Chapter 1
Elements and Compounds

1-1 The science of **chemistry** seeks to understand the composition, structure and properties of substances and the reactions by which one substance is converted into another. This is accomplished by performing experimental tests to recognize patterns of behavior among different substances, then developing models that explain these behaviors, and then using the models to predict behavior of other substances.

1-2 This procedure would not be considered chemistry, since there was no effort to understand why alum helped the tanning process. The practice of chemistry seeks to understand the nature of the substance or process rather than the development of the process or use of the material.

1-3 Experiments are an important part of chemistry. Through the observations made in an experiment, chemists develop a model to explain the results of the experiment. Further experiments are then performed to test the model's ability to predict the properties of other substances.

1-4 An **element** is a substance that contains only one kind of atom. An element cannot be chemically decomposed into a simpler substance. Oxygen, zinc, and bromine are examples of elements. A **compound** is a substance composed of more than one kind of atom. A compound has a constant composition. Elements in a compound can be isolated by chemical processes. Water, sodium chloride, and carbon dioxide are examples of compounds. A **mixture** is composed of more than one substance and its composition may vary. Substances that make up the mixture can be separated by physical means. Air, a soft drink, and bronze (a mixture of the two metals copper and tin) are examples of mixtures.

1-5 On the microscopic scale, an element consists of one particular type of atom. Nitrogen, N_2, oxygen, O_2, and iron metal, Fe, are examples of elements. A compound is made up of one molecule that contains more than one type of atom. Water, H_2O, and ammonia, NH_3, are examples of compounds. On a macroscopic scale, it is impossible to tell whether a sample is an element or a compound unless one tries to separate the sample into components. If it cannot be separated into different atoms, it is an element. If it can be separated, it is a compound.

1-6
- (a) diamond: element
- (b) brass: mixture
- (c) soil: mixture
- (d) glass: mixture
- (e) cotton: mixture
- (f) milk of magnesia: mixture
- (g) salt: compound
- (h) iron: element
- (i) steel: mixture

1-7 Granite satisfies two criteria to consider it a mixture: it has variable composition and it can be separated.

1-8 The formula P_4S_3 indicates that the elements phosphorus and sulfur are combined in the ratio of four to three. Four atoms of P combine with three atoms of S to form one molecular unit of P_4S_3.

1-9 The formula SO_3 indicates that the elements sulfur and oxygen are combined in the ratio of one to three. One atom of sulfur combines with three atoms of oxygen to form one molecular unit of SO_3.

1-10 (a)Sb (b)Au (c)Fe (d)Hg (e)K (f)Ag (g)Sn (h)W

1-11 (a)sodium (b)magnesium (c)aluminum (d)silicon (e)phosphorus (f)chlorine (g)argon

1-12 (a)titanium (b)vanadium (c)chromium (d)manganese (e)iron (f)cobalt (g)nickel (h)copper (i)zinc

1-13 (a)molybdenum (b)tungsten (c)rhodium (d)iridium (e)palladium (f)platinum (g)silver (h)gold (i)mercury

1-14 (a) Co represents the element cobalt. CO represents the compound carbon monoxide which consists of two separate kinds of atoms; one each of carbon and oxygen per molecular unit.
(b) Cs represents the element cesium. CS_2 represents the compound carbon disulfide that consists of two separate kinds of atoms; one of carbon and two of sulfur per molecular unit.
(c) Ho represents the element holmium. H_2O represents the compound water that consists of two separate kinds of atoms; two of hydrogen and one of oxygen per molecular unit.
(d) 4 P represents four individual phosphorus atoms. P_4 represents a molecular unit composed of four phosphorus atoms linked together.

1-15 The fact that chemical elements cannot be decomposed into simpler substances is consistent with the idea that there are elementary particles that can combine to form compounds but cannot be subdivided. The law of definite proportions argues strongly for the existence of atoms as a fundamental unit of combining. The seemingly continuous nature of matter as we sense it, the fluidity of the atmosphere, the fluidity of water, and the transparency of glass, all might be used to argue against the atomic nature of matter.

1-16 That atoms have different weights and that they combine together in whole number ratios can be observed by reacting 2 grams of hydrogen gas with 16 grams of oxygen gas to form 18 grams of liquid water releasing a large amount of energy. This also shows that atoms (matter) cannot be created or destroyed. However, when the same 2 grams of hydrogen can be placed with helium gas and no reaction will take place, it shows that helium and oxygen have different chemical properties.

1-17 **Atomic theory** is widely accepted because the model has been successfully used to predict the outcomes of a multitude of experiments.

1-18 Dalton's assumptions do say that atoms are indivisible and indestructible, but they do not give any clues as to the structure of the atom.

1-19 Atoms of different elements will have different weights and chemical properties.

1-20 Fusion experiments have shown that it is possible to take two small atoms and fuse them together to make a single larger atom. This process however requires extreme temperatures and pressures. However, it does indicate that the number of atoms in the universe is not a constant.

1-21 $$1\ \text{yr} \cdot \frac{365.25\ \delta\alpha\psi}{1\ \psi\rho} \cdot \frac{24\ \eta\rho}{1\ \delta\alpha\psi} \cdot \frac{3600\ \sigma\varepsilon\chi}{1\ \delta\alpha\psi} = 3.2 \times 10^{7}\ \text{sec}$$

1-22 In each case the unit is multiplied by a decimal factor to give the appropriate value.
(a) nano- means in units of 10^{-9}
(b) micro- means in units of 10^{-6}
(c) milli- means in units of 10^{-3}
(d) centi- means in units of 10^{-2}
(e) kilo- means in units of 10^{3}

1-23 Since a centimeter has units of 10^{-2} meters, to convert from centimeters to the other units we need to apply the appropriate conversions. Note that since a centimeter is 10^{-2} meters, there are 100 centimeters in a meter. Similarly, since a micrometer is 10^{-6} meters, there are 10^{6} micrometers in a meter.

$$4 \times 10^{-5}\ \text{centimeters} \cdot \frac{1\ \text{μ ετερ}}{100\ \text{χεντιμ ετερ}} \cdot \frac{10^{6}\ \text{μ ιχρομ ετερσ}}{1\ \text{μ ετερ}} = 4 \times 10^{-1}\ \text{micrometers}$$

$$4 \times 10^{-5}\ \text{centimeters} \cdot \frac{1\ \text{μ ετερ}}{100\ \text{χεντιμ ετερ}} \cdot \frac{10^{9}\ \text{νανομ ετερσ}}{1\ \text{μ ετερ}} = 4 \times 10^{2}\ \text{nanometers}$$

1-24 First we should convert 750 mL to gallons.

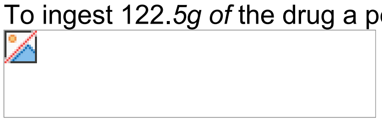
$$750\ \text{mL} \cdot \frac{1\ \text{θυαρτ}}{946.4\ \text{μ Λ}} \cdot \frac{1\ \text{γαλλον}}{4\ \text{θυαρτ}} = 0.1981\ \text{γαλλον}$$

So 750 mL is a little less than 1/5 of a gallon (0.2 gallon). The better buy then is the fifth rather than 750 mL.

1-25 $$100\ \frac{\text{ft}^{3}}{\text{min}} \cdot \frac{1\ \text{μ ιν}}{60\ \text{σεχ}} \cdot \left(\frac{1\ \text{ψαρδ}}{3\ \text{φτ}}\right)^{3} \cdot \left(\frac{0.9144\ \text{μ}}{1\ \text{ψαρδ}}\right)^{3} = 0.1416\ \frac{\mu^{3}}{\text{σεχ}}$$

1-26 The amount of the drug taken by a person weighing 70 kg is 

To ingest 122.*5g of* the drug a person would need to consume



1-27 (a) 3 The leading zeros (to the left) are not significant
(b) 4 The leading zeros (to the left) are not significant, but the trailing zero (to the right) is significant when a decimal point is shown
(c) 1 Trailing zeros are not significant when a decimal point is not present
(d) 5 The captured zeros (in between) are significant

1-28 Since all the numbers are given in scientific notation, all the digits shown are significant.
(a) 2 (b) 6 (c) 4 (d) 3

1-29 (a) 475 (b) 0.0680 (c) 9.46×10^{10} (d) 30.1

1-30 (a) 1.198×10^{1} (b) 4.6940×10^{1} (c) 4.679×10^{6}

1-31 (a) The first number has the fewest (2) digits to the right of the decimal point so we keep only those two digits upon addition: 153.92
(b) The first number has the fewest (none) digits to the right of the decimal point so we do not keep any digits to the right of the decimal point, but we still need to round appropriately after the addition: 33
(c) In multiplication we use the same number of figures as the number with the fewest total figures. Both numbers have three: 5.10×10^{7}
(d) Writing both in decimal form gives us 0.0418 + 0.00129. Using the rules above we should only keep four digits past the decimal: 0.0431

1-32 A proton and a neutron have approximately the same mass, but the proton has a positive charge while the neutron is neutral. The electron has a negative charge and has much less mass than either the proton or neutron. The mass of one proton is the same as approximately 1836 electrons.

1-33 Dalton's assumption that all atoms of the same element are identical is in error. For example, it is possible for atoms of the same element to have a different number of neutrons.

1-34 An atom of mercury and an atom of iron both have protons and neutrons in the nucleus of the atom. While the number of protons and neutrons in each is different, every atom will have them in the nucleus. Meanwhile the electrons in every atom will move around the nucleus.

1-35 Electron, relative charge: –1
Proton, relative charge: +1
Neutron, relative charge: 0

1-36 A neutral atom is one that has a net charge of zero. Since the relative charges of protons and electrons are opposite, having an equal number of each will result in a net charge of zero.

1-37 The electron is the particle that has the smallest mass.

1-38 Over 99% of the mass of the atom is located in the nucleus, which takes up a very small part of the space in an atom.

1-39 The radius of an atom is approximately 10,000 times larger than the radius of the nucleus.

1-40 The **atomic number** of Ca is 20 and that is also the number of protons in the Ca nucleus. An equal number of electrons are in the neutral atom, so there are 20 electrons present. The number of neutrons depends on the isotope. The **mass number** is the sum of the number of neutrons and protons. Since the mass number is 40 there are 20 neutrons.

1-41 24 protons = chromium (Cr) = 24 atomic number
24 protons + 28 neutrons = 52 mass number
24 protons - 24 electrons = 0 net charge (a neutral atom)
^{52}Cr

1-42 Potassium (K) = 19 protons = 19 atomic number
39 mass number - 19 protons = 20 neutrons
neutral atom so the number of protons and electrons is equal: 19 electrons
atomic number = Z = 19
mass number = 39

1-43 Iodine (I) = 53 protons = 53 atomic number
127 mass number - 53 protons = 74 neutrons
neutral atom so the number of protons and electrons is equal: 53 electrons
Z=53
mass number = 127

1-44 20 mass number - 11 neutrons = 9 protons
The element is ^{20}F

1-45 34 protons=Selenium (Se)
34 protons+45 neutrons=79 mass number
34 protons-34 electrons=0 net charge; neutral atom
^{79}Se

1-46 Ba = 56 protons
neutral atom so the number of protons and electrons is equal: 56 electrons

1-47

	Z	A	e
^{31}P	15	31	15
^{18}O	8	18	8

^{39}K	19	39	19
^{58}Ni	28	58	28

1-48 The mass of ^{12}C is 12.00000 amu. The mass of ^{13}C is 13.003 amu. The ratio is 0.92286.

1-49 The mass of ^{6}Li is 6.01512 amu. The mass of ^{1}H is 1.007825 amu. A ^{6}Li atom is 5.96842 times more massive than a ^{1}H atom.

1-50 2.6560 x 10^{-23} g (see Table 1.5), since there are many more ^{16}O atoms than there are either ^{17}O or ^{18}O.

1-51 $\frac{\text{mass of } ^{12}C}{\text{mass of } X} = 0.750239$, mass of X =15.9949. Atom X is ^{16}O.

1-52 $$\frac{1.007825}{1.6735 \cdot 10^{-24}} = 6.0222 \cdot 10^{23}$$
$$\frac{2.01410}{3.3443 \cdot 10^{-24}} = 6.0225 \cdot 10^{23}$$
$$\frac{12.0000}{1.9926 \cdot 10^{-23}} = 6.0223 \cdot 10^{23}$$

For every 1 gram of an atom there are 6.022×10^{23} amu of that atom.

1-53

Mass (grams)	Z	A	Number of neutrons	Mass (amu)
1.6627×10^{-23}	5	10	5	10.0129
3.9829×10^{-23}	12	24	12	23.9850
2.9888×10^{-23}	8	18	10	17.9992
1.7752×10^{-22}	47	107	60	106.903

1-54 ^{12}C is heavier than ^{11}B since it has a higher mass number.

1-55 Three, ^{16}O, ^{17}O, ^{18}O

1-56 All have the same number of protons but different number of neutrons.

1-57 1.99265 x 10^{-23} g; 12.0000 amu

1-58 1200.00 amu, 1300.3 amu

1-59 (b) The random selection will include isotopes ^{12}C and ^{13}C, but it will be mostly ^{12}C.

1-60 (a) H represents a hydrogen atom. H^+ represents a positive hydrogen ion. H^+ is formed by the removal of the electron from a hydrogen atom.
(b) H represents a hydrogen atom. H^- represents a negative hydrogen ion called the hydride ion. H^- is formed by the addition of an electron to a neutral hydrogen atom.
(c) 2 H represents two individual and separate hydrogen atoms. H_2 represents a hydrogen molecule in which two hydrogen atoms are paired together by a chemical bond.
(d) H^+ represents a hydrogen atom that has lost its electron to become a positively charged ion. H^- represents a hydrogen atom that has gained an electron to become a negatively charged ion.

1-61 H^+ represents a hydrogen atom that has lost an electron to become a positive ion. The single electron of a hydrogen atom moves around the nucleus and makes the apparent size of the atom about 2000 times larger than the H^+ ion. H_2 represents a diatomic molecule in which two hydrogen atoms are chemically bonded to each other.

1-62 Barium (Ba) = 56 protons = 56 atomic number
134 mass number – 56 protons =78 neutrons
This ion has a +2 charge, therefore there must be 54 electrons; two less than the number of protons.

1-63 Atomic number = number of protons = 24, chromium (Cr)
21 electrons which is three less than the number of protons, +3 charge
mass number = 24 protons + 28 neutrons = 52
$^{52}Cr^{+3}$

1-64 Iodine (I) = 53 atomic number = 53 protons
127 mass number - 53 protons = 74 neutrons
ionic charge = –1, so there is one more electron than proton: 54 electrons

1-65 34 protons=selenium (Se)
34 protons+45 neutrons=79 mass number
34 protons-36 electrons=–2 net charge
$^{79}Se^{-2}$

1-66

Isotope	Z	A	e
$^{31}P^{3-}$	15	31	18
$^{18}O^{2-}$	8	18	10
$^{58}Ni^{2+}$	28	58	26
$^{24}Mg^{2+}$	12	24	10
$^{27}Al^{3+}$	13	27	10
$^{80}Br^{-}$	35	80	36

1-67 Polyatomic ions are electronically charged substances that are composed of more than one atom. Note that a polyatomic ion is a single unit with a singular charge.

1-68 –1: Acetate, $CH_3CO_2^-$ (or $C_2H_3O_2^-$)
Nitrate, NO_3^-
Hydroxide, OH^-
–2 Carbonate, CO_3^{2-}
Sulfate, SO_4^{2-}
Dichromate, $Cr_2O_7^{2-}$
–3 Phosphate, PO_4^{3-}
Arsenate, AsO_4^{3-}
Borate, BO_3^{3-}

1-69 +1: Ammonium, NH_4^+
Hydronium, H_3O^+

1-70 As chemists began finding similarities and patterns among the elements the terms **periods** and **groups** were used to describe the relationship of the elements to one another. Elements that have similar chemical properties will be found in the same column of the periodic table called a group. As the elements increase in atomic number they fall into a pattern in which their properties repeat at regular intervals or periods. A horizontal row of the periodic table is called a period.

1-71 Compounds of the elements Cu and Ag with oxygen and chlorine, have the same formula as similar compounds of Li and Na. Ag_2O, Cu_2O, Li_2O Na_2O, AgCl, CuCl, LiCl, NaCl.

1-72 (d), (e) and (f) are nonmetals

1-73 (a) IA (b) IVA (c) IIA (d) VIA (e) IIA (f) VIIIA (g) VIIA

1-74 (a) same period (b) same group (c) same period (d) same group
(e) same period (f) neither

1-75 Seven: H, Li, Na, K, Rb, Cs, Fr

1-76 Second period, eight: Li, Be, B, C, N, O, F, Ne
Third period, eight: Na, Mg, Al, Si, P, S, Cl, Ar
Fourth period, eighteen: K, Ca, Sc, Ti, V, …… Se, Br, Kr

1-77 Similar chemical properties are exhibited by elements in the same group. Sets which are in the same group are (a) and (d).

1-78 (b) a gold ring, (c) a sample of gold ore and (d) gold dust are macroscopic scale.

1-79 Gold is symbolized in the atomic world by its atomic symbol, Au.

1-80 Solid gold is represented by Au(s).
Fe(s) would symbolize a solid bar of iron.
Fe(g) would symbolize a single iron atom in the gas phase.

1-81 The atomic weight of bromine is 0.5069 x 78.9183 amu + 0.4931 x 80.9163 amu = 79.90 amu.

1-82 The atomic weight of zinc is 0.486(63.9291 amu) + 0.279(65.9260 amu) + 0.041(66.9721 amu) + 0.188(67.9249 amu) + 0.006(69.9253 amu)= 65.4 amu

1-83 At random, the total mass is 1.2011 x 10^6 amu. The average mass of a carbon atom is 12.011 amu. No single carbon atom has this mass.

1-84 24.305 amu

1-85 126.90 amu

1-86 Silicon, Si

1-87 Since the atomic mass of an element is proportional to the relative percentages of its isotopes, this element would have a mass close to 11 amu. Boron with an atomic mass of 10.811 fits this criterion. The heavier isotope of boron would have 6 neutrons, 5 protons, and 5 electrons; the lighter would consist of 5 neutrons, 5 protons, and 5 electrons.

1-88 (a) The element is lithium, Li. The average atomic mass of Li is 6.941 amu, just a little less than 7.01600 amu, the mass of the predominant isotope of element X.
(b) Both isotopes have 3 protons and 3 electrons. The ^7Li has 4 neutrons and a mass number of 7. The other isotope is ^6Li, which has 3 neutrons and a mass number of 6.
(c) Lithium is a group IA element which forms +1 ions. This is confirmed by the compounds with Br (which forms a –1 ion), SO_4 (which is a –2 polyatomic ion) and PO_4 (which is a –3 polyatomic ion). The Li^+ ion will have two electrons.

1-89 (a) 0.5184 x 106.90509 + 0.4816 x 108.90476 = 107.87 amu. This answer is the atomic mass of Ag given on the periodic table.
(b) Both isotopes have 47 protons.
(c) Both isotopes have 47 electrons. ^{107}Ag has 60 neutrons and ^{109}Ag has 62 neutrons.

1-90 (a) The atomic mass is a weighted average of the relative masses. Bromine has an atomic mass in between the relative masses of the isotopes.
(b) The atomic mass of Br is 79.904 amu, almost exactly halfway in between the relative mass of ^{79}Br and ^{81}Br, therefore both isotopes occur at about a 50:50 abundance.

1-91

	Z	A	e	n	%A
^{6}Li	3	6	3	3	7.42
^{7}Li	3	7	3	4	92.58
^{20}Ne	10	20	10	10	90.51
^{21}Ne	10	21	10	11	0.27
^{22}Ne	10	22	10	12	9.22

1-92 (c) is the true answer. The average mass of a lithium atom is 6.941 amu. Therefore the mass of 100 selected at random will be 100 times the average mass.

Looking back at Table 1.3, 90.51% of all neon atoms will have a mass number of 20. Therefore of 10,000 random atoms, 9,051 will have a mass number of 20.

1-93 The average atomic mass cannot be greater than the largest mass isotope or smaller than the lowest mass isotope. Furthermore, the average atomic masses are listed on the periodic table.

1-94 The element is aluminum since the mass of 26.982 is on the periodic table.

1-95 The mass of the container and the contents will not change. The same number of atoms of each element will be present after burning the candle. However, the elements will be combined differently as product molecules.

1-96 The same number of atoms will be present. The atoms that made up the molecules of liquid gasoline have been changed chemically to gaseous molecules. But the same number of atoms is still present, just in a different chemical form.

1-97 Mass is conserved because atoms are not created or destroyed in a chemical reaction. Rather their arrangement changes to form different chemical compounds.

1-98 Lavoisier observed that the mass of the products of a chemical reaction is the same as the mass of the reactants one starts with.

1-99 All the atoms that start out on the reactant side of a chemical reaction equation must be accounted for on the product side of the reaction equation.

1-100 Two gaseous hydrogen molecules and one gaseous oxygen molecule can react to form two gaseous water molecules.
This is the same reaction except that the product is liquid water: Two gaseous hydrogen molecules and one gaseous oxygen molecule can react to form two liquid water molecules.

1-101 A solid molecule of potassium iodide can react to form an aqueous plus one potassium ion and an aqueous minus one iodide ion.

1-102 One gaseous molecule of carbon dioxide and one liquid water molecule can react to form an aqueous molecule of carbonic acid.

1-103 (a) $4\ Cr(s) + 3\ O_2(g) \rightarrow 2\ Cr_2O_3(s)$

(b) $SiH_4(g) \rightarrow Si(s) + 2\ H_2(g)$

(c) $2\ SO_3(g) \rightarrow 2\ SO_2(g) + O_2(g)$

1-104 (a) $2\ Pb(NO_3)_2(s) \rightarrow 2\ PbO(s) + 4\ NO_2(g) + O_2(g)$

(b) $NH_4NO_2(s) \rightarrow N_2(g) + 2\ H_2O(g)$

(c) $(NH_4)_2Cr_2O_7(s) \rightarrow Cr_2O_3(s) + 4\ H_2O(g) + N_2(g)$

1-105 (a) $CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(g)$

(b) $2\ H_2S(g) + 3\ O_2(g) \rightarrow 2\ H_2O(g) + 2\ SO_2(g)$

(c) $2\ B_5H_9(g) + 12\ O_2(g) \rightarrow 5\ B_2O_3(s) + 9\ H_2O(g)$

1-106 (a) $PF_3(g) + 3\ H_2O(l) \rightarrow H_3PO_3(aq) + 3\ HF(aq)$

(b) $P_4O_{10}(s) + 6\ H_2O(l) \rightarrow 4\ H_3PO_4(aq)$

1-107 (a) $1\ C_3H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(g)$

(b) $C_2H_5OH(l) + 3\ O_2(g) \rightarrow 2\ CO_2(g) + 3\ H_2O(g)$

(c) $C_6H_{12}O_6(s) + 6\ O_2(g) \rightarrow 6\ CO_2(g) + 6\ H_2O(l)$

1-108 $C_4H_{10}O(l) + 6\ O_2(g) \rightarrow 4\ CO_2(g) + 5\ H_2O(g)$

In the original flask there was a total of 7 moles of reactants: 1 mole of $C_4H_{10}O(l)$ and 6 moles of $O_{2(g).}$ After complete reaction, 9 moles of products formed: 4 moles of $CO_2(g)$ and 5 moles of $H_2O(g)$. The number of molecules increases.

1-109 The ion has 18 electrons, 20 protons, and 20 neutrons. The chemical symbol for X is Ca.

1-110 Element X is slightly heavier than ^{22}Ne from Table 1.4 and it has similar properties as potassium, K, which is in group IA. The group IA element that is slightly larger than neon is sodium, Na.

1-111

classification	group	period	electrons	element
metal	IA	3	11	Na
semimetal	IVA	4	32	Ge
semimetal	IIIA	2	5	B
semimetal	IVA	3	14	Si
nonmetal	VIIA	4	35	Br

1-112 $5261 \text{ pounds} = 5261\ \frac{\text{slug} \cdot \phi\tau}{\sigma\varepsilon\chi^2} \cdot \frac{14.6\ \kappa\gamma}{1\ \sigma\lambda\upsilon\gamma} \cdot \frac{0.9144\ \mu}{3\ \phi\tau} = 7.024 \cdot 10^4\ \nu\varepsilon\omega\tau o\nu\sigma$