Molecules, Compounds, and Chemical Equations

Problems by Topic

Chemical Formulas and Molecular View of the Elements

3.1 The properties of compounds are generally very different from the properties of the elements that compose them. When two elements combine to form a compound, an entirely new substance results.

3.2 Chemical bonds are the result of interactions between charged particles—electrons and protons—that compose atoms. Ionic bonds, which occur between metals and nonmetals, involve the transfer of electrons from one atom to another. Covalent bonds, which occur between two or more nonmetals, involve the sharing of electrons between two atoms.

3.3 Chemical compounds can be represented by chemical formulas and molecular models. The type of formula or model you use depends on how much information you have about the compound and how much you want to communicate. An empirical formula gives the relative number of atoms of each element in the compound. It contains the smallest whole-number ratio of the elements in the compound. A molecular formula gives the actual number of atoms of each element in the compound. A structural formula shows how the atoms are connected. A ball-and-stick model shows the geometry of the compound. A space-filling model shows the relative sizes of the atoms and how they merge together.

3.4 An empirical formula gives the relative number of atoms of each element in a compound.

A molecular formula gives the actual number of atoms of each element in a molecule of a compound.

3.5 Atomic elements exist in nature with single atoms as their base units. Neon (Ne), gold (Au), and potassium (K) are a few examples of atomic elements.

Molecular elements do not normally exist in nature with single atoms as their base unit; rather, they exist as molecules, two or more atoms of the same element bonded together. Most exist as diatomic molecules [e.g., hydrogen (H₂), nitrogen (N₂), and oxygen (O₂)]. Some exist as polyatomic molecules: phosphorus (P₄) and sulfur (S₈).

Ionic compounds are generally composed of one or more metal cations (usually one type of metal) and one or more nonmetal anions bound together by ionic bonds. Sodium chloride (NaCl) and potassium sulfate (K₂SO₄) are examples of ionic compounds.

Molecular compounds are composed of two or more covalently bonded nonmetals. Examples are water (H₂O), sulfur dioxide (SO₂), and nitrogen dioxide (NO₂).

3.6 To write a formula for an ionic compound, do the following: (1) Write the symbol for the metal cation and its charge followed by the symbol for the nonmetal or polyatomic anion and its charge. (2) Adjust the subscript on each cation and anion to balance the overall charge. (3) Check that the sum of the charges of the cations equals the sum of the charges of the anions.

3.7 Binary ionic compounds are named using the name of the cation (metal) and the base name of the anion (nonmetal) + the suffix -ide. Ionic compounds that contain a polyatomic anion are named using the name of the cation (metal) and the name of the polyatomic anion.
Ionic compounds formed from metals that can form more than one cation must include the charge of the cation in the name. The charge is indicated by putting the charge of the metal in Roman numerals in parentheses after the metal name. Metals that can form only one cation do not need the charge specified.

To name a binary molecular inorganic compound, list the name of the first element with a prefix to indicate the number of atoms in the compound if there is more than one, followed by the base name of the second element with a prefix to indicate the number of atoms in the compound, followed by the suffix -ide.

The prefix mono = 1; di = 2; tri = 3; tetra = 4; penta = 5; hexa = 6.

Binary acids are composed of hydrogen and a nonmetal. The names for binary acids have the form: hydro plus the base name of the nonmetal + -ic acid. Oxyacids contain hydrogen and an oxyanion. The names of oxyacids depend on the ending of the oxyanion and have the following forms: oxyanions ending with -ate: base name of the oxyanion + ic acid; oxyanions ending with -ite: base name of the oxyanion + ous acid.

The formula mass is the average mass of the molecule (or formula unit) of a compound. The formula mass allows the conversion between the mass of molecules and the number of molecules present.

The chemical formula indicates the elements present in the compound and the relative number of atoms of each type. The chemical formula gives the conversion factor between the kind of element and the formula; it also allows the determination of mass percent composition.

Mass percent composition is the mass of an element of the compound divided by the total mass of the compound times 100. Mass percent composition is used as a conversion factor between the mass of the element and the mass of the compound.

Chemical formulas contain inherent relationships between atoms (or moles of atoms) and molecules (or moles of molecules). For example, the formula CCl\textsubscript{2}F\textsubscript{2} tells us that one mole of CCl\textsubscript{2}F\textsubscript{2} contains one mole of C atoms, two moles of Cl atoms, and two moles of F atoms.

The experimental data showing the relative masses of the elements in a compound can be used to obtain an empirical formula.

The molecular formula is a whole-number multiple of the empirical formula. To find the molecular formula, the molar mass of the compound must be known. The molecular molar mass divided by the empirical molar mass gives the whole-number multiple used to convert the empirical formula to the molecular formula.

In combustion analysis, the unknown compound undergoes combustion (burning) in the presence of pure oxygen. All of the carbon in the sample is converted to CO\textsubscript{2}, and all of the hydrogen is converted to H\textsubscript{2}O. Combustion analysis can be used to determine the empirical formula of a hydrocarbon.

Organic compounds are composed of carbon; hydrogen; and a few other elements, including nitrogen, oxygen, and sulfur.

An alkane is a hydrocarbon containing only single C to C bonds. An alkene contains at least one double C to C bond, and an alkyne contains at least one triple C to C bond.

In functionalized hydrocarbons, a functional group—a characteristic atom or group of atoms—has been incorporated into the hydrocarbon. The family of organic compounds known as alcohols has an —OH functional group.
3.23 The chemical formula gives you the kind of atom and the number of each atom in the compound.
(a) \( \text{Mg}_2(\text{PO}_4)_2 \) contains: 3 magnesium atoms, 2 phosphorus atoms, and 8 oxygen atoms
(b) \( \text{BaCl}_2 \) contains: 1 barium atom and 2 chlorine atoms
(c) \( \text{Fe(NO}_2)_2 \) contains: 1 iron atom, 2 nitrogen atoms, and 4 oxygen atoms
(d) \( \text{Ca(OH)}_2 \) contains: 1 calcium atom, 2 oxygen atoms, and 2 hydrogen atoms

3.24 The chemical formula gives you the kind of atom and the number of each atom in the compound.
(a) \( \text{Ca(NO}_2)_2 \) contains: 1 calcium atom, 2 nitrogen atoms, and 4 oxygen atoms
(b) \( \text{CuSO}_4 \) contains: 1 copper atom, 1 sulfur atom, and 4 oxygen atoms
(c) \( \text{Al(NO}_3)_3 \) contains: 1 aluminum atom, 3 nitrogen atoms, and 9 oxygen atoms
(d) \( \text{Mg(HCO}_3)_2 \) contains: 1 magnesium atom, 2 hydrogen atoms, 2 carbon atoms, and 6 oxygen atoms

3.25 (a) 1 blue = nitrogen, 3 white = hydrogen: \( \text{NH}_3 \)
(b) 2 black = carbon, 6 white = hydrogen: \( \text{C}_2\text{H}_6 \)
(c) 1 yellow = sulfur, 3 red = oxygen: \( \text{SO}_3 \)

3.26 (a) 1 blue = nitrogen, 2 red = oxygen: \( \text{NO}_2 \)
(b) 1 yellow = sulfur, 2 white = hydrogen: \( \text{H}_2\text{S} \)
(c) 1 black = carbon, 4 white = hydrogen: \( \text{CH}_4 \)

3.27 (a) Neon is an element, and it is not one of the elements that exists as diatomic molecules; therefore, it is an atomic element.
(b) Fluorine is one of the elements that exists as diatomic molecules; therefore, it is a molecular element.
(c) Potassium is not one of the elements that exists as diatomic molecules; therefore, it is an atomic element.
(d) Nitrogen is one of the elements that exists as diatomic molecules; therefore, it is a molecular element.

3.28 (a) Hydrogen is one of the elements that exists as diatomic molecules; therefore, it has a molecule as its basic unit.
(b) Iodine is one of the elements that exists as diatomic molecules; therefore, it has a molecule as its basic unit.
(c) Lead is not one of the elements that exists as a diatomic molecule; therefore, it does not have a molecule as its basic unit.
(d) Oxygen is one of the elements that exists as diatomic molecules; therefore, it has a molecule as its basic unit.

3.29 (a) \( \text{CO}_2 \) is a compound composed of a nonmetal and a nonmetal; therefore, it is a molecular compound.
(b) \( \text{NiCl}_2 \) is a compound composed of a metal and a nonmetal; therefore, it is an ionic compound.
(c) \( \text{NaI} \) is a compound composed of a metal and a nonmetal; therefore, it is an ionic compound.
(d) \( \text{PCl}_3 \) is a compound composed of a nonmetal and a nonmetal; therefore, it is a molecular compound.

3.30 (a) \( \text{CF}_2\text{Cl}_2 \) is a compound composed of a nonmetal and two other nonmetals; therefore, it is a molecular compound.
(b) \( \text{CCl}_4 \) is a compound composed of a nonmetal and a nonmetal; therefore, it is a molecular compound.
(c) \( \text{PtO}_2 \) is a compound composed of a metal and a nonmetal; therefore, it is an ionic compound.
(d) \( \text{SO}_3 \) is a compound composed of a nonmetal and a nonmetal; therefore, it is a molecular compound.

3.31 (a) white = hydrogen: a molecule composed of two of the same elements; therefore, it is a molecular element.
(b) blue = nitrogen, white = hydrogen: a molecule composed of a nonmetal and a nonmetal; therefore, it is a molecular compound.
(c) purple = sodium: a substance composed of the same atoms; therefore, it is an atomic element.
Formsulas and Names for Ionic Compounds

3.33  To write the formula for an ionic compound, do the following: (1) Write the symbol for the metal cation and its charge and the symbol for the nonmetal anion and its charge. (2) Adjust the subscript on each cation and anion to balance the overall charge. (3) Check that the sum of the charges of the cations equals the sum of the charges of the anions.

(a) calcium and oxygen: $\text{Ca}^{2+}$ O$^2-$ CaO cations 2+, anions 2-
(b) zinc and sulfur: $\text{Zn}^{2+}$ S$^2-$ ZnS cations 2+, anions 2-
(c) rubidium and bromine: $\text{Rb}^+$ Br$^-$ RbBr cation +, anions -
(d) aluminum and oxygen: $\text{Al}^{3+}$ O$^2-$ Al$2$O$3$ cation 2(3+) = 6+, anions 3(2-) = 6-

3.34  To write the formula for an ionic compound, do the following: (1) Write the symbol for the metal cation and its charge and the symbol for the nonmetal anion and its charge. (2) Adjust the subscript on each cation and anion to balance the overall charge. (3) Check that the sum of the charges of the cations equals the sum of the charges of the anions.

(a) silver and chlorine: $\text{Ag}^+$ Cl$^-$ AgCl cation +, anions -
(b) sodium and sulfur: Na$^+$ S$2-$ Na$2$S cation 2(1+) = 2+, anion 2-
(c) aluminum and sulfur: $\text{Al}^{3+}$ S$2-$ Al$2$S$3$ cation 2(3+) = 6+, anions 3(2-) = 6-
(d) potassium and chlorine: K$^+$ Cl$^-$ KCl cation +, anion -

3.35  To write the formula for an ionic compound, do the following: (1) Write the symbol for the metal cation and its charge and the symbol for the polyatomic anion and its charge. (2) Adjust the subscript on each cation and anion to balance the overall charge. (3) Check that the sum of the charges of the cations equals the sum of the charges of the anions. 

Cation = calcium; Ca$^{2+}$

(a) hydroxide: OH$^-$ Ca(OH)$_2$ cation 2+, anion 2(1-) = 2-
(b) chromate: CrO$_4^{2-}$ CaCrO$_4$ cation 2+, anion 2-
(c) phosphate: PO$_4^{3-}$ Ca$_3$(PO$_4$)$_2$ cation 3(2+) = 6+, anion 2(3-) = 6-
(d) cyanide: CN$^-$ Ca(CN)$_2$ cation 2+, anion 2(1-) = 2-

3.36  To write the formula for an ionic compound, do the following: (1) Write the symbol for the metal cation and its charge and the symbol for the nonmetal anion and its charge. (2) Adjust the subscript on each cation and anion to balance the overall charge. (3) Check that the sum of the charges of the cations equals the sum of the charges of the anions.

Cation = potassium; K

(a) carbonate: CO$_3^{2-}$ K$_2$CO$_3$ cation 2(1+) = 2+, anion 2-
(b) phosph ate: PO$_4^{3-}$ K$_3$PO$_4$ cation 3(1+) = 3+, anion 3-
(c) hydrogen phosphate: HPO$_4^{2-}$ K$_2$HPO$_4$ cation 2(1+) = 2+, anion 2-
(d) acetate: C$_2$H$_3$O$_2^{-}$ KC$_2$H$_3$O$_2$ cation 1+, anion 1-

3.37  To name a binary ionic compound, name the metal cation followed by the base name of the anion + -ide.

(a) Mg$_3$N$_2$: The cation is magnesium; the anion is from nitrogen, which becomes nitride: magnesium nitride.
(b) KF: The cation is potassium; the anion is from fluorine, which becomes fluoride: potassium fluoride.
(c) Na$_2$O: The cation is sodium; the anion is from oxygen, which becomes oxide: sodium oxide.
(d) Li$_2$S: The cation is lithium; the anion is from sulfur, which becomes sulfide: lithium sulfide.
(e) CsF: The cation is cesium; the anion is fluorine, which becomes fluoride: cesium fluoride.
(f) KI: The cation is potassium; the anion is iodine, which becomes iodide: potassium iodide.

3.38  To name an ionic compound with a metal cation that can have more than one charge, name the metal cation followed by parentheses with the charge in Roman numerals followed by the base name of the anion + -ide.

(a) SnCl$_4$: The charge on Sn must be 4+ for the compound to be charge neutral: the cation is tin(IV); the anion is from chlorine, which becomes chloride: tin(IV) chloride.
(b) PbI$_2$: The charge on Pb must be 2+ for the compound to be charge neutral: the cation is lead(II); the anion is from iodine, which becomes iodide: lead(II) iodide.
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(c) Fe₂O₃: The charge on Fe must be 3+ for the compound to be charge neutral; the cation is iron(III); the anion is from oxygen, which becomes oxide: iron(III) oxide.

(d) Cu₂O: The charge on Cu must be 2+ for the compound to be charge neutral; the cation is copper(II); the anion is from iodine, which becomes iodide: copper(II) iodide.

(e) HgBr₂: The charge of Hg must be 2+ for the compound to be charge neutral; the cation is mercury(II); the anion is from bromine, which becomes bromide: mercury(II) bromide.

(f) CrCl₃: The charge on Cr must be 2+ for the compound to be charge neutral; the cation is chromium(II); the anion is from chlorine, which becomes chloride: chromium(II) chloride.

3.39 To name these compounds, you must first decide whether the metal cation is invariant or can have more than one charge. Then, name the metal cation followed by the base name of the anion + -ide.

(a) SnO: Sn can have more than one charge. The charge on Sn must be 2+ for the compound to be charge neutral: the cation is tin(II); the anion is from oxygen, which becomes oxide: tin(II) oxide.

(b) Cr₂S₃: Cr can have more than one charge. The charge on Cr must be 3+ for the compound to be charge neutral: the cation is chromium(III); the anion is from sulfur, which becomes sulfide: chromium(III) sulfide.

(c) RbI: Rb is invariant: the cation is rubidium; the anion is from iodine, which becomes iodide: rubidium iodide.

(d) BaBr₂: Ba is invariant: the cation is barium; the anion is from bromine, which becomes bromide: barium bromide.

3.40 To name these compounds, you must first decide whether the metal cation is invariant or can have more than one charge. Then, name the metal cation followed by the base name of the anion + -ide.

(a) BaS: Ba is invariant: The cation is barium; the anion is from sulfur, which becomes sulfide: barium sulfide.

(b) FeCl₃: Fe can have more than one charge. The charge on Fe must be 3+ for the compound to be charge neutral: The cation is iron(III); the anion is from chlorine, which becomes chloride: iron(III) chloride.

(c) PbI₂: Pb can have more than one charge. The charge on Pb must be 4+ for the compound to be charge neutral: The cation is lead(IV); the anion is from iodine, which becomes iodide: lead(IV) iodide.

(d) SrBr₂: Sr is invariant: The cation is strontium; the anion is from bromine, which becomes bromide: strontium bromide.

3.41 To name these compounds, you must first decide whether the metal cation is invariant or can have more than one charge. Then, name the metal cation followed by the name of the polyatomic anion.

(a) Cu(NO₂)₂: Cu can have more than one charge. The charge on Cu must be 1+ for the compound to be charge neutral: The cation is copper(I); the anion is nitrite: copper(I) nitrite.

(b) Mg(C₂H₅O₂)₂: Mg is invariant: The cation is magnesium; the anion is acetate: magnesium acetate.

(c) Ba(NO₃)₂: Ba is invariant: The cation is barium; the anion is nitrate: barium nitrate.

(d) Pb(C₂H₅O₂)₂: Pb can have more than one charge. The charge on Pb must be 2+ for the compound to be charge neutral: The cation is lead(II); the anion is acetate: lead(II) acetate.

3.42 To name these compounds, you must first decide whether the metal cation is invariant or can have more than one charge. Then name the metal cation followed by the name of the polyatomic anion.

(a) Ba(OH)₂: Ba is invariant: The cation is barium; the anion is hydroxide: barium hydroxide.

(b) NH₄I: The cation is ammonium; the anion is from iodine, which becomes iodide: ammonium iodide.

(c) NaBrO₄: Na is invariant: The cation is sodium; the anion is perbromate: sodium perbromate.

(d) Fe(OH)₃: Fe can have more than one charge. The charge on Fe must be 3+ for the compound to be charge neutral: The cation is iron(III); the anion is hydroxide: iron(III) hydroxide.

3.43 To write the formula for an ionic compound, do the following: (1) Write the symbol for the metal cation and its charge and the symbol for the nonmetal anion or polyatomic anion and its charge. (2) Adjust the subscript on each cation and anion to balance the overall charge. (3) Check that the sum of the charges of the cations equals the sum of the charges of the anions.

(a) sodium hydrogen sulfite: Na⁺ HSO₃⁻ NaHSO₃ cation 1+, anion 1−

(b) lithium permanganate: Li⁺ MnO₄⁻ LiMnO₄ cation 1+, anion 1−

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(c) silver nitrate: \( \text{Ag}^+ \quad \text{NO}_3^- \quad \text{AgNO}_3 \) cation 1+, anion 1–
(d) potassium sulfate: \( \text{K}^+ \quad \text{SO}_4^{2–} \quad \text{K}_2\text{SO}_4 \) cation 2(1+) = 2+, anion 2–
(e) rubidium hydrogen sulfate: \( \text{Rb}^+ \quad \text{HSO}_4^- \quad \text{RbHSO}_4 \) cation 1+, anion 1–
(f) potassium hydrogen carbonate: \( \text{K}^+ \quad \text{HCO}_3^- \quad \text{KHCO}_3 \) cation 1+, anion 1–

3.44 To write the formula for an ionic compound, do the following: (1) Write the symbol for the metal cation and its charge and the symbol for the nonmetal anion or polyatomic anion and its charge. (2) Adjust the subscript on each cation and anion to balance the overall charge. (3) Check that the sum of the charges of the cations equals the sum of the charges of the anions.

(a) copper(II) chloride: \( \text{Cu}^{2+} \quad \text{Cl}^- \quad \text{CuCl}_2 \) cation 2+, anion 2(1–) = 2–
(b) copper(I) iodate: \( \text{Cu}^+ \quad \text{IO}_3^- \quad \text{CuIO}_3 \) cation 1+, anion 1–
(c) lead(II) chromate: \( \text{Pb}^{2+} \quad \text{CrO}_4^{2–} \quad \text{PbCrO}_4 \) cation 2+, anion 2–
(d) calcium fluoride: \( \text{Ca}^{2+} \quad \text{F}^- \quad \text{CaF}_2 \) cation 2+, anion 2(1–) = 2–
(e) potassium hydroxide: \( \text{K}^+ \quad \text{OH}^- \quad \text{KOH} \) cation 1+, anion 1–
(f) iron(II) phosphate: \( \text{Fe}^{2+} \quad \text{PO}_4^{3–} \quad \text{Fe}_3(\text{PO}_4)_2 \) cation 3(2+) = 6+, anion 2(3–) = 6–

3.45 Hydrates are named the same way as other ionic compounds with the addition of the term prefixhydrate, where the prefix is the number of water molecules associated with each formula unit.

(a) \( \text{CoSO}_4 \cdot 7\text{H}_2\text{O} \) cobalt(II) sulfate heptahydrate
(b) \( \text{IrBr}_3 \cdot 4\text{H}_2\text{O} \) iridium(III) bromide tetrahydrate
(c) \( \text{Mg}(\text{BrO}_3)_2 \cdot 6\text{H}_2\text{O} \) magnesium bromate hexahydrate
(d) \( \text{K}_2\text{CO}_3 \cdot 2\text{H}_2\text{O} \) potassium carbonate dihydrate

3.46 Hydrates are named the same way as other ionic compounds with the addition of the term prefixhydrate, where the prefix is the number of water molecules associated with each formula unit.

(a) \( \text{Co}_2(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O} \) cobalt(II) phosphate octahydrate
(b) \( \text{BeCl}_2 \cdot 2\text{H}_2\text{O} \) beryllium chloride dihydrate
(c) \( \text{CrPO}_4 \cdot 3\text{H}_2\text{O} \) chromium(III) phosphate trihydrate
(d) \( \text{LiNO}_2 \cdot \text{H}_2\text{O} \) lithium nitrite monohydrate

Formulas and Names for Molecular Compounds and Acids

3.47 (a) CO The name of the compound is the name of the first element, carbon, followed by the base name of the second element, ox, prefixed by mono- to indicate 1 and given the suffix -ide. Because the prefix ends with “o” and the base name begins with “o,” the first “o” is dropped: carbon monoxide.
(b) NI\(_3\) The name of the compound is the name of the first element, nitrogen, followed by the base name of the second element, iod, prefixed by tri- to indicate 3 and given the suffix -ide: nitrogen triiodide.
(c) SiCl\(_4\) The name of the compound is the name of the first element, silicon, followed by the base name of the second element, chlor, prefixed by tetra- to indicate 4 and given the suffix -ide: silicon tetrachloride.
(d) N\(_4\)Se\(_4\) The name of the compound is the name of the first element, nitrogen, prefixed by tetra- to indicate 4 followed by the base name of the second element, selen, prefixed by tetra- to indicate 4 and given the suffix -ide: tetranitrogen tetraselenide.

3.48 (a) SO\(_3\) The name of the compound is the name of the first element, sulfur, followed by the base name of the second element, ox, prefixed by tri- to indicate 3 and given the suffix -ide: sulfur trioxide.
(b) SO\(_2\) The name of the compound is the name of the first element, sulfur, followed by the base name of the second element, ox, prefixed by di- to indicate 2 and given the suffix -ide: sulfur dioxide.
(c) BrF\(_5\) The name of the compound is the name of the first element, bromine, followed by the base name of the second element, fluor, prefixed by penta- to indicate 5 and given the suffix -ide: bromine pentfluoride.
(d) NO The name of the compound is the name of the first element, nitrogen, followed by the base name of the second element, ox, prefixed by mono- to indicate 1 and given the suffix -ide. Because the prefix ends with “o” and the base name begins with “o,” the first “o” is dropped: nitrogen monoxide.
3.49  (a) phosphorus trichloride: \( \text{PCl}_3 \)
(b) chlorine monoxide: \( \text{ClO} \)
(c) disulfur tetrafluoride: \( \text{S}_2\text{F}_4 \)
(d) phosphorus pentfluoride: \( \text{PF}_5 \)

3.50  (a) boron tribromide: \( \text{BBBr}_3 \)
(b) dichlorine monoxide: \( \text{Cl}_2\text{O} \)
(c) xenon tetrafluoride: \( \text{XeF}_4 \)
(d) carbon tetrafluoride: \( \text{CF}_4 \)

3.51  (a) HI: The base name of I is iod, so the name is hydroiodic acid.
(b) HNO₃: The oxyanion is nitrate, which ends in -ate; therefore, the name of the acid is nitric acid.
(c) \( \text{H}_2\text{CO}_3 \): The oxyanion is carbonate, which ends in -ate; therefore, the name of the acid is carbonic acid.

3.52  (a) HCl: The base name of Cl is chlor, so the name is hydrochloric acid.
(b) \( \text{HClO}_2 \): The oxyanion is chlorite, which ends in -ite; therefore, the name of the acid is chlorous acid.
(c) \( \text{H}_2\text{SO}_4 \): The oxyanion is sulfate, which ends in -ate; therefore, the name of the acid is sulfuric acid.

3.53  (a) hydrofluoric acid: \( \text{HF}(aq) \)
(b) hydrobromic acid: \( \text{HBr}(aq) \)
(c) sulfurous acid: \( \text{H}_2\text{SO}_3(aq) \)

3.54  (a) phosphoric acid: \( \text{H}_3\text{PO}_4(aq) \)
(b) hydrocyanic acid: \( \text{HCN}(aq) \)
(c) chloric acid: \( \text{HClO}_3(aq) \)

3.55  To use the flowchart, begin by determining the type of compound you are trying to name—ionic, molecular, or acid.

(a) \( \text{SrCl}_2 \) is composed of a metal and a nonmetal, so it is ionic. Begin at the box labeled "IONIC" at the far left of the flowchart. The metal in the compound can only form one type of ion; therefore, take the left branch in the flowchart. Then name the compound according to the blocks at the end of the path in the flowchart. Write the name of the cation followed by the base name of the anion appended with the ending -ide. The full name is stronitum chloride.

(b) \( \text{SnO}_2 \) is composed of a metal and a nonmetal, so it is ionic. Begin at the box labeled "IONIC" at the far left of the flowchart. The metal in the compound forms more than one type of ion; therefore, take the right branch in the flowchart. Then name the compound according to the blocks at the end of the path in the flowchart. Write the name of the cation followed by the charge of the cation in Roman numerals followed by the base name of the anion appended with the ending -ide. The full name is tin(IV) oxide.

(c) \( \text{P}_2\text{S}_5 \) is composed of two nonmetals and is a molecular compound. Begin at the box labeled "MOLECUAR" in the middle of the flowchart. Write the prefix to indicate the number of atoms of the first element, then the name of the first element followed by the prefix to indicate the number of atoms of the second element, then the base name of the second element followed by the ending -ide. The full name is diposphorus pentasulfide.

(d) \( \text{HC}_2\text{H}_2\text{O}_2(aq) \) is a compound composed of H and one or more nonmetals, so it is an acid. Begin at the box labeled "ACIDS" at the far right of the flowchart. The acid is an oxyacid; therefore, take the right branch in the flowchart. The anion has the ending -ite, so take the right branch of the flowchart. Then name the compound according to the blocks at the end of the path in the flowchart. Write the base name of the oxyanion appended with the ending -ic followed by acid. The name of the oxoanion is acetate, so the name of the acid is acetic acid.

3.56  To use the flowchart, begin by determining the type of compound you are trying to name—ionic, molecular, or acid.

(a) \( \text{HNO}_2(aq) \) is a compound composed of H and one or more nonmetals, so it is an acid. Begin at the box labeled "ACIDS" at the far right of the flowchart. The acid is an oxyacid; therefore, take the right branch in the flowchart. The anion has the ending -ite, so take the right branch of the flowchart. Then name the compound according to the blocks at the end of the path in the flowchart. Write the base name of the oxyanion appended with the ending -ous followed by acid. The name of the oxoanion is nitrite so the name of the acid is nitrous acid.

(b) \( \text{B}_2\text{Cl}_6 \) is composed of two nonmetals and is a molecular compound. Begin at the box labeled "MOLECUAR" in the middle of the flowchart. Write the prefix to indicate the number of atoms of the first element, then the name of the first element followed by the prefix to indicate the number of atoms of the second element, then the base name of the second element followed by the ending -ide. The full name is diboron dichloride.
(c) BaCl₂ is composed of a metal and a nonmetal, so it is ionic. Begin at the box labeled “IONIC” at the far left of the flowchart. The metal in the compound can only form one type of ion; therefore, take the left branch in the flowchart. Then name the compound according to the blocks at the end of the path in the flowchart. Write the name of the cation followed by the base name of the anion appended with the ending -ide. The full name is barium chloride.

(d) CrCl₃ is composed of a metal and a nonmetal, so it is ionic. Begin at the box labeled “IONIC” at the far left of the flowchart. The metal in the compound forms more than one type of ion; therefore, take the right branch in the flowchart. Then name the compound according to the blocks at the end of the path in the flowchart. Write the name of the cation followed by the charge of the cation in Roman numerals followed by the base name of the anion appended with the ending -ide. The full name is chromium(III) chloride.

3.57 To use the flowchart, begin by determining the type of compound you are trying to name—ionic, molecular, or acid.

(a) KCIO₃ is composed of a metal and an oxyanion, so it is ionic. Begin at the box labeled “IONIC” at the far left of the flowchart. The metal in the compound can only form one type of ion; therefore, take the left branch in the flowchart. Then name the compound according to the blocks at the end of the path in the flowchart. Write the name of the cation followed by the base name of the anion appended with the ending -ate. ClO₃⁻ is the polyatomic ion chlorate, so the name of the compound is potassium chlorate.

(b) I₂O₃ is composed of two nonmetals and is a molecular compound. Begin at the box labeled “MOLECULAR” in the middle of the flowchart. Write the prefix to indicate the number of atoms of the first element, then the name of the first element followed by the prefix to indicate the number of atoms of the second element, then the base name of the second element followed by the ending -ide. The full name is diiodine pentoxide.

(c) PbSO₄ is composed of a metal and an oxyanion, so it is ionic. Begin at the box labeled “IONIC” at the far left of the flowchart. The metal in the compound forms more than one type of ion; therefore, take the right branch in the flowchart. Then name the compound according to the blocks at the end of the path in the flowchart. Write the name of the cation followed by the charge of the cation in Roman numerals followed by the base name of the anion appended with the ending -ate. SO₄²⁻ is the polyatomic ion sulfate, so the name of the compound is lead(II) sulfate.

3.58 To use the flowchart, begin by determining the type of compound you are trying to name—ionic, molecular, or acid.

(a) XeO₃ is composed of two nonmetals and is a molecular compound. Begin at the box labeled “MOLECULAR” in the middle of the flowchart. Write the prefix to indicate the number of atoms of the first element, then the name of the first element followed by the prefix to indicate the number of atoms of the second element, then the base name of the second element followed by the ending -ide. The full name is xenon trioxide.

(b) KCIO is composed of a metal and an oxyanion, so it is ionic. Begin at the box labeled “IONIC” at the far left of the flowchart. The metal in the compound can only form one type of ion; therefore, take the left branch in the flowchart. Then name the compound according to the blocks at the end of the path in the flowchart. Write the name of the cation followed by the base name of the anion appended with the ending -ite. ClO⁻ is the polyatomic ion hypochlorite, so the name of the compound is potassium hypochlorite.

(c) CoSO₄ is composed of a metal and an oxyanion, so it is ionic. Begin at the box labeled “IONIC” at the far left of the flowchart. The metal in the compound forms more than one type of ion; therefore, take the right branch in the flowchart. Then name the compound according to the blocks at the end of the path in the flowchart. Write the name of the cation followed by the charge of the cation in Roman numerals followed by the base name of the anion appended with the ending -ate. SO₄²⁻ is the polyatomic ion sulfate. So the name of the compound is cobalt(II) sulfate.

**Formula Mass and the Mole Concept for Compounds**

3.59 To find the formula mass, sum the atomic masses of each atom in the chemical formula.

(a) NO₂ formula mass = 1 × (atomic mass N) + 2 × (atomic mass O)
= 1 × (14.01 amu) + 2 × (16.00 amu)
= 46.01 amu

(b) C₄H₁₀ formula mass = 4 × (atomic mass C) + 10 × (atomic mass H)
= 4 × (12.01 amu) + 10 × (1.008 amu)
= 58.12 amu

(c) C₆H₁₂O₆ formula mass = 6 × (atomic mass C) + 12 × (atomic mass H) + 6 × (atomic mass O)
= 6 × (12.01 amu) + 12 × (1.008 amu) + 6 × (16.00 amu)
= 180.16 amu

(d) Cr(NO₃)₃ formula mass = 1 × (atomic mass Cr) + 3 × (atomic mass N) + 9 × (atomic mass O)
= 1 × (52.00 amu) + 3 × (14.01 amu) + 9 × (16.00 amu)
= 238.03 amu

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3.60 To find the formula mass, sum the atomic masses of each atom in the chemical formula.
(a) \( \text{MgBr}_2 \) formula mass = \( 1 \times (\text{atomic mass Mg}) + 2 \times (\text{atomic mass Br}) \)
= \( 1 \times (24.31 \text{ amu}) + 2 \times (79.90 \text{ amu}) \)
= 184.11 amu
(b) \( \text{HNO}_2 \) formula mass = \( 1 \times (\text{atomic mass H}) + 1 \times (\text{atomic mass N}) + 2 \times (\text{atomic mass O}) \)
= \( 1 \times (1.008 \text{ amu}) + 1 \times (14.01 \text{ amu}) + 2 \times (16.00 \text{ amu}) \)
= 47.02 amu
(c) \( \text{CBr}_4 \) formula mass = \( 1 \times (\text{atomic mass C}) + 4 \times (\text{atomic mass Br}) \)
= \( 1 \times (12.01 \text{ amu}) + 4 \times (79.90 \text{ amu}) \)
= 331.61 amu
(d) \( \text{Ca(NO}_3)_2 \) formula mass = \( 1 \times (\text{atomic mass Ca}) + 2 \times (\text{atomic mass N}) + 6 \times (\text{atomic mass O}) \)
= \( 1 \times (40.08 \text{ amu}) + 2 \times (14.01 \text{ amu}) + 6 \times (16.00 \text{ amu}) \)
= 164.10 amu

3.61
(a) **Given:** 72.5 g \( \text{CCl}_4 \)  **Find:** number of moles
**Conceptual Plan:** g \( \text{CCl}_4 \rightarrow \text{mole CCl}_4 \)
\[
\frac{1 \text{ mol}}{153.81 \text{ g CCl}_4}
\]
**Solution:** 72.5 g \( \text{CCl}_4 \times \frac{1 \text{ mol CCl}_4}{153.81 \text{ g CCl}_4} = 0.4714 \text{ mol CCl}_4 = 0.471 \text{ mol CCl}_4 \)
**Check:** Units of the answer (mole CCl4) are correct. The magnitude is appropriate because it is less than 1 mole of CCl4.

(b) **Given:** 12.4 g \( \text{C}_{12}\text{H}_{22}\text{O}_{11} \)  **Find:** number of moles
**Conceptual Plan:** g \( \text{C}_{12}\text{H}_{22}\text{O}_{11} \rightarrow \text{mole KNO}_3 \)
\[
\frac{1 \text{ mol}}{342.30 \text{ g C}_{12}\text{H}_{22}\text{O}_{11}}
\]
**Solution:** 12.4 g \( \text{C}_{12}\text{H}_{22}\text{O}_{11} \times \frac{1 \text{ mol C}_{12}\text{H}_{22}\text{O}_{11}}{342.30 \text{ g C}_{12}\text{H}_{22}\text{O}_{11}} = 0.03622 \text{ mol C}_{12}\text{H}_{22}\text{O}_{11} = 0.0362 \text{ mol C}_{12}\text{H}_{22}\text{O}_{11} \)
**Check:** Units of the answer (mole \( \text{C}_{12}\text{H}_{22}\text{O}_{11} \)) are correct. The magnitude is appropriate because there is less than 1 mole of \( \text{C}_{12}\text{H}_{22}\text{O}_{11} \).

(c) **Given:** 25.2 kg \( \text{C}_2\text{H}_2 \)  **Find:** number of moles
**Conceptual Plan:** kg \( \text{CO}_2 \rightarrow \text{g C}_2\text{H}_2 \rightarrow \text{mole C}_2\text{H}_2 \)
\[
\frac{1000 \text{ g C}_2\text{H}_2}{1 \text{ mol C}_2\text{H}_2} \times \frac{1 \text{ mol C}_2\text{H}_2}{26.04 \text{ g C}_2\text{H}_2}
\]
**Solution:** 25.2 kg \( \text{CO}_2 \times \frac{1000 \text{ g C}_2\text{H}_2}{\text{kg C}_2\text{H}_2} \times \frac{1 \text{ mol C}_2\text{H}_2}{26.04 \text{ g C}_2\text{H}_2} = 967.7 \text{ mol C}_2\text{H}_2 = 968 \text{ mol C}_2\text{H}_2 \)
**Check:** Units of the answer (mole \( \text{C}_2\text{H}_2 \)) are correct. The magnitude is appropriate because more than a kilogram of \( \text{C}_2\text{H}_2 \) is present.

(d) **Given:** 12.3 g dinitrogen monoxide  **Find:** number of moles
**Conceptual Plan:** Dinitrogen monoxide \( \rightarrow \) formula and then g \( \text{N}_2\text{O} \rightarrow \) mole \( \text{N}_2\text{O} \)
\[
\frac{1 \text{ mol}}{44.02 \text{ g N}_2\text{O}}
\]
**Solution:** Dinitrogen monoxide is \( \text{N}_2\text{O} \).
12.3 g \( \text{N}_2\text{O} \times \frac{1 \text{ mol N}_2\text{O}}{44.02 \text{ g N}_2\text{O}} = 0.2794 \text{ mol N}_2\text{O} = 0.279 \text{ mol N}_2\text{O} \)
**Check:** Units of the answer (mole \( \text{N}_2\text{O} \)) are correct. The magnitude is appropriate because less than a mole of \( \text{N}_2\text{O} \) is present.

3.62
(a) **Given:** 15.7 mol \( \text{HNO}_3 \)  **Find:** number of grams
**Conceptual Plan:** Mole \( \text{HNO}_3 \rightarrow \) g \( \text{HNO}_3 \)
\[
\frac{63.02 \text{ g HNO}_3}{1 \text{ mol HNO}_3}
\]
**Solution:** 15.7 mol \( \text{HNO}_3 \times \frac{63.02 \text{ g HNO}_3}{1 \text{ mol HNO}_3} = 989.41 \text{ g HNO}_3 = 989 \text{ g HNO}_3 \)
**Check:** Units of the answer (g \( \text{HNO}_3 \)) are correct. The magnitude is appropriate because there are more than 15 moles of \( \text{HNO}_3 \).
(b) Given: \(1.04 \times 10^{-3} \text{ mol H}_2\text{O}_2\)  
Find: number of grams

Conceptual Plan: Mole \(\text{H}_2\text{O}_2\) \(\rightarrow\) g \(\text{H}_2\text{O}_2\)

\[
\frac{34.02 \text{ g H}_2\text{O}_2}{1 \text{ mol H}_2\text{O}_2}
\]

Solution: \(1.04 \times 10^{-3} \text{ mol H}_2\text{O}_2 \times \frac{34.02 \text{ g H}_2\text{O}_2}{1 \text{ mol H}_2\text{O}_2} = 0.03538 \text{ g H}_2\text{O}_2 = 0.0354 \text{ g H}_2\text{O}_2\)

Check: Units of the answer (g \(\text{H}_2\text{O}_2\)) are correct. The magnitude is appropriate because significantly less than 1 mole of \(\text{H}_2\text{O}_2\) is present.

(c) Given: 72.1 mol \(\text{SO}_2\)  
Find: number of grams

Conceptual Plan: Mole \(\text{SO}_2\) \(\rightarrow\) g \(\text{SO}_2\)

\[
\frac{64.06 \text{ g SO}_2}{1 \text{ mol SO}_2}
\]

Solution: 
\[
72.1 \text{ mol SO}_2 \times \frac{64.06 \text{ g SO}_2}{1 \text{ mol SO}_2} = 4718.7 \text{ g SO}_2 = 4.62 \times 10^3 \text{ g SO}_2
\]

Check: Units of the answer (g \(\text{SO}_2\)) are correct. The magnitude is appropriate because there are more than 70 moles of \(\text{SO}_2\).

(d) Given: 1.23 mol xenon difluoride  
Find: number of grams

Conceptual Plan: Name xenon difluoride \(\rightarrow\) formula and then mole \(\text{XeF}_2\) \(\rightarrow\) g \(\text{XeF}_2\)

\[
\frac{169.29 \text{ g XeF}_2}{1 \text{ mol XeF}_2}
\]

Solution: 
\[
1.23 \text{ mol XeF}_2 \times \frac{169.29 \text{ g XeF}_2}{1 \text{ mol XeF}_2} = 208.23 \text{ g XeF}_2 = 208 \text{ g XeF}_2
\]

Check: Units of the answer, g \(\text{XeF}_2\), are correct. The magnitude is appropriate because there is more than a mole of \(\text{XeF}_2\).

3.63 (a) Given: 25.5 g \(\text{NO}_2\)  
Find: number of moles

Conceptual Plan: g \(\text{NO}_2\) \(\rightarrow\) mole \(\text{NO}_2\)

\[
\frac{1 \text{ mol}}{46.01 \text{ g NO}_2}
\]

Solution: 
\[
25.5 \text{ g NO}_2 \times \frac{1 \text{ mol NO}_2}{46.01 \text{ g NO}_2} = 0.554 \text{ mol NO}_2
\]

Check: The units of the answer (mole \(\text{NO}_2\)) are correct. The magnitude is appropriate because it is less than 1 mole of \(\text{NO}_2\).

(b) Given: 1.25 kg \(\text{CO}_2\)  
Find: number of moles

Conceptual Plan: kg \(\text{CO}_2\) \(\rightarrow\) g \(\text{CO}_2\) \(\rightarrow\) mole \(\text{CO}_2\)

\[
\frac{1000 \text{ g CO}_2}{1 \text{ mol CO}_2}
\]

Solution: 
\[
1.25 \text{ kg CO}_2 \times \frac{1000 \text{ g CO}_2}{1 \text{ kg CO}_2} \times \frac{1 \text{ mol CO}_2}{44.01 \text{ g CO}_2} = 28.4 \text{ mol CO}_2
\]

Check: The units of the answer (mole \(\text{CO}_2\)) are correct. The magnitude is appropriate because over a kg of \(\text{CO}_2\) is present.

(c) Given: 38.2 g \(\text{KNO}_3\)  
Find: number of moles

Conceptual Plan: g \(\text{KNO}_3\) \(\rightarrow\) mole \(\text{KNO}_3\)

\[
\frac{1 \text{ mol}}{101.11 \text{ g KNO}_3}
\]

Solution: 
\[
38.2 \text{ g KNO}_3 \times \frac{1 \text{ mol KNO}_3}{101.11 \text{ g KNO}_3} = 0.378 \text{ mol KNO}_3
\]

Check: The units of the answer (mole \(\text{KNO}_3\)) are correct. The magnitude is appropriate because there is less than 1 mole of \(\text{KNO}_3\).

(d) Given: 155.2 kg \(\text{Na}_2\text{SO}_4\)  
Find: number of moles

Conceptual Plan: kg \(\text{Na}_2\text{SO}_4\) \(\rightarrow\) g \(\text{Na}_2\text{SO}_4\) \(\rightarrow\) mole \(\text{Na}_2\text{SO}_4\)

\[
\frac{1000 \text{ g Na}_2\text{SO}_4}{1 \text{ mol Na}_2\text{SO}_4}
\]

Solution: 
\[
155.2 \text{ kg Na}_2\text{SO}_4 \times \frac{1000 \text{ g Na}_2\text{SO}_4}{1 \text{ kg Na}_2\text{SO}_4} \times \frac{1 \text{ mol Na}_2\text{SO}_4}{142.04 \text{ g Na}_2\text{SO}_4} = 1093 \text{ mol Na}_2\text{SO}_4
\]
Chapter 3 Molecules, Compounds, and Chemical Equations

Check: The units of the answer (mole Na$_2$SO$_4$) are correct. The magnitude is appropriate because over 100 kg of Na$_2$SO$_4$ is present.

3.64 (a) **Given:** 55.98 g CF$_2$Cl$_2$  **Find:** number of moles

**Conceptual Plan:** g CF$_2$Cl$_2$ → mole CF$_2$Cl$_2$

\[
\frac{1 \text{ mol}}{120.91 \text{ g CF}_2\text{Cl}_2}
\]

**Solution:**

\[
55.98 \text{ g CF}_2\text{Cl}_2 \times \frac{1 \text{ mol CF}_2\text{Cl}_2}{120.91 \text{ g CF}_2\text{Cl}_2} = 0.46298 \text{ mol CF}_2\text{Cl}_2 = 0.4630 \text{ mol CF}_2\text{Cl}_2
\]

Check: The units of the answer (mole CF$_2$Cl$_2$) are correct. The magnitude is appropriate because it is less than 1 mole of CF$_2$Cl$_2$.

(b) **Given:** 23.6 kg Fe(NO$_3$)$_2$  **Find:** number of moles

**Conceptual Plan:** kg Fe(NO$_3$)$_2$ → g Fe(NO$_3$)$_2$ → mole Fe(NO$_3$)$_2$

\[
\frac{1000 \text{ g Fe(NO}_3\text{)}_2}{\text{kg Fe(NO}_3\text{)}_2} \times \frac{1 \text{ mol Fe(NO}_3\text{)}_2}{179.87 \text{ g Fe(NO}_3\text{)}_2}
\]

**Solution:**

\[
23.6 \text{ kg Fe(NO}_3\text{)}_2 \times \frac{1000 \text{ g Fe(NO}_3\text{)}_2}{\text{kg Fe(NO}_3\text{)}_2} \times \frac{1 \text{ mol Fe(NO}_3\text{)}_2}{179.87 \text{ g Fe(NO}_3\text{)}_2} = 131 \text{ mol Fe(NO}_3\text{)}_2
\]

Check: The units of the answer (mole Fe(NO$_3$)$_2$) are correct. The magnitude is appropriate because over a kg of Fe(NO$_3$)$_2$ is present.

(c) **Given:** 0.1187 g C$_6$H$_{18}$  **Find:** number of moles

**Conceptual Plan:** g C$_6$H$_{18}$ → mole C$_6$H$_{18}$

\[
\frac{1 \text{ mol}}{114.22 \text{ g C}_6\text{H}_{18}}
\]

**Solution:**

\[
0.1187 \text{ g C}_6\text{H}_{18} \times \frac{1 \text{ mol C}_6\text{H}_{18}}{114.22 \text{ g C}_6\text{H}_{18}} = 1.039 \times 10^{-3} \text{ mol C}_6\text{H}_{18}
\]

Check: The units of the answer (mole C$_6$H$_{18}$) are correct. The magnitude is appropriate because it is much less than 1 mole of C$_6$H$_{18}$.

(d) **Given:** 195 kg CaO  **Find:** number of moles

**Conceptual Plan:** kg CaO → g CaO → mole CaO

\[
\frac{1 \text{ mol}}{56.08 \text{ g CaO}}
\]

**Solution:**

\[
195 \text{ kg CaO} \times \frac{1000 \text{ g CaO}}{1 \text{ kg CaO}} \times \frac{1 \text{ mol CaO}}{56.08 \text{ g CaO}} = 3477 \text{ mol CaO} = 3.48 \times 10^3 \text{ mol CaO}
\]

Check: The units of the answer (mole CaO) are correct. The magnitude is appropriate because over a kg of CaO is present.

3.65 (a) **Given:** 6.5 g H$_2$O  **Find:** number of molecules

**Conceptual Plan:** g H$_2$O → mole H$_2$O → number H$_2$O molecules

\[
\frac{1 \text{ mol}}{18.02 \text{ g H}_2\text{O}} \times \frac{6.022 \times 10^{23} \text{ H}_2\text{O molecules}}{1 \text{ mol}}
\]

**Solution:**

\[
6.5 \text{ g H}_2\text{O} \times \frac{1 \text{ mol H}_2\text{O}}{18.02 \text{ g H}_2\text{O}} \times \frac{6.022 \times 10^{23} \text{ H}_2\text{O molecules}}{1 \text{ mol H}_2\text{O}} = 2.2 \times 10^{23} \text{ H}_2\text{O molecules}
\]

Check: The units of the answer (H$_2$O molecules) are correct. The magnitude is appropriate; it is smaller than Avogadro's number, as expected, because we have less than 1 mole of H$_2$O.

(b) **Given:** 389 g CBr$_4$  **Find:** number of molecules

**Conceptual Plan:** g CBr$_4$ → mole CBr$_4$ → number CBr$_4$ molecules

\[
\frac{1 \text{ mol}}{331.61 \text{ g CBr}_4} \times \frac{6.022 \times 10^{23} \text{ CBr}_4 \text{ molecules}}{1 \text{ mol CBr}_4}
\]

**Solution:**

\[
389 \text{ g CBr}_4 \times \frac{1 \text{ mol CBr}_4}{331.61 \text{ g CBr}_4} \times \frac{6.022 \times 10^{23} \text{ CBr}_4 \text{ molecules}}{1 \text{ mol CBr}_4} = 7.06 \times 10^{23} \text{ CBr}_4 \text{ molecules}
\]

Check: The units of the answer (CBr$_4$ molecules) are correct. The magnitude is appropriate; it is larger than Avogadro's number, as expected, because we have more than 1 mole of CBr$_4$.

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Given: 22.1 g O₂  Find: number of molecules
Conceptual Plan: g O₂ → mole O₂ → number O₂ molecules
\[
\frac{1 \text{ mol}}{32.00 \text{ g O₂}} \times \frac{6.022 \times 10^{23} \text{ O₂ molecules}}{1 \text{ mol O₂}} = 4.16 \times 10^{23} \text{ O₂ molecules}
\]
Solution: 
Check: The units of the answer (O₂ molecules) are correct. The magnitude is appropriate; it is smaller than Avogadro's number, as expected, because we have less than 1 mole of O₂.

Given: 19.3 g C₅H₁₀  Find: number of molecules
Conceptual Plan: g C₅H₁₀ → mole C₅H₁₀ → number C₅H₁₀ molecules

\[
\frac{1 \text{ mol}}{106.16 \text{ g C₅H₁₀}} \times \frac{6.022 \times 10^{23} \text{ C₅H₁₀ molecules}}{1 \text{ mol C₅H₁₀}} = 1.09 \times 10^{23} \text{ C₅H₁₀ molecules}
\]
Solution: 
Check: The units of the answer (C₅H₁₀ molecules) are correct. The magnitude is appropriate; it is smaller than Avogadro's number, as expected, because we have less than 1 mole of C₅H₁₀.

Given: 85.26 g CCl₄  Find: number of molecules
Conceptual Plan: g CCl₄ → mole CCl₄ → number CCl₄ molecules

\[
\frac{1 \text{ mol}}{153.81 \text{ g CCl₄}} \times \frac{6.022 \times 10^{23} \text{ CCl₄ molecules}}{1 \text{ mol CCl₄}} = 3.33 \times 10^{23} \text{ CCl₄ molecules}
\]
Solution: 
Check: The units of the answer (CCl₄ molecules) are correct. The magnitude is appropriate; it is smaller than Avogadro's number, as expected, because we have less than 1 mole of CCl₄.

Given: 55.93 kg NaHCO₃  Find: number of molecules
Conceptual Plan: kg NaHCO₃ → g NaHCO₃ → mole NaHCO₃ → number NaHCO₃ molecules

\[
\frac{1000 \text{ g}}{84.01 \text{ g NaHCO₃}} \times \frac{6.022 \times 10^{23} \text{ NaHCO₃ molecules}}{1 \text{ mol NaHCO₃}}
\]
Solution: 
Check: The units of the answer (NaHCO₃ molecules) are correct. The magnitude is appropriate; it is more than Avogadro's number, as expected, because we have many moles of NaHCO₃.

Given: 119.78 g C₄H₁₀  Find: number of molecules
Conceptual Plan: g C₄H₁₀ → mole C₄H₁₀ → number C₄H₁₀ molecules

\[
\frac{1 \text{ mol}}{58.12 \text{ g C₄H₁₀}} \times \frac{6.022 \times 10^{23} \text{ C₄H₁₀ molecules}}{1 \text{ mol C₄H₁₀}} = 1.24 \times 10^{24} \text{ C₄H₁₀ molecules}
\]
Solution: 
Check: The units of the answer (C₄H₁₀ molecules) are correct. The magnitude is appropriate; it is larger than Avogadro's number, as expected, because we have more than 1 mole of C₄H₁₀.

Given: 4.59 × 10⁵ g Na₃PO₄  Find: number of molecules
Conceptual Plan: g Na₃PO₄ → mole Na₃PO₄ → number Na₃PO₄ molecules

\[
\frac{1 \text{ mol}}{163.94 \text{ g Na₃PO₄}} \times \frac{6.022 \times 10^{23} \text{ Na₃PO₄ molecules}}{1 \text{ mol Na₃PO₄}}
\]
Solution: 
Check: The units of the answer (Na₃PO₄ molecules) are correct. The magnitude is appropriate; it is smaller than Avogadro's number, as expected, because we have less than 1 mole of Na₃PO₄.
Check: The units of the answer (Na₃PO₄ molecules) are correct. The magnitude is appropriate; it is larger than Avogadro’s number, as expected, because we have more than 1 mole of Na₃PO₄.

3.67 (a) Given: \(5.94 \times 10^{20}\) SO₃ molecules  Find: mass in g
Conceptual Plan: Number SO₃ molecules \(\rightarrow\) mole SO₂ \(\rightarrow\) g SO₃
\[
\text{1 mol SO}_3 \quad 80.06 \text{ g SO}_3
\]
\[
6.022 \times 10^{23}\text{SO}_3\text{molecules} \quad 1 \text{ mol SO}_3
\]
\[
\text{Solution: } 5.94 \times 10^{20}\text{SO}_3\text{molecules} \times \frac{1 \text{ mol SO}_3}{6.022 \times 10^{23}\text{SO}_3\text{molecules}} \times \frac{80.06 \text{ g SO}_3}{1 \text{ mol SO}_3} = 0.0790 \text{ g SO}_3
\]
Check: The units of the answer (grams SO₃) are correct. The magnitude is appropriate; there is less than Avogadro’s number of molecules, so we have less than 1 mole of SO₃.

(b) Given: \(2.8 \times 10^{22}\) H₂O molecules  Find: mass in g
Conceptual Plan: Number H₂O molecules \(\rightarrow\) mole H₂O \(\rightarrow\) g H₂O
\[
\text{1 mol H}_2\text{O} \quad 18.02 \text{ g H}_2\text{O}
\]
\[
6.022 \times 10^{23}\text{H}_2\text{O}\text{molecules} \quad 1 \text{ mol H}_2\text{O}
\]
\[
\text{Solution: } 2.8 \times 10^{22}\text{H}_2\text{O}\text{molecules} \times \frac{1 \text{ mol H}_2\text{O}}{6.022 \times 10^{23}\text{H}_2\text{O}\text{molecules}} \times \frac{18.02 \text{ g H}_2\text{O}}{1 \text{ mol H}_2\text{O}} = 0.84 \text{ g H}_2\text{O}
\]
Check: The units of the answer (grams H₂O) are correct. The magnitude is appropriate; there is less than Avogadro’s number of molecules, so we have less than 1 mole of H₂O.

(c) Given: 1 C₆H₁₂O₆ molecules  Find: mass in g
Conceptual Plan: Number C₆H₁₂O₆ molecules \(\rightarrow\) mole C₆H₁₂O₆ \(\rightarrow\) g C₆H₁₂O₆
\[
\text{1 mol C}_6\text{H}_12\text{O}_6 \quad 180.16 \text{ g C}_6\text{H}_12\text{O}_6
\]
\[
6.022 \times 10^{23}\text{C}_6\text{H}_12\text{O}_6\text{molecules} \quad 1 \text{ mol C}_6\text{H}_12\text{O}_6
\]
\[
\text{Solution: } 1 \text{ C}_6\text{H}_12\text{O}_6\text{molecule} \times \frac{1 \text{ mol C}_6\text{H}_12\text{O}_6}{6.022 \times 10^{23}\text{C}_6\text{H}_12\text{O}_6\text{molecules}} \times \frac{180.16 \text{ g C}_6\text{H}_12\text{O}_6}{1 \text{ mol C}_6\text{H}_12\text{O}_6} = 2.992 \times 10^{-22} \text{ g C}_6\text{H}_12\text{O}_6
\]
Check: The units of the answer (grams C₆H₁₂O₆) are correct. The magnitude is appropriate; there is much less than Avogadro’s number of molecules, so we have much less than 1 mole of C₆H₁₂O₆.

3.68 (a) Given: \(4.5 \times 10^{25}\) O₃ molecules  Find: mass in g
Conceptual Plan: Number O₃ molecules \(\rightarrow\) mole O₃ \(\rightarrow\) g O₃
\[
\text{1 mol O}_3 \quad 48.00 \text{ g O}_3
\]
\[
6.022 \times 10^{23}\text{O}_3\text{molecules} \quad 1 \text{ mol O}_3
\]
\[
\text{Solution: } 4.5 \times 10^{25}\text{O}_3\text{molecules} \times \frac{1 \text{ mol O}_3}{6.022 \times 10^{23}\text{O}_3\text{molecules}} \times \frac{48.00 \text{ g O}_3}{1 \text{ mol O}_3} = 3.6 \times 10^3 \text{ g O}_3
\]
Check: The units of the answer (grams O₃) are correct. The magnitude is appropriate; there is more than Avogadro’s number of molecules, so we have more than 1 mole of O₃.

(b) Given: \(9.85 \times 10^{19}\) CCl₂F₂ molecules  Find: mass in g
Conceptual Plan: Number CCl₂F₂ molecules \(\rightarrow\) mole CCl₂F₂ \(\rightarrow\) g CCl₂F₂
\[
\text{1 mol CCl}_2\text{F}_2 \quad 120.91 \text{ g CCl}_2\text{F}_2
\]
\[
6.022 \times 10^{23}\text{CCl}_2\text{F}_2\text{molecules} \quad 1 \text{ mol CCl}_2\text{F}_2
\]
\[
\text{Solution: } 9.85 \times 10^{19}\text{CCl}_2\text{F}_2\text{molecules} \times \frac{1 \text{ mol CCl}_2\text{F}_2}{6.022 \times 10^{23}\text{CCl}_2\text{F}_2\text{molecules}} \times \frac{120.91 \text{ g CCl}_2\text{F}_2}{1 \text{ mol CCl}_2\text{F}_2} = 1.98 \times 10^{-2} \text{ g CCl}_2\text{F}_2
\]
Check: The units of the answer (grams CCl₂F₂) are correct. The magnitude is appropriate; there is less than Avogadro’s number of molecules, so we have less than 1 mole of CCl₂F₂.

(c) Given: 1 H₂O molecule  Find: mass in g
Conceptual Plan: Number H₂O molecules \(\rightarrow\) mole H₂O \(\rightarrow\) g H₂O
\[
\text{1 mol H}_2\text{O} \quad 18.02 \text{ g H}_2\text{O}
\]
\[
6.022 \times 10^{23}\text{H}_2\text{O}\text{molecules} \quad 1 \text{ mol H}_2\text{O}
\]
\[
\text{Solution: } 1 \text{ H}_2\text{O}\text{molecule} \times \frac{1 \text{ mol H}_2\text{O}}{6.022 \times 10^{23}\text{H}_2\text{O}\text{molecules}} \times \frac{18.02 \text{ g H}_2\text{O}}{1 \text{ mol H}_2\text{O}} = 2.992 \times 10^{-23} \text{ g H}_2\text{O}
\]
Check: The units of the answer (grams H₂O) are correct. The magnitude is appropriate; there is much less than Avogadro’s number of molecules, so we have much less than 1 mole of H₂O.

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3.69  \textbf{Given}: 1.8 \times 10^{17} \text{C}_{12}\text{H}_{22}\text{O}_{11} \text{molecules} \quad \textbf{Find}: \text{mass in mg} \\
\textbf{Conceptual Plan}: \text{Number} \text{C}_{12}\text{H}_{22}\text{O}_{11} \text{molecules} \rightarrow \text{mole} \text{C}_{12}\text{H}_{22}\text{O}_{11} \rightarrow g \text{C}_{12}\text{H}_{22}\text{O}_{11} \rightarrow mg \text{C}_{12}\text{H}_{22}\text{O}_{11} \\
\frac{1 \text{ mol} \text{C}_{12}\text{H}_{22}\text{O}_{11}}{6.022 \times 10^{23} \text{C}_{12}\text{H}_{22}\text{O}_{11} \text{molecules}} \times \frac{342.30 \text{g} \text{C}_{12}\text{H}_{22}\text{O}_{11}}{1 \text{ mol} \text{C}_{12}\text{H}_{22}\text{O}_{11}} \times \frac{1 \times 10^{3} \text{mg} \text{C}_{12}\text{H}_{22}\text{O}_{11}}{1 \text{ g} \text{C}_{12}\text{H}_{22}\text{O}_{11}} \\
= 0.10 \text{ mg} \text{C}_{12}\text{H}_{22}\text{O}_{11} \\
\textbf{Check}: \text{The units of the answer (mg C}_{12}\text{H}_{22}\text{O}_{11}) \text{are correct. The magnitude is appropriate; there is much less than} \text{Avogadro’s number of molecules, so we have much less than} 1 \text{ mole of C}_{12}\text{H}_{22}\text{O}_{11}. \\

3.70  \textbf{Given}: 0.12 \text{mg} \text{NaCl} \quad \textbf{Find}: \text{number of formula units} \\
\textbf{Conceptual Plan}: \text{mg NaCl} \rightarrow g \text{NaCl} \rightarrow \text{mole NaCl} \rightarrow \text{number of formula units NaCl} \\
\frac{1 \text{ g NaCl}}{1 \times 10^{3} \text{mg NaCl}} \times \frac{1 \text{ mol NaCl}}{58.44 \text{ g NaCl}} \times \frac{6.022 \times 10^{23} \text{formula units NaCl}}{1 \text{ mol NaCl}} \\
= 1.2 \times 10^{18} \text{formula units NaCl} \\
\textbf{Check}: \text{The units of the answer (formula units NaCl) are correct. The magnitude is appropriate; there is less than} 1 \text{ mole of NaCl, so we have less than} \text{Avogadro’s number of formula units.} \\

\text{Composition of Compounds} \\

3.71  \text{(a) Given: CH}_4 \quad \textbf{Find}: \text{mass percent C} \\
\textbf{Conceptual Plan}: \text{Mass \% C} = \frac{1 \times \text{molar mass C}}{\text{molar mass CH}_4} \times 100\% \\
\textbf{Solution}: \\
1 \times \text{molar mass C} = 1(12.01 \text{ g/mol}) = 12.01 \text{ g} \\
\text{molar mass CH}_4 = 1(12.01 \text{ g/mol}) + 4(1.008 \text{ g/mol}) = 16.04 \text{ g/mol} \\
\text{mass \% C} = \frac{1 \times \text{molar mass C}}{\text{molar mass CH}_4} \times 100\% \\
= \frac{12.01 \text{ g/mol}}{16.04 \text{ g/mol}} \times 100\% \\
= 74.87\% \\
\textbf{Check}: \text{The units of the answer (\%) are correct. The magnitude is reasonable because it is between 0 and 100\% and carbon is the heaviest element.} \\

\text{(b) Given: C}_2\text{H}_6 \quad \textbf{Find}: \text{mass percent C} \\
\textbf{Conceptual Plan}: \text{Mass \% C} = \frac{2 \times \text{molar mass C}}{\text{molar mass C}_2\text{H}_6} \times 100\% \\
\textbf{Solution}: \\
2 \times \text{molar mass C} = 2(12.01 \text{ g/mol}) = 24.02 \text{ g} \\
\text{molar mass C}_2\text{H}_6 = 2(12.01 \text{ g/mol}) + 6(1.008 \text{ g/mol}) = 30.07 \text{ g/mol} \\
\text{mass \% C} = \frac{2 \times \text{molar mass C}}{\text{molar mass C}_2\text{H}_6} \times 100\% \\
= \frac{24.02 \text{ g/mol}}{30.07 \text{ g/mol}} \times 100\% \\
= 79.88\% \\
\textbf{Check}: \text{The units of the answer (\%) are correct. The magnitude is reasonable because it is between 0 and 100\% and carbon is the heaviest element.}
(c)  Given: $\text{C}_2\text{H}_2$  Find: mass percent $C$

Conceputal Plan: Mass % $C = \frac{2 \times \text{molar mass } C}{\text{molar mass } \text{C}_2\text{H}_2} \times 100\%$

Solution:

$2 \times \text{molar mass } C = 2(12.01 \text{ g/mol}) = 24.02 \text{ g C}\n
\text{molar mass } \text{C}_2\text{H}_2 = 2(12.01 \text{ g/mol}) + 2(1.008 \text{ g/mol}) = 26.04 \text{ g/mol}\n
\text{mass } % C = \frac{2 \times \text{molar mass } C}{\text{molar mass } \text{C}_2\text{H}_2} \times 100\%\n
= \frac{24.02 \text{ g/mol}}{26.04 \text{ g/mol}} \times 100\%\n
= 92.24\%$

Check: The units of the answer (%) are correct. The magnitude is reasonable because it is between 0 and 100% and carbon is the heaviest element.

(d)  Given: $\text{C}_2\text{H}_3\text{Cl}$  Find: mass percent $C$

Conceputal Plan: Mass % $C = \frac{2 \times \text{molar mass } C}{\text{molar mass } \text{C}_2\text{H}_3\text{Cl}} \times 100\%$

Solution:

$2 \times \text{molar mass } C = 2(12.01 \text{ g/mol}) = 24.02 \text{ g C}\n
\text{molar mass } \text{C}_2\text{H}_3\text{Cl} = 2(12.01 \text{ g/mol}) + 3(1.008 \text{ g/mol}) + 1(35.45 \text{ g/mol}) = 64.51 \text{ g/mol}\n
\text{mass } % C = \frac{2 \times \text{molar mass } C}{\text{molar mass } \text{C}_2\text{H}_3\text{Cl}} \times 100\%\n
= \frac{24.02 \text{ g/mol}}{64.51 \text{ g/mol}} \times 100\%\n
= 37.23\%$

Check: The units of the answer (%) are correct. The magnitude is reasonable because it is between 0 and 100% and chlorine is heavier than carbon.

3.72  (a)  Given: $\text{N}_2\text{O}$  Find: mass percent $N$

Conceputal Plan: Mass % $N = \frac{2 \times \text{molar mass } N}{\text{molar mass } \text{N}_2\text{O}} \times 100\%$

Solution:

$2 \times \text{molar mass } N = 2(14.01 \text{ g/mol}) = 28.02 \text{ g N}\n
\text{molar mass } \text{N}_2\text{O} = 2(14.01 \text{ g/mol}) + (16.00 \text{ g/mol}) = 44.02 \text{ g/mol}\n
\text{mass } % N = \frac{2 \times \text{molar mass } N}{\text{molar mass } \text{N}_2\text{O}} \times 100\%\n
= \frac{28.02 \text{ g/mol}}{44.02 \text{ g/mol}} \times 100\%\n
= 63.65\%$

Check: The units of the answer (%) are correct. The magnitude is reasonable because it is between 0 and 100% and there are two nitrogens per molecule.

(b)  Given: NO  Find: mass percent $N$

Conceputal Plan: Mass % $N = \frac{1 \times \text{molar mass } N}{\text{molar mass NO}} \times 100\%$

Solution:

$1 \times \text{molar mass } N = 1(14.01 \text{ g/mol}) = 14.01 \text{ g N}\n
\text{molar mass NO} = (14.01 \text{ g/mol}) + (16.00 \text{ g/mol}) = 30.01 \text{ g/mol}\n
\text{mass } % N = \frac{1 \times \text{molar mass } N}{\text{molar mass NO}} \times 100\%\n
= \frac{14.01 \text{ g/mol}}{30.01 \text{ g/mol}} \times 100\%\n
= 46.68\%$

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Check: The units of the answer (%) are correct. The magnitude is reasonable because it is between 0 and 100% and the mass of nitrogen is less than the mass of oxygen.

(c) **Given:** NO₂  **Find:** mass percent N

**Conceptual Plan:** Mass % N = \( \frac{1 \times \text{molar mass N}}{\text{molar mass NO}_2} \times 100\% \)

**Solution:**
\[
1 \times \text{molar mass N} = 1(14.01 \text{ g/mol}) = 14.01 \text{ g N}
\]
\[
\text{molar mass NO}_2 = (14.01 \text{ g/mol}) + 2(16.00 \text{ g/mol}) = 46.01 \text{ g/mol}
\]
\[
\text{mass % N} = \frac{1 \times \text{molar mass N}}{\text{molar mass NO}_2} \times 100\%
\]
\[
= \frac{14.01 \text{ g/mol}}{46.01 \text{ g/mol}} \times 100\%
\]
\[
= 30.45\%
\]

Check: The units of the answer (%) are correct. The magnitude is reasonable because it is between 0 and 100%. The mass of nitrogen is less than the mass of oxygen, and there are two oxygens per molecule.

(d) **Given:** HNO₃  **Find:** mass percent N

**Conceptual Plan:** Mass % N = \( \frac{1 \times \text{molar mass N}}{\text{molar mass HNO}_3} \times 100\% \)

**Solution:**
\[
1 \times \text{molar mass N} = 1(14.01 \text{ g/mol}) = 14.01 \text{ g N}
\]
\[
\text{molar mass HNO}_3 = (1.008 \text{ g/mol}) + (14.01 \text{ g/mol}) + 3(16.00 \text{ g/mol}) = 63.02 \text{ g/mol}
\]
\[
\text{mass % N} = \frac{1 \times \text{molar mass N}}{\text{molar mass HNO}_3} \times 100\%
\]
\[
= \frac{14.01 \text{ g/mol}}{63.02 \text{ g/mol}} \times 100\%
\]
\[
= 22.23\%
\]

Check: The units of the answer (%) are correct. The magnitude is reasonable because it is between 0 and 100%. The mass of nitrogen is less than the mass of oxygen, and there are three oxygens per molecule.

3.73 **Given:** NH₃  **Find:** mass percent N

**Conceptual Plan:** Mass % N = \( \frac{1 \times \text{molar mass N}}{\text{molar mass NH}_3} \times 100\% \)

**Solution:**
\[
1 \times \text{molar mass N} = 1(14.01 \text{ g/mol}) = 14.01 \text{ g N}
\]
\[
\text{molar mass NH}_3 = 3(1.008 \text{ g/mol}) + (14.01 \text{ g/mol}) = 17.03 \text{ g/mol}
\]
\[
\text{mass % N} = \frac{1 \times \text{molar mass N}}{\text{molar mass NH}_3} \times 100\%
\]
\[
= \frac{14.01 \text{ g/mol}}{17.03 \text{ g/mol}} \times 100\%
\]
\[
= 82.27\%
\]

Check: The units of the answer (%) are correct. The magnitude is reasonable because it is between 0 and 100% and nitrogen is the heaviest atom present.

**Given:** CO(NH₂)₂  **Find:** mass percent N

**Conceptual Plan:** Mass % N = \( \frac{2 \times \text{molar mass N}}{\text{molar mass CO(NH}_2)_2} \times 100\% \)
Solution:

\[ 2 \times \text{molar mass } N = 2(14.01 \text{ g/mol}) = 28.02 \text{ g N} \]

\[
\text{molar mass } \text{CO(NH}_2\text{)}_2 = (12.01 \text{ g/mol}) + (16.00 \text{ g/mol}) + 2(14.01 \text{ g/mol}) + 4(1.008 \text{ g/mol}) = 60.06 \text{ g/mol}
\]

\[
\text{mass } \% \text{ N} = \frac{2 \times \text{molar mass } N}{\text{molar mass } \text{CO(NH}_2\text{)}_2} \times 100\%
\]

\[= \frac{28.02 \text{ g/mol}}{60.06 \text{ g/mol}} \times 100\% \]

\[= 46.65\% \]

**Check:** The units of the answer (\%) are correct. The magnitude is reasonable because it is between 0 and 100\% and there are two nitrogens and one carbon and one oxygen per molecule.

**Given:** NH\textsubscript{4}NO\textsubscript{3}  **Find:** mass percent N

**Conceptual Plan:** Mass \( \% \text{ N} = \frac{2 \times \text{molar mass } N}{\text{molar mass } \text{NH}_4\text{NO}_3} \times 100\% \)

**Solution:**

\[ 2 \times \text{molar mass } N = 2(14.01 \text{ g/mol}) = 28.02 \text{ g N} \]

\[
\text{molar mass } \text{NH}_4\text{NO}_3 = 2(14.01 \text{ g/mol}) + 4(1.008 \text{ g/mol}) + 3(16.00 \text{ g/mol}) = 80.05 \text{ g/mol}
\]

\[
\text{mass } \% \text{ N} = \frac{2 \times \text{molar mass } N}{\text{molar mass } \text{NH}_4\text{NO}_3} \times 100\%
\]

\[= \frac{28.02 \text{ g/mol}}{80.05 \text{ g/mol}} \times 100\% \]

\[= 35.00\% \]

**Check:** The units of the answer (\%) are correct. The magnitude is reasonable because it is between 0 and 100\%. The mass of nitrogen is less than the mass of oxygen, and there are two nitrogens and three oxygens per molecule.

**Given:** (NH\textsubscript{4})\textsubscript{2}SO\textsubscript{4}  **Find:** mass percent N

**Conceptual Plan:** Mass \( \% \text{ N} = \frac{2 \times \text{molar mass } N}{\text{molar mass } (\text{NH}_4\text{)}_2\text{SO}_4} \times 100\% \)

**Solution:**

\[ 2 \times \text{molar mass } N = 2(14.01 \text{ g/mol}) = 28.02 \text{ g N} \]

\[
\text{molar mass } (\text{NH}_4\text{)}_2\text{SO}_4 = 2(14.01 \text{ g/mol}) + 8(1.008 \text{ g/mol}) + (32.07 \text{ g/mol}) + 4(16.00 \text{ g/mol}) = 132.15 \text{ g/mol}
\]

\[
\text{mass } \% \text{ N} = \frac{2 \times \text{molar mass } N}{\text{molar mass } (\text{NH}_4\text{)}_2\text{SO}_4} \times 100\%
\]

\[= \frac{28.02 \text{ g/mol}}{132.15 \text{ g/mol}} \times 100\% \]

\[= 21.20\% \]

**Check:** The units of the answer (\%) are correct. The magnitude is reasonable because it is between 0 and 100\% and the mass of nitrogen is less than the mass of oxygen and sulfur.

The fertilizer with the highest nitrogen content is NH\textsubscript{3} with a N content of 82.27\%.

---

**Given:** Fe\textsubscript{2}O\textsubscript{3}  **Find:** mass percent Fe

**Conceptual Plan:** Mass \( \% \text{ Fe} = \frac{2 \times \text{molar mass } Fe}{\text{molar mass } \text{Fe}_2\text{O}_3} \times 100\% \)

**Solution:**

\[ 2 \times \text{molar mass } Fe = 2(55.85 \text{ g/mol}) = 111.7 \text{ g Fe} \]

\[
\text{molar mass } \text{Fe}_2\text{O}_3 = 2(55.85 \text{ g/mol}) + 3(16.00 \text{ g/mol}) = 159.7 \text{ g/mol}
\]

\[
\text{mass } \% \text{ Fe} = \frac{2 \times \text{molar mass } Fe}{\text{molar mass } \text{Fe}_2\text{O}_3} \times 100\%
\]

\[= \frac{111.7 \text{ g/mol}}{159.7 \text{ g/mol}} \times 100\%
\]

\[= 69.94\% \]

**Check:** The units of the answer (\%) are correct. The magnitude is reasonable because it is between 0 and 100\% and iron provides most of the formula mass.
Given: $\text{Fe}_3\text{O}_4$  
Find: mass percent Fe

**Conceptual Plan:** Mass % Fe = \( \frac{3 \times \text{molar mass Fe}}{\text{molar mass Fe}_3\text{O}_4} \times 100\% \)

**Solution:**
\[
3 \times \text{molar mass Fe} = 3(55.85 \text{ g/mol}) = 167.6 \text{ g Fe} \\
\text{molar mass Fe}_3\text{O}_4 = 3(55.85 \text{ g/mol}) + 4(16.00 \text{ g/mol}) = 231.6 \text{ g/mol} \\
\text{mass % Fe} = \frac{3 \times \text{molar mass Fe}}{\text{molar mass Fe}_3\text{O}_4} \times 100\% \\
= \frac{167.6 \text{ g/mol}}{231.6 \text{ g/mol}} \times 100\% \\
= 72.37\% \\

**Check:** The units of the answer (\%) are correct. The magnitude is reasonable because it is between 0 and 100\% and iron provides most of the formula mass.

Given: $\text{FeCO}_3$  
Find: mass percent Fe

**Conceptual Plan:** Mass % Fe = \( \frac{1 \times \text{molar mass Fe}}{\text{molar mass FeCO}_3} \times 100\% \)

**Solution:**
\[
1 \times \text{molar mass Fe} = (55.85 \text{ g/mol}) = 55.85 \text{ g Fe} \\
\text{molar mass FeCO}_3 = 1(55.85 \text{ g/mol}) + 1(12.01 \text{ g/mol}) + 3(16.00 \text{ g/mol}) = 115.86 \text{ g/mol} \\
\text{mass % Fe} = \frac{1 \times \text{molar mass Fe}}{\text{molar mass FeCO}_3} \times 100\% \\
= \frac{55.85 \text{ g/mol}}{115.86 \text{ g/mol}} \times 100\% \\
= 48.20\% \\

**Check:** The units of the answer (\%) are correct. The magnitude is reasonable because it is between 0 and 100\% and iron provides slightly less than half of the formula mass. The ore with the highest iron content is $\text{Fe}_3\text{O}_4$ with an Fe content of 72.37\%.

3.75  
**Given:** 55.5 g CuF$_2$; 37.42 g F in CuF$_2$  
**Find:** g F in CuF$_2$

**Conceptual Plan:** g CuF$_2$ → g F
\[
\frac{37.42 \text{ g F}}{100.0 \text{ g CuF}_2} \\
\text{Solution:} 55.5 \text{ g CuF}_2 \times \frac{37.42 \text{ g F}}{100.0 \text{ g CuF}_2} = 20.77 = 20.8 \text{ g F} \\

**Check:** The units of the answer (g F) are correct. The magnitude is reasonable because it is less than the original mass.

3.76  
**Given:** 155 mg Ag; 75.27% Ag in AgCl  
**Find:** mg AgCl

**Conceptual Plan:** mg Ag → g Ag → g AgCl → mg AgCl
\[
\frac{1 \text{ g Ag}}{100.0 \text{ mg Ag}} \times \frac{1 \text{ g AgCl}}{75.27 \text{ g Ag}} \times \frac{1000 \text{ mg AgCl}}{1 \text{ g AgCl}} \\
\text{Solution:} 155 \text{ mg Ag} \times \frac{1 \text{ g Ag}}{1000 \text{ mg Ag}} \times \frac{1 \text{ g AgCl}}{75.27 \text{ g Ag}} \times \frac{1000 \text{ mg AgCl}}{1 \text{ g AgCl}} = 205.9 \text{ mg AgCl} = 206 \text{ mg AgCl} \\

**Check:** The units of the answer (mg AgCl) are correct. The magnitude is reasonable because it is greater than the original mass.

3.77  
**Given:** 150 μg I; 76.45% I in KI  
**Find:** μg KI

**Conceptual Plan:** μg I → g I → g KI → μg KI
\[
\frac{1 \text{ g I}}{1 \times 10^6 \mu\text{g I}} \times \frac{100.0 \text{ g KI}}{76.45 \text{ g I}} \times \frac{1 \times 10^6 \mu\text{g KI}}{1 \text{ g KI}} \\
\text{Solution:} 150 \mu\text{g I} \times \frac{1 \text{ g I}}{1 \times 10^6 \mu\text{g I}} \times \frac{100.0 \text{ g KI}}{76.45 \text{ g I}} \times \frac{1 \times 10^6 \mu\text{g KI}}{1 \text{ g KI}} = 196 \mu\text{g KI} \\

**Check:** The units of the answer (μg KI) are correct. The magnitude is reasonable because it is greater than the original mass.
3.78  Given: 3.0 mg F; 45.24% F in NaF  \text{ Find: mg NaF}  

Conceptual Plan: \text{mg F} \rightarrow \text{g F} \rightarrow \text{g NaF} \rightarrow \text{mg NaF}  

\[
\text{Solution: } 3.0 \text{ mg F} \times \frac{1 \text{ g F}}{1000 \text{ mg F}} \times \frac{100.0 \text{ g NaF}}{45.24 \text{ g NaF}} \times \frac{1000 \text{ mg NaF}}{1 \text{ g NaF}} = 6.6 \text{ mg NaF} 
\]

Check: The units of the answer (mg NaF) are correct. The magnitude is reasonable because it is greater than the original mass.

3.79  

(a) red = oxygen, white = hydrogen: \hspace{1cm} 2H:O \hspace{1cm} H_2O  
(b) black = carbon, white = hydrogen: \hspace{1cm} C=\text{H} \hspace{1cm} CH_4  
(c) black = carbon, white = hydrogen, red = oxygen: \hspace{1cm} 2C=6H:O \hspace{1cm} CH_2CH_2OH or C_2H_6O

3.80  

(a) red = oxygen, white = hydrogen: \hspace{1cm} 2O:C \hspace{1cm} CO_2  
(b) red = oxygen, white = hydrogen: \hspace{1cm} 2H:O \hspace{1cm} H_2O  
(c) red = oxygen, white = hydrogen: \hspace{1cm} 2H:O \hspace{1cm} H_2O

3.81  

(a) Given: 0.0885 mol C_4H_{10}  \text{ Find: mol H atoms}  
Conceptual Plan: Mol C_4H_{10} \rightarrow \text{mole H atom}  

\[
\text{Solution: } 0.0885 \text{ mol C}_4\text{H}_{10} \times \frac{10 \text{ mol H}}{1 \text{ mol C}_4\text{H}_{10}} = 0.885 \text{ mol H atoms} 
\]

Check: The units of the answer (mol H atoms) are correct. The magnitude is reasonable because it is greater than the original mol C_4H_{10}.

(b) Given: 1.3 mol CH_4  \text{ Find: mol H atoms}  
Conceptual Plan: Mol CH_4 \rightarrow \text{mole H atom}  

\[
\text{Solution: } 1.3 \text{ mol C}_4\text{H}_{10} \times \frac{4 \text{ mol H}}{1 \text{ mol C}_4\text{H}_{10}} = 5.2 \text{ mol H atoms} 
\]

Check: The units of the answer (mol H atoms) are correct. The magnitude is reasonable because it is greater than the original mol CH_4.

(c) Given: 2.4 mol C_6H_{12}  \text{ Find: mol H atoms}  
Conceptual Plan: Mol C_6H_{12} \rightarrow \text{mole H atom}  

\[
\text{Solution: } 2.4 \text{ mol C}_6\text{H}_{12} \times \frac{12 \text{ mol H}}{1 \text{ mol C}_6\text{H}_{12}} = 29 \text{ mol H atoms} 
\]

Check: The units of the answer (mol H atoms) are correct. The magnitude is reasonable because it is greater than the original mol C_6H_{12}.

(d) Given: 1.87 mol C_8H_{18}  \text{ Find: mol H atoms}  
Conceptual Plan: Mol C_8H_{18} \rightarrow \text{mole H atom}  

\[
\text{Solution: } 1.87 \text{ mol C}_8\text{H}_{18} \times \frac{18 \text{ mol H}}{1 \text{ mol C}_8\text{H}_{18}} = 33.7 \text{ mol H atoms} 
\]

Check: The units of the answer (mol H atoms) are correct. The magnitude is reasonable because it is greater than the original mol C_8H_{18}.

3.82  

(a) Given: 4.88 mol H_2O_2  \text{ Find: mol O atoms}  
Conceptual Plan: Mol H_2O_2 \rightarrow \text{mole O atom}  

\[
\text{Solution: } 4.88 \text{ mol H}_2\text{O}_2 \times \frac{2 \text{ mol O}}{1 \text{ mol H}_2\text{O}_2} = 9.76 \text{ mol O atoms} 
\]

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Check: The units of the answer (mol O atoms) are correct. The magnitude is reasonable because it is greater than the original mol H₂O₂.

(b) Given: 2.15 mol N₂O  Find: mol O atoms
Conceptual Plan: \( \text{Mol N}_2\text{O} \rightarrow \text{mole O atom} \)
\[
\begin{align*}
1 \text{ mol O} & \quad \text{1 mol N}_2\text{O} \\
1 \text{ mol N}_2\text{O} & \\
\hline
\end{align*}
\]
Solution: \( 2.15 \text{ mol N}_2\text{O} \times \frac{1 \text{ mol O}}{1 \text{ mol N}_2\text{O}} = 2.15 \text{ mol O atoms} \)

Check: The units of the answer (mol O atoms) are correct. The magnitude is reasonable because it is the same as the original mol N₂O.

(c) Given: 0.0237 mol H₂CO₃  Find: mol O atoms
Conceptual Plan: \( \text{Mol H}_2\text{CO}_3 \rightarrow \text{mole O atom} \)
\[
\begin{align*}
3 \text{ mol O} & \quad \text{1 mol H}_2\text{CO}_3 \\
1 \text{ mol H}_2\text{CO}_3 & \\
\hline
\end{align*}
\]
Solution: \( 0.0237 \text{ mol H}_2\text{CO}_3 \times \frac{3 \text{ mol O}}{1 \text{ mol H}_2\text{CO}_3} = 0.0711 \text{ mol O atoms} \)

Check: The units of the answer (mol O atoms) are correct. The magnitude is reasonable because it is greater than the original mol H₂CO₃.

(d) Given: 24.1 mol CO₂  Find: mol O atoms
Conceptual Plan: \( \text{Mol CO}_2 \rightarrow \text{mole O atom} \)
\[
\begin{align*}
2 \text{ mol O} & \quad \text{1 mol CO}_2 \\
1 \text{ mol CO}_2 & \\
\hline
\end{align*}
\]
Solution: \( 24.1 \text{ mol CO}_2 \times \frac{2 \text{ mol O}}{1 \text{ mol CO}_2} = 48.2 \text{ mol O atoms} \)

Check: The units of the answer (mol O atoms) are correct. The magnitude is reasonable because it is greater than the original mol CO₂.

3.83

(a) Given: 8.5 g NaCl  Find: g Na
Conceptual Plan: \( \text{g NaCl} \rightarrow \text{mole NaCl} \rightarrow \text{mol Na} \rightarrow \text{g Na} \)
\[
\begin{align*}
1 \text{ mol NaCl} & \quad 58.44 \text{ g NaCl} \\
1 \text{ mol Na} & \quad 22.99 \text{ g Na} \\
1 \text{ mol NaCl} & \\
\hline
\end{align*}
\]
Solution: \( 8.5 \text{ g NaCl} \times \frac{1 \text{ mol NaCl}}{58.44 \text{ g NaCl}} \times \frac{1 \text{ mol Na}}{1 \text{ mol NaCl}} \times \frac{22.99 \text{ g Na}}{1 \text{ mol Na}} = 3.3 \text{ g Na} \)

Check: The units of the answer (g Na) are correct. The magnitude is reasonable because it is less than the original g NaCl.

(b) Given: 8.5 g Na₃PO₄  Find: g Na
Conceptual Plan: \( \text{g Na}_3\text{PO}_4 \rightarrow \text{mole Na}_3\text{PO}_4 \rightarrow \text{mol Na} \rightarrow \text{g Na} \)
\[
\begin{align*}
1 \text{ mol Na}_3\text{PO}_4 & \quad 163.94 \text{ g Na}_3\text{PO}_4 \\
3 \text{ mol Na} & \quad 22.99 \text{ g Na} \\
1 \text{ mol Na}_3\text{PO}_4 & \\
\hline
\end{align*}
\]
Solution: \( 8.5 \text{ g Na}_3\text{PO}_4 \times \frac{1 \text{ mol Na}_3\text{PO}_4}{163.94 \text{ g Na}_3\text{PO}_4} \times \frac{3 \text{ mol Na}}{1 \text{ mol Na}_3\text{PO}_4} \times \frac{22.99 \text{ g Na}}{1 \text{ mol Na}} = 3.6 \text{ g Na} \)

Check: The units of the answer (g Na) are correct. The magnitude is reasonable because it is less than the original g Na₃PO₄.

(c) Given: 8.5 g NaC₇H₇O₅  Find: g Na
Conceptual Plan: \( \text{g NaC}_7\text{H}_7\text{O}_5 \rightarrow \text{mole NaC}_7\text{H}_7\text{O}_5 \rightarrow \text{mol Na} \rightarrow \text{g Na} \)
\[
\begin{align*}
1 \text{ mol NaC}_7\text{H}_7\text{O}_5 & \quad 144.10 \text{ g NaC}_7\text{H}_7\text{O}_5 \\
1 \text{ mol Na} & \quad 22.99 \text{ g Na} \\
1 \text{ mol NaC}_7\text{H}_7\text{O}_5 & \\
\hline
\end{align*}
\]
Solution: \( 8.5 \text{ g NaC}_7\text{H}_7\text{O}_5 \times \frac{1 \text{ mol NaC}_7\text{H}_7\text{O}_5}{144.10 \text{ g NaC}_7\text{H}_7\text{O}_5} \times \frac{1 \text{ mol Na}}{1 \text{ mol NaC}_7\text{H}_7\text{O}_5} \times \frac{22.99 \text{ g Na}}{1 \text{ mol Na}} = 1.4 \text{ g Na} \)

Check: The units of the answer (g Na) are correct. The magnitude is reasonable because it is less than the original g NaC₇H₇O₅.

(d) Given: 8.5 g Na₂C₆H₆O₇  Find: g Na
Conceptual Plan: \( \text{g Na}_2\text{C}_6\text{H}_6\text{O}_7 \rightarrow \text{mole Na}_2\text{C}_6\text{H}_6\text{O}_7 \rightarrow \text{mol Na} \rightarrow \text{g Na} \)
\[
\begin{align*}
1 \text{ mol Na}_2\text{C}_6\text{H}_6\text{O}_7 & \quad 286.1 \text{ g Na}_2\text{C}_6\text{H}_6\text{O}_7 \\
2 \text{ mol Na} & \quad 22.99 \text{ g Na} \\
1 \text{ mol Na}_2\text{C}_6\text{H}_6\text{O}_7 & \\
\hline
\end{align*}
\]
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Solution: 8.5 g Na₂CO₃ × \( \frac{1 \text{ mol Na}_2\text{CO}_3}{236.1 \text{ g Na}_2\text{CO}_3} \times \frac{2 \text{ mol Na}}{1 \text{ mol Na}_2\text{CO}_3} \times \frac{22.99 \text{ g Na}}{1 \text{ mol Na}} = 1.7 \text{ g Na} \)

Check: The units of the answer (g Na) are correct. The magnitude is reasonable because it is less than the original g Na₂CO₃.

3.84 (a) Given: 25 kg CF₂Cl₂ Find: kg Cl
Conceptual Plan: kg CF₂Cl₂ → g CF₂Cl₂ → mole CF₂Cl₂ → mol Cl → g Cl → kg Cl

\[
\begin{align*}
1000 \text{ g CF₂Cl₂} & \quad 1 \text{ mol CF₂Cl₂} & \quad 35.45 \text{ g Cl} & \quad 1 \text{ kg Cl} \\
1 \text{ kg CF₂Cl₂} & \quad 120.91 \text{ g CF₂Cl₂} & \quad & \quad \quad 1000 \text{ g Cl}
\end{align*}
\]

Solution:

\[
\begin{align*}
25 \text{ kg CF₂Cl₂} & \quad \times \frac{1000 \text{ g CF₂Cl₂}}{1 \text{ kg CF₂Cl₂}} \times \frac{1 \text{ mol CF₂Cl₂}}{120.91 \text{ g CF₂Cl₂}} \times \frac{2 \text{ mol Cl}}{1 \text{ mol CF₂Cl₂}} \times \frac{35.45 \text{ g Cl}}{1 \text{ mol Cl}} \times \frac{1 \text{ kg Cl}}{1000 \text{ g Cl}} \\
& = 15 \text{ kg Cl}
\end{align*}
\]

Check: The units of the answer (kg Cl) are correct. The magnitude is reasonable because it is less than the original kg CF₂Cl₂.

(b) Given: 25 kg CFCl₃ Find: kg Cl
Conceptual Plan: kg CFCl₃ → g CFCl₃ → mole CFCl₃ → mol Cl → g Cl → kg Cl

\[
\begin{align*}
1000 \text{ g CFCl₃} & \quad 1 \text{ mol CFCl₃} & \quad 35.45 \text{ g Cl} & \quad 1 \text{ kg Cl} \\
1 \text{ kg CFCl₃} & \quad 137.36 \text{ g CFCl₃} & \quad & \quad \quad 1000 \text{ g Cl}
\end{align*}
\]

Solution:

\[
\begin{align*}
25 \text{ kg CFCl₃} & \quad \times \frac{1000 \text{ g CFCl₃}}{1 \text{ kg CFCl₃}} \times \frac{1 \text{ mol CFCl₃}}{137.36 \text{ g CFCl₃}} \times \frac{3 \text{ mol Cl}}{1 \text{ mol CFCl₃}} \times \frac{35.45 \text{ g Cl}}{1 \text{ mol Cl}} \times \frac{1 \text{ kg Cl}}{1000 \text{ g Cl}} \\
& = 19 \text{ kg Cl}
\end{align*}
\]

Check: The units of the answer (kg Cl) are correct. The magnitude is reasonable because it is less than the original kg CFCl₃.

(c) Given: 25 kg C₂F₅Cl Find: kg Cl
Conceptual Plan: kg C₂F₅Cl → g C₂F₅Cl → mole C₂F₅Cl → mol Cl → g Cl → kg Cl

\[
\begin{align*}
1000 \text{ g C₂F₅Cl} & \quad 1 \text{ mol C₂F₅Cl} & \quad 35.45 \text{ g Cl} & \quad 1 \text{ kg Cl} \\
1 \text{ kg C₂F₅Cl} & \quad 187.37 \text{ g C₂F₅Cl} & \quad & \quad \quad 1000 \text{ g Cl}
\end{align*}
\]

Solution:

\[
\begin{align*}
25 \text{ kg C₂F₅Cl} & \quad \times \frac{1000 \text{ g C₂F₅Cl}}{1 \text{ kg C₂F₅Cl}} \times \frac{1 \text{ mol C₂F₅Cl}}{187.37 \text{ g C₂F₅Cl}} \times \frac{3 \text{ mol Cl}}{1 \text{ mol C₂F₅Cl}} \times \frac{35.45 \text{ g Cl}}{1 \text{ mol Cl}} \times \frac{1 \text{ kg Cl}}{1000 \text{ g Cl}} \\
& = 14 \text{ kg Cl}
\end{align*}
\]

Check: The units of the answer (kg Cl) are correct. The magnitude is reasonable because it is less than the original kg C₂F₅Cl.

(d) Given: 25 kg CF₃Cl Find: kg Cl
Conceptual Plan: kg CF₃Cl → g CF₃Cl → mole CF₃Cl → mol Cl → g Cl → kg Cl

\[
\begin{align*}
1000 \text{ g CF₃Cl} & \quad 1 \text{ mol CF₃Cl} & \quad 35.45 \text{ g Cl} & \quad 1 \text{ kg Cl} \\
1 \text{ kg CF₃Cl} & \quad 104.46 \text{ g CF₃Cl} & \quad & \quad \quad 1000 \text{ g Cl}
\end{align*}
\]

Solution:

\[
\begin{align*}
25 \text{ kg CF₃Cl} & \quad \times \frac{1000 \text{ g CF₃Cl}}{1 \text{ kg CF₃Cl}} \times \frac{1 \text{ mol CF₃Cl}}{104.46 \text{ g CF₃Cl}} \times \frac{1 \text{ mol Cl}}{1 \text{ mol CF₃Cl}} \times \frac{35.45 \text{ g Cl}}{1 \text{ mol Cl}} \times \frac{1 \text{ kg Cl}}{1000 \text{ g Cl}} \\
& = 8.5 \text{ kg Cl}
\end{align*}
\]

Check: The units of the answer (kg Cl) are correct. The magnitude is reasonable because it is less than the original kg CF₃Cl.

3.85 Given: 5.85 g C₂F₄ Find: F atoms
Conceptual Plan: g C₂F₄ → mol C₂F₄ → molecules C₂F₄ → F atoms

\[
\begin{align*}
1 \text{ mol C₂F₄} & \quad 6.022 \times 10^{23} \text{ C₂F₄ molecules} & \quad \frac{4 \text{ F atoms}}{1 \text{ C₂F₄ molecule}} \\
100.02 \text{ g C₂F₄} & \quad 2 \text{ C₂F₄ molecule}
\end{align*}
\]

Solution:

\[
\begin{align*}
5.85 \text{ g C₂F₄} & \quad \times \frac{1 \text{ mol C₂F₄}}{100.02 \text{ g C₂F₄}} \times \frac{6.022 \times 10^{23} \text{ C₂F₄ molecules}}{1 \text{ mol C₂F₄}} \times \frac{4 \text{ F atoms}}{1 \text{ C₂F₄ molecule}} \\
& = 1.4089 \times 10^{23} \text{ F atoms} = 1.41 \times 10^{23} \text{ F atoms}
\end{align*}
\]

Check: The units (F atoms) are correct. The magnitude of the answer (1.41 \times 10^{23}) makes physical sense because there is ~0.06 mole of molecules and there are 4 F atoms in each molecule.
3.86  Given: 35.2 g CH₃Br₂  Find: Br atoms  

**Conceptual Plan:** g CH₃Br₂ → mol CH₃Br₂ → molecules CH₃Br₂ → Br atoms

\[
\frac{1 \text{ mol CH₃Br₂}}{173.83 \text{ g CH₃Br₂}} \times \frac{6.022 \times 10^{23} \text{ CH₃Br₂ molecules}}{1 \text{ mol CH₃Br₂}} \times \frac{2 \text{ Br atoms}}{1 \text{ CH₃Br₂ molecule}}
\]

\[
= \frac{35.2 \text{ g CH₃Br₂}}{173.83 \text{ g CH₃Br₂}} \times \frac{6.022 \times 10^{23} \text{ CH₃Br₂ molecules}}{1 \text{ mol CH₃Br₂}} \times \frac{2 \text{ Br atoms}}{1 \text{ CH₃Br₂ molecule}}
\]

\[
= 2.4389 \times 10^{23} \text{ Br atoms} = 2.44 \times 10^{23} \text{ Br atoms}
\]

**Check:** The units (Br atoms) are correct. The magnitude of the answer (2.44 \times 10^{23}) makes physical sense because there is 0.2 mole of molecules and there are 2 Br atoms in each molecule.

### Chemical Formulas from Experimental Data

3.87  (a)  Given: 1.651 g Ag; 0.1224 g O  Find: empirical formula

**Conceptual Plan:** Convert mass to mol of each element → write pseudoformula → write empirical formula

\[
\frac{1 \text{ mol Ag}}{107.87 \text{ g Ag}} \times \frac{1 \text{ mol O}}{16.00 \text{ g O}}
\]

**Solution:** 1.651 g Ag × \frac{1 \text{ mol Ag}}{107.87 \text{ g Ag}} = 0.01531 mol Ag

0.1224 g O × \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 0.007650 mol O

\[
\text{Ag}_{0.01531} \text{O}_{0.007650} \rightarrow \text{Ag}_2\text{O}
\]

The correct empirical formula is Ag₂O.

(b)  Given: 0.672 g Co; 0.569 g As; 0.486 g O  Find: empirical formula

**Conceptual Plan:** Convert mass to mol of each element → write pseudoformula → write empirical formula

\[
\frac{1 \text{ mol Co}}{58.93 \text{ g Co}} \times \frac{1 \text{ mol As}}{74.92 \text{ g As}} \times \frac{1 \text{ mol O}}{16.00 \text{ g O}}
\]

**Solution:** 0.672 g Co × \frac{1 \text{ mol Co}}{58.93 \text{ g Co}} = 0.0114 mol Co

0.569 g As × \frac{1 \text{ mol As}}{74.92 \text{ g As}} = 0.00759 mol O

0.486 g O × \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 0.0304 mol O

\[
\text{Co}_{0.0114} \text{As}_{0.00759} \text{O}_{0.0304} \rightarrow \text{Co}_{1.5} \text{As}_1 \text{O}_4
\]

\[
\text{Co}_{1.5} \text{As}_1 \text{O}_4 \times 2 \rightarrow \text{Co}_3 \text{As}_2 \text{O}_8
\]

The correct empirical formula is Co₃As₂O₈.

(c)  Given: 1.443 g Se; 5.841 g Br  Find: empirical formula

**Conceptual Plan:** Convert mass to mol of each element → write pseudoformula → write empirical formula

\[
\frac{1 \text{ mol Se}}{78.96 \text{ g Se}} \times \frac{1 \text{ mol Br}}{79.90 \text{ g Br}}
\]

**Solution:** 1.443 g Se × \frac{1 \text{ mol Se}}{78.96 \text{ g Se}} = 0.01828 mol Se

5.841 g Br × \frac{1 \text{ mol Br}}{79.90 \text{ g Br}} = 0.07310 mol Br

\[
\text{Se}_{0.01828} \text{Br}_{0.07310}
\]

\[
\text{Se}_{0.01828} \text{Br}_{0.07310} \rightarrow \text{SeBr}_4
\]

The correct empirical formula is SeBr₄.
Given: 1.245 g Ni; 5.381 g I  Find: empirical formula
Conceptual Plan:
Convert mass to mol of each element → write pseudoformula → write empirical formula
\[
\frac{1 \text{ mol Ni}}{58.69 \text{ g Ni}} \quad \frac{1 \text{ mol I}}{126.9 \text{ g I}}
\]
Solution: 1.245 g Ni × \frac{1 \text{ mol Ni}}{58.69 \text{ g Ni}} = 0.02121 \text{ mol Ni}
5.381 g I × \frac{1 \text{ mol I}}{126.9 \text{ g I}} = 0.04240 \text{ mol I}

Ni_{0.02121} I_{0.04240} \rightarrow \text{NiI}_2

The correct empirical formula is NiI₂.

(b) Given: 2.677 g Ba; 3.115 g Br  Find: empirical formula
Conceptual Plan:
Convert mass to mol of each element → write pseudoformula → write empirical formula
\[
\frac{1 \text{ mol Ba}}{137.33 \text{ g Ba}} \quad \frac{1 \text{ mol Br}}{79.90 \text{ g Br}}
\]
Solution: 2.677 g Ba × \frac{1 \text{ mol Ba}}{137.33 \text{ g Ba}} = 0.01949 \text{ mol Ba}
3.115 g Br × \frac{1 \text{ mol Br}}{79.90 \text{ g Br}} = 0.03899 \text{ mol Br}

Ba_{0.01949} Br_{0.03899} \rightarrow \text{BaBr}_2

The correct empirical formula is BaBr₂.

(c) Given: 2.128 g Be; 7.557 g S; 15.107 g O  Find: empirical formula
Conceptual Plan:
Convert mass to mol of each element → write pseudoformula → write empirical formula
\[
\frac{1 \text{ mol Be}}{9.012 \text{ g Be}} \quad \frac{1 \text{ mol S}}{32.06 \text{ g S}} \quad \frac{1 \text{ mol O}}{16.00 \text{ g O}}
\]
Solution: 2.128 g Be × \frac{1 \text{ mol Be}}{9.012 \text{ g Be}} = 0.2361 \text{ mol Be}
7.557 g S × \frac{1 \text{ mol S}}{32.06 \text{ g S}} = 0.2357 \text{ mol S}
15.107 g O × \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 0.9442 \text{ mol O}

Be_{0.2361} S_{0.2357} O_{0.9442} \rightarrow \text{BeSO}_4

The correct empirical formula is BeSO₄.

3.89 (a) Given: in a 100 g sample of nicotine: 74.03 g C; 8.70 g H; 17.27 g N  Find: empirical formula
Conceptual Plan:
Convert mass to mol of each element → write pseudoformula → write empirical formula
\[
\frac{1 \text{ mol C}}{12.01 \text{ g C}} \quad \frac{1 \text{ mol H}}{1.008 \text{ g H}} \quad \frac{1 \text{ mol N}}{14.01 \text{ g N}}
\]
Solution: 74.03 g C × \frac{1 \text{ mol C}}{12.01 \text{ g C}} = 6.164 \text{ mol C}
8.70 g H × \frac{1 \text{ mol H}}{1.008 \text{ g H}} = 8.63 \text{ mol H}
17.27 g N × \frac{1 \text{ mol N}}{14.01 \text{ g N}} = 1.233 \text{ mol N}

C₆H₈N₃
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\[ C_{6.164}H_{8.63}N_{1.233} \rightarrow C_2H_2N \]

1.233 1.233 1.233

The correct empirical formula is C₂H₂N.

(b) **Given:** in a 100 g sample of caffeine: 49.48 g C; 5.19 g H; 28.85 g N; 16.48 g O  
**Find:** empirical formula

**Conceptual Plan:**
Convert mass to mol of each element → write pseudoformula → write empirical formula

\[
\begin{align*}
\text{1 mol C} & \times \frac{1 \text{ mol C}}{12.01 \text{ g C}} = 4.120 \text{ mol C} \\
\text{1 mol H} & \times \frac{1 \text{ mol H}}{1.008 \text{ g H}} = 5.15 \text{ mol H} \\
\text{1 mol N} & \times \frac{1 \text{ mol N}}{14.01 \text{ g N}} = 2.059 \text{ mol N} \\
\text{1 mol O} & \times \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 1.030 \text{ mol O} \\
C_4H_{12.059}N_{2.059}O_{1.030} & \rightarrow C_2H_2N_2O \\
1.030 & \quad 1.030 \\
\end{align*}
\]

The correct empirical formula is C₂H₂N₂O.

3.90 (a) **Given:** in a 100 g sample of methyl butyrate: 58.80 g C; 9.87 g H; 31.33 g O  
**Find:** empirical formula

**Conceptual Plan:**
Convert mass to mol of each element → write pseudoformula → write empirical formula

\[
\begin{align*}
\text{1 mol C} & \times \frac{1 \text{ mol C}}{12.01 \text{ g C}} = 4.896 \text{ mol C} \\
\text{1 mol H} & \times \frac{1 \text{ mol H}}{1.008 \text{ g H}} = 9.79 \text{ mol H} \\
\text{1 mol O} & \times \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 1.958 \text{ mol O} \\
C_4H_{9.79}O_{1.958} & \quad C_4H_{9.79}O_{1.958} \rightarrow C_2H_2O \\
1.958 & \quad 1.958 \\
\end{align*}
\]

The correct empirical formula is C₁₂H₁₀O₂.

(b) **Given:** in a 100 g sample of vanillin: 63.15 g C; 5.30 g H; 31.55 g O  
**Find:** empirical formula

**Conceptual Plan:**
Convert mass to mol of each element → write pseudoformula → write empirical formula

\[
\begin{align*}
\text{1 mol C} & \times \frac{1 \text{ mol C}}{12.01 \text{ g C}} = 5.258 \text{ mol C} \\
\text{1 mol H} & \times \frac{1 \text{ mol H}}{1.008 \text{ g H}} = 5.26 \text{ mol H} \\
\text{1 mol O} & \times \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 1.972 \text{ mol O} \\
C_5H_{5.26}O_{1.972} & \quad C_5H_{5.26}O_{1.972} \rightarrow C_2H_2O \\
1.972 & \quad 1.972 \\
\end{align*}
\]

The correct empirical formula is C₆H₅O₃.

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3.91 Given: in a 100 g sample of ibuprofen 75.69 g C; 8.80 g H; 15.51 g O
Find: empirical formula
Conceptual Plan: Convert mass to mol of each element → write pseudoformula → write empirical formula
\[
\begin{align*}
1 \text{ mol C} & \quad 1 \text{ mol H} & \quad 1 \text{ mol O} \\
12.01 \text{ g C} & \quad 1.008 \text{ g H} & \quad 16.00 \text{ g O}
\end{align*}
\]
divide by smallest number

Solution: $75.69 \text{ g C} \times \frac{1 \text{ mol C}}{12.01 \text{ g C}} = 6.302 \text{ mol C}$
$8.80 \text{ g H} \times \frac{1 \text{ mol H}}{1.008 \text{ g H}} = 8.73 \text{ mol H}$
$15.51 \text{ g O} \times \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 0.9694 \text{ mol O}$

\[
\begin{align*}
\text{C}_6\text{H}_8\text{O}_3 & \quad \text{C}_{0.30}\text{H}_{0.01}\text{O} \\
\text{C}_{6.30}\text{H}_{8.73}\text{O}_{0.9694} & \quad \text{C}_{13}\text{H}_{18}\text{O}_2
\end{align*}
\]
The correct empirical formula is \text{C}_{13}\text{H}_{18}\text{O}_2.

3.92 Given: in a 100 g sample of ascorbic acid 40.92 g C; 4.58 g H; 54.50 g O
Find: empirical formula
Conceptual Plan: Convert mass to mol of each element → write pseudoformula → write empirical formula
\[
\begin{align*}
1 \text{ mol C} & \quad 1 \text{ mol H} & \quad 1 \text{ mol O} \\
12.01 \text{ g C} & \quad 1.008 \text{ g H} & \quad 16.00 \text{ g O}
\end{align*}
\]
divide by smallest number

Solution: $40.92 \text{ g C} \times \frac{1 \text{ mol C}}{12.01 \text{ g C}} = 3.407 \text{ mol C}$
$4.58 \text{ g H} \times \frac{1 \text{ mol H}}{1.008 \text{ g H}} = 4.54 \text{ mol H}$
$54.50 \text{ g O} \times \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 3.406 \text{ mol O}$

\[
\begin{align*}
\text{C}_3\text{H}_4\text{O}_3 & \quad \text{C}_{1.00}\text{H}_{1.30}\text{O}_{1.00} \\
\text{C}_{3.407}\text{H}_{4.54}\text{O}_{3.406} & \quad \text{C}_3\text{H}_3\text{O}_3
\end{align*}
\]
The correct empirical formula is \text{C}_3\text{H}_3\text{O}_3.

3.93 Given: 0.77 mg N; 6.61 mg \text{N}_2\text{Cl}_y
Find: empirical formula
Conceptual Plan: Find mg Cl → convert mg to g for each element → convert mass to mol of each element →
write pseudoformula → write empirical formula
\[
\begin{align*}
1 \text{ g} & \quad 1000 \text{ mg} & \quad 1 \text{ mol N} & \quad 1 \text{ mol Cl} \\
14.01 \text{ g N} & \quad 35.45 \text{ g Cl}
\end{align*}
\]
divide by smallest number

Solution: \text{6.61 mg N}_2\text{Cl}_y - 0.77 mg N = 5.84 mg Cl
$0.77 \text{ mg N} \times \frac{1 \text{ g N}}{1000 \text{ mg N}} \times \frac{1 \text{ mol N}}{14.01 \text{ g N}} = 5.5 \times 10^{-5} \text{ mol N}$
$5.84 \text{ mg Cl} \times \frac{1 \text{ g Cl}}{1000 \text{ mg Cl}} \times \frac{1 \text{ mol Cl}}{35.45 \text{ g Cl}} = 1.6 \times 10^{-4} \text{ mol Cl}$

\[
\begin{align*}
\text{N}_5\text{.5x10^{-4} Cl}_{1.6x10^{-4}} & \quad \text{NCl}_3 \\
5.5 \times 10^{-4} & \quad 5.5 \times 10^{-5}
\end{align*}
\]
The correct empirical formula is \text{NCl}_3.

3.94 Given: 45.2 mg P; 131.6 mg \text{P}_2\text{Se}_y
Find: empirical formula
Conceptual Plan: Find mg Se → convert mg to g for each element → convert mass to mol of each element →
write pseudoformula → write empirical formula
\[
\begin{align*}
1 \text{ g} & \quad 1000 \text{ mg} & \quad 1 \text{ mol P} & \quad 1 \text{ mol Se} \\
30.97 \text{ g P} & \quad 78.96 \text{ g Se}
\end{align*}
\]
divide by smallest number

\[
\begin{align*}
\text{mg P}_2\text{Se}_y & \quad \text{mg P} \\
\text{mg P}_2\text{Se}_y & \quad \text{mg P}
\end{align*}
\]

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Solution: 131.6 mg P₄Se₅ - 45.2 mg P = 86.4 mg Se

\[
\begin{align*}
45.2 \text{ mg P} & \times \frac{1 \text{ g P}}{1000 \text{ mg P}} \times \frac{1 \text{ mol P}}{30.97 \text{ g P}} = 0.00146 \text{ mol P} \\
86.4 \text{ g Se} & \times \frac{1 \text{ g Se}}{1000 \text{ mg Se}} \times \frac{1 \text{ mol Se}}{78.96 \text{ g Se}} = 0.00109 \text{ mol Se} \\
\text{P}_{0.00146} \text{ Se}_{0.00109} & \rightarrow \text{P}_{1.34} \text{Se} \\
\text{P}_{1.34} \text{Se} \times 3 & = \text{P}_{4} \text{Se}_{3}.
\end{align*}
\]

The correct empirical formula is \( \text{P}_4\text{Se}_3 \).

3.95 (a) \text{Given: empirical formula = C}_6\text{H}_7\text{N}; \text{molar mass = 186.24 g/mol} \quad \text{Find: molecular formula}

\text{Conceptual Plan: Molecular formula = empirical formula} \times n \quad n = \frac{\text{molar mass}}{\text{empirical formula mass}}

\text{Solution: empirical formula mass = 6(12.01 g/mol) + 7(1.008 g/mol) + 1(14.01 g/mol) = 93.13 g/mol}

\[
n = \frac{186.24 \text{ g/mol}}{93.13 \text{ g/mol}} = 1.9998 = 2
\]

\text{molecular formula = C}_6\text{H}_7\text{N} \times 2 = \text{C}_6\text{H}_4\text{N}_2

(b) \text{Given: empirical formula = C}_2\text{HCl; molar mass = 181.44 g/mol} \quad \text{Find: molecular formula}

\text{Conceptual Plan: Molecular formula = empirical formula} \times n \quad n = \frac{\text{molar mass}}{\text{empirical formula mass}}

\text{Solution: empirical formula mass = 2(12.01 g/mol) + 1(1.008 g/mol) + 1(35.45 g/mol) = 60.48 g/mol}

\[
n = \frac{181.44 \text{ g/mol}}{60.48 \text{ g/mol}} = 3
\]

\text{molecular formula = C}_2\text{HCl} \times 3 = \text{C}_2\text{H}_3\text{Cl}_3

3.96 (a) \text{Given: empirical formula = C}_6\text{H}_8; \text{molar mass = 114.22 g/mol} \quad \text{Find: molecular formula}

\text{Conceptual Plan: Molecular formula = empirical formula} \times n \quad n = \frac{\text{molar mass}}{\text{empirical formula mass}}

\text{Solution: empirical formula mass = 4(12.01 g/mol) + 9(1.008 g/mol) = 57.11 g/mol}

\[
n = \frac{114.22 \text{ g/mol}}{57.11 \text{ g/mol}} = 2
\]

\text{molecular formula = C}_6\text{H}_8 \times 2 = \text{C}_6\text{H}_{16}

(b) \text{Given: empirical formula = CCl;} \text{molar mass = 284.77 g/mol} \quad \text{Find: molecular formula}

\text{Conceptual Plan: Molecular formula = empirical formula} \times n \quad n = \frac{\text{molar mass}}{\text{empirical formula mass}}

\text{Solution: empirical formula mass = 1(12.01 g/mol) + 1(35.45 g/mol) = 47.46 g/mol}
Chapter 3 Molecules, Compounds, and Chemical Equations

\[ n = \frac{\text{molar mass}}{\text{formula molar mass}} = \frac{284.77 \text{ g/mol}}{47.46 \text{ g/mol}} = 6 \]
\[ \text{molecular formula} = \text{C}_6\text{Cl}_6 \]

(c) **Given**: empirical formula = C$_3$H$_7$N; molar mass = 312.29 g/mol  **Find**: molecular formula

**Conceptual Plan**: Molecular formula = empirical formula $\times n$

**Solution**: empirical formula mass = 3(12.01 g/mol) + 2(1.008 g/mol) + 1(14.01 g/mol) = 52.06 g/mol

\[ n = \frac{\text{molar mass}}{\text{formula molar mass}} = \frac{312.29 \text{ g/mol}}{52.06 \text{ g/mol}} = 6 \]
\[ \text{molecular formula} = \text{C}_3\text{H}_7\text{N} \times 6 = \text{C}_{18}\text{H}_{34}\text{N}_6 \]

3.97  **Given**: 33.01 g CO$_2$; 13.51 g H$_2$O  **Find**: empirical formula

**Conceptual Plan**: Mass CO$_2$, H$_2$O $\rightarrow$ mol CO$_2$, H$_2$O $\rightarrow$ mol C, mol H $\rightarrow$ pseudoformula $\rightarrow$ empirical formula

\[ \frac{1 \text{ mol CO}_2}{44.01 \text{ g CO}_2} = \frac{1 \text{ mol H}_2\text{O}}{18.02 \text{ g H}_2\text{O}} = \frac{2 \text{ mol H}}{1 \text{ mol H}_2\text{O}} \]

**Solution**:

\[ 33.01 \text{ g CO}_2 \times \frac{1 \text{ mol CO}_2}{44.01 \text{ g CO}_2} = 0.7501 \text{ mol CO}_2 \]
\[ 13.51 \text{ g H}_2\text{O} \times \frac{1 \text{ mol H}_2\text{O}}{18.02 \text{ g H}_2\text{O}} = 0.7497 \text{ mol H}_2\text{O} \]
\[ 0.7501 \text{ mol CO}_2 \times \frac{1 \text{ mol C}}{1 \text{ mol CO}_2} = 0.7501 \text{ mol C} \]
\[ 0.7497 \text{ mol H}_2\text{O} \times \frac{2 \text{ mol H}}{1 \text{ mol H}_2\text{O}} = 1.499 \text{ mol H} \]
\[ \text{C}_0.7501\text{H}_{1.499} \rightarrow \text{CH}_2 \]
\[ 0.7501 \quad 0.7501 \]

The correct empirical formula is CH$_2$.

3.98  **Given**: 8.80 g CO$_2$; 1.44 g H$_2$O  **Find**: empirical formula

**Conceptual Plan**: Mass CO$_2$, H$_2$O $\rightarrow$ mol CO$_2$, H$_2$O $\rightarrow$ mol C, mol H $\rightarrow$ pseudoformula $\rightarrow$ empirical formula

\[ \frac{1 \text{ mol CO}_2}{44.01 \text{ g CO}_2} = \frac{1 \text{ mol H}_2\text{O}}{18.02 \text{ g H}_2\text{O}} = \frac{2 \text{ mol H}}{1 \text{ mol H}_2\text{O}} \]

**Solution**:

\[ 8.80 \text{ g CO}_2 \times \frac{1 \text{ mol CO}_2}{44.01 \text{ g CO}_2} = 0.200 \text{ mol CO}_2 \]
\[ 1.44 \text{ g H}_2\text{O} \times \frac{1 \text{ mol H}_2\text{O}}{18.02 \text{ g H}_2\text{O}} = 0.0799 \text{ mol H}_2\text{O} \]
\[ 0.200 \text{ mol CO}_2 \times \frac{1 \text{ mol C}}{1 \text{ mol CO}_2} = 0.200 \text{ mol C} \]
\[ 0.0799 \text{ mol H}_2\text{O} \times \frac{2 \text{ mol H}}{1 \text{ mol H}_2\text{O}} = 0.160 \text{ mol H} \]
\[ \text{C}_{0.200}\text{H}_{0.160} \rightarrow \text{C}_{1.23}\text{H}_1 \]
\[ 0.200 \quad 0.160 \]
\[ \text{C}_{1.23}\text{H}_1 \times 4 = \text{C}_4\text{H}_4 \]

The correct empirical formula is C$_4$H$_4$.

3.99  **Given**: 4.30 g sample; 8.59 g CO$_2$; 3.52 g H$_2$O  **Find**: empirical formula

**Conceptual Plan**: Mass CO$_2$, H$_2$O $\rightarrow$ mol CO$_2$, H$_2$O $\rightarrow$ mol C, mol H $\rightarrow$ mass C, mass H, mass O $\rightarrow$ mol C $\rightarrow$

\[ \frac{1 \text{ mol CO}_2}{44.01 \text{ g CO}_2} = \frac{1 \text{ mol H}_2\text{O}}{18.02 \text{ g H}_2\text{O}} = \frac{2 \text{ mol H}}{1 \text{ mol H}_2\text{O}} \]

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pseudoformula → empirical formula

divide by smallest number

Solution:

\[ \text{8.59 g CO}_2 \times \frac{1 \text{ mol CO}_2}{44.01 \text{ g CO}_2} = 0.195 \text{ mol CO}_2 \]

\[ \text{3.52 g H}_2\text{O} \times \frac{1 \text{ mol H}_2\text{O}}{18.02 \text{ g H}_2\text{O}} = 0.195 \text{ mol H}_2\text{O} \]

\[ 0.195 \text{ mol CO}_2 \times \frac{1 \text{ mol C}}{1 \text{ mol CO}_2} = 0.195 \text{ mol C} \]

\[ 0.195 \text{ mol H}_2\text{O} \times \frac{2 \text{ mol H}}{1 \text{ mol H}_2\text{O}} = 0.390 \text{ mol H} \]

\[ 0.195 \text{ mol CO} \times \frac{12.01 \text{ g C}}{1 \text{ mol CO}} = 2.34 \text{ g C} \]

\[ 0.390 \text{ mol H}_2\text{O} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 0.393 \text{ g H} \]

\[ 4.30 \text{ g} - 2.34 \text{ g} - 0.393 \text{ g} = 1.57 \text{ g O} \]

\[ 1.57 \text{ g O} \times \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 0.0981 \text{ mol O} \]

\[ \text{C}_{0.195} \text{H}_{0.390} \text{O}_{0.0981} \rightarrow \text{C}_3\text{H}_6\text{O}_3 \]

The correct empirical formula is C₃H₆O₃.

3.100 Given: 12.01 g sample; 14.08 g CO₂; 4.32 g H₂O \hspace{1cm} \text{Find: empirical formula}

Conceptual Plan: Mass CO₂, H₂O → mol CO₂, H₂O → mol C, mol H → mass C, mass H, mass O → mol O →

\[ \frac{1 \text{ mol CO}_2}{44.01 \text{ g CO}_2} \]

\[ \frac{1 \text{ mol H}_2\text{O}}{18.02 \text{ g H}_2\text{O}} \]

\[ \frac{1 \text{ mol C}}{1 \text{ mol CO}_2} \]

\[ \frac{2 \text{ mol H}}{1 \text{ mol H}_2\text{O}} \]

\[ \frac{12.01 \text{ g C}}{1 \text{ mol C}} \]

\[ \frac{1.008 \text{ g H}}{1 \text{ mol H}} \]

\[ \frac{1 \text{ mol O}}{16.00 \text{ g O}} \]

pseudoformula → empirical formula

divide by smallest number

Solution:

\[ 14.08 \text{ g CO}_2 \times \frac{1 \text{ mol CO}_2}{44.01 \text{ g CO}_2} = 0.3199 \text{ mol CO}_2 \]

\[ 4.32 \text{ g H}_2\text{O} \times \frac{1 \text{ mol H}_2\text{O}}{18.02 \text{ g H}_2\text{O}} = 0.2397 \text{ mol H}_2\text{O} \]

\[ 0.3199 \text{ mol CO}_2 \times \frac{1 \text{ mol C}}{1 \text{ mol CO}_2} = 0.3199 \text{ mol C} \]

\[ 0.2397 \text{ mol H}_2\text{O} \times \frac{2 \text{ mol H}}{1 \text{ mol H}_2\text{O}} = 0.4795 \text{ mol H} \]

\[ 0.3199 \text{ mol C} \times \frac{12.01 \text{ g C}}{1 \text{ mol C}} = 3.842 \text{ g C} \]

\[ 0.4795 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 0.4833 \text{ g H} \]

\[ 12.01 \text{ g} - 3.842 \text{ g} - 0.4833 \text{ g} = 7.68 \text{ g O} \]

\[ 7.68 \text{ g O} \times \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 0.480 \text{ mol O} \]

\[ \text{C}_{0.3199} \text{H}_{0.4795} \text{O}_{0.480} \rightarrow \text{CH}_1.5 \text{O}_{1.5} \]

\[ \text{CH}_1.5 \text{O}_{1.5} \times 2 = \text{C}_3\text{H}_6\text{O}_3 \]

The correct empirical formula is C₃H₆O₃.
Writing and Balancing Chemical Equations

3.101 Conceptual Plan: Write a skeletal reaction $\rightarrow$ balance atoms in more complex compounds $\rightarrow$ balance elements that occur as free elements $\rightarrow$ clear fractions

Solution:
- Skeletal reaction: \( \text{SO}_2(g) + \text{O}_2(g) + \text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{SO}_4(aq) \)
- Balance O: \( \text{SO}_2(g) + 1/2 \text{O}_2(g) + \text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{SO}_4(aq) \)
- Clear fraction: \( 2 \text{SO}_2(g) + \text{O}_2(g) + 2 \text{H}_2\text{O}(l) \rightarrow 2 \text{H}_2\text{SO}_4(aq) \)

Check:
- left side: 2 S atoms, 8 O atoms, 4 H atoms
- right side: 2 S atoms, 8 O atoms, 4 H atoms

3.102 Conceptual Plan: Write a skeletal reaction $\rightarrow$ balance atoms in more complex compounds $\rightarrow$ balance elements that occur as free elements $\rightarrow$ clear fractions

Solution:
- Skeletal reaction: \( \text{NO}_2(g) + \text{O}_2(g) + \text{H}_2\text{O}(l) \rightarrow \text{HNO}_3(aq) \)
- Balance H: \( \text{NO}_2(g) + \text{O}_2(g) + \text{H}_2\text{O}(l) \rightarrow 2 \text{HNO}_3(aq) \)
- Balance N: \( 2 \text{NO}_2(g) + \text{O}_2(g) + \text{H}_2\text{O}(l) \rightarrow 2 \text{HNO}_3(aq) \)
- Balance O: \( 2 \text{NO}_2(g) + 1/2 \text{O}_2(g) + \text{H}_2\text{O}(l) \rightarrow 2 \text{HNO}_3(aq) \)
- Clear fraction: \( 4 \text{NO}_2(g) + \text{O}_2(g) + 2 \text{H}_2\text{O}(l) \rightarrow 4 \text{HNO}_3(aq) \)

Check:
- left side: 4 N atoms, 12 O atoms, 4 H atoms
- right side: 4 N atoms, 12 O atoms, 4 H atoms

3.103 Conceptual Plan: Write a skeletal reaction $\rightarrow$ balance atoms in more complex compounds $\rightarrow$ balance elements that occur as free elements $\rightarrow$ clear fractions

Solution:
- Skeletal reaction: \( \text{Na}(s) + \text{H}_2\text{O}(l) \rightarrow \text{H}_2(g) + \text{NaOH}(aq) \)
- Balance H: \( \text{Na}(s) + \text{H}_2\text{O}(l) \rightarrow 1/2 \text{H}_2(g) + \text{NaOH}(aq) \)
- Clear fraction: \( 2 \text{Na}(s) + 2 \text{H}_2\text{O}(l) \rightarrow \text{H}_2(g) + 2 \text{NaOH}(aq) \)

Check:
- left side: 2 Na atoms, 4 H atoms, 2 O atoms
- right side: 2 Na atoms, 4 H atoms, 2 O atoms

3.104 Conceptual Plan: Write a skeletal reaction $\rightarrow$ balance atoms in more complex compounds $\rightarrow$ balance elements that occur as free elements $\rightarrow$ clear fractions

Solution:
- Skeletal reaction: \( \text{Fe}(s) + \text{O}_2(g) \rightarrow \text{Fe}_2\text{O}_3(s) \)
- Balance O: \( \text{Fe}(s) + 3 \text{O}_2(g) \rightarrow 2 \text{Fe}_2\text{O}_3(s) \)
- Balance Fe: \( 4 \text{Fe}(s) + 3 \text{O}_2(g) \rightarrow 2 \text{Fe}_2\text{O}_3(s) \)

Check:
- left side: 4 Fe atoms, 6 O atoms
- right side: 4 Fe atoms, 6 O atoms

3.105 Conceptual Plan: Write a skeletal reaction $\rightarrow$ balance atoms in more complex compounds $\rightarrow$ balance elements that occur as free elements $\rightarrow$ clear fractions

Solution:
- Skeletal reaction: \( \text{C}_6\text{H}_{12}\text{O}_{11}(aq) + \text{H}_2\text{O}(l) \rightarrow \text{C}_3\text{H}_2\text{OH}(aq) + \text{CO}_2(g) \)
- Balance H: \( \text{C}_6\text{H}_{12}\text{O}_{11}(aq) + \text{H}_2\text{O}(l) \rightarrow 4 \text{C}_3\text{H}_2\text{OH}(aq) + \text{CO}_2(g) \)
- Balance C: \( \text{C}_6\text{H}_{12}\text{O}_{11}(aq) + \text{H}_2\text{O}(l) \rightarrow 4 \text{C}_3\text{H}_2\text{OH}(aq) + 4 \text{CO}_2(g) \)

Check:
- left side: 12 C atoms, 24 H atoms, 12 O atoms
- right side: 12 C atoms, 24 H atoms, 12 O atoms

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Conceptual Plan: Write a skeletal reaction → balance atoms in more complex compounds → balance elements that occur as free elements → clear fractions

Solution:
Skeletal reaction: \( \text{CO}_2(g) + \text{H}_2\text{O}(l) \rightarrow \text{C}_6\text{H}_{12}\text{O}_6(aq) + \text{O}_2(g) \)
Balance C: \( 6 \text{ CO}_2(g) + \text{H}_2\text{O}(l) \rightarrow \text{C}_6\text{H}_{12}\text{O}_6(aq) + \text{O}_2(g) \)
Balance H: \( 6 \text{ CO}_2(g) + 6 \text{ H}_2\text{O}(l) \rightarrow \text{C}_6\text{H}_{12}\text{O}_6(aq) + \text{O}_2(g) \)
Balance O: \( 6 \text{ CO}_2(g) + 6 \text{ H}_2\text{O}(l) \rightarrow \text{C}_6\text{H}_{12}\text{O}_6(aq) + 6 \text{ O}_2(g) \)

Check:
left side right side
6 C atoms 6 C atoms
18 O atoms 18 O atoms
12 H atoms 12 H atoms

(a) Conceptual Plan: Write a skeletal reaction → balance atoms in more complex compounds → balance elements that occur as free elements → clear fractions

Solution:
Skeletal reaction: \( \text{PbS}(s) + \text{HBr}(aq) \rightarrow \text{PbBr}_2(s) + \text{H}_2\text{S}(g) \)
Balance Br: \( \text{PbS}(s) + 2 \text{HBr}(aq) \rightarrow \text{PbBr}_2(s) + \text{H}_2\text{S}(g) \)

Check:
left side right side
1 Pb atom 1 Pb atom
1 S atom 1 S atom
2 H atoms 2 H atoms
2 Br atoms 2 Br atoms

(b) Conceptual Plan: Write a skeletal reaction → balance atoms in more complex compounds → balance elements that occur as free elements → clear fractions

Solution:
Skeletal reaction: \( \text{CO}(g) + \text{H}_2(g) \rightarrow \text{CH}_4(g) + \text{H}_2\text{O}(l) \)
Balance H: \( \text{CO}(g) + 3 \text{ H}_2(g) \rightarrow \text{CH}_4(g) + \text{H}_2\text{O}(l) \)

Check:
left side right side
1 C atom 1 C atom
1 O atom 1 O atom
6 H atoms 6 H atoms

(c) Conceptual Plan: Write a skeletal reaction → balance atoms in more complex compounds → balance elements that occur as free elements → clear fractions

Solution:
Skeletal reaction: \( \text{HCl}(aq) + \text{MnO}_2(s) \rightarrow \text{MnCl}_2(aq) + \text{H}_2\text{O}(l) + \text{Cl}_2(g) \)
Balance Cl: \( 4 \text{ HCl}(aq) + \text{MnO}_2(s) \rightarrow \text{MnCl}_2(aq) + \text{H}_2\text{O}(l) + \text{Cl}_2(g) \)
Balance O: \( 4 \text{ HCl}(aq) + \text{MnO}_2(s) \rightarrow \text{MnCl}_2(aq) + 2 \text{H}_2\text{O}(l) + \text{Cl}_2(g) \)

Check:
left side right side
4 H atoms 4 H atoms
4 Cl atoms 4 Cl atoms
1 Mn atom 1 Mn atom
2 O atoms 2 O atoms

(d) Conceptual Plan: Write a skeletal reaction → balance atoms in more complex compounds → balance elements that occur as free elements → clear fractions

Solution:
Skeletal reaction: \( \text{C}_2\text{H}_2(l) + \text{O}_2(g) \rightarrow \text{CO}_2(g) + \text{H}_2\text{O}(l) \)
Balance C: \( \text{C}_2\text{H}_2(l) + \text{O}_2(g) \rightarrow 5 \text{CO}_2(g) + \text{H}_2\text{O}(l) \)
Balance H: \( \text{C}_2\text{H}_2(l) + \text{O}_2(g) \rightarrow 5 \text{CO}_2(g) + 6 \text{H}_2\text{O}(l) \)
Balance O: \( \text{C}_2\text{H}_2(l) + 8 \text{O}_2(g) \rightarrow 5 \text{CO}_2(g) + 6 \text{H}_2\text{O}(l) \)

Check:
left side right side
5 C atoms 5 C atoms
12 H atoms 12 H atoms
16 O atoms 16 O atoms

(a) Conceptual Plan: Write a skeletal reaction → balance atoms in more complex compounds → balance elements that occur as free elements → clear fractions

Solution:
Skeletal reaction: \( \text{Cu}(s) + \text{S}(s) \rightarrow \text{Cu}_2\text{S}(s) \)
Balance Cu: \( 2 \text{Cu}(s) + \text{S}(s) \rightarrow \text{Cu}_2\text{S}(s) \)

Check:
left side right side
2 Cu atoms 2 Cu atoms
1 S atom 1 S atom
(b) Conceptual Plan: Write a skeletal reaction $\rightarrow$ balance atoms in more complex compounds $\rightarrow$ balance elements that occur as free elements $\rightarrow$ clear fractions

Solution:
- Skeletal reaction: \[ \text{Fe}_2\text{O}_3(s) + \text{H}_2(g) \rightarrow \text{Fe}(s) + 3 \text{H}_2\text{O}(l) \]
- Balance O: \[ \text{Fe}_2\text{O}_3(s) + \text{H}_2(g) \rightarrow \text{Fe}(s) + 3 \text{H}_2\text{O}(l) \]
- Balance Fe: \[ \text{Fe}_2\text{O}_3(s) + \text{H}_2(g) \rightarrow 2 \text{Fe}(s) + 3 \text{H}_2\text{O}(l) \]
- Balance H: \[ \text{Fe}_2\text{O}_3(s) + 3 \text{H}_2(g) \rightarrow 2 \text{Fe}(s) + 3 \text{H}_2\text{O}(l) \]

Check:
- left side: 2 Fe atoms, 3 O atoms, 6 H atoms
- right side: 2 Fe atoms, 3 O atoms, 6 H atoms

(c) Conceptual Plan: Write a skeletal reaction $\rightarrow$ balance atoms in more complex compounds $\rightarrow$ balance elements that occur as free elements $\rightarrow$ clear fractions

Solution:
- Skeletal reaction: \[ \text{SO}_2(g) + \text{O}_2(g) \rightarrow \text{SO}_3(g) \]
- Balance O: \[ \text{SO}_2(g) + 1/2 \text{O}_2(g) \rightarrow \text{SO}_3(g) \]
- Clear fraction: \[ 2 \text{SO}_2(g) + \text{O}_2(g) \rightarrow 2 \text{SO}_3(g) \]

Check:
- left side: 2 S atoms, 6 O atoms
- right side: 2 S atoms, 6 O atoms

(d) Conceptual Plan: Write a skeletal reaction $\rightarrow$ balance atoms in more complex compounds $\rightarrow$ balance elements that occur as free elements $\rightarrow$ clear fractions

Solution:
- Skeletal reaction: \[ \text{NH}_3(g) + \text{O}_2(g) \rightarrow \text{NO}(g) + \text{H}_2\text{O}(g) \]
- Balance H: \[ 2 \text{NH}_3(g) + \text{O}_2(g) \rightarrow \text{NO}(g) + 3 \text{H}_2\text{O}(g) \]
- Balance N: \[ 2 \text{NH}_3(g) + \text{O}_2(g) \rightarrow 2 \text{NO}(g) + 3 \text{H}_2\text{O}(g) \]
- Balance O: \[ 2 \text{NH}_3(g) + 5/2 \text{O}_2(g) \rightarrow 2 \text{NO}(g) + 3 \text{H}_2\text{O}(g) \]
- Clear fraction: \[ 4 \text{NH}_3(g) + 5 \text{O}_2(g) \rightarrow 4 \text{NO}(g) + 6 \text{H}_2\text{O}(g) \]

Check:
- left side: 4 N atoms, 6 H atoms, 10 O atoms
- right side: 4 N atoms, 6 H atoms, 10 O atoms

3.109 Conceptual Plan: Write a skeletal reaction $\rightarrow$ balance atoms in more complex compounds $\rightarrow$ balance elements that occur as free elements $\rightarrow$ clear fractions

Solution:
- Skeletal reaction: \[ \text{Na}_2\text{CO}_3(aq) + \text{CuCl}_2(aq) \rightarrow \text{CuCO}_3(s) + \text{NaCl}(aq) \]
- Balance Na: \[ \text{Na}_2\text{CO}_3(aq) + \text{CuCl}_2(aq) \rightarrow \text{CuCO}_3(s) + 2 \text{NaCl}(aq) \]

Check:
- left side: 2 Na atoms, 1 C atom, 3 O atoms, 1 Cu atom, 2 Cl atoms
- right side: 2 Na atoms, 1 C atom, 3 O atoms, 1 Cu atom, 2 Cl atoms

3.110 Conceptual Plan: Write a skeletal reaction $\rightarrow$ balance atoms in more complex compounds $\rightarrow$ balance elements that occur as free elements $\rightarrow$ clear fractions

Solution:
- Skeletal reaction: \[ \text{KOH}(aq) + \text{FeCl}_3(aq) \rightarrow \text{Fe(OH)}_3(s) + \text{KCl}(aq) \]
- Balance Cl: \[ \text{KOH}(aq) + \text{FeCl}_3(aq) \rightarrow \text{Fe(OH)}_3(s) + 3 \text{KCl}(aq) \]
- Balance K: \[ 3 \text{KOH}(aq) + \text{FeCl}_3(aq) \rightarrow \text{Fe(OH)}_3(s) + 3 \text{KCl}(aq) \]

Check:
- left side: 3 K atoms, 3 O atoms, 3 H atoms, 1 Fe atom, 3 Cl atoms
- right side: 3 K atoms, 3 O atoms, 3 H atoms, 1 Fe atom, 3 Cl atoms
3.111 (a) Conceptual Plan: Balance atoms in more complex compounds → balance elements that occur as free elements → clear fractions

Solution: Skeletal reaction: \( \text{CO}_2(g) + \text{CaSiO}_3(s) + \text{H}_2\text{O}(l) \rightarrow \text{SiO}_2(s) + \text{Ca(HCO}_3)_2(aq) \)

Balance C:
- left side: 2 C atoms, 8 O atoms, 1 Ca atom, 1 Si atom, 2 H atoms
- right side: 2 C atoms, 8 O atoms, 1 Ca atom, 1 Si atom, 2 H atoms

(b) Conceptual Plan: Balance atoms in more complex compounds → balance elements that occur as free elements → clear fractions

Solution: Skeletal reaction: \( \text{Co(NO}_3)_3(aq) + (\text{NH}_4)_2\text{S}(aq) \rightarrow \text{Co}_2\text{S}_3(s) + \text{NH}_4\text{NO}_3(aq) \)

Balance S:
- left side: 2 Co atoms, 12 N atoms, 18 O atoms, 3 S atoms
- right side: 2 Co atoms, 12 N atoms, 18 O atoms, 3 S atoms

Balance Co:
- left side: 2 Co atoms, 12 N atoms, 18 O atoms, 3 S atoms
- right side: 2 Co atoms, 12 N atoms, 18 O atoms, 3 S atoms

Balance N:
- left side: 2 Co atoms, 12 N atoms, 18 O atoms, 3 S atoms
- right side: 2 Co atoms, 12 N atoms, 18 O atoms, 3 S atoms

(c) Conceptual Plan: Balance atoms in more complex compounds → balance elements that occur as free elements → clear fractions

Solution: Skeletal reaction: \( \text{Cu}_2\text{O}(s) + \text{C}(s) \rightarrow \text{Cu}(s) + \text{CO}(g) \)

Balance Cu:
- left side: 2 Cu atoms, 1 O atom, 1 C atom
- right side: 2 Cu atoms, 1 O atom, 1 C atom

(d) Conceptual Plan: Balance atoms in more complex compounds → balance elements that occur as free elements → clear fractions

Solution: Skeletal reaction: \( \text{H}_2(g) + \text{Cl}_2(g) \rightarrow \text{HCl}(g) \)

Balance Cl:
- left side: 2 H atoms, 2 Cl atoms
- right side: 2 H atoms, 2 Cl atoms

3.112 (a) Conceptual Plan: Balance atoms in more complex compounds → balance elements that occur as free elements → clear fractions

Solution: Skeletal reaction: \( \text{Na}_2\text{S}(aq) + \text{Cu(NO}_3)_2(aq) \rightarrow \text{NaNO}_3(aq) + \text{CuS}(s) \)

Balance Na:
- left side: 2 Na atoms, 1 S atom, 1 Cu atom, 2 N atoms, 6 O atoms
- right side: 2 Na atoms, 1 S atom, 1 Cu atom, 2 N atoms, 6 O atoms

(b) Conceptual Plan: Balance atoms in more complex compounds → balance elements that occur as free elements → clear fractions

Solution: Skeletal reaction: \( \text{N}_2\text{H}_4(l) \rightarrow \text{NH}_3(g) + \text{N}_2(g) \)

Balance H:
- left side: 6 N atoms, 12 H atoms
- right side: 6 N atoms, 12 H atoms

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(c) **Conceptual Plan: Balance atoms in more complex compounds → balance elements that occur as free elements → clear fractions**

**Solution:**
- **Skeletal reaction:** \( \text{HCl}(aq) + \text{O}_2(g) \rightarrow \text{H}_2\text{O}(l) + \text{Cl}_2(g) \)
- **Balance Cl:**
  - \( 2 \text{HCl}(aq) + \text{O}_2(g) \rightarrow \text{H}_2\text{O}(l) + \text{Cl}_2(g) \)
- **Balance O:**
  - \( 2 \text{HCl}(aq) + 1/2 \text{O}_2(g) \rightarrow \text{H}_2\text{O}(l) + \text{Cl}_2(g) \)
- **Clear fraction:**
  - \( 4 \text{HCl}(aq) + \text{O}_2(g) \rightarrow 2 \text{H}_2\text{O}(l) + 2 \text{Cl}_2(g) \)

**Check:**
- Left side: 4 H atoms, 4 Cl atoms, 2 O atoms
- Right side: 4 H atoms, 4 Cl atoms, 2 O atoms

(d) **Conceptual Plan: Balance atoms in more complex compounds → balance elements that occur as free elements → clear fractions**

**Solution:**
- **Skeletal reaction:** \( \text{FeS(s)} + \text{HCl}(aq) \rightarrow \text{FeCl}_2(aq) + \text{H}_2\text{S}(g) \)
- **Balance Cl:**
  - \( \text{FeS(s)} + 2 \text{HCl}(aq) \rightarrow \text{FeCl}_2(aq) + \text{H}_2\text{S}(g) \)

**Check:**
- Left side: 1 Fe atom, 1 S atom, 2 H atoms, 2 Cl atoms
- Right side: 1 Fe atom, 1 S atom, 2 H atoms, 2 Cl atoms

**Organic Compounds**

3.113  
(a) composed of metal cation and polyatomic anion—inorganic compound  
(b) composed of carbon and hydrogen—organic compound  
(c) composed of carbon, hydrogen, and oxygen—organic compound  
(d) composed of metal cation and nonmetal anion—inorganic compound

3.114  
(a) composed of carbon and hydrogen—organic compound  
(b) composed of carbon, hydrogen, and nitrogen—organic compound  
(c) composed of metal cation and nonmetal anion—inorganic compound  
(d) composed of metal cation and polyatomic anion—inorganic compound

3.115  
(a) contains a double bond—alkene  
(b) contains only single bonds—alkane  
(c) contains triple bond—alkyne  
(d) contains only single bonds—alkane

3.116  
(a) contains triple bond—alkyne  
(b) contains double bond—alkene  
(c) contains only single bonds—alkane  
(d) contains triple bond—alkyne

3.117  
(a) prop = 3 C, ane = single bonds: \( \text{CH}_3\text{CH}_2\text{CH}_3 \)  
(b) 3 C = prop, single bonds = ane: propane  
(c) oct = 8 C, ane = single bonds: \( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3 \)  
(d) 5 C = pent, single bonds = ane: pentane

3.118  
(a) 2 C = eth, single bonds = ane: ethane  
(b) pent = 5 C, ane = single bonds: \( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3 \)  
(c) 6 C = hex, single bonds = ane: hexane  
(d) hept = 7 C, ane = single bonds: \( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3 \)

3.119  
(a) contains O: functionalized hydrocarbon: alcohol  
(b) contains only C and H: hydrocarbon  
(c) contains O: functionalized hydrocarbon: ketone  
(d) contains N: functionalized hydrocarbon: amine
Cumulative Problems

3.121  **Given:** 145 mL C₂H₅OH;  
**Find:** number of molecules  
**Conceptual Plan:** cm³ → mL : mL C₂H₅OH → g C₂H₅OH → mol C₂H₅OH → molecules C₂H₅OH  

**Solution:**  

\[
145 \text{ mL C}_2\text{H}_5\text{OH} \times \frac{1 \text{ cm}^3}{1 \text{ mL}} \times \frac{0.789 \text{ g C}_2\text{H}_5\text{OH}}{1 \text{ cm}^3} \times \frac{1 \text{ mol C}_2\text{H}_5\text{OH}}{46.07 \text{ g C}_2\text{H}_5\text{OH}} \times \frac{6.022 \times 10^{23} \text{ molecules C}_2\text{H}_5\text{OH}}{1 \text{ mol C}_2\text{H}_5\text{OH}} = 1.50 \times 10^{24} \text{ molecules C}_2\text{H}_5\text{OH}
\]

**Check:** The units of the answer (molecules C₂H₅OH) are correct. The magnitude is reasonable because we had more than two moles of C₂H₅OH and we have more than two times Avogadro’s number of molecules.

3.122  **Given:** 0.05 mL H₂O;  
**Find:** number of molecules  
**Conceptual Plan:** cm³ → mL : mL H₂O → g H₂O → mol H₂O → molecules H₂O  

**Solution:**  

\[
0.05 \text{ mL H}_2\text{O} \times \frac{1 \text{ cm}^3}{1 \text{ mL}} \times \frac{1 \text{ mL H}_2\text{O}}{1.00 \text{ g H}_2\text{O}} \times \frac{1 \text{ mol H}_2\text{O}}{18.02 \text{ g H}_2\text{O}} \times \frac{6.022 \times 10^{23} \text{ molecules H}_2\text{O}}{1 \text{ mol H}_2\text{O}} = 2 \times 10^{21} \text{ molecules H}_2\text{O}
\]

**Check:** The units of the answer (molecules H₂O) are correct. The magnitude is reasonable because we have less than 1 mole of H₂O and we have less than Avogadro’s number of molecules.

3.123  (a) To write the formula for an ionic compound, do the following: (1) Write the symbol for the metal cation and its charge and the symbol for the nonmetal anion or polyatomic anion and its charge. (2) Adjust the subscript on each cation and anion to balance the overall charge. (3) Check that the sum of the charges of the cations equals the sum of the charges of the anions.

**Potassium chromate:** K⁺ CrO₄²⁻; K₂CrO₄  
**Cation 2(1+)=2+; Anion 2⁻**  
**Given:** K₂CrO₄  
**Find:** mass percent of each element  

**Conceptual Plan:** % K, then % Cr, then % O  

**Solution:**  

\[
\text{mass } \% \text{ K} = \frac{2 \times \text{ molar mass K}}{\text{ molar mass K}_2\text{CrO}_4} \times 100\% \quad \text{mass } \% \text{ Cr} = \frac{1 \times \text{ molar mass Cr}}{\text{ molar mass K}_2\text{CrO}_4} \times 100\% \quad \text{mass } \% \text{ O} = \frac{4 \times \text{ molar mass O}}{\text{ molar mass K}_2\text{CrO}_4} \times 100\%
\]

\[
\text{molar mass of K} = 39.10 \text{ g/mol}; \text{ molar mass Cr} = 52.00 \text{ g/mol}; \text{ molar mass O} = 16.00 \text{ g/mol}
\]

\[
\text{Solution: molar mass K}_2\text{CrO}_4 = 2(39.10 \text{ g/mol}) + 1(52.00 \text{ g/mol}) + 4(16.00 \text{ g/mol}) = 194.20 \text{ g/mol}
\]

\[
\text{2 molar mass K} = 2(39.10 \text{ g/mol}) = 78.20 \text{ g/mol}
\]

\[
\text{1 molar mass Cr} = 1(52.00 \text{ g/mol}) = 52.00 \text{ g/mol}
\]

\[
\text{mass } \% \text{ K} = \frac{78.20 \text{ g/mol}}{194.20 \text{ g/mol}} \times 100\% = 40.27\%
\]

\[
\text{mass } \% \text{ Cr} = \frac{52.00 \text{ g/mol}}{194.20 \text{ g/mol}} \times 100\% = 26.78\%
\]

\[
4 \times \text{ molar mass O} = 4(16.00 \text{ g/mol}) = 64.00 \text{ g O}
\]

\[
\text{mass } \% \text{ O} = \frac{64.00 \text{ g/mol}}{194.20 \text{ g/mol}} \times 100\% = 32.96\%
\]

**Check:** The units of the answer (%) are correct. The magnitude is reasonable because each is between 0 and 100% and the total is 100%.

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(b) To write the formula for an ionic compound, do the following: (1) Write the symbol for the metal cation and its charge and the symbol for the nonmetal anion or polyatomic anion and its charge. (2) Adjust the subscript on each cation and anion to balance the overall charge. (3) Check that the sum of the charges of the cations equals the sum of the charges of the anions.

Lead(II)phosphate: \( \text{Pb}^{2+} \text{PO}_4^{2-} \); \( \text{Pb}_3(\text{PO}_4)_2 \) cation \( 3(2+) = 6+; \) anion \( 2(3-) = 6- \)

**Given:** \( \text{Pb}_3(\text{PO}_4)_2 \)  
**Find:** mass percent of each element

**Conceptual Plan:** \% Pb, then \% P, then \% O

\[
\text{mass \% Pb} = \frac{3 \times \text{molar mass Pb}}{	ext{molar mass Pb}_3(\text{PO}_4)_2} \times 100\% \\
\text{mass \% P} = \frac{2 \times \text{molar mass P}}{	ext{molar mass Pb}_3(\text{PO}_4)_2} \times 100\% \\
\text{mass \% O} = \frac{8 \times \text{molar mass O}}{\text{molar mass Pb}_3(\text{PO}_4)_2} \times 100\%
\]

**Solution:** molar mass \( \text{Pb}_3(\text{PO}_4)_2 = 3(207.2 \text{ g/mol}) + 2(30.97 \text{ g/mol}) + 8(16.00 \text{ g/mol}) = 811.5 \text{ g/mol} \)

\[
3 \times \text{molar mass Pb} = 3(207.2 \text{ g/mol}) = 621.6 \text{ g Pb} \\
2 \times \text{molar mass P} = 2(30.97 \text{ g/mol}) = 61.94 \text{ g P}
\]

\[
\begin{align*}
\text{mass \% Pb} &= \frac{3 \times 621.6 \text{ g/mol}}{811.5 \text{ g/mol}} \times 100\% = 76.60\% \\
\text{mass \% P} &= \frac{2 \times 61.94 \text{ g/mol}}{811.5 \text{ g/mol}} \times 100\% = 7.633\% \\
\text{mass \% O} &= \frac{8 \times 128.0 \text{ g/mol}}{811.5 \text{ g/mol}} \times 100\% = 15.77\%
\end{align*}
\]

**Check:** The units of the answer (\%) are correct. The magnitude is reasonable because each is between 0 and 100\% and the total is 100\%.

(c) sulfurous acid: \( \text{H}_2\text{SO}_3 \)

**Given:** \( \text{H}_2\text{SO}_3 \)  
**Find:** mass percent of each element

**Conceptual Plan:** \% H, then \% S, then \% O

\[
\text{mass \% H} = \frac{2 \times \text{molar mass H}}{	ext{molar mass H}_2\text{SO}_3} \times 100\% \\
\text{mass \% S} = \frac{1 \times \text{molar mass S}}{	ext{molar mass H}_2\text{SO}_3} \times 100\% \\
\text{mass \% O} = \frac{3 \times \text{molar mass O}}{	ext{molar mass H}_2\text{SO}_3} \times 100\%
\]

**Solution:** molar mass \( \text{H}_2\text{SO}_3 = 2(1.008 \text{ g/mol}) + 1(32.06 \text{ g/mol}) + 3(16.00 \text{ g/mol}) = 82.076 \text{ g/mol} \)

\[
2 \times \text{molar mass H} = 2(1.008 \text{ g/mol}) = 2.016 \text{ g} \\
1 \times \text{molar mass S} = 1(32.06 \text{ g/mol}) = 32.06 \text{ g}
\]

\[
\begin{align*}
\text{mass \% H} &= \frac{2 \times 2.016 \text{ g/mol}}{82.076 \text{ g/mol}} \times 100\% = 2.456\% \\
\text{mass \% S} &= \frac{1 \times 32.06 \text{ g/mol}}{82.076 \text{ g/mol}} \times 100\% = 39.07\% \\
\text{mass \% O} &= \frac{3 \times 48.00 \text{ g/mol}}{82.076 \text{ g/mol}} \times 100\% = 58.48\%
\end{align*}
\]

**Check:** The units of the answer (\%) are correct. The magnitude is reasonable because each is between 0 and 100\% and the total is 100\%.

(d) To write the formula for an ionic compound, do the following: (1) Write the symbol for the metal cation and its charge and the symbol for the nonmetal anion or polyatomic anion and its charge. (2) Adjust the subscript on each cation and anion to balance the overall charge. (3) Check that the sum of the charges of the cations equals the sum of the charges of the anions.

Cobalt(II)bromide: \( \text{Co}^{2+} \text{Br}^-; \text{CoBr}_2 \) cation \( 2+ = 2+; \) anion \( 2(1-) = 2- \)
Given: CoBr₂  Find: mass percent of each element

Conceptual Plan: % Co, then % Br

\[
\text{mass } \% \text{ Co} = \frac{1 \times \text{molar mass Co}}{\text{molar mass CoBr}_2} \times 100\% \\
\text{mass } \% \text{ Br} = \frac{2 \times \text{molar mass Br}}{\text{molar mass CoBr}_2} \times 100\%
\]

Solution: molar mass CoBr₂ = (58.93 g/mol) + 2(79.90 g/mol) = 2.873 g/mol

\[
\begin{align*}
\text{mass } \% \text{ Co} & = \frac{1 \times \text{molar mass Co}}{218.73 \text{ g/mol}} \times 100\% \\
& = 26.94\%
\end{align*}
\]

Check: The units of the answer (%) are correct. The magnitude is reasonable because each is between 0 and 100% and the total is 100%.

3.124 (a) perchloric acid: HClO₄

Given: HClO₄  Find: mass percent of each element

Conceptual Plan: % H, then % Cl, then % O

\[
\begin{align*}
\text{mass } \% \text{ H} & = \frac{1 \times \text{molar mass H}}{\text{molar mass HClO}_4} \times 100\% \\
\text{mass } \% \text{ Cl} & = \frac{1 \times \text{molar mass Cl}}{\text{molar mass HClO}_4} \times 100\% \\
\text{mass } \% \text{ O} & = \frac{1 \times \text{molar mass O}}{\text{molar mass HClO}_4} \times 100\%
\end{align*}
\]

Solution: molar mass HClO₄ = 1(1.008 g/mol) + 1(35.45 g/mol) + 4(16.00 g/mol) = 100.46 g/mol

\[
\begin{align*}
\text{mass } \% \text{ H} & = \frac{1 \times \text{molar mass H}}{100.46 \text{ g/mol}} \times 100\% \\
& = 1.003\% \\
\text{mass } \% \text{ Cl} & = \frac{1 \times \text{molar mass Cl}}{100.46 \text{ g/mol}} \times 100\% \\
& = 35.29\%
\end{align*}
\]

4 × molar mass O = 4(16.00 g/mol) = 64.00 g O

\[
\begin{align*}
\text{mass } \% \text{ O} & = \frac{4 \times \text{molar mass O}}{\text{molar mass HSO}_3} \times 100\% \\
& = \frac{64.00 \text{ g/mol}}{100.46 \text{ g/mol}} \times 100\% \\
& = 63.71\%
\end{align*}
\]

Check: The units of the answer (%) are correct. The magnitude is reasonable because each is between 0 and 100% and the total is 100%.

(b) phosphorus pentachloride: PCl₅

Given: PCl₅  Find: mass percent of each element

Conceptual Plan: % P, then % Cl

\[
\begin{align*}
\text{mass } \% \text{ H} & = \frac{1 \times \text{molar mass P}}{\text{molar mass PCl}_5} \times 100\% \\
\text{mass } \% \text{ H} & = \frac{5 \times \text{molar mass Cl}}{\text{molar mass PCl}_5} \times 100\%
\end{align*}
\]

Solution: molar mass PCl₅ = 1(30.97 g/mol) + 5(35.45 g/mol) = 288.22 g/mol

\[
\begin{align*}
\text{mass } \% \text{ P} & = \frac{1 \times \text{molar mass P}}{208.22 \text{ g/mol}} \times 100\% \\
& = 14.87\%
\end{align*}
\]

Check: The units of the answer (%) are correct. The magnitude is reasonable because each is between 0 and 100% and the total is 100%.

(c) nitrogen triiodide: NI₃

Given: NI₃  Find: mass percent of each element

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Chapter 3 Molecules, Compounds, and Chemical Equations

Conceptual Plan: % N, then % I

\[
\text{mass } \% \text{ N} = \left( \frac{1 \times \text{molar mass N}}{\text{molar mass } \text{N}_3} \right) \times 100\% \quad \text{mass } \% \text{ I} = \left( \frac{3 \times \text{molar mass I}}{\text{molar mass } \text{N}_3} \right) \times 100\%
\]

Solution: molar mass \( \text{N}_3 = 1(14.01 \text{ g/mol}) + 3(12.69 \text{ g/mol}) = 39.74 \text{ g/mol} \)

\[
1 \times \text{molar mass N} = 1(14.01 \text{ g/mol}) = 14.01 \text{ g N} \quad 1 \times \text{molar mass I} = 3(12.69 \text{ g/mol}) = 38.07 \text{ g I}
\]

\[
\text{mass } \% \text{ N} = \left( \frac{1 \times 14.01 \text{ g/mol}}{39.74 \text{ g/mol}} \right) \times 100\% = 35.49\%
\]

\[
\text{mass } \% \text{ I} = \left( \frac{3 \times 38.07 \text{ g/mol}}{39.74 \text{ g/mol}} \right) \times 100\% = 96.45\%
\]

Check: The units of the answer (\%) are correct. The magnitude is reasonable because each is between 0 and 100\% and the total is 100\%.

(d) carbon dioxide: \( \text{CO}_2 \)

Given: \( \text{CO}_2 \)  Find: mass percent of each element

Conceptual Plan: % C, then % O

\[
\text{mass } \% \text{ C} = \left( \frac{1 \times \text{molar mass C}}{\text{molar mass } \text{CO}_2} \right) \times 100\% \quad \text{mass } \% \text{ O} = \left( \frac{2 \times \text{molar mass O}}{\text{molar mass } \text{CO}_2} \right) \times 100\%
\]

Solution: molar mass \( \text{CO}_2 = 1(12.01 \text{ g/mol}) + 2(16.00 \text{ g/mol}) = 44.01 \text{ g/mol} \)

\[
1 \times \text{molar mass C} = 1(12.01 \text{ g/mol}) = 12.01 \text{ g C} \quad 2 \times \text{molar mass O} = 2(16.00 \text{ g/mol}) = 32.00 \text{ g O}
\]

\[
\text{mass } \% \text{ C} = \left( \frac{12.01 \text{ g/mol}}{44.01 \text{ g/mol}} \right) \times 100\% = 27.29\%
\]

\[
\text{mass } \% \text{ O} = \left( \frac{32.00 \text{ g/mol}}{44.01 \text{ g/mol}} \right) \times 100\% = 72.71\%
\]

Check: The units of the answer (\%) are correct. The magnitude is reasonable because each is between 0 and 100\% and the total is 100\%.

3.125 Given: 25 g \( \text{CF}_2\text{Cl}_2 \)/mo  Find: g \( \text{Cl}_2 \)/yr

Conceptual Plan: g \( \text{CF}_2\text{Cl}_2 \)/mo \( \rightarrow \) g \( \text{Cl}_2 \)/mo \( \rightarrow \) g \( \text{Cl}_2 \)/yr

\[
\frac{70.90 \text{ g Cl}_2}{120.91 \text{ g CF}_2\text{Cl}_2} \times \frac{1 \text{ yr}}{1 \text{ mo}} = 1.8 \times 10^2 \text{ g Cl}_2/\text{yr}
\]

Solution: \[
\frac{25 \text{ g CF}_2\text{Cl}_2}{\text{mo}} \times \frac{70.90 \text{ g Cl}_2}{120.91 \text{ g CF}_2\text{Cl}_2} \times \frac{1 \text{ yr}}{1 \text{ mo}} = 1.8 \times 10^2 \text{ g Cl}_2/\text{yr}
\]

Check: The units of the answer (g \( \text{Cl}_2 \)) are correct. Magnitude is reasonable because it is less than the total \( \text{CF}_2\text{Cl}_2 \)/yr.

3.126 Given: 12 kg \( \text{CHF}_2\text{Cl}/\text{mo} \)  Find: kg \( \text{Cl}_2 \)/yr

Conceptual Plan: kg \( \text{CHF}_2\text{Cl} \)/mo \( \rightarrow \) kg \( \text{Cl}_2 \)/mo \( \rightarrow \) kg \( \text{Cl}_2 \)/yr

\[
\frac{35.45 \text{ kg Cl}_2}{86.47 \text{ kg CHF}_2\text{Cl}} \times \frac{1 \text{ yr}}{1 \text{ mo}} = 59 \text{ kg Cl}_2/\text{yr}
\]

Solution: \[
\frac{12 \text{ kg CHF}_2\text{Cl}}{\text{mo}} \times \frac{35.45 \text{ kg Cl}_2}{86.47 \text{ kg CHF}_2\text{Cl}} \times \frac{1 \text{ yr}}{1 \text{ mo}} = 59 \text{ kg Cl}_2/\text{yr}
\]

Check: The units of the answer (kg \( \text{Cl}_2 \)) are correct. Magnitude is reasonable because it is less than the total \( \text{CHF}_2\text{Cl} \)/yr.

3.127 Given: \( \text{MCl}_3 \); 65.57\% Cl  Find: identify M

Conceptual Plan: g Cl \( \rightarrow \) mol Cl \( \rightarrow \) mol M \( \rightarrow \) atomic mass M

\[
\frac{1 \text{ mol Cl}}{35.45 \text{ g Cl}} \times \frac{1 \text{ mol M}}{3 \text{ mol Cl}} = 0.6165 \text{ mol M} \quad \frac{34.43 \text{ g M}}{0.6165 \text{ mol M}} = 55.85 \text{ g/mol M}
\]

Solution: in 100 g sample: 65.57 g Cl; 34.43 g M

\[
\frac{65.57 \text{ g Cl}}{35.45 \text{ g Cl}} \times \frac{1 \text{ mol Cl}}{3 \text{ mol Cl}} = 0.6165 \text{ mol M} \quad \text{molar mass of 55.85} = \text{Fe}
\]

The identity of M = Fe.
3.128  Given: M₂O; 16.99% O  Find: identify M
Conceptual Plan: g O \rightarrow \text{mol O} \rightarrow \text{mol M} \rightarrow \text{atomic mass M}

\begin{align*}
\frac{1 \text{ mol O}}{16.00 \text{ g O}} \times \frac{2 \text{ mol M}}{1 \text{ mol O}} \times \frac{83.01 \text{ g M}}{2.124 \text{ mol M}} = 39.08 \text{ g/mol M}
\end{align*}

The identity of M = K.

3.129  Given: in a 100 g sample of estradiol: 79.37 g C; 8.88 g H; 11.75 g O; molar mass = 272.37 g/mol  Find: molecular formula

Conceptual Plan:
Convert mass to mol of each element \rightarrow \text{pseudoformula} \rightarrow \text{empirical formula} \rightarrow \text{molecular formula}

\begin{align*}
\frac{1 \text{ mol C}}{12.01 \text{ g C}} & \times \frac{1 \text{ mol H}}{1.008 \text{ g H}} = 6.609 \text{ mol C} \\
8.88 \text{ g H} & \times \frac{1 \text{ mol H}}{1.008 \text{ g H}} = 8.81 \text{ mol H} \\
11.75 \text{ g O} & \times \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 0.7344 \text{ mol O} \\
C_{6.609}H_{8.81}O_{0.7344} & \rightarrow C_9H_{12}O
\end{align*}

The correct empirical formula is C₉H₁₂O.

\begin{align*}
\text{empirical formula mass} & = 9(12.01 \text{ g/mol}) + 12(1.008 \text{ g/mol}) + 1(16.00 \text{ g/mol}) = 136.19 \text{ g/mol} \\
n & = \frac{\text{molar mass}}{\text{formula molar mass}} = \frac{272.37 \text{ g/mol}}{136.19 \text{ g/mol}} = 2 \\
\text{molecular formula} & = C_9H_{12}O \times 2 = C_{13}H_{24}O_2
\end{align*}

3.130  Given: in a 100 g sample of fructose: 40.00 g C; 6.72 g H; 53.28 g O; molar mass = 180.16 g/mol  Find: molecular formula

Conceptual Plan:

Convert mass to mol of each element \rightarrow \text{pseudoformula} \rightarrow \text{empirical formula} \rightarrow \text{molecular formula}

\begin{align*}
\frac{1 \text{ mol C}}{12.01 \text{ g C}} & \times \frac{1 \text{ mol H}}{1.008 \text{ g H}} = 3.331 \text{ mol C} \\
6.72 \text{ g H} & \times \frac{1 \text{ mol H}}{1.008 \text{ g H}} = 6.67 \text{ mol H} \\
53.28 \text{ g O} & \times \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 3.330 \text{ mol O} \\
C_{3.331}H_{6.67}O_{3.330} & \rightarrow CH_2O \\
C_{3.331}H_{6.67}O_{3.330} & \rightarrow CH_2O
\end{align*}

The correct empirical formula is CH₂O.

\begin{align*}
\text{empirical formula mass} & = 1(12.01 \text{ g/mol}) + 2(1.008 \text{ g/mol}) + 1(16.00 \text{ g/mol}) = 30.03 \text{ g/mol} \\
n & = \frac{\text{molar mass}}{\text{formula molar mass}} = \frac{180.16 \text{ g/mol}}{30.03 \text{ g/mol}} = 6 \\
\text{molecular formula} & = CH_2O \times 6 = C_6H_{12}O_6
\end{align*}
3.131  Given: 13.42 g sample of equilin; 39.61 g CO₂; 9.01 g H₂O; molar mass = 268.34 g/mol  
Find: molecular formula  
Conceptual Plan:  
Mass CO₂, H₂O → mol CO₂, H₂O → mol C, mol H → mass C, mass H, mass O → mol O →  
\[
\begin{array}{cccccc}
1 \text{ mol CO}_2 & 1 \text{ mol H}_2O & 1 \text{ mol C} & 2 \text{ mol H} & 12.01 \text{ g C} & 1.008 \text{ g H} \\
44.01 \text{ g CO}_2 & 18.02 \text{ g H}_2O & 1 \text{ mol CO}_2 & 1 \text{ mol H}_2O & 1 \text{ mol C} & 1 \text{ mol H} \\
\end{array}
\]

pseudoformula → empirical formula → molecular formula  
divide by smallest number  empirical formula × n  
\[
\begin{align*}
39.61 \text{ g CO}_2 & \times \frac{1 \text{ mol CO}_2}{44.01 \text{ g CO}_2} = 0.9000 \text{ mol CO}_2 \\
9.01 \text{ g H}_2O & \times \frac{1 \text{ mol H}_2O}{18.02 \text{ g H}_2O} = 0.5000 \text{ mol H}_2O \\
0.9000 \text{ mol CO}_2 & \times \frac{1 \text{ mol C}}{1 \text{ mol CO}_2} = 0.9000 \text{ mol C} \\
0.5000 \text{ mol H}_2O & \times \frac{2 \text{ mol H}}{1 \text{ mol H}_2O} = 1.00 \text{ mol H} \\
0.9000 \text{ mol C} & \times \frac{12.01 \text{ g C}}{1 \text{ mol C}} = 10.81 \text{ g C} \\
1.00 \text{ mol H}_2O & \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 1.01 \text{ g H} \\
13.42 \text{ g} & - 10.81 \text{ g} - 1.01 \text{ g} = 1.60 \text{ g O} \\
1.60 \text{ g O} & \times \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 0.1000 \text{ mol O} \\
C_{0.9000} \text{ H}_{1.000} \text{ O}_{0.100} & \rightarrow C_9H_{10}O \\
0.100 & 0.100 & 0.100
\end{align*}
\]

The correct empirical formula is C₉H₁₀O.  
empirical formula mass = 9(12.01 g/mol) + 10(1.008 g/mol) + 1(16.00 g/mol) = 134.17 g/mol  
\[
n = \frac{\text{molar mass}}{\text{formula molar mass}} = \frac{268.34 \text{ g/mol}}{134.17 \text{ g/mol}} = 2
\]

molecular formula = C₉H₁₀O × 2 = C₁₈H₂₀O₂

3.132  Given: 1.893 g sample; 5.545 g CO₂; 1.388 g H₂O; molar mass = 270.36 g/mol  
Find: molecular formula  
Conceptual Plan:  
Mass CO₂, H₂O → mol CO₂, H₂O → mol C, mol H → mass C, mass H, mass O → mol O →  
\[
\begin{array}{cccccc}
1 \text{ mol CO}_2 & 1 \text{ mol H}_2O & 1 \text{ mol C} & 2 \text{ mol H} & 12.01 \text{ g C} & 1.008 \text{ g H} \\
44.01 \text{ g CO}_2 & 18.02 \text{ g H}_2O & 1 \text{ mol CO}_2 & 1 \text{ mol H}_2O & 1 \text{ mol C} & 1 \text{ mol H} \\
\end{array}
\]

pseudoformula → empirical formula → molecular formula  
divide by smallest number  empirical formula × n  
\[
\begin{align*}
5.545 \text{ g CO}_2 & \times \frac{1 \text{ mol CO}_2}{44.01 \text{ g CO}_2} = 0.1260 \text{ mol CO}_2 \\
1.388 \text{ g H}_2O & \times \frac{1 \text{ mol H}_2O}{18.02 \text{ g H}_2O} = 0.07703 \text{ mol H}_2O \\
0.1260 \text{ mol CO}_2 & \times \frac{1 \text{ mol C}}{1 \text{ mol CO}_2} = 0.1260 \text{ mol C} \\
0.07703 \text{ mol H}_2O & \times \frac{2 \text{ mol H}}{1 \text{ mol H}_2O} = 0.1541 \text{ mol H}
\end{align*}
\]
0.1260 mol C \times \frac{12.01 \text{ g C}}{1 \text{ mol C}} = 1.513 \text{ g C}

0.1541 \text{ mol H}_2 \text{O} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 0.1553 \text{ g H}

1.893 \text{ g} - 1.513 \text{ g} - 0.1553 \text{ g} = 0.225 \text{ g O}

0.225 \text{ g O} \times \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 0.0141 \text{ mol O}

C_{0.1260} \text{ H}_{0.1541} \text{ O}_{0.0141}

C_{0.1260} \text{ H}_{0.1541} \text{ O}_{0.0141} \rightarrow C_9 \text{ H}_11 \text{ O}

The correct empirical formula is C_9 H_{11} O.

empirical formula mass = 9(12.01 \text{ g/mol}) + 11(1.008 \text{ g/mol}) + 1(16.00 \text{ g/mol}) = 135.18 \text{ g/mol}

\[ n = \frac{\text{molar mass}}{\text{formula molar mass}} = \frac{270.36 \text{ g/mol}}{135.18 \text{ g/mol}} = 2 \]

molecular formula = C_9 H_{11} O \times 2 = C_{18} H_{22} O_2

3.133 \textbf{ Given:} 4.93 \text{ g MgSO}_4 \cdot x \text{H}_2 \text{O}; 2.41 \text{ g MgSO}_4 \quad \textbf{Find:} \text{ value of } x

\textbf{Conceptual Plan:} g \text{ MgSO}_4 \rightarrow \text{mol MgSO}_4 \quad g \text{ H}_2 \text{O} \rightarrow \text{mol H}_2 \text{O} \quad \text{Determine mole ratio.}

\begin{align*}
1 \text{ mol MgSO}_4 & \quad 1 \text{ mol H}_2 \text{O} & \quad \frac{\text{mol H}_2 \text{O}}{\text{mol MgSO}_4} \\
120.37 \text{ g MgSO}_4 & \quad 18.02 \text{ g H}_2 \text{O} & \quad 0.140 \text{ mol H}_2 \text{O} \\
\end{align*}

\textbf{Solution:}

2.41 \text{ g MgSO}_4 \times \frac{1 \text{ mol MgSO}_4}{120.37 \text{ g MgSO}_4} = 0.0200 \text{ mol MgSO}_4

Determine g H_2 O: 4.93 \text{ g MgSO}_4 \cdot x \text{H}_2 \text{O} - 2.41 \text{ g MgSO}_4 = 2.52 \text{ g H}_2 \text{O}

2.52 \text{ g H}_2 \text{O} \times \frac{1 \text{ mol H}_2 \text{O}}{18.02 \text{ g H}_2 \text{O}} = 0.140 \text{ mol H}_2 \text{O}

\[ \frac{0.140 \text{ mol H}_2 \text{O}}{0.0200 \text{ mol MgSO}_4} = 7 \]

\[ x = 7 \]

3.134 \textbf{ Given:} 3.41 \text{ g CuCl}_2 \cdot x \text{H}_2 \text{O}; 2.69 \text{ g CuCl}_2 \quad \textbf{Find:} \text{ value of } x

\textbf{Conceptual Plan:} g \text{ CuCl}_2 \rightarrow \text{mol CuCl}_2 \quad g \text{ H}_2 \text{O} \rightarrow \text{mol H}_2 \text{O} \quad \text{Determine mole ratio.}

\begin{align*}
1 \text{ mol CuCl}_2 & \quad 1 \text{ mol H}_2 \text{O} & \quad \frac{\text{mol H}_2 \text{O}}{\text{mol CuCl}_2} \\
134.45 \text{ g CuCl}_2 & \quad 18.02 \text{ g H}_2 \text{O} & \quad 0.040 \text{ mol H}_2 \text{O} \\
\end{align*}

\textbf{Solution:}

2.69 \text{ g CuCl}_2 \times \frac{1 \text{ mol CuCl}_2}{134.45 \text{ g CuCl}_2} = 0.0200 \text{ mol CuCl}_2

Determine g H_2 O: 3.41 \text{ g CuCl}_2 \cdot x \text{H}_2 \text{O} - 2.69 \text{ g CuCl}_2 = 0.72 \text{ g H}_2 \text{O}

0.72 \text{ g H}_2 \text{O} \times \frac{1 \text{ mol H}_2 \text{O}}{18.02 \text{ g H}_2 \text{O}} = 0.040 \text{ mol H}_2 \text{O}

\[ \frac{0.040 \text{ mol H}_2 \text{O}}{0.0200 \text{ mol CuCl}_2} = 2 \]

\[ x = 2 \]

3.135 \textbf{ Given:} \text{molar mass} = 177 \text{ g/mol}; g \text{ C} = 8(g H) \quad \textbf{Find:} \text{ molecular formula}

\textbf{Conceptual Plan:} C_9 \text{H}_{18} \text{BrO}

\textbf{Solution:} \text{in 1 mol compound, let } x = \text{ mol C} \text{ and } y = \text{ mol H}. \text{ assume mol Br} = 1, \text{ assume mol O} = 1

177 \text{ g/mol} = x(12.01 \text{ g/mol}) + y(1.008 \text{ g/mol}) + 1(79.90 \text{ g/mol}) + 1(16.00 \text{ g/mol})

x(12.01 \text{ g/mol}) = 8[y(1.008 \text{ g/mol})]
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177 g/mol = 8y(1.008 g/mol) + y(1.008 g/mol) + 79.90 g/mol + 16.00 g/mol
81 = 9y(1.008)
y = 9 = mol H
x(12.01) = 8 \times 9(1.008)
x = 6 = mol C
molecular formula = C_6H_8BrO

Check: molar mass = 6(12.01 g/mol) + 9(1.008 g/mol) + 1(79.90 g/mol) + 1(16.00 g/mol) = 177.03 g/mol

3.136 Given: 3.54 g sample yields 8.49 g CO₂ and 2.14 g H₂O; 2.35 g sample yields 0.199 g N; molar mass = 165

Find: molecular formula

Conceptual Plan:

<table>
<thead>
<tr>
<th>Mass N → mol N; then mass CO₂, H₂O → mol CO₂, H₂O → mol C, mol H → mass C, mass H;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mol N</td>
</tr>
<tr>
<td>14.01 g N</td>
</tr>
</tbody>
</table>

mass O → mol O → pseudoformula → empirical formula → molecular formula

g sample → g C → g H

\[ \frac{0.199 \text{ g N}}{2.35 \text{ g sample}} = \frac{x \text{ g N}}{1 \text{ mol N}} \]

\[ 0.300 \text{ g N} \times \frac{1 \text{ mol N}}{14.01 \text{ g N}} = 0.0214 \text{ mol N} \]

8.49 g CO₂ × \frac{1 \text{ mol CO₂}}{44.01 g CO₂} = 0.193 \text{ mol CO₂}

2.14 g H₂O × \frac{1 \text{ mol H₂O}}{18.02 g H₂O} = 0.119 \text{ mol H₂O}

0.193 \text{ mol CO₂} × \frac{1 \text{ mol C}}{1 \text{ mol CO₂}} = 0.193 \text{ mol C}

0.119 \text{ mol H₂O} × \frac{2 \text{ mol H}}{1 \text{ mol H₂O}} = 0.238 \text{ mol H}

0.193 \text{ mol H₂O} × \frac{12.01 \text{ g C}}{1 \text{ mol H₂O}} = 2.32 \text{ g C}

0.238 \text{ mol H₂O} × \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 0.240 \text{ g H}

3.54 g - 2.32 g C - 0.240 g H - 0.300 g N = 0.680 g O

\[ \frac{0.680 \text{ g O}}{1 \text{ mol O}} = 0.0425 \text{ mol O} \]

C₀.₁₉₃ H₀.₂₃₈ N₀.₀₁₂₄ O₀.₀₄₂₅ \[ \rightarrow \] C₆H₁₁NO₂

The correct empirical formula is C₆H₁₁NO₂.

empirical formula mass = 9(12.01 g/mol) + 11(1.008 g/mol) + 1(14.01 g/mol) + 2(16.00 g/mol)

n = \frac{\text{molar mass}}{\text{formula molar mass}} = \frac{165 \text{ g/mol}}{165.19 \text{ g/mol}} = 1

molecular formula = C₆H₁₁NO₂ × 1

molecular formula = C₆H₁₁NO₂

3.137 Given: 23.5 mg C₁₇H₂₅ClNO₄

Find: total number of atoms

Conceptual Plan: mg compound → g compound → mol compound → mol atoms → number of atoms

\[ \frac{1 \text{ g}}{1000 \text{ mg}} \]

\[ \frac{1 \text{ mol}}{339.81 \text{ g}} \]

45 mol atoms \[ \frac{45 \text{ mol atoms}}{1 \text{ mol compound}} \]

\[ \frac{6.022 \times 10^{23} \text{ atoms}}{1 \text{ mol atoms}} \]

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Solution: 23.5 mg \times \frac{1 \text{ g}}{1000 \text{ mg}} \times \frac{1 \text{ mol V}}{33.91 \text{ g}} \times \frac{45 \text{ mol- atoms}}{1 \text{ mol V}} \times \frac{6.022 \times 10^{23} \text{ atoms}}{1 \text{ mol}} = 1.87 \times 10^{21} \text{ atoms}

Check: The units of the answer (number of atoms) are correct. The magnitude of the answer is reasonable because the molecule is so complex.

3.138

(a) **Given:** in a 100 g sample: 76 g V; 24 g O  **Find:** formula and name

**Conceptual Plan:**

Convert mass to mol of each element → write pseudoformula → write empirical formula

\[
\text{divide by smallest number}
\]

\[
\begin{align*}
1 \text{ mol V} & \quad 1 \text{ mol O} \\
50.94 \text{ g V} & \\
16.00 \text{ g O} &
\end{align*}
\]

**Solution:**

\[
76 \text{ g V} \times \frac{1 \text{ mol V}}{50.94 \text{ g V}} = 1.5 \text{ mol V}
\]

\[
24 \text{ g O} \times \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 1.5 \text{ mol O}
\]

V_{1.5}O_{1.5} → VO

The correct formula is VO: vanadium(II) oxide.

(b) **Given:** in a 100 g sample: 68 g V; 32 g O  **Find:** formula and name

**Conceptual Plan:**

Convert mass to mol of each element → write pseudoformula → write empirical formula

\[
\text{divide by smallest number}
\]

\[
\begin{align*}
1 \text{ mol V} & \quad 1 \text{ mol O} \\
50.94 \text{ g V} & \\
16.00 \text{ g O} &
\end{align*}
\]

**Solution:**

\[
68 \text{ g V} \times \frac{1 \text{ mol V}}{50.94 \text{ g V}} = 1.33 \text{ mol V}
\]

\[
32 \text{ g O} \times \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 2 \text{ mol O}
\]

V_{1.33}O_{2} → VO_{1.5} → V_{2}O_{3}

The correct formula is V_{2}O_{3}: vanadium(III) oxide.

(c) **Given:** in a 100 g sample: 61 g V; 39 g O  **Find:** formula and name

**Conceptual Plan:**

Convert mass to mol of each element → write pseudoformula → write empirical formula

\[
\text{divide by smallest number}
\]

\[
\begin{align*}
1 \text{ mol V} & \quad 1 \text{ mol O} \\
50.94 \text{ g V} & \\
16.00 \text{ g O} &
\end{align*}
\]

**Solution:**

\[
61 \text{ g V} \times \frac{1 \text{ mol V}}{50.94 \text{ g V}} = 1.2 \text{ mol V}
\]

\[
39 \text{ g O} \times \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 2.4 \text{ mol O}
\]

V_{1.2}O_{2.4} → VO_{2}

The correct formula is VO_{2}: vanadium(IV) oxide.

(d) **Given:** in a 100 g sample: 56 g V; 44 g O  **Find:** formula and name

**Conceptual Plan:**

Convert mass to mol of each element → write pseudoformula → write empirical formula

\[
\text{divide by smallest number}
\]

\[
\begin{align*}
1 \text{ mol V} & \quad 1 \text{ mol O} \\
50.94 \text{ g V} & \\
16.00 \text{ g O} &
\end{align*}
\]
Solution:

\[ 56 \text{ g} \times \frac{1 \text{ mol V}}{50.94 \text{ g} \text{ V}} = 1.1 \text{ mol V} \]

\[ 44 \text{ g} \text{ O} \times \frac{1 \text{ mol O}}{16.00 \text{ g} \text{ O}} = 2.75 \text{ mol O} \]

\[ V_{1.1}O_{2.75} \rightarrow VO_{2.5} \rightarrow V_2O_5 \]

The correct formula is \( V_2O_5 \); vanadium(V) oxide.

3.139  
**Given:** MCl₃; 2.395 g sample; 3.606 \times 10^{-2} \text{ mol Cl}  
**Find:** atomic mass \( M \)

**Conceptual Plan:** \( \text{mol Cl} \rightarrow \text{g Cl} \rightarrow \text{g X} \)

\[ \frac{35.45 \text{ g Cl}}{1 \text{ mol Cl}} \times \frac{1 \text{ mol Cl}}{\text{ g sample}} = \text{g Cl} = gM \]

**Solution:**

\[ 3.606 \times 10^{-2} \text{ mol Cl} \times \frac{35.45 \text{ g Cl}}{1 \text{ mol Cl}} = 1.278 \text{ g Cl} \]

\[ 2.395 \text{ g} - 1.278 \text{ g} = 1.117 \text{ g M} \]

\[ 3.606 \times 10^{-2} \text{ mol Cl} \times \frac{1 \text{ mol M}}{3 \text{ mol Cl}} = 1.202 \times 10^{-2} \text{ mol M} \]

\[ \frac{1.117 \text{ g M}}{0.01202 \text{ mol M}} = 92.93 \text{ g/mol} \]

Molar mass of \( M \) = 92.93 g/mol

3.140

![Chemical structures](image)

3.141  
**Given:** \( \text{Fe}_7\text{Cr}_4\text{O}_{12} \); 28.59% O  
**Find:** \( x \) and \( y \)

**Conceptual Plan:** \( \% \text{ O} \rightarrow \text{ molar mass } \text{Fe}_7\text{Cr}_4\text{O}_{12} \rightarrow \text{ mass Fe + Cr} \)

\[ \text{mass O} \times \frac{100\%}{100\%} = \% \text{ O} \quad \text{mass cpd} - \text{mass O} = \text{mass Fe + Cr} \]

**Solution:**

\[ \frac{28.59 \text{ g O}}{100.0} = \frac{64.00 \text{ g O}}{\text{molar mass cpd}} \quad \text{molar mass} = 223.9 \text{ g/mol} \]

Mass \( \text{Fe} + \text{Cr} = \text{molar mass} - (4 \times \text{ molar mass O}) = 223.9 - 64.00 = 159.9 \text{ g} \)

Molar mass \( \text{Fe} = 55.85 \); molar mass \( \text{Cr} = 52.00 \)

Because the mass of the two metals is close, the average mass can be used to determine the total moles of Fe and Cr present in the compound. Average mass of Fe and Cr = 53.9. \[ \frac{159.9 \text{ g}}{53.9 \text{ g/mol}} = 2.97 = 3 \text{ mol metal} \]
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Let \( x = \text{mol Fe} \) and \( y = \text{mol Cr} \)

\[
x \text{mol Fe} + y \text{mol Cr} = 3 \text{mol total}
\]

\[
x \text{mol Fe}(55.85 \text{ g Fe/mol}) + y \text{mol Cr}(52.00 \text{ g Cr/mol}) = 159.8
\]

\[
y \text{mol Cr} = 3 - x \text{mol Fe}
\]

\[
x(55.85) + (3-x)(52.00) = 159.8
\]

So \( x = 1 \) and \( y = 2 \).

**Check:** Formula \( \text{FeCr}_2\text{O}_4 \) would have a molar mass of \( \text{Fe} + 2\text{Cr} + 4\text{O} = 55.85 + 2(52.00) + 4(16.00) = 223.85 \), and the molar mass of the compound is 223.8.

3.142 **Given:** \( \text{X}_3\text{P}_2 \); 34.00 P; 100 g sample contains 34.00 g P  **Find:** X

**Conceptual Plan:**

\[
g \text{P} \rightarrow \text{mol P} \rightarrow \text{mol X}
\]

\[
\frac{1 \text{ mol P}}{30.97 \text{ g P}} \times \frac{3 \text{ mol X}}{2 \text{ mol P}} \rightarrow \text{molar mass X}
\]

**Solution:**

\[
34.00 \text{ g P} \times \frac{1 \text{ mol P}}{30.97 \text{ g P}} \times \frac{3 \text{ mol X}}{2 \text{ mol P}} = 1.647 \text{ mol X}
\]

\[
100.00 \text{ g sample} - 34.00 \text{ g P} = 66.00 \text{ g X}
\]

\[
\frac{66.00 \text{ g X}}{1.647 \text{ mol X}} = 40.07 \text{ g/mol} \rightarrow \text{Ca}
\]

**Check:** The units (g/mol) are correct. The answer, Ca, is reasonable because \( \text{Ca}_3\text{P}_2 \) is a molecule that exists.

3.143 **Given:** 0.0552% \( \text{NaNO}_2 \); 8.00 oz bag  **Find:** mass \( \text{Na} \) in bag

**Conceptual Plan:**

\[
\text{oz bag} \rightarrow \text{g bag} \rightarrow \text{g \text{NaNO}_2} \rightarrow \text{g Na}
\]

**Solution:**

\[
8.00 \text{ oz - bag} \times \frac{453.6 \text{ g bag}}{16.00 \text{ oz - bag}} \times \frac{0.0552 \text{ g NaNO}_2}{100.0 \text{ g bag}} \times \frac{22.99 \text{ g Na}}{69.00 \text{ g NaNO}_2} \times \frac{1000 \text{ mg Na}}{1 \text{ g Na}} = 41.7 \text{ mg Na}
\]

**Check:** The units of the answer (mg Na) are correct. The magnitude of the answer is reasonable because only a small percentage of the total mass is Na.

3.144 **Given:** ore is 57.8% \( \text{Ca}_3(\text{PO}_4)_2 \)  **Find:** mass of ore to get 1.00 kg P

**Conceptual Plan:**

Mass ore \( \rightarrow \) mass \( \text{Ca}_3(\text{PO}_4)_2 \) \( \rightarrow \) mass P

**Solution:** Assume a 100.0 gram sample of ore.

\[
100.0 \text{ g - ore} \times \frac{57.8 \text{ g Ca}_3(\text{PO}_4)_2}{100.0 \text{ g - ore}} \times \frac{61.94 \text{ g P}}{310.18 \text{ g Ca}_3(\text{PO}_4)_2} = 11.54 \text{ g P}
\]

\[
1.00 \text{ kg P} \times \frac{1000 \text{ g P}}{1 \text{ kg P}} \times \frac{100.0 \text{ g - ore}}{11.54 \text{ g P}} \times \frac{1 \text{ kg ore}}{1000 \text{ g - ore}} = 8.666 \text{ kg ore} \rightarrow 8.67 \text{ kg ore}
\]

**Check:** The units of the answer (kg ore) are correct. The magnitude of the answer is reasonable because the amount is greater than 1 kilogram.

**Challenge Problems**

3.145 **Given:** g \( \text{NaCl} \) + g \( \text{NaBr} \) = 2.00 g; g Na = 0.75 g  **Find:** g \( \text{NaBr} \)

**Conceptual Plan:**

\[x = \text{mol NaCl}, \ y = \text{mol NaBr}, \text{then } x(\text{molar mass NaCl}) = \text{g NaCl}, \ y(\text{molar mass NaBr}) = \text{g NaBr}\]

**Solution:**

\[x(58.44) + y(102.89) = 2.00\]

\[x(22.99) + y(22.99) = 0.75 \quad y = 0.0326 - x\]

\[58.44x + 102.89(0.0326 - x) = 2.00\]

\[58.44x + 3.354 - 102.89x = 2.00\]

\[44.45x = 1.354\]
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\[ x = 0.03046 \text{ mol NaCl} \]
\[ y = 0.0326 - 0.03046 = 0.00214 \text{ mol NaBr} \]
\[ g \text{ NaBr} = (0.00214)(102.89 \text{ g/mol}) = 0.220 \text{ g NaBr} \]

Check: The units of the answer (g NaBr) are correct. The magnitude is reasonable because it is less than the total mass.

3.146 **Given:** sample 1: 1.00 g X, 0.472 g Z, X₂Z₃; sample 2: 1.00 g X, 0.630 g Z; sample 3: 1.00 g X, 0.789 g Z

**Find:** empirical formula for samples 2 and 3

**Conceptual Plan:** Moles X remains constant; determine relative moles of Z for three samples.

**Solution:** Let X = atomic mass X, Z = atomic mass Z

\[ n_X = \frac{1.00 \text{ g X}}{X} \quad n_Z = \frac{0.472 \text{ g Z}}{Z} \]

for sample 1: \[ n_X \quad n_Z = \frac{2}{3} \]

for sample 2: \[ 0.630 \text{ g} \quad 0.472 \text{ g} = 1.33 \text{ mol} = 1.33n_Z \]

mol ratio: \[ \frac{n_X}{1.33n_Z} = \frac{2}{(1.33)3} = \frac{2}{4} = \frac{1}{2} \]

Empirical formula sample 2: XZ₂

for sample 3: \[ 0.789 \text{ g} \quad 0.472 \text{ g} = 1.67 \text{ mol} = 1.67n_Z \]

mol ratio: \[ \frac{n_X}{1.67n_Z} = \frac{2}{(1.67)3} = \frac{2}{5} \]

Empirical formula sample 3: X₂Z₃

3.147 **Given:** sample of CaCO₃ and (NH₄)₂CO₃ is 61.9% CO₃²⁻ **Find:** % CaCO₃

**Conceptual Plan:** Let \( x = \text{CaCO}_3, y = \text{(NH}_4)_2\text{CO}_3 \), then \( x \) (molar mass CaCO₃) = g CaCO₃,

\( y \) (molar mass (NH₄)₂CO₃) = g (NH₄)₂CO₃

then a 100.00 g sample contains \( x(100.00) \) g CaCO₃, \( y(96.09) \) g (NH₄)₂CO₃; 61.89 g CO₃²⁻

**Solution:**

\[ x(100.09) + y(96.09) = 100.00 \]
\[ x(60.01) + y(60.01) = 61.9 \quad y = 1.03149 - x \]
\[ 100.09x + 96.09(1.03 - x) = 100.00 \]
\[ 100.09x + 99.0 - 96.09x = 100 \]
\[ 4.00x = 1.00 \]
\[ x = 0.250 \text{ mol CaCO}_3 \]
\[ y = 1.03149 - 0.250 = 0.781 \text{ mol (NH}_4)_2\text{CO}_3 \]

g CaCO₃ = (0.250 mol)(100.00 g/mol) = 25.0 g CaCO₃ in a 100.00 g sample mass % CaCO₃ = 25.0%

Check: The units of the answer (mass % CaCO₃) are correct. The magnitude is reasonable because it is between 0 and 100%.

3.148 **Given:** 50.0 g S; 1.00 × 10² g Cl₂; 150. g mixture S₂Cl₂ and SCl₂ **Find:** g S₂Cl₂

**Conceptual Plan:** Total mol S = \( 2(\text{mol S}_2\text{Cl}_2) + \text{mol S}_2\text{Cl}_2 \)

\( \frac{135.02}{\text{mol S}_2\text{Cl}_2} \times 100\% \)

then \( S_2\text{Cl}_2 = 135.02 \text{ g/mol}, SCl}_2 = 102.96 \text{ g/mol}, \) let \( x = \text{mol S}_2\text{Cl}_2, y = \text{mol SCl}_2 \)

\( x(135.02) + y(102.96) = 50 \text{ g in S}_2\text{Cl}_2 \)

**Solution:**

\[ \text{mol S} = 50.0 \text{ g S} \times \frac{1 \text{ mol S}}{32.06 \text{ g S}} = 1.56 \text{ mol} \]
\[ 2x = \text{mol S in S}_2\text{Cl}_2, y = \text{mol S in SCl}_2 \]
\[ 2x + y = 1.56 \]
\[ x(135.02) + y(102.96) = 150.0 \]
\[ 135.02x + 102.96(1.56 - 2x) = 150.0 \]
\[ 70.96x = 10.6y \]

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$x = 0.150$
$y = 1.26$

$0.150 \text{ mol } S_2\text{Cl}_2 \times \frac{135.02 \text{ g } S_2\text{Cl}_2}{1 \text{ mol } S_2\text{Cl}_2} = 20.3 \text{ g } S_2\text{Cl}_2$

Check: The units of the answer (g $S_2\text{Cl}_2$) are correct. The magnitude is reasonable because there would be fewer moles of $S_2\text{Cl}_2$ than SCl$_2$.

3.149

Given: 1.1 kg CF$_2$Cl$_2$/automobile; 25% leaked/year; 100 $\times$ $10^6$ automobiles  Find: kg Cl/yr
Conceptual Plan: kg CF$_2$Cl$_2$/auto $\rightarrow$ kg CF$_2$Cl$_2$ leaked/yr $\rightarrow$ kg Cl/yr/auto $\rightarrow$ kg Cl

Solution: $\frac{1.1 \text{ kg CF}_2\text{Cl}_2}{100 \text{ kg CF}_2\text{Cl}_2} \times \frac{25 \text{ kg CF}_2\text{Cl}_2}{120.91 \text{ kg CF}_2\text{Cl}_2} \times \frac{70.90 \text{ kg Cl}}{100 \times 10^6 \text{ auto}} = 1.6 \times 10^7 \text{ kg Cl/yr}$

Check: The units of the answer (kg Cl) are correct. The magnitude is reasonable because it is less than the kilogram CF$_2$Cl$_2$ leaked per year.

3.150

Given: coal = 2.55% S; H$_2$SO$_4$; 1.0 metric ton coal  Find: metric ton H$_2$SO$_4$ produced
Conceptual Plan: H$_2$SO$_4$ $\rightarrow$ % S

Solution: $\frac{32.06 \text{ g S}}{98.08 \text{ g H}_2\text{SO}_4} \times 100\% = 32.69 \% \text{ S}$

Conceptual Plan: Metric ton coal $\rightarrow$ kg coal $\rightarrow$ kg S $\rightarrow$ kg H$_2$SO$_4$ $\rightarrow$ metric ton H$_2$SO$_4$

Solution: $\frac{1000 \text{ kg metric ton coal}}{1 \text{ metric ton coal}} \times \frac{2.55 \text{ kg S}}{1 \text{ metric ton coal}} \times \frac{100 \text{ kg H}_2\text{SO}_4}{32.69 \text{ kg S}} \times \frac{1 \text{ metric ton H}_2\text{SO}_4}{1000 \text{ kg}} = 0.078 \text{ metric ton H}_2\text{SO}_4$

Check: The units of the answer (metric ton H$_2$SO$_4$) are correct. Magnitude is reasonable because it is more than 2.55% of a metric ton and the mass of H$_2$SO$_4$ is greater than the mass of S.

3.151

Given: rock contains: 38.0% PbS; 25.0% PbCO$_3$; 17.4% PbSO$_4$  Find: kg rock needed for 5.0 metric ton Pb
Conceptual Plan: Determine kg Pb/100 kg rock then ton Pb $\rightarrow$ kg Pb $\rightarrow$ kg rock

Solution: in 100 kg rock:

$$\left( \frac{38.0 \text{ kg PbS}}{239.3 \text{ kg PbS}} \times \frac{207.2 \text{ kg Pb}}{239.3 \text{ kg PbS}} \right) + \left( \frac{25.0 \text{ kg PbCO}_3}{267.2 \text{ kg PbCO}_3} \times \frac{207.2 \text{ kg Pb}}{267.2 \text{ kg PbCO}_3} \right) + \left( \frac{17.4 \text{ kg PbSO}_4}{303.3 \text{ kg PbSO}_4} \times \frac{207.2 \text{ kg Pb}}{303.3 \text{ kg PbSO}_4} \right)$$

= 64.2 kg Pb

$5.0 \text{ metric ton Pb} \times \frac{1000 \text{ kg Pb}}{64.2 \text{ kg Pb}} = 7.8 \times 10^3 \text{ kg rock}$

Check: The units of the answer (kg rock) are correct. Magnitude is reasonable because it is greater than the amount of Pb needed.

3.152

Given: sample 1: 2.52 g sample, 4.23 g CO$_2$, 1.01 g H$_2$O; sample 2: 4.14 g, 2.11 g SO$_3$; sample 3: 5.66 g, 2.27 g HNO$_3$  Find: empirical formula of the compound
Conceptual Plan: g CO$_2$ $\rightarrow$ g C $\rightarrow$ % C; g H$_2$O $\rightarrow$ g H $\rightarrow$ % H; g SO$_2$ $\rightarrow$ g S $\rightarrow$ % S;
g HNO$_3$ $\rightarrow$ g N $\rightarrow$ % N and then $\rightarrow$ % O and then % composition $\rightarrow$ mol of each atom $\rightarrow$

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**pseudoformula → empirical formula**

**Solution:**

\[\text{4.23 g \text{C}_2\text{O}_5} \times \frac{12.01 \text{ g C}}{44.01 \text{ g C}_2\text{O}_5} = 1.154 \text{ g C}\]

\[\frac{1.154 \text{ g C}}{2.52 \text{ g sample}} \times 100\% = 45.81\% \text{ C}\]

\[\frac{0.1132 \text{ g H}}{2.52 \text{ g sample}} \times 100\% = 4.49\% \text{ H}\]

\[\frac{0.8449 \text{ g S}}{4.14 \text{ g sample}} \times 100\% = 20.41\% \text{ S}\]

\[\frac{0.5046 \text{ g N}}{5.66 \text{ g sample}} \times 100\% = 8.92\% \text{ N}\]

\% O = 100 - 45.81 - 4.49 - 20.41 - 8.92 = 20.37\% O

Assume a 100 g sample:

\[\frac{45.81 \text{ g C}}{12.01 \text{ g C}} \times 1 \text{ mol C} = 3.814 \text{ mol C}\]

\[\frac{4.49 \text{ g H}}{1.01 \text{ g H}} \times 1 \text{ mol H} = 4.445 \text{ mol H}\]

\[\frac{20.41 \text{ g S}}{32.06 \text{ g S}} \times 1 \text{ mol S} = 0.6366 \text{ mol S}\]

\[\frac{8.92 \text{ g N}}{14.01 \text{ g N}} \times 1 \text{ mol N} = 0.6367 \text{ mol N}\]

\[\frac{20.37 \text{ g O}}{16.00 \text{ g O}} \times 1 \text{ mol O} = 1.273 \text{ mol O}\]

**C_{3.814} H_{4.445} S_{0.6366} N_{0.6367} O_{1.273}\]

\[\rightarrow \text{C}_9\text{H}_7\text{SNO}_2\]

3.153 **Given:** molar mass = 229 g/mol, 6 times mass C as H  **Find:** molecular formula

**Conceptual Plan:** Let \(x =\) mass of C, then \(6x =\) mass of C

**Solution:** in 1 mol of the compound: \(6 \times x + g\) H + \(g\) S + \(g\) I = 229 g

Because the molar mass of I = 127, there cannot be more than 1 mol of I in the compound; so

\[x + 6x + g\) S + 127 = 229.\]

If the compound contains 1 mol S, then \(7x = 102 - 32 = 70\) and \(x = 10\) g H and \(6x = 60\) g C.

\[10 \times \text{g H} \times \frac{1 \text{ mol H}}{1.0 \text{ g H}} = 10 \text{ mol H}\]

\[60 \times \text{g C} \times \frac{1 \text{ mol C}}{12 \text{ g C}} = 5 \text{ mol C}\]

1 mol I and 1 mol S; so empirical formula is \(\text{C}_9\text{H}_7\text{SNO}_2\)

**Check:** Molar mass of \(\text{C}_9\text{H}_7\text{SNO}_2\) = \(5(12) + 10(1.0) + 32 + 127 = 229\) g/mcl, which is the mass given.

3.154 **Given:** compound is 40% X and 60% Y; atomic mass X = 2 (atomic mass Y)  **Find:** empirical formula

**Conceptual Plan:** Mass X and Y \(\rightarrow\) mass ratio X: Y and then \(g\) X \(\rightarrow\) mol X and \(g\) Y \(\rightarrow\) mol Y and then

**mole ratio**

**Solution:**

\[\frac{\text{mass X}}{\text{mass Y}} = \frac{40}{60} = \frac{2}{3}\]

\[\text{mol X} = \frac{2 \text{ g}}{\text{atomic mass X}}\]

\[\text{and}\ \text{mol Y} = \frac{3 \text{ g}}{\text{atomic mass Y}}\]

But atomic mass X = 2(atomic mass Y)

\[\text{mol X} = \frac{2 \text{ g}}{2(\text{atomic mass Y})}\]

\[\text{and}\ \text{mol Y} = \frac{3 \text{ g}}{\text{atomic mass Y}}\]

\[\text{mol X} = \frac{2(\text{atomic mass Y})}{3 \text{ g}} = \frac{1}{3}\]

**empirical formula:** \(X_2Y_3\)

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3.155 Given: compound is 1/3 X by mass; atomic mass X is 1/3 atomic mass Y

Find: empirical formula

Conceptual Plan: Mass X and Y → mass ratio X: Y and then \( g \) X → mol X and \( g \) Y → mol Y and then

\[
\text{mole ratio} \quad \frac{\text{mass X}}{\text{mass Y}} = \frac{1}{2} \quad \text{and} \quad \frac{\text{mol X}}{\text{mol Y}} = \frac{1}{3} \text{atomic mass Y}
\]

Solution: \( \frac{\text{mass X}}{\text{mass Y}} = \frac{1}{2} \quad \text{and} \quad \frac{\text{mol X}}{\text{mol Y}} = \frac{2}{3} \text{atomic mass Y} \)

But atomic mass X = 1/3 (atomic mass Y)

\[
\text{mol X} = \frac{1}{3(\text{atomic mass Y})} \quad \text{and} \quad \text{mol Y} = \frac{2}{3(\text{atomic mass Y})}
\]

\[
\text{mol X} = \frac{1}{3(\text{atomic mass Y})} \quad \text{and} \quad \text{mol Y} = \frac{2}{3(\text{atomic mass Y})} = 1/6 \quad \text{empirical formula} = XY_6
\]

3.156 Given: 9.0 g sample of C and S; 23.3 g mixture of CO₂ and SO₂

Find: mass of S in sample

Conceptual Plan: Let \( x = g \) C and \( y = g \) S and then \( x \) g C → mol C → mol CO₂ → g CO₂ and then

\[
\begin{align*}
\frac{y \text{ g S}}{32.06 \text{ g S}} & \quad \frac{1 \text{ mol SO}_2}{64.06 \text{ g SO}_2} \\
\frac{x \text{ g C}}{12.01 \text{ g C}} & \quad \frac{1 \text{ mol CO}_2}{44.01 \text{ g CO}_2}
\end{align*}
\]

Solution: \( (x \text{ g C}) \times \frac{1 \text{ mol C}}{12.01 \text{ g C}} \times \frac{1 \text{ mol CO}_2}{1 \text{ mol C}} \times \frac{44.01 \text{ g CO}_2}{1 \text{ mol CO}_2} = 3.66x \text{ g CO}_2 \)

\( (y \text{ g S}) \times \frac{1 \text{ mol S}}{32.06 \text{ g S}} \times \frac{1 \text{ mol SO}_2}{1 \text{ mol S}} \times \frac{64.06 \text{ g SO}_2}{1 \text{ mol SO}_2} = 2.00y \text{ g SO}_2 \)

\[
x + y = 9.0
\]

3.66x + 2.00y = 23.3

3.66x + (9 - x)2.00 = 23.3

\[
x = 3.2 \text{ g C} \quad \text{and} \quad y = 5.8 \text{ g S}
\]

Check: The units of the answer (g S) are correct. The magnitude is reasonable because it is less than 9.0 g.

**Conceptual Problems**

3.157 The sphere in the molecular models represents the electron cloud of the atom. On this scale, the nucleus would be too small to see.

3.158 (a) Atomic mass O > atomic mass C; % O would be higher.

(b) Atomic mass N and O close; molecule contains 2N to 1O; % N would be higher.

(c) Atomic mass O > atomic mass C and both are much greater than the atomic mass of H; same number of atoms of C and O; % O would be higher.

(d) Atomic mass N much greater than atomic mass H; % N would be higher.

3.159 The statement is incorrect because a chemical formula is based on the ratio of atoms combined, not the ratio of grams combined. The statement should read as follows: The chemical formula for ammonia (\( \text{NH}_3 \)) indicates that ammonia contains three hydrogen atoms to each nitrogen atom.

3.160 The statement is incorrect because equations are balanced based on the number and kind of atoms, not molecules. The statement should read as follows: When a chemical equation is balanced, the number of atoms of each type on both sides of the equation is equal.

3.161 \( \text{H}_2\text{SO}_4 \): Atomic mass S is approximately twice atomic mass O; both are much greater than atomic mass H. The order of % mass is % O > % S > % H.

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Questions for Group Work

3.163 In an ionic bond an electron is transferred from the Na atom to the Cl atom, so a student would move from the Na atom to the Cl atom. For the covalent bond, a pair of electrons is shared between the O atom and each of the two H atoms.

3.164

Does the formula contain more than one type of atom?

Yes

The substance is a compound.

No

The substance is an element.

Does the formula contain only nonmetals and no NH₄ units?

Yes

The substance is a molecular compound.

No

The substance is an ionic compound.

3.165 Some examples of similarities are:
- The systematic names of both binary ionic compounds and binary molecular compounds contain two words.
- The systematic names of both binary ionic compounds and binary molecular compounds end in -ide.
- The systematic names of both binary ionic compounds and binary molecular compounds indicate how many atoms of each element are in the formula.
- The systematic names of both binary ionic compounds and binary molecular compounds name the element listed first first.

Some examples of differences are:
- Only the systematic names of binary molecular compounds contain Greek prefixes.
- There are no polyatomic group names used in generating the systematic name of a binary molecular compound.
- The systematic names of only ionic compounds can have a variety of endings (-ide, -ate, and -ite).
- Binary molecular compounds end in -ide.

3.166 Given: In a 100 g sample: 88.14 g C; 11.86 g H; molar mass = 136.26 g/mol Find: molecular formula

Conceptual Plan:
convert mass to mol of each element → write pseudoformula → write empirical formula

\[
\begin{align*}
1 \text{ mol C} & : 12.01 \text{ g C} \\
1 \text{ mol H} & : 1.0008 \text{ g H}
\end{align*}
\]

divide by smaller number

then empirical formula → molecular formula

divide molar mass by molar mass of empirical formula
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Solution: 88.14 g C \times \frac{1 \text{ mol C}}{12.01 \text{ g C}} = 7.339 \text{ mol C} \\
11.86 g H \times \frac{1 \text{ mol H}}{1.008 \text{ g H}} = 11.77 \text{ mol H} \\
C_{2.339}H_{11.77} \overset{\text{Divide by smaller number}}{\rightarrow} \frac{C_{2.339}}{7.339}H_{\frac{11.77}{7.339}} \rightarrow C_2H_{4.60} \\
C_2H_{1.60} \times 2 = C_2H_4 \\
The molar mass of the empirical formula is 2(12.01 g/mol) + 3(1.008 g/mol) = 27.04 g/mol. \\
\(n = \frac{136.26 \text{ g/mol}}{27.04 \text{ g/mol}} = 5.03\) So, C_2H_3 \times 5 = C_{10}H_{15} is the molecular formula. \\
The hardest part might be to determine which integer to multiply the pseudoformula by, since the atom ratio is 1:1.60 (and not 1:1.50 or 1:1.67).

3.167 Conceptual Plan: write a skeletal reaction \rightarrow balance atoms in more complex compounds \rightarrow balance elements that occur as free elements \rightarrow clear fractions

Solution: 

**Skeletal reaction:** \(C_2H_{18}(l) + O_2(g) \rightarrow CO_2(g) + H_2O(g)\) 

**Balance C:** \(C_2H_{18}(l) + O_2(g) \rightarrow 8 CO_2(g) + H_2O(g)\) 

**Balance H:** \(C_2H_{18}(l) + O_2(g) \rightarrow 8 CO_2(g) + 9 H_2O(g)\) 

**Balance O:** \(C_2H_{18}(l) + 25/2 O_2(g) \rightarrow 8 CO_2(g) + 9 H_2O(g)\) 

**Clear fraction:** \(2 C_2H_{18}(l) + 25 O_2(g) \rightarrow 16 CO_2(g) + 18 H_2O(g)\) 

**Check:** left side right side  
16 C atoms 16 C atoms 
36 H atoms 36 H atoms 
50 O atoms 50 O atoms

Data Interpretation and Analysis

3.168 (a) (i) 9.60 billion metric tons carbon - 9.20 billion metric tons carbon = 0.40 billion metric tons carbon

(ii) \(0.40 \text{ billion metric tons C} \times \frac{2,200 \text{ lb C}}{1 \text{ metric ton C}} \times \frac{453.59 \text{ g C}}{1 \text{ lb C}} \times \frac{1 \text{ mole C}}{12.01 \text{ g C}} \times \frac{1 \text{ mole CO}_2}{1 \text{ mole C}} = 33,236 \text{ billion moles CO}_2\)

\(33,236 \text{ billion moles CO}_2 \times \frac{44,01 \text{ g CO}_2}{1 \text{ mole CO}_2} \times \frac{1 \text{ lb CO}_2}{453.59 \text{ g CO}_2} \times \frac{1 \text{ metric ton CO}_2}{2,200 \text{ lb CO}_2}\) = 1.466 billion metric tons CO_2

(b) (i) In 1880: 290 ppmv CO_2 = 290 \mu L CO_2/L air, so

\(1.00 \text{ m}^3 \text{ air} \times \frac{290 \mu L \text{ CO}_2}{1 \text{ m}^3 \text{ air}} \times \frac{10^{-6} \text{ L} \text{ CO}_2}{1 \mu L \text{ CO}_2} \times \frac{1 \text{ mole} \text{ CO}_2}{10^3 \text{ mL CO}_2} = 0.290 \text{ mL CO}_2\)

In 2014: 399 ppmv CO_2 = 399 \mu L CO_2/L air, so

\(1.00 \text{ m}^3 \text{ air} \times \frac{399 \mu L \text{ CO}_2}{1 \text{ m}^3 \text{ air}} \times \frac{10^{-6} \text{ L} \text{ CO}_2}{1 \mu L \text{ CO}_2} \times \frac{1 \text{ mole} \text{ CO}_2}{10^3 \text{ mL CO}_2} = 0.399 \text{ mL CO}_2\)

(ii) \(0.399 \text{ mL CO}_2 - 0.290 \text{ mL CO}_2 = 0.109 \text{ mL CO}_2\)

(iii) \(\% \text{ increase} = \frac{\text{ change}}{\text{ initial value}} \times 100\% = \left(\frac{0.109 \text{ mL CO}_2}{0.290 \text{ mL CO}_2}\right) \times 100\% = 37.6\% \text{ increase CO}_2\)

(iv) \(5.1 \times 10^9 \text{ km}^3 \text{ air} \times \frac{(10^3 \text{ m}^3)}{(1 \text{ km}^3)} \times \frac{0.399 \text{ cm}^3 \text{ CO}_2}{1 \text{ m}^3} \times \frac{(10^{-2} \text{ ml})^3}{(1 \text{ cm}^3)} \times \frac{(10^{-3} \text{ km}^3)}{(1 \text{ ml})^3} = 2.0 \times 10^3 \text{ km}^3 \text{ CO}_2\)

\(= 2.0 \times 10^{12} \text{ metric tons CO}_2\)

(c) Based on the information presented in Figure a, the average yearly increase in the concentration of CO_2 in the atmosphere is estimated at about 2 ppm CO_2 (looking at the fairly linear increase in CO_2 concentration from 1980 to 2010). Since the concentration of CO_2 in 2010 is about 390 ppm, in 2030 the concentration would be 430 ppm CO_2 (390 ppm + (20 years × 2 ppm/year))