (d block element) you must use a Roman numeral unless the element is silver, zinc, or cadmium.* (The first one is done for you.)

a) $NiNO_3$	b) $Cr_2(CO_3)_3$	c) $FeNO_3$	d) $CoCl_2$
nickel(I) nitrate	chromium(III) carbonate	iron(I) nitrate	cobalt(II) chloride
e) $Cu_3(PO_4)_2$	f) MnS	g) $ZnCl_2$	h) $AgNO_3$
copper(II) phosphate	manganese(II) sulfide	zinc chloride	silver nitrate

(No Roman numerals are needed for zinc or silver, but if you included them it is OK.)

7. Write the formulas for the following compounds. (The first one is done for you.)

a) mercury(II) acetate	b) chromium(III) sulfate	c) iron(I) carbonate
$Hg(C_2H_3O_2)_2$	$Cr_2(SO_4)_3$	Fe_2CO_3
d) potassium carbonate	e) strontium nitride	f) manganese(IV) chlorate
K_2CO_3	Sr_3N_2	$Mn(ClO_3)_4$

8. Look at the previous question, parts 7d and 7e. Notice how "potassium carbonate" and "strontium nitride" do NOT contain a Roman numeral in the name. The other names in question 7 all have a Roman numeral in the name. Why?

Potassium and strontium are not transition metals and therefore no roman numeral is needed when writing the names of the compounds.

9. Name the following compounds. Only use a Roman numeral when necessary!

a) $MgCl_2$ b) $Mg(ClO_3)_2$ c) $MnCl_2$ d) $MnClO_3$

magnesium chloride magnesium chlorate manganese(II) chloride manganese(I) chlorate

e) $Mn(ClO_3)_2$ f) Rb_2SO_4 g) Rb_2S h) $Cr_2(SO_4)$

manganese(II) chlorate rubidium sulfate rubidium sulfide chromium(I) sulfate

10. Name the following compounds. All of them are transition metals, but you only need Roman numerals for a, NOT for b and c.

a) $Ni(SO_4)_2$ b) $AgNO_3$ c) $CdCl_2$

nickel(IV) sulfate silver nitrate cadmium chloride

11. Why didn't you need Roman numerals for b) and c) in question 10?

Silver and cadmium are both always +1 and +2, respectively.