Solutions for Chemistry for Engineering Students 4th Edition by Brown

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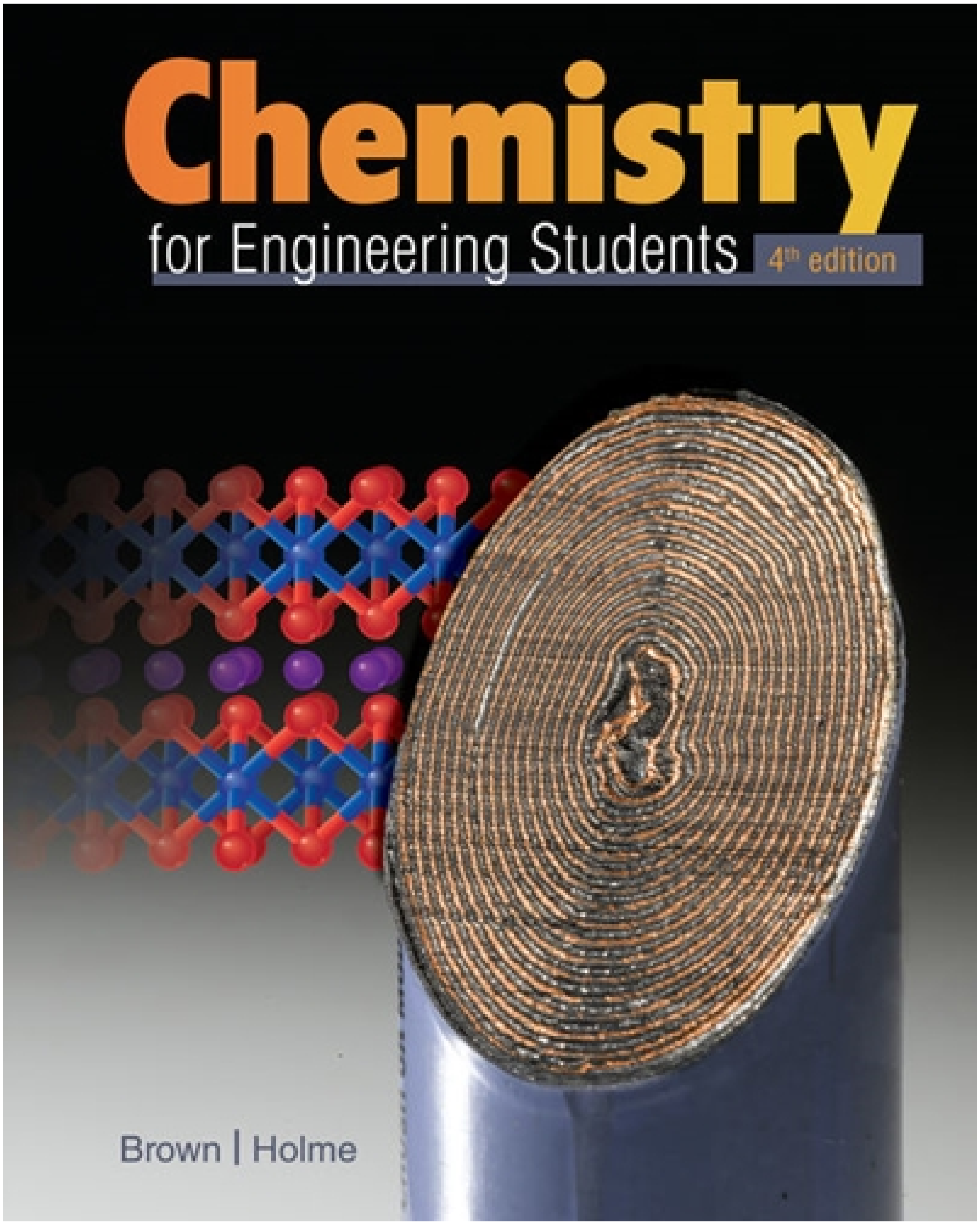


Solutions

Chapter 2

Atoms and Molecules

INSIGHT Polymers

2.1 Define the terms *polymer* and *monomer* in your own words.

A polymer is a large molecule made up of many small repeating units of atoms, called monomers, bonded together. A monomer is a small, unique group of atoms which can be bonded together many times to produce a large molecule (polymer) made from a repeating unit of atoms.

2.2 How do polymers compare to their respective monomers?

Polymers are simply "chains" of their respective monomers.

2.3 Look around you and identify several objects that you think are probably made from polymers.

Answers will vary. Some possible responses include clothes, carpet fibers, a calculator case, soda bottles, etc.

2.4 Which one element forms the backbone of nearly all common polymers? What other elements are also found in conductive polyacetylene?

Carbon tends to form the backbone of all common polymers. Small amounts of iodine and bromine are added to polyacetylene to make it more conductive. This process is called doping.

2.5 The fact that a polymer's physical properties depend on its atomic composition is very important in making these materials so useful. Why do you think this would be so?

Different monomers have different physical properties, because they are made with different combinations of atoms. By making polymers with different monomers, a scientist can design a polymer for a specific purpose.

2.6 One application of conductive polymers is in photovoltaic solar cells. Such devices have traditionally been silicon based. What possible advantages might conducting polymers offer?

The conducting polymers offer considerable cost savings for both materials and processing as opposed to traditional silicon-based photoactive materials.

2.7 Most polymers have densities slightly less than 1 g/cm^3. How does this compare to the densities of metals as shown in Figure 2.11? What does this comparison imply for devices in which conducting polymers might replace metal wires or other components?

The densities of the metals are much higher. Most of the metals have densities much greater than 5000 kg/m^3, compared to a polymer that would have a density of around 1000 kg/m^3. This implies that devices using conducting polymers instead of metal wires would be considerably lighter.

Atomic Structure and Mass

2.8 In a typical illustration of the atom such as Figure 2.3, which features lead to misunderstandings about the structure of atoms? Which ones give important insight?

The depiction of the electrons moving around the nucleus in perfect circles does nothing to address the fact that the electron's position is described by a wave function. Another large shortcoming is that there is no information conveyed as to the true geometric shape of the atomic orbitals. The positioning of the rings does represent the "size" of orbitals increasing with increasing principal quantum number *n*. The model does accurately separate the nucleus and the electrons of the atom.

2.9 Why is the number of protons called the atomic number?

Each different element has a unique number of protons in its nucleus that distinguishes it from other elements. Therefore, that "atomic" number can identify an atom. The number of neutrons in the nucleus is not unique nor is the number of electrons, if ions are included.

2.10 Which isotope in each pair contains more neutrons?

(a) chlorine-35 or sulfur-33, **(b)** fluorine-19 or neon-19,
(c) copper-63 or zinc-65, **(d)** iodine-126 or tellurium-127

(a) chlorine-35, (b) fluorine-19, (c) zinc-65, (d) tellurium-127

2.11 Define the term *isotope*.

Isotopes are different atomic forms of an element that have different numbers of neutrons in the nucleus.

2.12 Write the complete atomic symbol for each of the following isotopes. **(a)** carbon-13 **(b)** phosphorus-31 **(c)** sodium-23 **(d)** boron-10

(a) $^{13}_{6}C$, **(b)** $^{31}_{15}P$, **(c)** $^{23}_{11}Na$, **(d)** $^{10}_{5}B$

2.13 How many electrons, protons, and neutrons are there in each of the following atoms?

a. magnesium−24, ^{24}Mg	**12 electrons, 12 protons, 24 – 12 = 12 neutrons**
b. tin−119, ^{119}Sn	**50 electrons, 50 protons, 119 – 50 = 69 neutrons**
c. thorium−232, ^{232}Th	**90 electrons, 90 protons, 232 – 90 = 142 neutrons**
d. carbon−13, ^{13}C	**6 electrons, 6 protons, 13 – 6 = 7 neutrons**

e. copper−63, ^{63}Cu **29 electrons, 29 protons, 63 – 29 = 34 neutrons**
f. bismuth−205, ^{205}Bi **83 electrons, 83 protons, 205 – 83 = 122 neutrons**

The atomic number of the element gives the number of protons. This will equal the number of electrons in a neutral atom. The mass number is the sum of protons and neutrons; so subtracting the atomic number from the mass number gives the number of neutrons.

2.14 Consider the following nuclear symbols. How many protons, neutrons, and electrons does each element have? What elements do R, T, and X represent?

(a) $^{30}_{14}R$ **(b)** $^{89}_{39}T$ **(c)** $^{133}_{55}X$

(a) $^{30}_{14}R$ has 14 protons, 14 electrons, and 16 neutrons; R represents silicon, Si

(b) $^{89}_{39}T$ has 39 protons, 39 electrons, and 50 neutrons; T represents yttrium, Y

(c) $^{133}_{55}X$ has 55 protons, 55 electrons, and 78 neutrons; X represents cesium, Cs

2.15 Mercury is 16.716 times more massive than ^{12}C. What is the atomic weight of mercury? Remember to express your answer with the correct number of significant figures.

The mass of a ^{12}C atom is *exactly* 12 atomic mass units (amu). The mass of a mercury atom is 16.716 × 12 amu = 200.59 amu (rounded to 5 significant digits)

2.16 The element gallium, used in gallium arsenide semiconductors, has an atomic weight of 69.72 amu. There are only two isotopes of gallium, ^{69}Ga with a mass of 68.9257 amu and ^{71}Ga with a mass of 70.9249 amu. What are the isotopic abundances of gallium?

60.3% ^{69}Ga and 39.7% ^{71}Ga

2.17 The atomic weight of copper is 63.55 amu. There are only two isotopes of copper, ^{63}Cu with a mass of 62.93 amu and ^{65}Cu with a mass of 64.93 amu. What is the percentage abundance for each of these two isotopes?

Since there are only two isotopes, the percent abundance must sum to 100, and their fractions must sum to one. We can let X = the fraction of ^{63}Cu and (1 – X) = the fraction of ^{65}Cu. The given atomic mass of copper is the weighted average of the two isotopes. To calculate the "weighted" average mass of copper, we convert each percentage into a fraction, multiply each fraction by the mass of that isotope, and add them together.

X (mass of ^{63}Cu) + (1 – X) (mass of ^{65}Cu) = 63.55 amu (weighted average mass of copper)
X (62.93 amu) + (1 – X) (64.93 amu) = 63.55 amu
62.93 X amu + 64.93 amu – 64.93 X amu = 63.55 amu

$$1.38 \text{ amu} = 2.00\, X \text{ amu} \quad \rightarrow \quad X = \frac{1.38 \text{ amu}}{2.00 \text{ amu}} = 0.690$$

Therefore the percentage of ^{63}Cu is 69.0%.
The percentage of ^{65}Cu is 100% – 69.0% = 31.0%

2.18 The following table presents the abundances and masses of the isotopes of zinc. What is the atomic weight of zinc?

Isotope	Abundance	Mass
^{64}Zn	48.6%	63.9291 amu
^{66}Zn	27.9%	65.9260 amu
^{67}Zn	4.10%	66.9271 amu
^{68}Zn	18.8%	67.9249 amu
^{70}Zn	0.60%	69.9253 amu

65.40 amu

2.19 Naturally occurring uranium consists of two isotopes, whose masses and abundances are shown below.

Isotope	Abundance	Mass
^{235}U	0.720%	235.044 amu
^{238}U	99.275%	238.051 amu

Only ^{235}U can be used as fuel in a nuclear reactor, so uranium for use in the nuclear industry must be enriched in this isotope. If a sample of enriched uranium has an average atomic mass of 235.684 amu, what percentage of ^{235}U is present?

The percent abundances in the enriched sample are different from above, but they must still sum to 100% and the isotopic masses are still the same. We can let X = the fraction of ^{235}U and (1 – X) = the fraction of ^{238}U. The given average atomic mass of uranium is the weighted average of the two isotopes. To calculate a "weighted" average mass of uranium, we convert each percentage into a fraction, multiply each fraction by the mass of that isotope, and add them together.

X (mass of ^{235}U) + (1 – X) (mass of ^{238}U) = 235.684 amu (weighted average mass of uranium)
X (235.044 amu) + (1 – X) (238.051 amu) = 235.684 amu

235.044X amu + 238.051 amu – 238.051X amu = 235.684 amu

$$2.367 \text{ amu} = 3.007X \text{ amu} \quad \rightarrow \quad X = \frac{2.367 \text{ amu}}{3.007 \text{ amu}} = 0.7872$$

Therefore the percentage of ^{235}U is 78.72%.

Ions

2.20 Define the term *ion* in your own words.

An ion is an atom or group of atoms that has gained or lost one or more electrons, acquiring a negative or positive electrical charge, respectively.

2.21 What is the difference between cations and anions?

A cation is an atom or group of atoms that have *lost* one or more electrons, making them positively charged. Anions are atoms or groups of atoms that have *gained* one or more electrons, making them negatively charged.

2.22 Provide the symbol of the following monoatomic ions, given the number of protons and electrons in each.

(a) 8 protons, 10 electrons **ANS** $\mathbf{O^{2-}}$
(b) 20 protons, 18 electrons **ANS** $\mathbf{Ca^{2+}}$
(c) 53 protons, 54 electrons **ANS** $\mathbf{I^{-}}$
(d) 26 protons, 24 electrons **ANS** $\mathbf{Fe^{2+}}$

2.23 How many protons and electrons are in each of the following ions?

(a) Na^{+}	**Atomic number = 11,**	**11 protons; 11 – 1 = 10 electrons**
(b) Al^{3+}	**Atomic number = 13,**	**13 protons; 13 – 3 = 10 electrons**
(c) S^{2-}	**Atomic number = 16,**	**16 protons; 16 + 2 = 18 electrons**
(d) Br^{-}	**Atomic number = 35,**	**35 protons; 35 + 1 = 36 electrons**

The atomic number will give the number of protons for the ion. The charge of the ion indicates how many electrons were gained or lost. A positive charge means electrons (negative) were lost, a negative charge means electrons were gained. Subtract the charge number from the atomic number to get the number of electrons in a cation, or add the charge number to the atomic number to get the number of electrons in an anion.

2.24 Identify each of the following species as an anion, a cation, or a molecule.

(a) CO_3^{2-} **(b)** CO_2 **(c)** NH_4^{+} **(d)** N^{3-} **(e)** CH_3COO^{-}

(a) anion, (b) molecule, (c) cation, (d) anion, (e) anion

2.25 Write the atomic symbol for the element whose ion has a 2− charge, has 20 more neutrons than electrons, and has a mass number of 126.

We'll use the symbols p, n, and e for the number of protons, neutrons and electrons.
The mass number, 126 = p + n. The neutrons outnumber the electrons by 20, n = e + 20.
And because of the 2− charge, there are two more electrons than protons, e = p + 2.
Substituting, 126 = (e − 2) + (e + 20), 126 = 2e + 18, e = 54
Thus, p = 54 – 2 = 52
Therefore the atomic number is 52, making this the telluride ion, $\mathbf{{}^{126}_{52}Te^{2-}}$.

2.26 In what region of the periodic table are you likely to find elements that form more than one stable ion?

Transition elements tend to have multiple oxidation states.

2.27 Give the symbol, including the correct charge, for each of the following ions.

(a) barium ion, **Ba^{2+},** **(b)** titanium(IV) ion, **Ti^{4+}**, **(c)** phosphate ion, **PO_4^{3-}** ,
(d) hydrogen carbonate ion, **HCO_3^-**, **(e)** sulfide ion, **S^{2-}**, **(f)** perchlorate ion, **ClO_4^-**,
(g) cobalt(II) ion, **Co^{2+}**, **(h)** sulfate ion, **SO_4^{2-}**.

2.28 An engineer is designing a water-softening unit based on ion exchange. Use the web to learn what ions typically are "exchanged" in such a system. Given that the ion exchanger cannot build up a large positive charge, what can you conclude about the relative numbers of the various ions involved?

Use a World Wide Web search engine to find the requested information. One may conclude that the relative numbers of positive and negative ions are equal.

2.29 Use the web to find a catalyst for a polymerization reaction that uses an ion. What are the apparent advantages of using this catalyst for creating the polymer?

Answers will vary. One such catalyst used in ionic polymerization is butyl-lithium. This substance decomposes into a lithium ion (1+ charge) and a butyl ion (1− charge). One advantage of ionic polymerization is that the polymer formed is easier to process further to produce desirable properties.

2.30 Using Coulomb's law, explain how the difference between attractive and repulsive interactions between ions is expressed mathematically.

Coulomb's law states that as the magnitude of the charges increases, so does the force between the two ions. The law also holds that the magnitude of the force is inversely proportional to the distance between the two charges. $F = \dfrac{q_1q_2}{4\pi\varepsilon_0 r^2}$, where *q* represents the magnitude of charge and *r* represents the distance between ions.

Compounds and Chemical Bonds

2.31 How many atoms of each element are represented in the formula, $Ba(OH)_2$?

Subscripts give the numbers of atoms present in the formula. Subscripts outside parenthesis mean all atoms inside are multiplied by that number.
In one formula unit of $Ba(OH)_2$, there are one Ba atom, two O atoms, and two H atoms.

2.32 Which of the following formulas contains the most hydrogen atoms? C_2H_6, $(NH_4)_2CO_3$, H_2SO_4, or $Fe(OH)_3$

$(NH_4)_2CO_3$ shows eight hydrogen atoms.

2.33 When talking about the formula for an ionic compound, why do we typically refer to a formula unit rather than a molecule?

Molecules are discrete groups of neutral atoms bonded together with covalent bonds. An ionic compound is not made of discrete units but large collections of cations and anions held together with electrostatic attractive forces (ionic bonds). Because ionic compounds are not made of molecules, it is incorrect to refer to them with the term "molecule". The smallest ratio of these ions that gives a neutral formula is called the "formula unit" of the compound.

2.34 Which formula below is the correct one for an ionic compound? What is incorrect about each of the others? **(a)** $AlO_{3/2}$ **(b)** Ca_2Br_4 **(c)** $Mg(PO_4)_{3/2}$ **(d)** $BaCO_3$

(a) Incorrect because the number of atoms in a single molecule or formula unit must be an integer.
(b) Incorrect because Ca reacts in a one: two ratio with Br atoms to form the ionic compound $CaBr_2$.
(c) Incorrect because the number of atoms in a single molecule or formula unit must be an integer.
(d) This is the correct formula for an ionic compound.

2.35 Explain the difference between ionic and metallic bonding.

In ionic bonding, electrons are transferred from one atom to another, creating positive cations and negative anions. These are attracted to each other with electrostatic forces, and they form a large array in a particular lattice structure. In metallic bonding, metal atoms release some of their electrons (outer ones) to form a common pool of electrons, shared by all the atoms. The positive metal atom cores are attracted to this "mobile sea of electrons" and are held together in some particular lattice arrangement.

2.36 Explain the difference between a molecular formula and an empirical formula.

An empirical formula is the most simplified ratio of atoms in a molecule. A molecular formula gives the specific numbers of each type of atom in a molecule.

2.37 Why are empirical formulas preferred for describing polymer molecules?

Polymers are made of a very large number of monomers bonded together: hundreds or even thousands. Sometimes it is not even possible to tell exactly how many. It is much more convenient to represent a polymer with its empirical or monomer formula.

2.38 The molecular formula for the ethylene monomer is C_2H_4. What is its empirical formula?

C_1H_2

2.39 Polybutadiene is a synthetic elastomer, or rubber. The corresponding monomer is butadiene, which has a molecular formula C_4H_6. What is the empirical formula of butadiene?

The empirical formula is the smallest whole number ratio of atoms present in the compound. The empirical formula for butadiene, C_4H_6, is C_2H_3.

The Periodic Table

2.40 What distinguished the work of Mendeleev that caused scientists to accept his concept of the periodic table when others before him were not believed?

He left "holes" in the table rather than force known elements into those positions. As the new elements were discovered and placed into these "holes", the community recognized the importance of Mendeleev's work.

2.41 How does the periodic table help to make the study of chemistry more systematic?

The periodic table organizes elements according to the size and structure of the atom. This allows us to identify trends in properties of atoms and to make predictions in their behavior.

2.42 What is a period in the periodic table? From what does it derive its name?

A period is one horizontal row on the periodic table. As we move across a row (or period) on the table, some of the important properties of the elements tend to vary in a systematic way.

2.43 Name the group to which each of the following elements belongs:

(a) K **Group 1**
(b) Mg **Group 2**
(c) Ar **Group 18**
(d) Br **Group 17**

Groups are the columns of the periodic table. Each one is labeled sequentially from left to right, 1–18.

2.44 What are some of the physical properties that distinguish metals from nonmetals?

Distinguishing properties include sheen, ductility, and malleability.

2.45 Identify the area of the periodic table in which you would expect to find each of the following types of elements. (**a**) a metal, (**b**) a nonmetal, (**c**) a metalloid

The metals are located in the middle and left side of the table, with the exception of hydrogen, a nonmetal. The nonmetals are found on the right side of the periodic table, and more so the upper right. Metalloids are sandwiched in between the metals and nonmetals along a stair-step line going down from boron down to astatine.

2.46 Why are nonmetals important even though they account for only a very small fraction of the elements in periodic table?

Many non-metals are essential components in living systems.

2.47 What is a metalloid?

Metalloids are elements that exhibit some properties of both nonmetals and metals. Since they cannot be classified as either metals or nonmetals, they have a separate category and they exist in the region between metals and nonmetals on the periodic table.

2.48 A materials engineer has filed for a patent for a new alloy to be used in golf club heads. The composition by mass ranges from 25 to 31% manganese, 6.3 to 7.8% aluminum, 0.65 to 0.85% carbon, and 5.5 to 9.0% chromium, with the remainder being iron. What are the maximum and minimum percentages of iron possible in this alloy? Use Figure 2.12 to make a prediction about how the density of this alloy would compare with that of iron; justify your prediction.

The iron concentration is between 51% and 63%. Aluminum and carbon are less dense than the other metals used in this alloy; therefore the alloy should have a density less than iron.

2.49 Classify the following elements as metals, metalloids, or nonmetals:

(a) Si	**Metalloid**	**(b) Zn**	**Metal**	**(c) B**	**Metalloid**
(d) N	**Nonmetal**	**(e) K**	**Metal**	**(f) S**	**Nonmetal**

Metals are generally to the left and in the middle on the periodic table, with nonmetals on the right, and metalloids in between.

2.50 A materials engineer wants to make a new material by taking pure silicon and replacing some fraction of the silicon atoms with other atoms that have similar chemical properties. Based on the periodic table, what elements probably should be tried first?

Carbon, germanium, and tin

Inorganic and Organic Chemistry

2.51 The chemistry of the main group elements is generally simpler than that of the transition metals. Why is this so?

Most of the transition metals can form more than one cation, sometimes five or more. Elements in the main groups usually form only one anion or cation.

2.52 Calcium and fluorine combine to produce an ionic calcium fluoride, CaF_2. Use the periodic table to predict at least two other compounds that you would expect to have structures similar to that of CaF_2.

MgF_2 and SrF_2

2.53 What is meant by the phrase *organic chemistry*?

***Organic* chemistry is the branch of chemistry primarily concerned with molecules containing carbon bonded to other carbon atoms. It is sometime referred to as the chemistry of living things because living organisms are made mostly of organic molecules.**

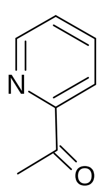
2.54 Based on what you've learned in this chapter, would you classify the chemistry of polymers as organic or inorganic? Why?

Organic, because the monomers are most often organic units AND the bonding of the monomers to form the polymer involves the creation of C–C bonds in many cases.

2.55 What is a *functional group*? How does the concept of the functional group help to make the study of organic chemistry more systematic?

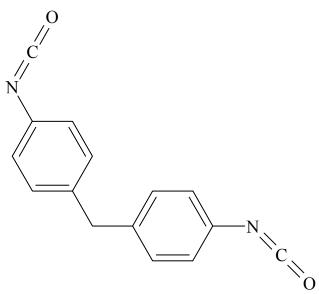
A *functional group* is a specific group of atoms that is bonded to an organic molecule. This group has certain properties and causes the molecule to behave in a certain way. Organic molecules are classified according to which functional groups are present and the name of the molecule will reflect that functional group.

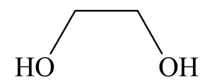
2.56 The molecule shown below is responsible for the smell of popcorn. Write the correct molecular formula for this compound.



C_7H_7NO

2.57 Not all polymers are formed by simply linking identical monomers together. Polyurethane, for example, can be formed by reacting the two compounds shown below with one another. Write molecular and empirical formulas for each of these two substances.

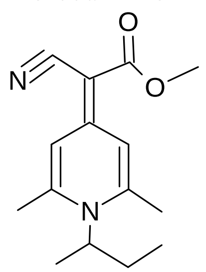




In line structures for organic molecules, each line represents a single bond. The symbols for carbon atoms are not shown, therefore at the terminus of each line, if a symbol is not shown, a C atom is assumed. The symbols of hydrogen atoms bonded to C are also not shown, so if carbon does not have four bonds shown in the structure, we assume the missing bonds are C – H bonds.

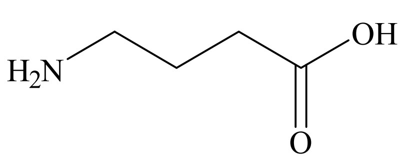
The empirical and molecular formulas for the molecule on the left are $C_{15}H_{10}N_2O_2$. The molecular formula for the molecule on the right is $C_2H_6O_2$. The empirical formula is CH_3O.

2.58 The compound shown below forms an amorphous solid (a glass) at room temperature, and has been used as a medium for storing information holographically. Write the correct molecular formula for this molecule.



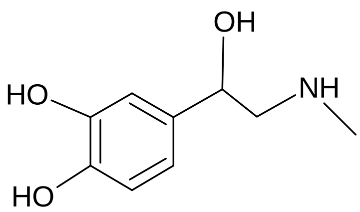
$C_{15}H_{20}N_2O_2$

2.59 The accompanying figure shows the structure gamma-aminobutanoic acid, or GABA. This molecule is a neurotransmitter. Some of the effects of alcohol consumption are due to the interaction between ethanol and GABA. Write the correct molecular formula for this compound.



The molecular formula for GABA is $C_4H_9NO_2$.

2.60 The following figure shows the structure of the adrenaline molecule. Write the correct molecular formula for this substance.



$C_9H_{13}NO_3$

Chemical Nomenclature

2.61 Name the following covalent compounds:

(a) N_2O_5	**dinitrogen pentoxide**
(b) S_2Cl_2	**disulfur dichloride**
(c) NBr_3	**nitrogen tribromide**
(d) P_4O_{10}	**tetraphosphorus decoxide**

When naming binary covalent compounds, name the first element, leave a space, then name the second element. The second element's name is modified to end in "– ide". For multiples of a type of atom, Greek prefixes are used. Two-syllable prefixes that end in a vowel drop the second vowel when preceding "oxide".

2.62 Give the formula for each of the following compounds. **(a)** sulfur dichloride, **(b)** dinitrogen pentoxide, **(c)** silicon tetrachloride, **(d)** diboron trioxide (commonly called boric oxide)

(a) SCl_2, (b) N_2O_5, (c) $SiCl_4$, (d) B_2O_3

2.63 Write the molecular formula for each of the following covalent compounds:

(a) sulfur hexafluoride	**SF_6**
(b) bromine pentafluoride	**BrF_5**
(c) disulfur dichloride	**S_2Cl_2**
(d) tetrasulfur tetranitride	**S_4N_4**

2.64 Name each of the following ionic compounds. **(a)** K_2S, **(b)** $CoSO_4$, **(c)** $(NH_4)_3PO_4$, **(d)** $Ca(ClO)_2$

(a) potassium sulfide, (b) cobalt(II) sulfate, (c) ammonium phosphate, (d) calcium hypochlorite

2.65 Name each of the following compounds: (**a**) $MgCl_2$, (**b**) $Fe(NO_3)_2$, (**c**) Na_2SO_4, (**d**) $Ca(OH)_2$, (**e**) $FeSO_4$

(a) $MgCl_2$	**magnesium chloride**
(b) $Fe(NO_3)_2$	**iron(II) nitrate**

(c) Na_2SO_4 **sodium sulfate**
(d) $Ca(OH)_2$ **calcium hydroxide**
(e) $FeSO_4$ **iron(II) sulfate**

When naming ionic compounds, first name the cation, leave a space, and then name the anion. Greek prefixes are never used, even if there is more than one of a type of ion. If a cation has more than one possible charge, a roman numeral in parenthesis indicating the charge directly follows the name of the cation with no space.

2.66 Give the formula for each of the following ionic compounds. **(a)** ammonium carbonate, **(b)** calcium iodide, **(c)** copper(II) bromide, **(d)** aluminum phosphate, **(e)** silver (I) acetate

(a) $(NH_4)_2CO_3$, (b) CaI_2, (c) $CuBr_2$, (d) $AlPO_4$, (e) $AgC_2H_3O_2$

2.67 Name the following compounds:

(a) PCl_5 **phosphorus pentachloride**
(b) Na_2SO_4 **sodium sulfate**
(c) Ca_3N_2 **calcium nitride**
(d) $Fe(NO_3)_3$ **iron(III) nitrate**
(e) SO_2 **sulfur dioxide**
(f) Br_2O_5 **dibromine pentoxide**

When naming ionic compounds with polyatomic ions, the rules are the same. Name the cation, leave a space, and name the anion.

INSIGHT Polyethylene

2.68 What is a free radical? How are free radicals important in the formation of polyethylene?

A free radical is a highly reactive species with an unpaired electron. Free radicals serve as the initiator molecules in this polymerization.

2.69 How do molecules of low-density polyethylene and high-density polyethylene differ? How do these molecular scale differences explain the differences in the macroscopic properties of these materials?

Low-density polyethylene (LDPE) is made of polymer molecules that are highly branched. Because of this branching, the molecules cannot pack closely together, much like a pile of twisted branches from a tree. The resulting density is lower because the mass per volume is decreased. High-density polyethylene (HDPE) has polymer molecules that are much straighter with little branching. These can pack more tightly together, increasing the mass per volume, or density. LDPE is weaker, softer, and more flexible; HDPE is stronger and harder.

2.70 Why do you think an initiator molecule is needed to induce the polymerization of ethylene?

Ethylene itself is a stable molecule. The highly reactive initiator is necessary to start the reaction.

2.71 Use the web to determine the amount of low-density and high-density polyethylene produced annually in the United States. Which uses predominate in the applications of these two materials?

According to the American Chemistry Council, 21 billion pounds of LDPE and 18 billion pounds of HDPE were produced in the United States in 2016. The largest use for HDPE is consumer product bottles; milk jugs and quart bottles of motor oil are examples. LDPE is used in plastic liners, garbage and storage bags.

Conceptual Problems

2.72 How can an element have an atomic weight that is not an integer?

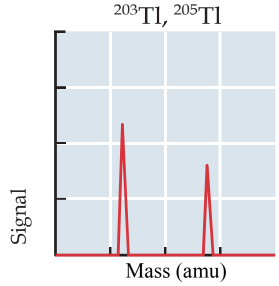
If the element has multiple isotopes, the atomic weight is a weighted average of those isotopes. This will most likely result in a non-integer.

2.73 Explain the concept of a "weighted" average in your own words.

A weighted average is the average of several samples that also accounts for the abundance of individual samples.

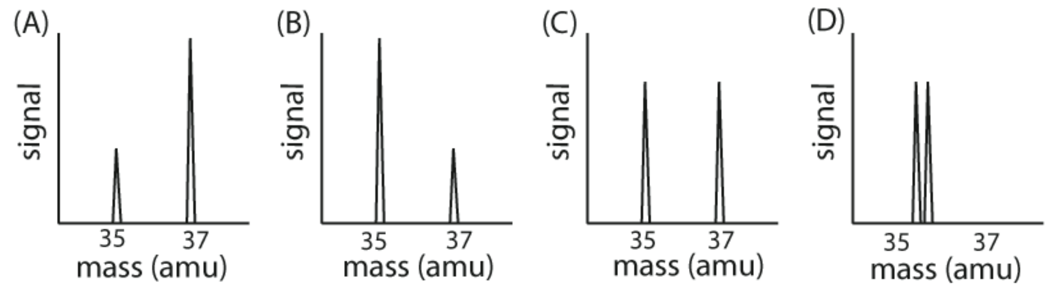
2.74 The accompanying table provides the identity of the two naturally occurring isotopes for four elements and the atomic weights for those elements. (In each case the two isotopes differ in mass number by two.) Which element has the mass spectrum shown? Explain your answer.

Isotopes	Mass (amu)
^{121}Sb, ^{123}Sb	121.8
^{185}Re, ^{187}Re	186.2
^{191}Ir, ^{193}Ir	192.2
^{203}Tl, ^{205}Tl	204.4



^{121}Sb, ^{123}Sb; The isotope ^{121}Sb is present at 60%, and the isotope ^{123}Sb is present at 40%; which corresponds to the signal shown in the figure of the mass spectrum.

2.75 Chlorine has only two isotopes, one with mass 35 and the other with mass 37. One is present at roughly 75% abundance and the atomic mass of chlorine on a periodic table is 35.45. Which must be the correct mass spectrum for chlorine?



The correct spectrum is (B), which shows the 35-amu isotope with approximately three times greater abundance (signal strength) than the 37-amu isotope. This corresponds to the 75% abundance of one isotope, and it has to be the one at 35 amu to yield an atomic mass of 35.45 amu:

0.75 (35 amu) + 0.25 (37 amu) = 35.5 amu

2.76 What is the difference between an ionic bond and a covalent bond?

In an ionic bond, one species will give up electrons while another species gains the electrons. In a covalent bond, there is a genuine sharing of electrons between species to form the bond.

2.77 In general, how are electrons involved in chemical bonding?

There are 3 major types of chemical bonds: ionic, covalent, and metallic. They all involve *sharing* or *transfer* of electrons in some way. Ionic bonds have electrons transferred from the cation to the anion. Covalent bonds result from shared pairs of electrons between two atoms. Metallic bonding has metal atoms transfer some of their electrons to a "common pool" where they are all shared collectively across the entire mass of metal.

2.78 Conduction of electricity usually involves the movement of electrons. Based on the concept of metallic bonding, explain why metals are good conductors of electricity.

There is an ample supply of electrons that are free to move about in metallic bonding. This mobility results in excellent electrical conductance.

2.79 Describe how a covalently bonded molecule is different from compounds that are either ionic or metallic.

In a molecule, electrons are shared in pairs between two atoms, as opposed to transferring electrons from one atom to another in ionic compounds or transferring electrons to a common pool in metallic solids. Molecular substances exist as discrete particles, but ionic and metallic substances exist as large arrays of particles.

2.80 Of the following elements, which two would you expect to exhibit the greatest similarity in physical and chemical properties? Cl, P, S, Se, Ti. Explain your choice.

Sulfur and selenium, because they are members of the same group (or family) of elements.

2.81 How do binary compounds with hydrogen illustrate the concept of periodicity?

It is observed that hydrogen forms a compound with elements in a given group always in the same ratio. This ratio changes across the periodic table, indicating a change in the structure of the atom from the left to right side of the periodic table. For example:
Group 17 – HF, HCl, HBr, HI

Group 16 – H_2O, H_2S, H_2Se, H_2Te

Group 15 – NH_3, PH_3, AsH_3

2.82 Which binary combinations of elements are most likely to give ionic substances?

Combinations of an alkali metal element and a halogen element are most likely to result in an ionic substance (a salt).

2.83 Why are there different rules for naming covalent and ionic binary compounds?

In molecules, the atoms combined are neutral and they can bond in many ratios. The only way to distinguish different formulas with a name is by using Greek prefixes. In ionic compounds, the bonded species have a charge and there is only one possible ratio that will give a neutral formula: prefixes are not needed.

2.84 Early attempts to arrange the elements often focused on atomic weight. Mendeleev considered a number of properties in addition to atomic weight, so he realized that some elements seemed out of place when ordered by atomic weight. Using the modern periodic table, identify elements for which Mendeleev must have had to switch the order in order to get the correct sequence of elements.

In the following atom pairs, the atom with greater atomic number has a lower atomic weight: Ar and K, Co and Ni, Cu and Zn, Te and I. These would likely have been out of order on Mendeleev's periodic table.

2.85 Describe how the saying "opposites attract" corresponds with the mathematical representation of Coulomb's law shown in Equation 2.1. Remember that attractive forces have negative values and repulsive forces have positive values.

In Coulomb's law, the charges of the particles are multiplied ($q_1 \times q_2$), so if one particle was positively charged and the other negative, the resulting force would be negative (an attractive force).

2.86 For some uses, the relative abundance of isotopes must be manipulated. For example, a medical technique called boron neutron capture therapy needs a higher fraction of ^{10}B than occurs naturally to achieve its best efficiency. What would happen to the atomic weight of a sample of boron that had been enriched in ^{10}B? Explain your answer in terms of the concept of a weighted average.

The atomic weight of boron is 10.81 amu. This is the weighted average of all isotopes and since this number is closer to 11 than 10, it implies that ^{10}B is a lighter, less abundant isotope. Increasing the fraction of ^{10}B would decrease the atomic weight.

2.87 What is the heaviest element to have an atomic weight that is roughly twice its atomic number? What does this suggest must be true about the nuclei of atoms with higher atomic numbers?

Calcium has an atomic weight equal to 40.08 amu compared to its atomic number of 20. It suggests that atoms with a higher atomic number than calcium have more neutrons than protons and the ratio of neutrons to protons becomes increasingly higher.

Focus on Problem Solving Exercises

2.88 Describe how you can identify the isotope, X, in this puzzle. The nucleus contains one more neutron than proton, and the mass number is nine times larger than the charge on the ion X^{3+}.

$3 \times 9 = 27$ amu. The 3+ charge and relatively light mass rules out the transition elements. Focusing on the periodic table, Al is an element that readily forms a 3+ charge and has an average atomic mass around 27. With atomic number = 13, aluminum satisfies the last clue because it would have 14 (13 + 1) neutrons and have a total mass of 27 amu.

2.89 Many transition metals produce more than one ion. For example, iron has ions with charges of 2+ and 3+ that are both common. How could you use the compounds of a transition metal with oxygen to determine the charge of a metal ion? Use iron as your example.

The key is the fact that oxygen almost always forms a 2– charge when it bonds with metals, especially transition metals like iron. An experiment could be performed where the mass of metal before and after reacting with oxygen is determined. Then the ratios of moles of atoms could be calculated (the formula).

In the case of iron the formula of the resulting oxide would be either FeO or Fe_2O_3, depending on reaction conditions. Then, assuming that the charge of the oxide ion is 2–, we can calculate the charge of iron that gives us a neutral compound:

Fe + (O^{2-}) = 0 net charge, Fe = 2+ or Fe^{2+}

2 (Fe) + 3 (O^{2-}) = 0 net charge, Fe = 3+ or Fe^{3+}

2.90 Naturally occurring europium has an average atomic mass of 151.964 amu. If the only isotopes of europium present are ^{151}Eu and ^{153}Eu, describe how you would determine the relative abundance of the two isotopes. Include in your description any information that would need to be looked up.

Let x equal the percentage of Eu-151 and (1 – x) equal Eu-153. From there: 151 amu (x) + 153 amu (1 – x) = 151.965 amu. Solve for x.

2.91 Strontium has four stable isotopes. Strontium−84 has a very low natural abundance, but ^{86}Sr, ^{87}Sr, and ^{88}Sr are all reasonably abundant. Knowing that the atomic mass of strontium is 87.62, which of the more abundant isotopes predominates?

The weighted average mass of Sr is 87.62 amu, which is closest to the mass of strontium-88. Equal abundance of the three isotopes would yield an average around 87 amu. Therefore the most abundant isotope must be strontium−88.

2.92 A candy manufacturer makes chocolate-covered cherries. While all of the products look roughly the same, 3% of them are missing the cherry. The mass of the candy with a cherry is 18.5 g; those missing the cherry weigh only 6.4 g. **(a)** How would you compute the average mass of a box of 100 of these chocolate-covered cherries from this manufacturer? **(b)** How is this question analogous to the determination of atomic weights?

(a) 97 cherried × 18.5 grams + 3 non-cherried × 6.4 g = 1813.7 grams
(b) Both rely upon weighted averages.

2.93 Two common oxides of iron are FeO and Fe_2O_3. Based on this information, tell how you would predict two common compounds of chlorine and iron.

The oxide anion is always a 2– charge. Therefore we can determine what the two charges for iron are in FeO and Fe_2O_3.

Fe + (O^{2-}) = 0 net charge, Fe = 2+ or Fe^{2+}
2 (Fe) +3 (O^{2-}) = 0 net charge, Fe = 3+ or Fe^{3+}

Chloride anions are always 1–, so we can predict the formula of compounds containing iron and chlorine based on what combination of cation and anion gives us a neutral formula.

(Fe^{2+}) + 2 (Cl^-) = 0 net charge: $FeCl_2$ (Fe^{3+}) + 3 (Cl^-) = 0 net charge: $FeCl_3$

Cumulative Problems

2.94 Use a molecular level description to distinguish between LDPE and HDPE.
HDPE is referred to as linear polyethylene and contains few hydrocarbon branches. This tight packing results in a strong, hard material. LDPE contains more hydrocarbon branches and is not the hard material that HDPE is.

2.95 Engineers who design bicycle frames are familiar with the densities of aluminum (2.699 g/cm^3), steel (7.87 g/cm^3), and titanium (4.507 g/cm^3). How does this information compare with Figure 2.12 and what would it suggest for changes in this figure if more shades were used for the density color-coding? (Iron is the principal component of steel.)

The density of iron is about 1.75 times greater than that of titanium, yet their shade color is the same in Figure 2.12. The color shades should be darker towards the middle of Period 2, around Groups 7−11, as the density of those metals increases towards the right.

2.96 Use the web to look up the density of different forms of steel, such as stainless steel or magnetic steel, and discuss whether or not the differences in the densities follow what might be predicted by looking at the periodic properties of elements.

Please refer to the World Wide Web for this information.

2.97 LDPE has a density range of 0.915–0.935 g/cm^3, and HDPE has a density in the range of 0.940–0.965 g/cm^3. You receive a small disk, 2.0 cm high with a 6.0 cm diameter from a manufacturer of polyethylene, but its label is missing. You measure the mass of the disk and find that it is 53.8 g. Is the material HDPE or LDPE?

We can calculate the volume of the disk and then use the mass to determine the density.

Volume of a cylinder = $\pi \times r^2 \times l$; $V = \pi \times (6.0 \text{ cm} \div 2)^2 \times 2.0 \text{ cm} = 57 \text{ cm}^3$

Density = mass/volume; $d = 53.8 \text{ g} \div 57 \text{ cm}^3 = 0.95 \text{ g/cm}^3$

This density falls in the range of HDPE; therefore the disk is HDPE.