Example Exercise 7.1 Classifying Compounds and Acids

Classify each of the following as a binary ionic compound, ternary ionic compound, binary molecular compound, binary acid, or ternary oxyacid:

(a) calcium oxide, CaO
(b) sulfur dioxide, SO_2
(c) silver chromate, Ag_2CrO_4
(d) hydrofluoric acid, $HF(aq)$
(e) carbonic acid, $H_2CO_3(aq)$

Solution

We can refer to the periodic table and classify each compound or solution as follows:

(a) CaO contains two elements, a metal and nonmetal. Thus, CaO is a *binary ionic compound*.

(b) SO_2 contains two elements, both nonmetals. Thus, SO_2 is a *binary molecular compound*.

(c) Ag_2CrO_4 contains three elements, two metals and a nonmetal. Thus, Ag_2CrO_4 is a *ternary ionic compound*.

(d) $HF(aq)$ is a compound of hydrogen and a nonmetal dissolved in water. Thus, $HF(aq)$ is a *binary acid*.

(e) $H_2CO_3(aq)$ is a compound containing three elements, including hydrogen and oxygen, dissolved in water. Thus, H2CO$_3$(aq) is a *ternary oxyacid*.

Example Exercise 7.1 Classifying Compounds and Acids

Continued

Practice Exercise

Classify each of the following as a binary ionic compound, ternary ionic compound, binary molecular compound, binary acid, or ternary oxyacid:

(a) carbon disulfide, CS_2
(b) lithium dichromate, $Li_2Cr_2O_7$
(c) magnesium iodide, MgI_2
(d) nitric acid, $HNO_3(aq)$
(e) hydrochloric acid, $HCl(aq)$

Answers: (a) binary molecular compound; (b) ternary ionic compound; (c) binary ionic compound; (d) ternary oxyacid; (e) binary acid

Concept Exercise

How do you distinguish a binary molecular compound from a binary acid?

Answer: See Appendix G.

Example Exercise 7.2 Classifying Cations and Anions

Classify each of the following ions as a monoatomic cation, monoatomic anion, polyatomic cation, or polyatomic anion:

(a) barium ion, Ba^{2+} (b) chloride ion, Cl^-
(c) nickel(II) ion, Ni^{2+} (d) chlorate ion, ClO_3^-

Solution

We can classify each ion as follows:

(a) Ba^{2+} is a single atom with a positive charge. Thus, Ba^{2+} is a *monoatomic cation*.
(b) Cl^- is a single atom with a negative charge. Thus, Cl^- is a *monoatomic anion*.
(c) Ni^{2+} is a single atom with a positive charge. Thus, Ni^{2+} is a *monoatomic cation*.
(d) ClO_3^- has four atoms and a negative charge. Thus, ClO_3^- is a *polyatomic anion*.

Practice Exercise

Classify each of the following ions as a monoatomic cation, monoatomic anion, polyatomic cation, or polyatomic anion:

(a) ammonium ion, NH_4^+ (b) sulfide ion, S^{2-}
(c) permanganate ion, MnO_4^- (d) stannous ion, Sn^{2+}

Answers: (a) polyatomic cation; (b) monoatomic anion; (c) polyatomic anion; (d) monoatomic cation

Concept Exercise

What is the distinction between Hg^{2+} and Hg_2^{2+}?

Answer: See Appendix G.

Example Exercise 7.3 Names and Formulas of Monoatomic Cations

Provide the formula for the following monoatomic cations:

(a) barium ion (b) cobalt(II) ion

Solution

We can use the periodic table to predict the charge on a cation.

(a) Barium is found in Group IIA/2 and can lose two valence electrons. We predict the formula of the ion is Ba^{2+}.

(b) Cobalt is a transition metal and can lose two or more valence electrons.The Roman number (II) indicates the loss of two electrons, and so the formula of the ion is Co^{2+}.

Practice Exercise

Supply a systematic name for the following monoatomic cations:

(a) Al^{3+} (b) Co^{3+}

Answers: (a) aluminum ion; (b) cobalt(III) ion or cobaltic ion

Concept Exercise

How does the Stock system specify a variable charge on a cation?

Answer: See Appendix G.

Example Exercise 7.4 Names and Formulas of Monoatomic Anions

Provide the formula for each of the following monoatomic anions:

(a) fluoride ion (b) oxide ion

Solution

Recall that nonmetals gain electrons so as to acquire a noble gas electron configuration.

(a) Fluorine is found in Group VIIA/17 and can gain one electron to become isoelectronic with neon. We predict the formula for the fluoride ion is F^{-}.

(b) Oxygen is found in Group VIA/16 and can gain two electrons to become isoelectronic with neon. We predict the formula for the oxide ion is O^{2-}.

Practice Exercise

Supply a systematic name for each of the following monoatomic anions:

(a) Br^{-} (b) N^{3-}

Answers: (a) bromide ion; (b) nitride ion

Concept Exercise

Which one of the following is a monoatomic anion: iodide, iodate, or iodite?

Answer: See Appendix G.

Example Exercise 7.5 Names and Formulas of Polyatomic Ions

Provide a systematic name for each of the following polyatomic oxyanions:

(a) CO_3^{2-} (b) CrO_4^{2-}

(c) ClO_2^- (d) HSO_4^-

Solution

We can make reasonable predictions for the names of many polyatomic ions. This makes the task of memorization much easier.

(a) CO_3^{2-} contains carbon, and we predict the name has the suffix -*ate*. Thus, we predict CO_3^{2-} is named the *carbonate ion*.

(b) CrO_4^{2-} contains chromium, and we predict the name has the suffix -*ate*. Thus, we predict CrO_4^{2-} is named the *chromate ion*.

(c) ClO_2^- is related to ClO_3^-, which is named the chlorate ion. Since ClO_2^- has one less oxygen atom, the suffix changes to -*ite*. Thus, we predict ClO_2^- is named the *chlorite ion*.

(d) HSO_4^- is related to the sulfate ion, SO_4^{2-}. With the addition of hydrogen, the name becomes the *hydrogen sulfate ion*.

Example Exercise 7.5 Names and Formulas of Polyatomic Ions

Continued

Practice Exercise

Provide the formula for each of the following polyatomic oxyanions:

(a) acetate ion (b) dichromate ion

(c) perchlorate ion (d) hydrogen carbonate ion

Answers: (a) $C_2H_3O_2^-$; (b) $Cr_2O_7^{2-}$; (c) ClO_4^-; (d) HCO_3^-

Concept Exercise

How does systematic naming distinguish between a monoatomic anion and a polyatomic anion?

Answer: See Appendix G.

Example Exercise 7.6 Writing Formulas of Binary Ionic Compounds

Write the chemical formula for the following binary compounds given their constituent ions:

(a) copper(I) oxide, Cu^{+} and O^{2-} (b) cadmium oxide, Cd^{2+} and O^{2-}

(c) cobalt(III) oxide, Co^{3+} and O^{2-}

Solution

(a) The copper(I) ion has a charge of 1+, and the oxide ion has a charge of 2–. Thus, two positive ions are required for each negative ion in a neutral formula unit. The formula of copper(I) oxide is written Cu_2O.

(b) Since the cadmium ion and oxide ion each have a charge of 2, the ratio is 1:1, that is, Cd_1O_1. It is not necessary to write the subscript 1, and so the formula of cadmium oxide is simply CdO.

(c) This example is more difficult. The cobalt(III) ion has a charge of 3+ and the oxide ion has a charge of 2–. Since the lowest common multiple is 6, two 3+ ions are required to cancel the charge of three 2– ions. The ratio is 2:3, and the formula of cobalt(III) oxide is written Co_2O_3.

Practice Exercise

Write the chemical formula for the following binary compounds given their constituent ions:

(a) iron(II) sulfide, Fe^{2+} and S^{2-} (b) mercury(I) fluoride, Hg_2^{2+} and F^{-}

(c) lead(IV) oxide, Pb^{4+} and O^{2-}

Answers: (a) FeS; (b) Hg_2F_2; (c) PbO_2

Concept Exercise

What is the formula for a metal oxide if the charge on the metal (M) is +3?

Answer: See Appendix G.

Example Exercise 7.7 Writing Formulas of Ternary Ionic Compounds

Write the chemical formula for each of the following ternary compounds given their constituent ions:

(a) calcium carbonate, Ca^{2+} and CO_3^{2-} (b) calcium hydroxide, Ca^{2+} and OH^-

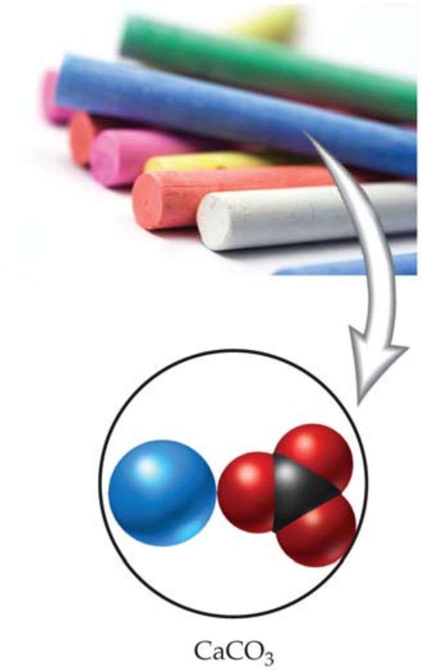
(c) calcium phosphate, Ca^{2+} and PO_4^{3-}

Solution

(a) Since the positive and negative ions each have a charge of 2, one positive ion and one negative ion are required to produce a neutral formula unit, and the formula is $CaCO_3$. Calcium carbonate occurs naturally as ordinary chalk.

(b) The positive ion has a charge of 2+, and the negative ion has a charge of 1–. Therefore, one positive ion and two negative ions are required to produce a neutral formula unit. Since OH^- is a polyatomic ion, parentheses are required, and the formula is written $Ca(OH)_2$. Calcium hydroxide is known as "slaked lime" and is sometimes used to mark the boundaries of an athletic field.

(c) The positive ion has a charge of 2+, and the negative ion has a charge of 3–. The lowest common multiple of the charges is 6. Three positive ions are required for every two negative ions to produce a neutral formula unit. A calcium phosphate formula unit is written $Ca_3(PO_4)_2$. Calcium phosphate is found in tooth enamel.



Chalk, $CaCO_3$ Chalk is an example of a ternary ionic compound composed of calcium ions and carbonate ions.

Example Exercise 7.7 Writing Formulas of Ternary Ionic Compounds

Continued

Practice Exercise

Write the chemical formula for each of the following ternary compounds given their constituent ions:

(a) copper(II) permanganate, Cu^{2+} and MnO_4^{-}

(b) iron(III) carbonate, Fe^{3+} and CO_3^{2-}

(c) potassium dichromate, K^{+} and $Cr_2O_7^{2-}$

Answers: (a) $Cu(MnO_4)_2$; (b) $Fe_2(CO_3)_3$; (c) $K_2Cr_2O_7$

Concept Exercise

What is the formula for a metal carbonate if the charge on the metal (M) is +3?

Answer: See Appendix G.

Example Exercise 7.8 Determining Ionic Charge in a Compound

Determine the ionic charge for iron in the mineral hematite, Fe_2O_3.

Solution

The charge on an oxide ion is 2–, and there are three oxide ions. The total negative charge must be equal to six negative:

$$O^{2-} + O^{2-} + O^{2-} = 6 \text{ negative}$$

Since all compounds are electrically neutral, the total positive charge must equal the total negative charge: 6 negative = 6 positive. Thus, the two iron ions have a charge of six positive:

$$Fe^{x+} + Fe^{x+} = 6 \text{ positive}$$
$$Fe^{x+} = 3 \text{ positive}$$

The iron ion is therefore Fe^{3+}. The name of Fe_2O_3 is iron(III) oxide according to the Stock system. It is named ferric oxide according to the Latin system.

Practice Exercise

Determine the ionic charge for each transition metal in the following compounds:

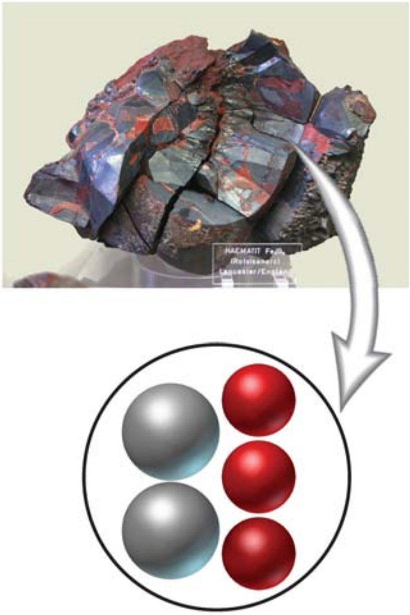
(a) Cu_3P (b) CoN

Answers: (a) Cu^{+}; (b) Co^{3+}

Concept Exercise

What is the ionic charge on a metal (M), given the formula of the oxide, MO_2?

Answer: See Appendix G.



Fe_2O_3

Hematite, Fe_2O_3
Hematite is a mineral found in nature that contains iron.

Example Exercise 7.9 Names of Binary Ionic Compounds

Supply a systematic name for each of the following binary ionic compounds:

(a) ZnO (b) SnF_2

Solution

We can name an ionic compound by designating the two ions.

(a) ZnO contains the zinc ion and the oxide ion; ZnO is named zinc oxide.

(b) SnF_2 contains the tin(II) ion and the fluoride ion. Thus, SnF_2 is named tin(II) fluoride. The Latin system name is stannous fluoride, which is an active ingredient in a popular toothpaste.

Practice Exercise

Supply a systematic name for each of the following binary ionic compounds:

(a) Mn_3P_2 (b) Fe_2S_3

Answers: (a) manganese(II) phosphide; (b) iron(III) sulfide or ferric sulfide

Concept Exercise

Which of the following is a binary ionic compound: sodium chloride, sodium chlorate, or sodium chlorite?

Answer: See Appendix G.

Example Exercise 7.10 Formulas of Binary Ionic Compounds

Provide the formula for each of the following binary ionic compounds:

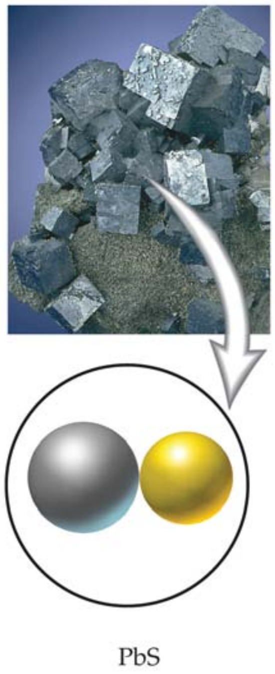
(a) lithium fluoride (b) lead(II) sulfide

Solution

We can write the formula by combining the cation and the anion into a neutral formula unit. Refer to Section 7.4 to review the writing of formula units.

(a) Lithium fluoride is composed of Li^{+} and F^{-}; thus, the formula of the compound is written LiF.

(b) Lead(II) sulfide is composed of Pb^{2+} and S^{2-}; thus, the formula of the compound is written PbS.



Galena, PbS
Galena is a mineral found in nature that contains lead.

Practice Exercise

Provide the formula for the following binary ionic compounds:

(a) copper(II) iodide (b) mercury(II) oxide

Answers: (a) CuI_2; (b) HgO

Concept Exercise

Which of the following is a binary ionic compound: LiCl, $LiClO_3$, or $LiClO_2$?

Answer: See Appendix G.

Example Exercise 7.11 Predicting Formulas of Binary Ionic Compounds

Predict the chemical formula for each of the following binary compounds given the formula of aluminum oxide, Al_2O_3:

(a) gallium oxide (b) aluminum sulfide

Solution

To predict the chemical formula, we compare the elements that are different in the similar compounds.

(a) The elements Ga and Al are both in Group IIIA/3, and so the formula is Ga_2O_3.

(b) The elements S and O are both in Group VIA/16, and so the formula is Al_2S_3.

Practice Exercise

Predict the chemical formula for each of the following binary compounds given the formula of magnesium chloride, $MgCl_2$:

(a) radium chloride (b) magnesium fluoride

Answers: (a) $RaCl_2$; (b) MgF_2

Concept Exercise

Predict the formula for potassium iodide, given the formula of sodium fluoride, NaF.

Answer: See Appendix G.

Example Exercise 7.12 Determining Ionic Charge in a Compound

Determine the ionic charge for iron in $Fe_3(PO_4)_2$.

Solution

The charge on a phosphate ion is 3– and there are two phosphate ions. Therefore, the total negative charge must be equal to six negative:

$$PO_4^{3-} + PO_4^{3-} = 6 \text{ negative}$$

Since all compounds are electrically neutral, the total positive charge must equal the total negative charge: 6 negative = 6 positive. Thus, the three iron ions have a charge of six positive.

$$Fe^{x+} + Fe^{x+} + Fe^{x+} = 6 \text{ positive}$$

$$Fe^{x+} = 2 \text{ positive}$$

The iron ion is therefore Fe^{2+}. The name of $Fe_3(PO_4)_2$ is iron(II) phosphate according to the Stock system. It is named ferrous phosphate according to the Latin system.

Practice Exercise

Determine the ionic charge for the metal cation in each of the following compounds:

(a) $Hg(OH)_2$ (b) $Co(ClO_3)_3$

Answers: (a) Hg^{2+}; (b) Co^{3+}

Concept Exercise

What is the ionic charge on a metal (M), given the formula of the carbonate, MCO_3?

Answer: See Appendix G.

Example Exercise 7.13 Names of Ternary Ionic Compounds

Supply a systematic name for the following ternary ionic compounds:

(a) $KMnO_4$ (b) $Hg(NO_3)_2$

Solution

We can name an ionic compound by designating the two ions.

(a) $KMnO_4$ is composed of the potassium ion and the permanganate ion. Thus, the compound is named potassium permanganate.

(b) $Hg(NO_3)_2$ contains the mercury(II) ion and the nitrate ion. Therefore, it is named mercury(II) nitrate, or mercuric nitrate.

Practice Exercise

Supply a systematic name for each of the following ternary ionic compounds.

(a) $BaCrO_4$ (b) $Cu(NO_2)_2$

Answers: (a) barium chromate; (b) copper(II) nitrite or cupric nitrite

Concept Exercise

Which of the following is a ternary ionic compound: potassium nitride, potassium nitrate, or potassium nitrite?

Example Exercise 7.14 Formulas of Ternary Ionic Compounds

Provide the formula for each of the following ternary ionic compounds:

(a) nickel(II) acetate (b) iron(III) sulfate

Solution

We can write the formula by combining the cation and polyatomic anion into a neutral formula unit.

(a) Nickel(II) acetate is composed of Ni^{2+} and $C_2H_3O_2^-$. The formula of the compound is written $Ni(C_2H_3O_2)_2$.

(b) Iron(III) sulfate contains Fe^{3+} and SO_4^{2-}; the formula is written $Fe_2(SO_4)_3$.

Practice Exercise

Provide the formula for each of the following ternary ionic compounds.

(a) mercury(I) nitrite (b) tin(IV) permanganate

Answers: (a) $Hg_2(NO_2)_2$; (b) $Sn(MnO_4)_4$

Concept Exercise

Which of the following is a ternary ionic compound: LiCl, LiClO, or $LiClO_2$?

Answer: See Appendix G.

Example Exercise 7.15 Predicting Formulas of Ternary Ionic Compounds

Predict the chemical formula for each of the following ternary ionic compounds given the formula of calcium carbonate, $CaCO_3$:

(a) radium carbonate (b) calcium silicate

Solution

To predict the formula, we compare the elements that are different in the similar compounds.

(a) The elements Ra and Ca are both in Group IIA/2. Thus, the formula for radium carbonate is $RaCO_3$.

(b) The elements Si and C are both in Group IVA/14. Therefore, the formula for calcium silicate is $CaSiO_3$.

Practice Exercise

Predict the chemical formula for each of the following ternary compounds given the formula of potassium chlorate, $KClO_3$:

(a) lithium chlorate (b) potassium bromate

Answers: (a) $LiClO_3$; (b) $KBrO_3$

Concept Exercise

Predict the formula for strontium sulfate, given the formula of calcium sulfate, $CaSO_4$.

Answer: See Appendix G.

Example Exercise 7.16 Names of Binary Molecular Compounds

Give the IUPAC systematic name for each of the following binary molecular compounds:

(a) IF_6 (b) Br_3O_8

Solution

We name binary molecular compounds by attaching the suffix *-ide* to the second nonmetal and indicate the atomic ratios by Greek prefixes.

(a) IF_6 is first named iodine fluoride. After supplying the Greek prefixes for the atomic ratios, we have *iodine hexafluoride*.

(b) Br_3O_8 is first named bromine oxide. After supplying the Greek prefixes for the atomic ratios, we have *tribromine octaoxide*.

Practice Exercise

Give the IUPAC systematic name for each of the following binary molecular compounds:

(a) Cl_2O_5 (b) P_4S_{10}

Answers: (a) dichlorine pentaoxide; (b) tetraphosphorus decasulfide

Concept Exercise

Which of the following is named using Greek prefixes to specify the number of atoms of each element: Fe_2O_3 or P_2O_3?

Answer: See Appendix G.

Example Exercise 7.17 Formulas of Binary Molecular Compounds

Provide the formula for each of the following binary molecular compounds:

(a) diphosphorus pentasulfide (b) tetraiodine nonaoxide

Solution

To write the formula, we give the symbol for each element followed by a subscript indicating the number of atoms.

(a) Diphosphorus pentasulfide is composed of two phosphorus atoms and five sulfur atoms. The formula of the compound is written P_2S_5.

(b) Tetraiodine nonaoxide is composed of four iodine atoms and nine oxygen atoms. The formula of the compound is written I_4O_9.

Practice Exercise

Provide the formula for each of the following binary molecular compounds:

(a) diphosphorus tetraiodide (b) sulfur hexafluoride

Answers: (a) P_2I_4; (b) SF_6

Concept Exercise

Which of the following is a binary molecular compound: magnesium oxide or nitrogen oxide?

Answer: See Appendix G.

Example Exercise 7.18 Names of Binary Acids

Give the IUPAC systematic name for HF(*aq*), a binary acid.

Solution

Hydrofluoric Acid, HF Aqueous hydrofluoric acid, HF, is used to etch silicon oxide during the manufacture of computer chips.

Binary acids are named as *hydro*- plus nonmetal stem plus -*ic acid*. Since HF(*aq*) contains the nonmetal fluorine, we construct the systematic name as follows: hydro + fluor + ic acid gives *hydrofluoric acid*.

Practice Exercise

Give the IUPAC systematic name for H2S(*aq*).

Answer: hydrosulfuric acid

Concept Exercise

Which of the following acids is named using a *hydro*- prefix: HBr(*aq*), $HBrO_2$(*aq*), $HBrO_3$(*aq*)?

Answer: See Appendix G.

Example Exercise 7.19 Names of Ternary Oxyacids

Give the IUPAC systematic name for $H_3PO_4(aq)$, a ternary oxyacid.

Solution

Ternary oxyacids are named as *-ic acids* or *-ous acids*. Since $H_3PO_4(aq)$ contains the phosphate oxyanion, it is an *-ic acid*. We construct the systematic name as follows: phosphor + ic acid gives *phosphoric acid*.

Practice Exercise

Give the IUPAC systematic name for H_3PO_3 (aq), a ternary oxyacid.

Answer: phosphorous acid

Concept Exercise

Which of the following acids is named *nonmetal stem* plus *-ic acid*: $HBr(aq)$, $HBrO_2(aq)$, $HBrO_3(aq)$?

Answer: See Appendix G.