CHAPTER 2
ATOMS, MOLECULES, AND IONS

2.1 **(a)** Alpha (α) particles are helium ions with a charge of +2. **(b)** Beta (β) particles are electrons emitted during the decay of certain radioactive substances. **(c)** Gamma (γ) rays are high-energy radiation. **(d)** X-rays are also high-energy radiation but with a lower energy than γ rays.

2.2 The most common types of radiation known to be emitted by radioactive elements are alpha (α) radiation, beta (β) radiation, and gamma (γ) radiation.

2.3 Alpha (α) particles composed of two protons and two neutrons. Cathode rays are a stream of electrons. Protons, neutrons, and electrons are fundamental particles. Fundamental particles are particles that were once thought to be the indivisible components of all matter.

2.4 Please see Section 2.2 of the text where early experiments on atomic structure are discussed in detail.

2.5 The sample is emitting particles from its nucleus (α, β, etc.).

2.6 Rutherford used α particles to probe the structure of the atom. Most α particles aimed at thin foils of gold passed through the foil with little or no deflection. A few α particles were deflected at large angles and occasionally an α particle bounced back in the direction from which it had come. Rutherford concluded that most of the atom was empty space with a small, dense, positively charged core (the nucleus).

2.7 First, convert 1 cm to picometers.

$$1 \text{ cm} \times \frac{0.01 \text{ m}}{1 \text{ cm}} \times \frac{1 \text{ pm}}{1 \times 10^{-12} \text{ m}} = 1 \times 10^{10} \text{ pm}$$

$$\textbf{? He atoms} = (1 \times 10^{10} \text{ pm}) \times \frac{1 \text{ He atom}}{1 \times 10^2 \text{ pm}} = \textbf{1} \times \textbf{10}^8 \textbf{ He atoms}$$

2.8 Note that you are given information to set up the unit factor relating meters and miles.

$$r_{\textbf{atom}} = 10^4 \, r_{\text{nucleus}} = 10^4 \times 10 \text{ cm} \times \frac{1 \text{ m}}{100 \text{ cm}} \times \frac{1 \text{ mi}}{1609 \text{ m}} = \textbf{0.62 mi}$$

2.9 **(a)** The atomic number is the number of protons in a nucleus. **(b)** The mass number is the sum of the number of protons and neutrons in the nucleus of an atom. In an atom, the numbers of protons and electrons are equal. Therefore, if the atomic number of an atom is known, both the number of protons and the electrons are also known.

2.10 The chemical identity of an atom is determined by its number of protons (atomic number). Isotopes of an element contain differing numbers of neutrons, hence the mass numbers of isotopes of an element will differ. Z is the atomic number, A is the mass number, and X represents the symbol of the element.

2.11 For iron, the atomic number Z is 26. Therefore, the mass number A is:

$$A = 26 + 28 = \textbf{54}$$

2.12 **Strategy:** The 239 in Pu-239 is the mass number. The **mass number (A)** is the total number of neutrons and protons present in the nucleus of an atom of an element. You can look up the atomic number (number of protons) on the periodic table.

Solution:

mass number = number of protons + number of neutrons

number of neutrons = mass number − number of protons = 239 − 94 = **145**

2.13

Isotope	$_2^3\text{He}$	$_2^4\text{He}$	$_{12}^{24}\text{Mg}$	$_{12}^{25}\text{Mg}$	$_{22}^{48}\text{Ti}$	$_{35}^{79}\text{Br}$	$_{78}^{195}\text{Pt}$
No. Protons	2	2	12	12	22	35	78
No. Neutrons	1	2	12	13	26	44	117

2.14

Isotope	$_7^{15}\text{N}$	$_{16}^{33}\text{S}$	$_{29}^{63}\text{Cu}$	$_{38}^{84}\text{Sr}$	$_{56}^{130}\text{Ba}$	$_{74}^{186}\text{W}$	$_{80}^{202}\text{Hg}$
No. Protons	7	16	29	38	56	74	80
No. Neutrons	8	17	34	46	74	112	122
No. Electrons	7	16	29	38	56	74	80

2.15   **(a)** $_{11}^{23}\text{Na}$ **(b)** $_{28}^{64}\text{Ni}$

2.16   The accepted way to denote the atomic number and mass number of an element X is as follows:

$$_Z^A\textbf{X}$$

where,

A = mass number
Z = atomic number

(a) $_{74}^{186}\text{W}$ **(b)** $_{80}^{201}\text{Hg}$

2.17   Elements can be grouped together according to their chemical and physical properties in a chart called the periodic table. The periodic table enables us to classify elements (as metals, metalloids, and nonmetals) and correlate their properties in a systematic way. Groups are the vertical columns of the periodic table, and periods are the horizontal rows of the table.

2.18   Metals are good conductors of heat and electricity, while nonmetals are usually poor conductors of heat and electricity. Metals, excluding mercury, are solids, whereas many nonmetals are gases.

2.19   **(a)** Hydrogen (H_2), carbon (C), oxygen (O_2), argon (Ar).
(b) Sodium (Na), titanium (Ti), tungsten (W), lead (Pb).
(c) Silicon (Si), germanium (Ge), arsenic (As), astatine (At).

2.20   Column A is the **alkali metals**. Two examples are sodium (Na) and potassium (K).
Column B is the **alkaline earth metals**. Two examples are calcium (Ca) and barium (Ba).
Column C is the **halogens**. Two examples are fluorine (F) and iodine (I).
Column D is the **noble gases**. Two examples are argon (Ar) and xenon (Xe).

2.21   Helium and Selenium are nonmetals whose name ends with *ium*. (Tellerium is a metalloid whose name ends in *ium*.)

2.22 **(a)** Metallic character increases as you progress down a group of the periodic table. For example, moving down Group 4A, the nonmetal carbon is at the top and the metal lead is at the bottom of the group.

   (b) Metallic character decreases from the left side of the table (where the metals are located) to the right side of the table (where the nonmetals are located).

2.23 The following data were measured at 20°C.

   (a) Li (0.53 g/cm^3)   K (0.86 g/cm^3) H_2O (0.98 g/cm^3)

   (b) Au (19.3 g/cm^3)   Pt (21.4 g/cm^3)   Hg (13.6 g/cm^3)

   (c) Os (22.6 g/cm^3)

   (d) Te (6.24 g/cm^3)

2.24 F and Cl are Group 7A elements; they should have similar chemical properties. Na and K are both Group 1A elements; they should have similar chemical properties. P and N are both Group 5A elements; they should have similar chemical properties.

2.25 An atom is the basic unit of an element that can enter into chemical combination. A molecule is an aggregate of at least two atoms in a definite arrangement held together by chemical forces (also called chemical bonds).

2.26 Allotropes are two or more forms of the same element that differ significantly in chemical and physical properties. Diamond and graphite are allotropes of carbon. Allotropes of an element differ in structure and properties, whereas isotopes of a given element contain different numbers of neutrons but have similar chemistries.

2.27 Two commonly used molecular models are the ball-and-stick model and the space-filling model.

2.28 **(a)** Na^+ **(b)** I^- **(c)** NH_4^+ **(d)** SO_4^{2-}

2.29 **(a)** This is a polyatomic molecule that is an elemental form of the substance. It is not a compound.
   (b) This is a polyatomic molecule that is a compound.
   (c) This is a diatomic molecule that is a compound.

2.30 **(a)** This is a diatomic molecule that is a compound.
   (b) This is a polyatomic molecule that is a compound.
   (c) This is a polyatomic molecule that is the elemental form of the substance. It is not a compound.

2.31 **Elements:** N_2, S_8, H_2
   Compounds: NH_3, NO, CO, CO_2, SO_2

2.32 There are more than two correct answers for each part of the problem.

   (a) H_2 and F_2 **(b)**   HCl and CO   **(c)** S_8 and P_4
   (d) H_2O and $C_{12}H_{22}O_{11}$ (sucrose)

2.33

Ion	Na^+	Ca^{2+}	Al^{3+}	Fe^{2+}	I^-	F^-	S^{2-}	O^{2-}	N^{3-}
No. protons	11	20	13	26	53	9	16	8	7
No. electrons	10	18	10	24	54	10	18	10	10

2.34 The **atomic number (Z)** is the number of protons in the nucleus of each atom of an element. You can find this on

a periodic table. The number of **electrons** in an *ion* is equal to the number of protons minus the charge on the ion.

number of electrons (ion) = number of protons − charge on the ion

Ion	K^+	Mg^{2+}	Fe^{3+}	Br^-	Mn^{2+}	C^{4-}	Cu^{2+}
No. protons	19	12	26	35	25	6	29
No. electrons	18	10	23	36	23	10	27

2.35 Chemical formulas express the composition of molecules and ionic compounds in terms of chemical symbols. **(a)** 1:1. **(b)** 1:3. **(c)** 1:2. **(d)** 2:3.

2.36 A molecular formula shows the exact number of atoms of each element in the smallest unit of a substance. An empirical formula shows the elements present and the simplest whole number ratio of the atoms but not necessarily the actual number of atoms in a given molecule.

2.37 Cyclobutane (C_4H_8) and cyclohexane (C_6H_{12}) have the same empirical formula (CH_2) but different molecular formulas.

2.38 P_4 signifies one molecule that is composed of four P atoms. 4P represents four atoms of P (phosphorus).

2.39 An ionic compound contains cations and anions. Electrical neutrality is maintained because the positive charge of the cations is balanced by the negative charge of the anions.

2.40 Ionic compounds do not consist of discrete molecular units but are three-dimensional networks of ions. The formula of ionic compounds represents the simplest ratio (empirical formula) in which the cation and anion combine.

2.41   **(a)** CN   **(b)** CH   **(c)** C_9H_{20} **(d)** P_2O_5 **(e)** BH_3

2.42   **Strategy:** An *empirical formula* tells us which elements are present and the *simplest* whole number ratio of their atoms. Can you divide the subscripts in the formula by some factor to end up with smaller whole number subscripts?

Solution:

(a) Dividing both subscripts by 2, the simplest whole number ratio of the atoms in Al_2Br_6 is **$AlBr_3$**.

(b) Dividing all subscripts by 2, the simplest whole number ratio of the atoms in $Na_2S_2O_4$ is **$NaSO_2$**.

(c) The molecular formula as written, **N_2O_5**, contains the simplest whole number ratio of the atoms present. In this case, the molecular formula and the empirical formula are the same.

(d) The molecular formula as written, **$K_2Cr_2O_7$**, contains the simplest whole number ratio of the atoms present. In this case, the molecular formula and the empirical formula are the same.

2.43 The molecular formula of glycine is **$C_2H_5NO_2$**.

2.44 The molecular formula of ethanol is **C_2H_6O**.

2.45 Compounds of metals with nonmetals are usually ionic. Nonmetal–nonmetal compounds are usually molecular.

Ionic: LiF, $BaCl_2$, KCl

Molecular: $SiCl_4$, B_2H_6, C_2H_4

2.46 Compounds of metals with nonmetals are usually ionic. Nonmetal–nonmetal compounds are usually molecular.

Ionic: $NaBr$, BaF_2, $CsCl$.

Molecular: CH_4, CCl_4, ICl, NF_3

2.47 **(a)** sodium chromate   **(i)** phosphorus pentafluoride
      (b) potassium hydrogen phosphate   **(j)** tetraphosphorus hexoxide
      (c) hydrogen bromide (molecular compound) **(k)** cadmium iodide
      (d) hydrobromic acid   **(l)** strontium sulfate
      (e) lithium carbonate   **(m)** aluminum hydroxide
      (f) potassium dichromate   **(n)** sodium carbonate decahydrate
      (g) ammonium nitrite   **(o)** sulfite ion
      (h) phosphorus trifluoride   **(p)** hydrogen arsenate ion

2.48 **Strategy:** When naming ionic compounds, our reference for the names of cations and anions is Table 2.3 of the text. Ions not listed in Table 2.3 can often be named by extension of the name of analogous ions in the same family; for example, because ClO_3^- is chlorate, BrO_3^- is named bromate. Keep in mind that if a metal can form cations of different charges, we need to use the Stock system. In the Stock system, Roman numerals are used to specify the charge of the cation. The metals that have only one charge in ionic compounds are the alkali metals (+1), the alkaline earth metals (+2), Ag^+, Zn^{2+}, Cd^{2+}, and Al^{3+}.

When naming acids, binary acids are named differently than oxoacids. For binary acids, the name is based on the nonmetal. For oxoacids, the name is based on the polyatomic anion. For more detail, see Section 2.7 of the text.

Solution:

(a) This is an ionic compound in which the metal cation (K^+) has only one charge. The correct name is **potassium hypochlorite**. Hypochlorite is a polyatomic ion with one less O atom than the chlorite ion, ClO_2^-

(b) **silver carbonate**

(c) This is an ionic compound in which the metal can form more than one cation. Use a Roman numeral to specify the charge of the Fe ion. Since each chloride ion has a −1 charge, the Fe ion has a +2 charge. The correct name is **iron(II) chloride**.

(d) **potassium permanganate**   **(e)** **cesium chlorate**   **(f)** **hypoiodous acid**

(g) This is an ionic compound in which the metal can form more than one cation. Use a Roman numeral to specify the charge of the Fe ion. Since the oxide ion has a −2 charge, the Fe ion has a +2 charge. The correct name is **iron(II) oxide**.

(h) **iron(III) oxide**

(i) This is an ionic compound in which the metal can form more than one cation. Use a Roman numeral to specify the charge of the Ti ion. Since each of the four chloride ions has a −1 charge (total of −4), the Ti ion has a +4 charge. The correct name is **titanium(IV) chloride**.

(j) **sodium hydride**   **(k)** **lithium nitride**   **(l)** **sodium oxide**

(m) This is an ionic compound in which the metal cation (Na^+) has only one charge. The O_2^{2-} ion is called the peroxide ion. Each oxygen has a −1 charge. You can determine that each oxygen only has a −1 charge, because each of the two Na ions has a +1 charge. Compare this to sodium oxide in part (l). The correct name is **sodium peroxide**.

(n) This is an ionic compound in which the metal can form more than one cation. Use a Roman numeral to specify the charge of the Fe ion. Since each chloride ion has a −1 charge, the Fe ion has a +3 charge. At the end of the name, we add hexahydrate for the six waters of hydration. The correct name is **iron(III) chloride hexahydrate**.

(o)   The phosphate ion is PO_4^{3-} , and arsenic is in the same family as phosphorus, so AsO_4^{3-} is the **arsenate ion**.

(p) HSO_3^- is formed by adding a hydrogen ion (H^+) to the sulfite ion (SO_3^{2-}), so the ion is named **hydrogen sulfite**.

2.49   **(a)** $RbNO_2$ **(b)** K_2S **(c)** $HBrO_4$ **(d)** $Mg_3(PO_4)_2$ **(e)** $CaHPO_4$
       (f) BCl_3 **(g)** IF_7 **(h)** $(NH_4)_2SO_4$ **(i)** $AgClO_4$ **(j)** $Fe_2(CrO_4)_3$
       (k) $CaSO_4 \cdot 2H_2O$

2.50   **Strategy:** When writing formulas of molecular compounds, the prefixes specify the number of each type of atom in the compound.

When writing formulas of ionic compounds, the subscript of the cation is numerically equal to the charge of the anion, and the subscript of the anion is numerically equal to the charge on the cation. If the charges of the cation and anion are numerically equal, then no subscripts are necessary. Charges of common cations and anions are listed in Table 2.3 of the text. Keep in mind that Roman numerals specify the charge of the cation *not* the number of metal atoms. Remember that a Roman numeral is not needed for some metal cations, because the charge is known. These metals are the alkali metals (+1), the alkaline earth metals (+2), Ag^+, Zn^{2+}, Cd^{2+}, and Al^{3+}.

When writing formulas of oxoacids, you must know the names and formulas of polyatomic anions (see Table 2.3 of the text).

Solution:

(a)   The Roman numeral I tells you that the Cu cation has a +1 charge. Cyanide has a −1 charge. Since, the charges are numerically equal, no subscripts are necessary in the formula. The correct formula is **CuCN**.

(b)   Strontium is an alkaline earth metal. It only forms a +2 cation. The polyatomic ion chlorite, ClO_2^-, has a −1 charge. Since the charges on the cation and anion are numerically different, the subscript of the cation is numerically equal to the charge on the anion, and the subscript of the anion is numerically equal to the charge on the cation. The correct formula is **Sr(ClO2)2**.

(c)   Perchloric tells you that the anion of this oxoacid is perchlorate, ClO_4^-. The correct formula is **HClO4(*aq*)**. Remember that (*aq*) means that the substance is dissolved in water.

(d)   Hydroiodic tells you that the anion of this binary acid is iodide, I^-. The correct formula is **HI(*aq*)**.

(e)   Na is an alkali metal. It only forms a +1 cation. The polyatomic ion ammonium, NH_4^+, has a +1 charge and the polyatomic ion phosphate, PO_4^{3-}, has a −3 charge. To balance the charge, you need 2 Na^+ cations. The correct formula is **Na2(NH4)PO4**.

(f)   The Roman numeral II tells you that the Pb cation has a +2 charge. The polyatomic ion carbonate, CO_3^{2-}, has a −2 charge. Since, the charges are numerically equal, no subscripts are necessary in the formula. The correct formula is **PbCO3**.

(g)   The Roman numeral II tells you that the Sn cation has a +2 charge. Fluoride has a −1 charge. Since the charges on the cation and anion are numerically different, the subscript of the cation is numerically equal to the charge on the anion, and the subscript of the anion is numerically equal to the charge on the cation. The correct formula is **SnF2**.

(h)   This is a molecular compound. The Greek prefixes tell you the number of each type of atom in the molecule. The correct formula is **P4S10**.

(i)   The Roman numeral II tells you that the Hg cation has a +2 charge. Oxide has a −2 charge. Since, the charges are numerically equal, no subscripts are necessary in the formula. The correct formula is **HgO**.

(j)   The Roman numeral I tells you that the Hg cation has a +1 charge. However, this cation exists as Hg_2^{2+}. Iodide has a −1 charge. You need two iodide ions to balance the +2 charge of Hg_2^{2+}. The correct formula is **Hg2I2**.

(k) The Roman numeral II tells you that the Co cation has a +2 charge. Chloride has a −1 charge. Since the charges on the cation and anion are numerically different, the subscript of the cation is numerically equal to the charge on the anion, and the subscript of the anion is numerically equal to the charge on the cation. We add $6H_2O$ at the end of the formula for the six waters of hydration. The correct formula is **$CoCl_2 \cdot 6H_2O$**.

2.51 The number of protons = 65 − 35 = 30. The element that contains 30 protons is zinc, Zn. There are two fewer electrons than protons, so the charge of the cation is +2. The symbol for this cation is **Zn^{2+}**.

2.52 Changing the electrical charge of an atom usually has a major effect on its chemical properties. The two electrically neutral carbon isotopes should have nearly identical chemical properties; that is **(c)**.

2.53 **(a)** Species with the same number of protons and electrons will be neutral. **A, F, G**.
  (b) Species with more electrons than protons will have a negative charge. **B, E**.
  (c) Species with more protons than electrons will have a positive charge. **C, D**.
  (d) A: $^{10}_{5}B$ B: $^{14}_{7}N^{3-}$ C: $^{39}_{19}K^{+}$ D: $^{66}_{30}Zn^{2+}$ E: $^{81}_{35}Br^{-}$ F: $^{11}_{5}B$ G: $^{19}_{9}F$

2.54 **(a)** Does this refer to hydrogen atoms or hydrogen molecules? One cannot be sure.
  (b) NaCl is an ionic compound; it does not form molecules.

2.55 **Yes**. The law of multiple proportions requires that the masses of sulfur combining with phosphorus must be in the ratios of small whole numbers. For the three compounds shown, four phosphorus atoms combine with three, seven, and ten sulfur atoms, respectively. If the atom ratios are in small whole number ratios, then the mass ratios must also be in small whole number ratios.

2.56 The species and their identification are as follows:

  (a) SO_2 molecule and compound   **(g)** O_3 element and molecule
  (b) S_8 element and molecule   **(h)** CH_4 molecule and compound
  (c) Cs   element   **(i)** KBr   compound
  (d) N_2O_5 molecule and compound   **(j)** S   element
  (e) O   element   **(k)** P_4 element and molecule
  (f) O_2 element and molecule   **(l)** LiF   compound

2.57 **(a)** molecular, C_3H_8 **(b)** molecular, C_2H_2 **(c)** molecular, C_2H_6 **(d)** molecular, C_6H_6
      empirical, C_3H_8 empirical, CH   empirical, CH_3 empirical, CH

2.58 **(a)** CO_2 (*s*), solid carbon dioxide   **(e)** CaO, calcium oxide
  (b) NaCl, sodium chloride   **(f)** $Ca(OH)_2$, calcium hydroxide
  (c) N_2O, nitrous oxide   **(g)** $NaHCO_3$, sodium bicarbonate
  (d) $CaCO_3$, calcium carbonate   **(h)** $Mg(OH)_2$, magnesium hydroxide

2.59

Symbol	$^{11}_{5}B$	$^{54}_{26}Fe^{2+}$	$^{31}_{15}P^{3-}$	$^{196}_{79}Au$	$^{222}_{86}Rn$
Protons	5	26	15	79	86
Neutrons	6	28	16	117	136
Electrons	5	24	18	79	86
Net Charge	0	+2	−3	0	0

2.60 **(a)** Ionic compounds are typically formed between metallic (especially Groups 1A, 2A, and aluminum) and nonmetallic elements.

(b)   In general the transition metals, the actinides and lanthanides have variable charges.

2.61   Group 1A metals form M^+ ions. Group 2A metals form Y^{2+} ions. Aluminum forms an Al^{3+} ion. Oxygen forms an O^{2-} ion (oxide). Nitrogen forms an N^{3-} ion (nitride), and the halogens form X^- ions. Making a table:

Nonmetals	1A Metals	2A Metals	Aluminum
Halogens	MX	YX_2	AlX_3
Oxygen	M_2O	YO	Al_2O_3
Nitrogen	M_3N	Y_3N_2	AlN

2.62   The symbol ^{23}Na provides more information than $_{11}Na$. The mass number plus the chemical symbol identifies a specific isotope of Na (sodium), while combining the atomic number with the chemical symbol tells you nothing new. Can other isotopes of sodium have different atomic numbers?

2.63   The binary Group 7A element acids are HF, hydrofluoric acid; HCl, hydrochloric acid; HBr, hydrobromic acid; and HI, hydroiodic acid. Oxoacids containing Group 7A elements (using the specific examples for chlorine) are $HClO_4$, perchloric acid; $HClO_3$, chloric acid; $HClO_2$, chlorous acid; and HClO, hypochlorous acid.

Examples of oxoacids containing other Group A-block elements are H_3BO_3, boric acid (Group 3A); H_2CO_3, carbonic acid (Group 4A); HNO_3, nitric acid; H_3PO_4, phosphoric acid (Group 5A); and H_2SO_4, sulfuric acid (Group 6A). Hydrosulfuric acid, H_2S, is an example of a binary Group 6A acid while HCN, hydrocyanic acid, contains both a Group 4A and 5A element.

2.64

Isotope:	^{40}Mg	^{44}Si	^{48}Ca	^{43}Al
No. Neutrons:	**28**	**30**	**28**	**30**

2.65   F and Cl are Group 7A elements; they should have similar chemical properties. Na and K are both Group 1A elements; they should have similar chemical properties. P and N are both Group 5A elements; they should have similar chemical properties.

**2.66** H_2, N_2, O_2, F_2, Cl_2, He, Ne, Ar, Kr, Xe, Rn

2.67   Cu, Ag, and Au are fairly chemically unreactive. This makes them specifically suitable for making coins and jewelry, which you want to last a very long time.

2.68   They do not have a strong tendency to form compounds. Helium and neon are chemically inert.
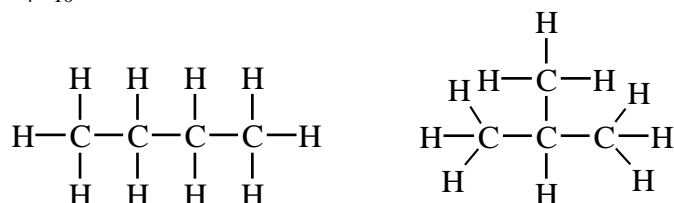
2.69   **(a)**   dinitrogen pentoxide (N_2O_5)
     (b)   boron trifluoride (BF_3)
     (c)   dialuminum hexabromide (Al_2Br_6)

2.70   The empirical and molecular formulas of acetaminophen are **$C_8H_9NO_2$**.
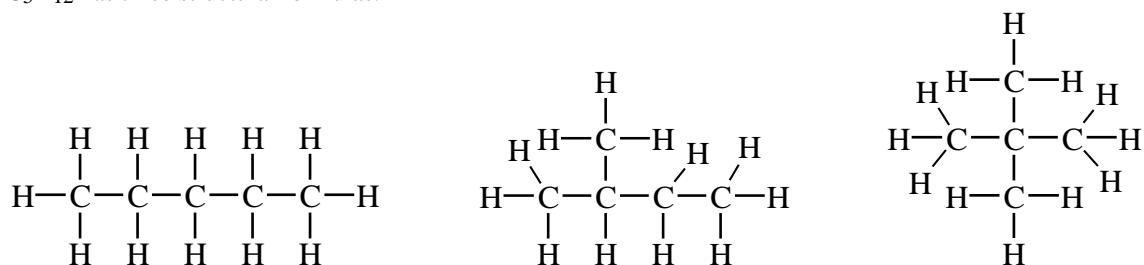
2.71 CH_4, C_2H_6, and C_3H_8 each only have one structural formula.
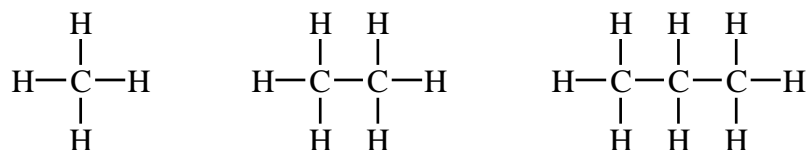
C_4H_{10} has two structural formulas.

C_5H_{12} has three structural formulas.

2.72 **(a)** The following strategy can be used to convert from the volume of the Pt cube to the number of Pt atoms.

$cm^3 \rightarrow$ grams $\rightarrow$ atoms

$$1.0 \ cm^3 \times \frac{21.45 \ g \ Pt}{1 \ cm^3} \times \frac{1 \ atom \ Pt}{3.240 \times 10^{-22} \ g \ Pt} = \textbf{6.6} \times \textbf{10}^{22} \textbf{ Pt atoms}$$

(b) Since 74% of the available space is taken up by Pt atoms, 6.6×10^{22} atoms occupy the following volume:

$0.74 \times 1.0 \ cm^3 = 0.74 \ cm^3$

We are trying to calculate the radius of a single Pt atom, so we need the volume occupied by a single Pt atom.

$$\text{volume Pt atom} = \frac{0.74 \ cm^3}{6.6 \times 10^{22} \ Pt \ atoms} = 1.12 \times 10^{-23} \ cm^3/Pt \ atom$$

The volume of a sphere is $\frac{4}{3}\pi r^3$. Solving for the radius:

$V = 1.12 \times 10^{-23} \ cm^3 = \frac{4}{3}\pi r^3$

$r^3 = 2.67 \times 10^{-24} \ cm^3$

$r = 1.4 \times 10^{-8} \ cm$

Converting to picometers:

$$\textbf{radius Pt atom} = (1.4 \times 10^{-8} \ cm) \times \frac{0.01 \ m}{1 \ cm} \times \frac{1 \ pm}{1 \times 10^{-12} \ m} = \textbf{1.4} \times \textbf{10}^{2} \textbf{ pm}$$

2.73

Cation	Anion	Formula	Name

Mg^{2+}	HCO_3^-	$Mg(HCO_3)_2$	Magnesium bicarbonate
Sr^{2+}	Cl^-	$SrCl_2$	**Strontium chloride**
Fe^{3+}	NO_2^-	$Fe(NO_2)_3$	**Iron(III) nitrite**
Mn^{2+}	ClO_3^-	$Mn(ClO_3)_2$	Manganese(II) chlorate
Sn^{4+}	Br^-	$SnBr_4$	**Tin(IV) bromide**
Co^{2+}	PO_4^{3-}	$Co_3(PO_4)_2$	**Cobalt(II) phosphate**
Hg_2^{2+}	I^-	Hg_2I_2	**Mercury(I) iodide**
Cu^+	CO_3^{2-}	Cu_2CO_3	**Copper(I) carbonate**
Li^+	N^{3-}	Li_3N	Lithium nitride
Al^{3+}	S^{2-}	Al_2S_3	**Aluminum sulfide**

2.74   **(a)**   Br   **(b)**   Rn   **(c)**   Se   **(d)**   Rb   **(e)**   Pb

2.75   From left to right: NF_3, nitrogen trifluoride; PBr_5, phosphorus pentabromide; and SCl_2, sulfur dichloride.

2.76   The change in energy is equal to the energy released. We call this ΔE. Similarly, Δm is the change in mass. Because $m = \dfrac{E}{c^2}$, we have

$$\Delta m = \frac{\Delta E}{c^2} = \frac{(1.715 \times 10^3 \text{ kJ}) \times \dfrac{1000 \text{ J}}{1 \text{ kJ}}}{(3.00 \times 10^8 \text{ m/s})^2} = 1.91 \times 10^{-11} \text{ kg} = \mathbf{1.91 \times 10^{-8} \text{ g}}$$

Note that we need to convert kJ to J so that we end up with units of kg for the mass. $\left(1 \text{ J} = \dfrac{1 \text{ kg} \cdot \text{m}^2}{\text{s}^2}\right)$

We can add together the masses of hydrogen and oxygen to calculate the mass of water that should be formed.

12.096 g + 96.000 = 108.096 g

The predicted change (loss) in mass is only 1.91×10^{-8} g, which is too small a quantity to measure accurately. Therefore, for all practical purposes, the law of conservation of mass is assumed to hold for ordinary chemical processes.

2.77   **(a)**   Rutherford's experiment is described in detail in Section 2.2 of the text. From the average magnitude of scattering, Rutherford estimated the number of protons (based on electrostatic interactions) in the nucleus.

(b)   Assuming that the nucleus is spherical, the volume of the nucleus is:

$$V = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi(3.04 \times 10^{-13} \text{ cm})^3 = 1.18 \times 10^{-37} \text{ cm}^3$$

The density of the nucleus can now be calculated.

$$d = \frac{m}{V} = \frac{3.82 \times 10^{-23} \text{ g}}{1.18 \times 10^{-37} \text{ cm}^3} = \mathbf{3.24 \times 10^{14} \text{ g/cm}^3}$$

To calculate the density of the space occupied by the electrons, we need both the mass of 11 electrons and the volume occupied by these electrons.

The mass of 11 electrons is:

$$11 \text{ electrons} \times \frac{9.1095 \times 10^{-28} \text{ g}}{1 \text{ electron}} = 1.0020 \times 10^{-26} \text{ g}$$

The volume occupied by the electrons will be the difference between the volume of the atom and the volume of the nucleus. The volume of the nucleus was calculated above. The volume of the atom is calculated as follows:

$$186 \text{ pm} \times \frac{1 \times 10^{-12} \text{ m}}{1 \text{ pm}} \times \frac{1 \text{ cm}}{1 \times 10^{-2} \text{ m}} = 1.86 \times 10^{-8} \text{ cm}$$

$$V_{\text{atom}} = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi(1.86 \times 10^{-8} \text{ cm})^3 = 2.70 \times 10^{-23} \text{ cm}^3$$

$$V_{\text{electrons}} = V_{\text{atom}} - V_{\text{nucleus}} = (2.70 \times 10^{-23} \text{ cm}^3) - (1.18 \times 10^{-37} \text{ cm}^3) = 2.70 \times 10^{-23} \text{ cm}^3$$

As you can see, the volume occupied by the nucleus is insignificant compared to the space occupied by the electrons.

The density of the space occupied by the electrons can now be calculated.

$$d = \frac{m}{V} = \frac{1.0020 \times 10^{-26} \text{ g}}{2.70 \times 10^{-23} \text{ cm}^3} = \mathbf{3.71 \times 10^{-4} \text{ g/cm}^3}$$

The above results do support Rutherford's model. Comparing the space occupied by the electrons to the volume of the nucleus, it is clear that most of the atom is empty space. Rutherford also proposed that the nucleus was a *dense* central core with most of the mass of the atom concentrated in it. Comparing the density of the nucleus with the density of the space occupied by the electrons also supports Rutherford's model.

2.78   The formula of the ionic compound is **XY₂**. Element X is most likely in Group 4B and element Y is most likely in Group 6A. A possible compound is TiO_2, **titanium(IV) oxide**. Other choices are elements in Group 4A: SnO_2 [tin(IV) oxide] and PbO_2 [lead(IV) oxide].

2.79   Two different structural formulas for the molecular formula C_2H_6O are:
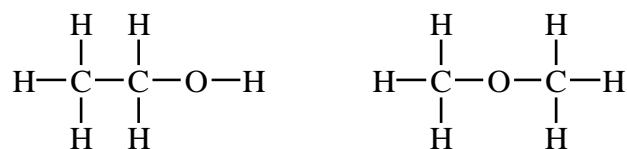
In the second hypothesis of Dalton's Atomic Theory, he states that in any compound, the ratio of the number of atoms of any two of the elements present is either an integer or a simple fraction. In the above two compounds, the ratio of atoms is the same. This does not necessarily contradict Dalton's hypothesis, but Dalton was not aware of chemical bond formation and structural formulas.

2.80   The diameter of a pea is about 0.5 cm, and the radius of the nucleus is about 5×10^{-13} cm. Therefore, the expansion factor for the radius of the nucleus is

$$\frac{0.5 \text{ cm} / 2}{5 \times 10^{-13} \text{ cm}} = 5 \times 10^{11} \text{ times}$$

A typical atom has a radius of about 100 pm (10^{-8} cm). Using that value as the distance of the electron from the

nucleus in an atom, then if the atom was scaled to the size of a pea, the electron would be $(1 \times 10^{-8}$ cm$) \times (5 \times 10^{11}) = 5 \times 10^3$ cm or **50 m** (roughly half a football field) from the nucleus!

2.81   Over long periods of time (on a geological scale), minerals containing potassium and sodium are slowly decomposed by wind and rain, and their K^+ and Na^+ ions are converted to more soluble compounds. Eventually, rain leaches these compounds out of the soil and carries them to the sea. Plants take up many of the K^+ ions along the way, while the Na^+ ions are free to move on to the sea because they are not needed for biological functions by the plants.

2.82   The acids, from left to right, are **chloric acid**, **nitrous acid**, **hydrocyanic acid**, and **sulfuric acid**.

ANSWERS TO REVIEW OF CONCEPTS

Section 2.1 (p. 31)   **Yes**, the ratio of atoms represented by B that combine with A in these two compounds is (2/1):(5/2) or 4:5.

Section 2.2 (p. 36)   The proton and neutron have approximately the same mass.

Section 2.3 (p. 37)   **(a)** **78**. **(b)**^{17}**O**.

Section 2.4 (p. 39)   Chemical properties change more markedly across a **period**.

Section 2.5 (p. 40)   **(a)** S_8 signifies one molecule of sulfur that is composed of 8 sulfur atoms. 8S represents 8 individual atoms of sulfur.
   (b) (a) 15 protons, 18 electrons.
      (b) 22 protons, 18 electrons.

Section 2.6 (p. 45)   **(a)** $Mg(NO_3)_2$ **(b)** Al_2O_3 **(c)** LiH   **(d)** Na_2S.

Section 2.7 (p. 52)   **(a)** Aluminum sulfide   **(b)** IF_7

Section 2.8 (p. 53)   **Two**.