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AP® Chemistry 1

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AP Chemistry 1

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Contents

2.4 Names and Formulas of Inorganic Compounds

Warm Up

Ions are charged atoms or charged groups of atoms. Ions always associate (bond) together in the ratio that results in their charges cancelling to form neutral compounds. Complete the table by providing the formulas of the compounds formed by the ions specified.

	Br^-	O^{2-}	N^{3-}	OH^-	SO_4^{2-}	PO_4^{3-}
Na^+	NaBr		Na_3N			
Ca^{2+}						$Ca_3(PO_4)_2$
Al^{3+}				$Al(OH)_3$		
NH_4^+		$(NH_4)_2O$				
Sn^{4+}					$Sn(SO_4)_2$	

Binary Ionic Compounds

Recall that non-metals form molecular compounds with other non-metals but they form ionic compounds with metals. The names and formulas of these two types of compounds are handled differently.

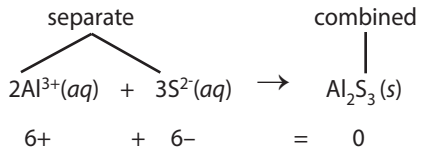
A **binary compound** contains the atoms of only two elements, and binary ionic compounds contain only two types of **monatomic ions** (charged individual atoms).

The name of any ionic compound is simply the name of its constituent metal ion followed by the name of its constituent non-metal ion.

For example, a compound containing sodium ions and chloride ions is called sodium chloride.

The ratio of the ions formed when a particular metal and non-metal react can be predicted through the charge of their common ions, which can be found in the table of common ions at the back of this book. Positively charged ions are called **cations** (think of the letter 't" as a + sign). Negatively charged ions are called **anions.** Note that the sign of the ion charge (+ or –) is written after the numeral. For example, the aluminum ion is denoted as Al^{3+} rather than as Al^{+3}. Scientists felt that placing the plus or minus charge before the numeral might mislead people into believing that it meant greater than or less than zero. In fact, these plus and minus signs designate the type of electrical charge. The different types of electrical charge are called opposite charges because they have opposing effects. They can cancel each other. Note that there is a difference between cancelling two things and two things cancelling. Cancelling two things (e.g., magazine subscriptions) means eliminating them. By contrast, two things cancelling means they negate each other's effects. This is what happens with positive and negative ion charges. When particles with equal but opposite charges bond together, the charges cancel to yield a product with a net charge of zero.

The concept of a net property means that the property of the whole is equal to the sum of the still existing properties of its parts. Ions always associate together in a ratio that results in their charges cancelling to form neutral compounds. For example:



All compounds are neutral. There is no such thing as a charged compound.

The formula Al_2S_3 means that there are $2Al^{3+}$ ions for every $3S^{2-}$ ions. Chemists know the charges but don't show the charges in the formulas of ionic compounds. The ionic nature of the compound is implicit in the combination of a metal and a non-metal. The formula of an ionic compound shows that the compound as a whole is neutral even though it contains both positively and negatively charged ions. Remember that a neutral atom also contains positively and negatively charged particles (protons and electrons) that are not evident in its symbol.

Look at the formula of aluminum sulfide shown below on the left. The number of aluminum ions equals the numerical value of the sulfide ion's charge and vice versa. This simple shortcut for determining the formula of ionic compounds is sometimes called the cross-over method. The cross-over method matches up the opposite charges so that they cancel and will always work if you reduce the formula to its simplest ratio.

$Al^{③+}\ S^{②-}$ Al_2S_3 $\quad$ $Pb^{④+}\ S^{②-}$ Pb_2S_4 which reduces to PbS_2

$2(3+) = 3(2-)$ $\quad$ $2(4+) = 4(2-)$

Multivalent Ions

Some elements have two or more possible valence shell electron configurations (ways of arranging its electrons). These **multivalent** elements have more than one form of stable ion. Many of the transition metals (groups 3 to 12 in the periodic table) are multivalent. For example, iron has two stable ions, Fe^{2+} and Fe^{3+}. Rather than Fe^{2+} being called the iron two plus ion, it is simply called the iron two ion, but it is written as iron(II), bracketing the roman numeral for the numerical value of the ion's charge after the name. Likewise Fe^{3+} is called the iron(III) ion. The roman numerals only appear in the compound's name, never in its formula.

A different method for naming the ions of multivalent elements was used in the not too distant past, and you may encounter it occasionally. In that method, an *–ous* or *–ic* suffix was added to the root of the element's name from which the symbol was derived. The *–ous* suffix denoted the lesser ion charge and the *–ic* suffix denoted the greater ion charge. For example, the iron(II) ion, Fe^{2+}, was called the ferrous ion, and the iron(III) ion, Fe^{3+}, was called the ferric ion.

Sample Problem — Determining the Formula of a Binary Ionic Compound from Its Name

What is the formula of tin(IV) sulfide?

What to Think about	How to Do It
1. Write the symbols of the ions named. 2. Combine the ions in the simplest ratio that results in their charges cancelling.	$Sn^{4+}\ \ S^{2-}$ $1\,Sn^{4+} + 2\,S^{2-} \rightarrow SnS_2$ $4+ \ + \ 4- \ = \ 0$

Sample Problem — Determining the Name of a Binary Ionic Compound from Its Formula

What is the name of Fe_2S_3?

What to Think about	How to Do It
1. Write the names of the two constituent ions. 2. Write the formulas of the possible compounds to see which one has the correct formula.	iron(II) or iron(III), sulfide iron(II) sulfide $Fe^{2+} + S^{2-} \rightarrow FeS$ × iron(III) sulfide $2\,Fe^{3+} + 3\,S^{2-} \rightarrow Fe_2S_3$ ✓

Practice Problems — Determining the Names and Formulas of Binary Ionic Compounds

1. Write the formula of each of the following binary ionic compounds:

   (a) lithium sulfide
   (b) chromium(III) oxide
   (c) aluminum chloride
   (d) lead(II) sulfide
   (e) tin(II) iodide
   (f) zinc bromide

2. Name each of the following binary ionic compounds:

   (a) ZnO _____
   (b) $PbCl_4$ _____
   (c) $CuCl_2$ _____
   (d) NaI _____
   (e) K_2S _____
   (f) CrO _____

Polyatomic Ions

Recall that a molecule is a *neutral* group of covalently bonded atoms. A **polyatomic ion** is a *charged* group of covalently bonded atoms so it's like a molecule except that it has a charge. Polyatomic ions play an extremely important role in the environment, the laboratory, and industry. They are relatively stable species that often remain intact in chemical reactions. Many polyatomic ions are **oxyanions**, consisting of an atom of a given element and some number of oxygen atoms. Typically the element forms polyatomic ions with different numbers of oxygen atoms. When the element forms two such ions, the one with the lesser number of oxygen atoms takes an *–ite* suffix, while the one with the greater number of oxygen atoms takes an *–ate* suffix. For example:

nitrite	NO_2^-	nitrate	NO_3^-
sulfite	SO_3^{2-}	sulfate	SO_4^{2-}

When there are more than two oxyanions in a series, the prefixes *hypo-* (less than) and *per-* (more than) are used to indicate polyatomic ions with still less or still more oxygen atoms. For example:

hypochlorite	ClO^-
chlorite	ClO_2^-
chlorate	ClO_3^-
perchlorate	ClO_4^-

The prefix bi- before the name of a polyatomic ion adds an H^+ to it. For example:

carbonate	CO_3^{2-}	hydrogen carbonate or bicarbonate	HCO_3^- ($H^+ + CO_3^{2-}$)
sulfate	SO_4^{2-}	hydrogen sulfate or bisulfate	HSO_4^- ($H^+ + SO_4^{2-}$)

Note that there are some exceptions to these naming conventions. The hydroxide ion is the only polyatomic ion to have an *–ide* suffix. The dichromate ion has the formula $Cr_2O_7^{2-}$ and despite its prefix does not refer to two chromate ions.

Because they are charged, polyatomic ions associate with oppositely charged ions to form ionic compounds. Polyatomic ions are bracketed in formulas. For example, the formula of calcium nitrate is $Ca(NO_3)_2$. This means that the atoms within the parentheses are bonded covalently to each other and as a group they are bonded ionically to the atom or atoms outside the parentheses. The parentheses are necessary to show that the formula ratio applies to the entire polyatomic ion, not just to its last atom. For example, the formula of calcium hydroxide is $Ca(OH)_2$ meaning that there are two hydroxide (OH^-) ions for each calcium ion. If the parentheses were omitted, the formula would look like this: $CaOH_2$. In that case, the subscript 2 would apply only to the hydrogen atom. By convention, chemists omit the parentheses if no subscript is required. For example, Na(OH) is written as just NaOH.

The ionic compounds that you'll encounter in this course will each have only two types of ions unless otherwise specified. Therefore, the first element in the formula will represent the cation and

the remainder will represent the anion. The one exception is in ammonium compounds; the only polyatomic cation you'll encounter is the ammonium ion, NH_4^+. For example:

$ZnCr_2O_7$ must consist of Zn^{2+} ions and $Cr_2O_7^{2-}$ ions (to cancel the 2+).

$Cr_2O_7^{2-}$ is the dichromate ion so this compound is called zinc dichromate.

$NaClO_2$ must consist of Na^+ ions and ClO_2^- ions (to cancel the 1+).

ClO_2^- is the chlorite ion so this compound is called sodium chlorite.

Sample Problem — Determining the Formula of any Ionic Compound from Its Name

What is the formula of potassium sulfite?

What to Think about	How to Do It
1. Write the symbols of the ions named. 2. Combine the ions in the simplest ratio that results in their charges cancelling.	K^+ SO_3^{2-} $2K^+ + SO_3^{2-} \rightarrow K_2SO_3$ $2+ + 2- = 0$

Sample Problem — Determining the Name of any Ionic Compound from Its Formula

What is the name of $Cr(HSO_4)_2$?

What to Think about	How to Do It
1. Write the names of the two constituent ions. 2. Write the formulas of the possible compounds to see which one has the correct formula.	chromium(II) or chromium(III), bisulfate chromium(II) bisulfate $Cr^{2+} + 2\,HSO_4^- \rightarrow Cr(HSO_4)_2$ ✓ chromium(III) bisulfate $Cr^{3+} + 3\,HSO_4^- \rightarrow Cr(HSO_4)_3$ ✗

Practice Problems — Determining the Names and Formulas of Ionic Compounds

1. Write the formula of each of the following ionic compounds:
   (a) barium sulfate
   (b) silver nitrate
   (c) mercury(II) bromide
   (d) tin(IV) oxalate
   (e) aluminum dichromate
   (f) potassium fluoride

2. Name each of the following ionic compounds:
   (a) $Zn(OH)_2$ _____
   (b) SnO _____
   (c) $Cu(ClO)_2$ _____
   (d) $NaCH_3COO$ _____
   (e) MgI_2 _____
   (f) $FeCr_2O_7$ _____

Names and Formulas of Binary Molecular Compounds

Any cation and anion combine in a single ratio that is easily predictable from their charges. This is why ionic compounds' names do not need to explicitly contain their formulas. On the other hand, two non-metal atoms may share electrons and combine in several ratios. Therefore, the name of the molecular compound must reveal its formula to distinguish it from the other compounds of the same two elements. The name of a molecular compound uses a prefix code to provide its formula. The prefixes used are shown in Table 2.4.1.

Table 2.4.1 *Prefixes for Molecular Compounds*

Number	Prefix
1	mono-
2	di-
3	tri-
4	tetra-
5	penta-
6	hexa-
7	hepta-
8	octa-
9	nona-
10	deca-

The names of all binary compounds have an *–ide* suffix. N_2O_4 is therefore dinitrogen tetroxide. Note that the number of atoms comes before the *name* of the element but after the *symbol* of the element. The prefix *mono-* is understood for the first element named if no prefix is stated. For example, carbon dioxide is CO_2.

Sample Problem — Determining the Formula of a Molecular Compound from Its Name

What is the formula of xenon tetrafluoride?

What to Think about

1. Write the symbols of each element and the number of atoms of each.
2. Rewrite this information as a formula.

How to Do It

1 Xe and 4 F

XeF_4

Sample Problem — Determining the Name of a Molecular Compound from Its Formula

What is the name of P_4S_{10}?

What to Think about

1. Write the names of each element and the number of atoms of each.
2. Rewrite this information using the prefix code.

How to Do It

4 phosphorus and 10 sulfur

tetraphosphorus decasulfide

Practice Problems — Determining the Names and Formulas of Molecular Compounds

1. Write the formula of each of the following molecular compounds:
   (a) nitrogen monoxide
   (b) nitrogen dioxide
   (c) dinitrogen tetroxide
   (d) dinitrogen trioxide

2. Name each of the following molecular compounds:
   (a) PCl_5 _____
   (b) SO_2 _____
   (c) CO _____
   (d) P_2O_5 _____

Hydrates

When many salts crystallize out of aqueous solution they incorporate water molecules in a fixed ratio and pattern into their ionic crystal lattice. These salts are called **hydrates.** Many salts are supplied as hydrates. The water in the crystal doesn't usually present a problem as most salts are destined for aqueous solutions anyway. Water is an integral part of hydrates and thus must be accounted for in both their names and their formulas. The same prefixes used for naming molecules precede the term *-hydrate* to denote the number of water molecules in the formula. This tells you the ratio of water molecules to ions.

Gently warming a hydrated salt will usually remove the water from the crystal. The term "**anhydrous**" refers to the form of the salt without ("an") water ("hydrous"). Some anhydrous salts are *hygroscopic* which means that they can absorb water from the air to form hydrates. Hygroscopic salts that are being used to keep the air dry in a container are called **desiccants**. Pouches containing silicate salts are sometimes used as desiccants in boxes or cases containing binoculars, guitars, shoes, etc. Most labs have a special airtight glass container designed to store containers of hygroscopic salts. This

container is called a **desiccator**. One of the salts is poured onto the bottom of the desiccator to keep its air dry so the others are not exposed to water vapour.

Sample Problem — Determining the Formula of a Hydrate from Its Name

What is the formula of copper(II) sulfate heptahydrate?

What to Think about	How to Do It
1. Write the symbols of the ions named. 2. Combine the ions in the simplest ratio that results in their charges cancelling. 3. Tack on the appropriate number of water molecules to complete the formula.	Cu^{2+} SO_4^{2-} $Cu^{2+} + SO_4^{2-} \rightarrow CuSO_4$ heptahydrate means $7H_2O$ $CuSO_4 \cdot 7H_2O$

Sample Problem — Determining the Name of a Hydrate from its Formula

What is the name of $NaCH_3COO \cdot 3H_2O$?

What to Think about	How to Do It
1. Write the names of the two constituent ions. 2. Tack on the appropriate number of water molecules using the prefix code (–hydrate).	sodium, acetate sodium acetate trihydrate

Practice Problems — Determining the Names and Formulas of Hydrates

1. Write the formula of each of the following hydrates:
   (a) barium chloride dihydrate
   (b) sodium carbonate monohydrate
   (c) iron(III) nitrate nonahydrate
   (d) barium hydroxide octahydrate

2. Name each of the following hydrates:
   (a) $CoCl_2 \cdot 6H_2O$ _____
   b) $FeCl_3 \cdot 4H_2O$ _____
   (c) $Na_2Cr_2O_7 \cdot 2H_2O$ _____
   (d) $MgSO_4 \cdot 7H_2O$ _____

Acids

Acids have a number of interesting and unique properties. An acid can be thought of as one or more H^+ ions bonded to an anion. Remember that in ionic compounds the charges cancel (negate each other) without being cancelled (eliminated). In acids however, these ion charges are actually cancelled as the ions convert into neutral atoms and the group of atoms into a molecule. **Acids** are a special type of molecular compound that can be induced to form ions. The names of acids are based on the name of the anion formed.

The rules for naming acids depend on whether the anion contains oxygen. If the *anion doesn't contain oxygen*, the prefix *hydro-* precedes the name of the anion and the suffix *–ic* replaces the *–ide* in

the anion's name. Hydrogen fluoride (HF) is hydrofluoric acid; hydrogen chloride (HCl) is hydrochloric acid; hydrogen cyanide (HCN) is hydrocyanic acid, etc. There are of course some exceptions. S^{2-} is the sulfide ion, not the sulfuride ion yet hydrogen sulfide (H_2S) is hydrosulfuric acid.

If the *anion does contain oxygen* then the suffix *–ic* replaces *–ate* in the anion's name or the suffix *–ous* replaces *–ite* in the anion's name. Hydrogen sulfate (H_2SO_4) is sulfuric acid and hydrogen sulfite (H_2SO_3) is sulfurous acid.

It bears mentioning that the term "acid" is sometimes ambiguous in that it may refer either to the compound or to its solution. For example, $H_2SO_4(l)$ and $H_2SO_4(aq)$ are both called sulfuric acid. Although the latter might be referred to as a solution of sulfuric acid, it is commonly referred to simply as sulfuric acid. Hydrogen chloride is a gas that condenses into a liquid at –85°C. Because neither the gas nor the liquid is commonly encountered, the term "hydrochloric acid" virtually always refers to an aqueous solution of hydrogen chloride.

Sample Problem — Determining the Formula of an Acid from Its Name

What is the formula of hydrobromic acid?

What to Think about	How to Do It
1. Decode the suffix to determine possible anions: bromic denotes bromide or bromate. 2. Decode the prefix (if any) to select the anion: *hydro-* indicates that the anion doesn't contain oxygen. 3. Determine the formula from the ion charges.	Br^- or BrO_3^- Br^- $H^+ + Br^- \rightarrow HBr$

Sample Problem — Determining the Name of an Acid from Its Formula

What acid has the formula HNO_2?

What to Think about	How to Do It
1. Write the names of the two constituent ions. 2. Use the code for naming acids. The anion contains oxygen so the suffix *–ous* replaces *–ite* in the anion's name.	hydrogen nitrite nitrous acid

Practice Problems — Determining the Names and Formulas of Acids

1. Write the formula of each of the following acids:

   (a) hydrofluoric acid

   (b) hypochlorous acid

   (c) phosphoric acid

   (d) hydrosulfuric acid

2. Name each of the following (as) acids:

   (a) HCH_3COO _____

   (b) H_2SO_3 _____

   (c) H_2CO_3 _____

   (d) HI _____

2.4 Activity: The Ionic Compound Card Game

Question

Are students more likely to study or practise if it's fun?

Background

The basic premise of fun theory is that the easiest way to change people's behaviour is to make the desired behaviour more fun than the other options. Learning is sometimes defined as changing behaviour. From that perspective, we are testing the theory that people are more likely to learn if it's fun than simply virtuous or to our advantage. Learn more about fun theory by searching for "The Fun Theory" online.

Procedure

1. Your teacher will have made some special cards for this fun activity. Thank your teacher. (Teachers: go to edvantagescience.com for templates and instructions.)
2. Deal seven cards to each player.
3. The player to the left of the dealer flips one card face up from the deck. The player then attempts to make a compound by combining one or more cards from his or her hand with the card that is face up on the table. Each compound may only consist of two types of ions.
   If the player makes a compound then the player must correctly state the formula or name of the compound. Those cards are then removed from the game. If the player cannot make a compound or correctly state the formula or name of the compound, the player leaves the card face up on the table.
4. Play rotates clockwise around the table. A player always begins a turn by flipping over a card from the deck so there is always at least one card to combine with. A player may make only one formula per turn. Cards flipped over from the deck remain there until combined with a card or cards from a player's hand. Every time a player is unable to form a compound, the number of cards face up on the table increases by one.
5. The game continues until someone wins by having no cards remaining in his or her hand. The first player to win two hands wins the game.

Results and Discussion

1. Did you enjoy this card game? Why or why not?

2. Did it help you learn how to write chemical formulas or remember the names of ions? Why or why not?

3. Feel free to devise an ionic formula card game of your own: ionic formula rummy, ionic formula "Go Fish," etc.

2.4 Review Questions

1. In each case below, write out the chemical equation for the association of the ions that form the given binary ionic compound.
   Example: magnesium phosphide
   $3\ Mg^{2+} + 2\ P^{3-} \longrightarrow Mg_3P_2$
   (a) sodium fluoride

   (b) iron(II) bromide

   (c) tin(IV) chloride

   (d) chromium(III) sulfide

2. Write the formulas of the following binary ionic compounds:
   (a) chromium(III) chloride

   (b) aluminum fluoride

   (c) magnesium iodide

   (d) tin(IV) oxide

3. Write the names of the following binary ionic compounds:
   (a) K_2O

   (b) $ZnBr_2$

   (c) PbO_2

   (d) $HgCl_2$

4. Write the name and formula of the binary ionic compound formed by:
   (a) potassium and chlorine

   (b) manganese(IV) and oxygen

   (c) iron(III) and sulfur

   (d) copper(II) and iodine

5. In each case below, write out the chemical equation for the association of the ions that form the given ionic compound,
   Example: magnesium nitrate
   $Mg^{2+} + 2\ NO_3^- \longrightarrow Mg(NO_3)_2$
   (a) sodium nitrite

   (b) silver phosphate

   (c) lithium ethanoate (lithium acetate)

   (d) chromium(III) oxalate

6. Write the formulas of the following ionic compounds:
   (a) copper(I) perchlorate

   (b) calcium sulfide

   (c) aluminum monohydrogen phosphate
   (d) magnesium hydroxide

7. Write the names of the following ionic compounds:

   (a) $Ba_3(PO_4)_2$

   (b) $Fe(HSO_3)_2$

   (c) $Pb(HC_2O_4)_4$

   (d) CuH_2PO_4

8. Many minerals contain three types of ions. You can mine several minerals of copper including two forms of copper(II) carbonate hydroxide.
   malachite
   $2\ Cu^{2+} + CO_3^{2-} + 2\ OH^- \longrightarrow Cu_2(CO_3)(OH)_2$
   $4+ \ + \ 2- \ + \ 2- \ = \ 0$
   azurite
   $3\ Cu^{2+} + 2\ CO_3^{2-} + 2\ OH^- \longrightarrow Cu_3(CO_3)_2(OH)_2$
   $6+ \ + \ 4- \ + \ 2- \ = \ 0$
   Notice that more than one ratio of the ions results in their charges cancelling. Thus there is more than one possible compound of three ion combinations. Write a <u>possible</u> formula for:
   (a) iron(III) sodium chromate

   (b) zinc sulfate nitrate

9. Write the formulas of the following molecular compounds:
   (a) chlorine monoxide

   (b) tetraphosphorus hexaoxide

   (c) arsenic pentafluoride

   (d) nitrogen tri-iodide

10. Write the names of the following molecular compounds:
   (a) P_3Br_5

   (b) B_2H_6

   (c) SO_3

   (d) CF_4

11. Write the formulas of the following hydrated salts:
   (a) sodium sulfate decahydrate

   (b) calcium chloride dihydrate

   (c) copper(II) acetate monohydrate

   (d) chromium(III) chloride hexahydrate

12. Write the names of the following hydrated salts:
   (a) $Cd(NO_3)_2 \cdot 4H_2O$

   (b) $Na_2HPO_4 \cdot 7H_2O$

   (c) $CuSO_4 \cdot 5H_2O$

   (d) $Fe(NO_3)_3 \cdot 9H_2O$

13. Why is a hydrate not a mixture of salt and water?

14. Suggest why hydrate formulas are written in the manner they are, rather than using parentheses for the number of water molecules in the formula (e.g., $SrCl_2 \cdot 6H_2O$ rather than $SrCl_2(H_2O)_6$).

15. Write the formulas of the following acids:
   (a) hydrobromic acid

   (b) chromic acid

   (c) chloric acid

   (d) hypochlorous acid

16. Write the names of the following acids:
   (a) H_2S

   (b) $HClO_4$

   (c) HNO_2

   (d) HSCN

17. Write the formulas of the following variety of compounds:
   (a) potassium oxide

   (b) permanganic acid

   (c) sulfur dioxide

   (d) ammonium carbonate

   (e) iron(II) sulfate heptahydrate

   (f) hydrocyanic acid

   (g) sulfur hexafluoride

   (h) calcium acetate monohydrate

   (i) chromium(III) bisulfite

   (j) magnesium hydroxide