CHAPTER 2

Atoms, Molecules, and Ions

■ SOLUTIONS TO EXERCISES

Note on significant figures: If the final answer to a solution needs to be rounded off, it is given first with one nonsignificant figure, and the last significant figure is underlined. The final answer is then rounded to the correct number of significant figures. In multistep problems, intermediate answers are given with at least one nonsignificant figure; however, only the final answer has been rounded off.

2.1. The element with atomic number 17 (the number of protons in the nucleus) is chlorine, symbol Cl. The mass number is 17 + 18 = 35. The symbol is ${}^{35}_{17}\text{Cl}$.

2.2. Multiply each isotopic mass by its fractional abundance; then sum:

$$34.96885 \text{ amu} \times 0.75771 = 26.49\underline{6}247$$

$$36.96590 \text{ amu} \times 0.24229 = \underline{8.956467}$$

$$35.45\underline{2}714 = 35.453 \text{ amu}$$

The atomic weight of chlorine is 35.453 amu.

2.3.
a. Se: Group 6A, Period 4; nonmetal
b. Cs: Group 1A, Period 6; metal
c. Fe: Group 8B, Period 4; metal
d. Cu: Group 1B, Period 4; metal
e. Br: Group 7A, Period 4; nonmetal

2.4. Take as many cations as there are units of charge on the anion and as many anions as there are units of charge on the cation. Two K^+ ions have a total charge of 2+, and one CrO_4^{2-} ion has a charge of 2–, giving a net charge of zero. The simplest ratio of K^+ to CrO_4^{2-} is 2:1, and the formula is K_2CrO_4.

2.5.
a. CaO: Calcium, a Group 2A metal, is expected to form only a 2+ ion (Ca^{2+}, the calcium ion). Oxygen (Group 6A) is expected to form an anion of charge equal to the group number minus 8 (O^{2-}, the oxide ion). The name of the compound is calcium oxide.

b. $PbCrO_4$: Lead has more than one monatomic ion. You can find the charge on the Pb ion if you know the formula of the anion. From Table 2.5, the CrO_4 refers to the anion CrO_4^{2-} (the chromate ion). Therefore, the Pb cation must be Pb^{2+} to give electrical neutrality. The name of Pb^{2+} is lead(II) ion, so the name of the compound is lead(II) chromate.

2.6. Thallium(III) nitrate contains the thallium(III) ion, Tl^{3+}, and the nitrate ion, NO_3^-. The formula is $Tl(NO_3)_3$.

2.7. a. Dichlorine hexoxide
b. Phosphorus trichloride
c. Phosphorus pentachloride

2.8. a. CS_2 b. SO_3

2.9. a. Boron trifluoride b. Hydrogen selenide

2.10. When you remove one H^+ ion from $HBrO_4$, you obtain the BrO_4^- ion. You name the ion from the acid by replacing -*ic* with -*ate*. The anion is called the perbromate ion.

2.11. Sodium carbonate decahydrate

2.12. Sodium thiosulfate is composed of sodium ions (Na^+) and thiosulfate ions ($S_2O_3^{2-}$), so the formula of the anhydrous compound is $Na_2S_2O_3$. Since the material is a pentahydrate, the formula of the compound is $Na_2S_2O_3{\bullet}5H_2O$.

2.13. Balance O first in parts (a) and (b) because it occurs in only one product. Balance S first in part (c) because it appears in only one product. Balance H first in part (d) because it appears in just one reactant as well as in the product.

a. Write a 2 in front of $POCl_3$ for O; this requires a 2 in front of PCl_3 for final balance:

$$O_2 + 2PCl_3 \rightarrow 2POCl_3$$

b. Write a 6 in front of N_2O to balance O; this requires a 6 in front of N_2 for final balance:

$$P_4 + 6N_2O \rightarrow P_4O_6 + 6N_2$$

c. Write $2As_2S_3$ and $6SO_2$ to achieve an even number of oxygens on the right to balance what will always be an even number of oxygens on the left. The $2As_2S_3$ then requires $2As_2O_3$. Finally, to balance (6 + 12) O's on the right, write $9O_2$.

$$2As_2S_3 + 9O_2 \rightarrow 2As_2O_3 + 6SO_2$$

d. Write a 4 in front of H_3PO_4; this requires a 3 in front of $Ca(H_2PO_4)_2$ for twelve H's.

$$Ca_3(PO_4)_2 + 4H_3PO_4 \rightarrow 3Ca(H_2PO_4)_2$$

■ ANSWERS TO CONCEPT CHECKS

2.1. CO_2 is a compound that is a combination of 1 carbon atom and 2 oxygen atoms. Therefore, the chemical model must contain a chemical combination of 3 atoms stuck together with 2 of the atoms being the same (oxygen). Since each "ball" represents an individual atom, the three models on the left can be eliminated since they don't contain the correct number of atoms. Keeping in mind that balls of the same color represent the same element, only the model on the far right contains two elements with the correct ratio of atoms, 1:2; therefore, it must be CO_2.

2.2. If 7999 out of 8000 alpha particles deflected back at the alpha-particle source, this would imply that the atom was a solid, impenetrable mass. Keep in mind that this is in direct contrast to what was observed in the actual experiments, where the majority of the alpha particles passed through without being deflected.

2.3. Elements are listed together in groups because they have similar chemical and/or physical properties.

2.4. Statement (a) is the best statement regarding molecular compounds. Although you may have wanted to classify Br_2 as a molecular compound, it is an element and not a compound. Regarding statement (b), quite a few molecular compounds exit that don't contain carbon. Water and the nitrogen oxides associated with smog are prime examples. Statement (c) is false; ionic compounds consist of anions and cations. Statement (d) is very close to the right selection but it is too restrictive. Some molecular compounds containing both metal and nonmetal atoms are known to exist, e.g., cisplatin, $Ni(CO)_4$, etc. Because numerous molecular compounds are either solids or liquids at room temperature, statement (e) is false.

2.5. a. This compound is an ether because it has a functional group of an oxygen atom between two carbon atoms (–O–).

b. This compound is an alcohol because it has an –OH functional group.

c. This compound is a carboxylic acid because it has the –COOH functional group.

d. This compound is a hydrocarbon because it contains only carbon and hydrogen atoms.

2.6. The SO_4^{2-}, NO_2^-, and I_3^- are considered to be polyatomic ions. Statement (a) is true based on the prefix *poly*. By definition, any ion must have a negative or positive charge; thus, statement (b) is true. Bring that the triiodide ion has only iodine atoms bonded together, and no other elements present, statement (c) is false. There are numerous examples to show that statement (d) is true, e.g., chromate, dichromate, permanganate to name a few. Oxoanions are polyatomic ions containing a central characteristic element surrounded by a number of oxygen atoms, e.g., sulfate and nitrite given in this concept check's. Statement (e) is true.

2.7. A bottle containing a compound with the formula Al_2Q_3 would have an anion, Q, with a charge of 2−. The total positive charge in the compound due to the Al^{3+} is 6+ (2 x 3+), so the total negative charge must be 6−; therefore, each Q ion must have a charge of 2−. Thus, Q would probably be an element from Group 6A on the periodic table.

■ ANSWERS TO SELF-ASSESSMENT AND REVIEW QUESTIONS

2.1. Atomic theory is an explanation of the structure of matter in terms of different combinations of very small particles called atoms. Since compounds are composed of atoms of two or more elements, there is no limit to the number of ways in which the elements can be combined. Each compound has its own unique properties. A chemical reaction consists of the rearrangement of the atoms present in the reacting substances to give new chemical combinations present in the substances formed by the reaction.

2.2. Divide each amount of chlorine, 1.270 g and 1.904 g, by the lower amount, 1.270 g. This gives 1.000 and 1.499, respectively. Convert these to whole numbers by multiplying by 2, giving 2.000 and 2.998. The ratio of these amounts of chlorine is essentially 2:3. This is consistent with the law of multiple proportions because, for a fixed mass of iron (1 gram), the masses of chlorine in the other two compounds are in a ratio of small whole numbers.

2.3. A cathode-ray tube consists of a negative electrode, or cathode, and a positive electrode, or anode, in an evacuated tube. Cathode rays travel from the cathode to the anode when a high voltage is turned on. Some of the rays pass through the hole in the anode to form a beam, which is then bent toward positively charged electric plates in the tube. This implies that a cathode ray consists of a beam of negatively charged particles (or electrons) and that electrons are constituents of all matter.

2.4. Millikan performed a series of experiments in which he obtained the charge on the electron by observing how a charged drop of oil falls in the presence and in the absence of an electric field. An atomizer introduces a fine mist of oil drops into the top chamber (Figure 2.6). Several drops happen to fall through a small hole into the lower chamber, where the experimenter follows the motion of one drop with a microscope. Some of these drops have picked up one or more electrons as a result of friction in the atomizer and have become negatively charged. A negatively charged drop will be attracted upward when the experimenter turns on a current to the electric plates. The drop’s upward speed (obtained by timing its rise) is related to its mass-to-charge ratio, from which you can calculate the charge on the electron.

2.5. The nuclear model of the atom is based on experiments of Geiger, Marsden, and Rutherford. Rutherford stated that most of the mass of an atom is concentrated in a positively charged center called the nucleus around which negatively charged electrons move. The nucleus, although it contains most of the mass, occupies only a very small portion of the space of the atom. Most of the alpha particles passed through the metal atoms of the foil undeflected by the lightweight electrons. When an alpha particle does happen to hit a metal-atom nucleus, it is scattered at a wide angle because it is deflected by the massive, positively charged nucleus (Figure 2.8).

2.6. The atomic nucleus consists of two kinds of particles, protons and neutrons. The mass of each is about the same, on the order of 1.67×10^{-27} kg, and about 1800 times that of the electron. An electron has a much smaller mass, on the order of 9.11×10^{-31} kg. The neutron is electrically neutral, but the proton is positively charged. An electron is negatively charged. The charges on the proton and the electron are equal in magnitude.

2.7. Protons (hydrogen nuclei) were discovered as products of experiments involving the collision of alpha particles with nitrogen atoms that resulted in a proton being knocked out of the nitrogen nucleus. Neutrons were discovered as the radiation product of collisions of alpha particles with beryllium atoms. The resulting radiation was discovered to consist of particles having a mass approximately equal to that of a proton and having no charge (neutral).

2.8. Oxygen consists of three different isotopes, each having 8 protons but a different number of neutrons.

2.9. The percentages of the different isotopes in most naturally occurring elements have remained essentially constant over time and in most cases are independent of the origin of the element. Thus, what Dalton actually calculated were average atomic weights (relative weights). He could not weigh individual atoms, but he could find the average mass of one atom relative to the average mass of another.

2.10. A mass spectrometer measures the mass-to-charge ratio of positively charged atoms (and molecules). It produces a mass spectrum, which shows the relative numbers of atoms (fractional abundances) of various masses (isotopic masses). The mass spectrum gives us all the information needed to calculate the atomic weight.

2.11. The atomic weight of an element is the average atomic weight for the naturally occurring element expressed in atomic mass units. The atomic weight would be different elsewhere in the universe if the percentages of isotopes in the element were different from those on earth. Recent research has shown that isotopic abundances actually do differ slightly depending on the location found on earth.

2.12. The element in Group 4A and Period 5 is tin (atomic number 50).

2.13. A metal is a substance or mixture that has characteristic luster, or shine, and is generally a good conductor of heat and electricity.

2.14. The formula for ethane is C_2H_6.

2.15. A molecular formula gives the exact number of different atoms of an element in a molecule. A structural formula is a chemical formula that shows how the atoms are bonded to one another in a molecule.

2.16. Organic molecules contain carbon combined with other elements such as hydrogen, oxygen, and nitrogen. An inorganic molecule is composed of elements other than carbon. Some inorganic molecules that contain carbon are carbon monoxide (CO), carbon dioxide (CO_2), carbonates, and cyanides.

2.17. An ionic binary compound: NaCl; a molecular binary compound: H_2O.

2.18.
a. The elements are represented by B, F, and I.
b. The compounds are represented by A, E, and G.
c. The mixtures are represented by C, D, and H.
d. The ionic solid is represented by A.
e. The gas made up of an element and a compound is represented by C.
f. The mixtures of elements are represented by D and H.
g. The solid element is represented by F.
h. The solids are represented by A and F.
i. The liquids are represented by E, H, and I.

2.19. In the Stock system, CuCl is called copper(I) chloride, and $CuCl_2$ is called copper(II) chloride. One of the advantages of the Stock system is that more than two different ions of the same metal can be named with this system. In the former (older) system, a new suffix other than -*ic* and -*ous* must be established and/or memorized.

2.20. A balanced chemical equation has the numbers of atoms of each element equal on both sides of the arrow. The coefficients are the smallest possible whole numbers.

2.21. The answer is a: 50 p, 69 n, and 48 e^-.

2.22. The answer is d: 65%.

2.23. The answer is c: magnesium hydroxide, $Mg(OH)_2$.

2.24. The answer is b: Li.

■ ANSWERS TO CONCEPT EXPLORATIONS

2.25. **Part I**

a. Average mass = $\dfrac{2.00\text{ g} + 2.00\text{ g} + 2.00\text{ g} + 2.00\text{ g}}{4} = 2.00\text{ g}$

Part II

a. Average mass = $\dfrac{2.00\text{ g} + 1.75\text{ g} + 3.00\text{ g} + 1.25\text{ g}}{4} = 2.00\text{ g}$

b. The average mass of a sphere in the two samples is the same. The average does not represent the individual masses. Also, it does not indicate the variability in the individual masses.

Part III

a. $\dfrac{50\text{ blue spheres}}{1} \times \dfrac{2.00\text{ g}}{1\text{ blue sphere}} = 100.00\text{ g}$

b. If 50 spheres were removed at random, then 50 spheres would remain in the jar. You can use the average mass to calculate the total mass.

$$\frac{50\text{ spheres}}{1} \times \frac{2.00\text{ g}}{1\text{ sphere}} = 100.00\text{ g}$$

c. No, the average mass does not represent the mass of an individual sphere.

d. $\dfrac{80.0\text{ g}}{1} \times \dfrac{1\text{ blue sphere}}{2.00\text{ g}} = 40.0\text{ blue spheres}$

e. $\dfrac{60.0\text{ g}}{1} \times \dfrac{1\text{ sphere}}{2.00\text{ g}} = 30.0\text{ spheres}$

The assumption is that the average mass of a sphere (2.00 g) can be used in the calculation. Also, assume the sample is well mixed.

Part IV

a. For green spheres: $X = \dfrac{3\text{ green}}{3\text{ green} + 1\text{ blue}} = 0.750$

For blue spheres: $X = \dfrac{1\text{ blue}}{3\text{ green} + 1\text{ blue}} = 0.250$

b. Average mass = $(0.750) \times \dfrac{3.00\text{ g}}{1\text{ green sphere}} + (0.250) \times \dfrac{1.00\text{ g}}{1\text{ blue sphere}} = 2.50\text{ g}$

c. The atomic weight of an element is the weighted average calculated as in part (b) of Part IV above, using fractional abundances and individual masses.

2.26. a. Atom A has three protons.

b. The number of protons is the same as the atomic number for that element.

c. Lithium, Li, has atomic number 3.

d. The charge on element A is zero. There are three protons, each +1, and three electrons, each −1. This yields a net charge of zero.

e. The nuclide symbol for A is ${}^{7}_{3}\text{Li}$.

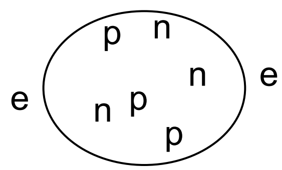
f. Atom B has three protons and thus atomic number 3. It is lithium, with symbol Li.

g. Atom B has three protons and three neutrons. Its mass number is 6. This is different from the mass number of atom A, which is 7.

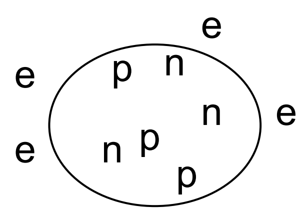
h. Atom B has three protons and three electrons and thus is neutral.

i. The nuclide symbol for B is ${}^{6}_{3}\text{Li}$. The atomic number is 3 and the mass number is 6 for both nuclides.

j.



${}^{6}_{3}\text{Li}^{+}$



${}^{6}_{3}\text{Li}^{-}$

In both cases the mass number is 6 and the atomic number is 3

k. Two different lithium isotopes are depicted, lithium-6 and lithium-7.

l. The mass number of an isotope is the total number of protons and neutrons in its nucleus. Its value is an integer. It is related to the mass of the isotope but not related to the atomic weight, which is a weighted average over the fractional abundances and isotopic masses.

■ ANSWERS TO CONCEPTUAL PROBLEMS

2.27. If atoms were balls of positive charge with the electrons evenly distributed throughout, there would be no massive, positive nucleus to deflect the beam of alpha particles when it is shot at the gold foil.

2.28. Once the subscripts of the compounds in the original chemical equation are changed (the molecule N_2 was changed to the atom N), the substances reacting are no longer the same. Your friend may be able to balance the second equation, but it is no longer the same chemical reaction.

2.29. You could group elements by similar physical properties such as density, mass, color, conductivity, etc., or by chemical properties, such as reaction with air, reaction with water, etc.

2.30. You would name the ions with the formulas XO_4^{2-}, XO_3^{2-}, and XO^{2-} using the name for XO_2^{2-} (excite) as the example to determine the root name of the element X (exc). Thus XO_4^{2-}, with the greatest number of oxygen atoms in the group, would be perexcate; XO_3^{2-} would be excate; and XO^{2-}, with the fewest oxygen atoms in the group, would be hypoexcite.

2.31. a. In each case, the total positive charge and the total negative charge in the compounds must cancel. Therefore, the compounds with the cations X^+, X^{2+}, and X^{5+}, combined with the SO_4^{2-} anion, are X_2SO_4, XSO_4, and $X_2(SO_4)_5$, respectively.

b. You recognize the fact that whenever a cation can have multiple oxidation states (1+, 2+, and 5+ in this case), the name of the compound must indicate the charge. Therefore, the names of the compounds in part (a) would be exy(I) sulfate, exy(II) sulfate, and exy(V) sulfate, respectively.

2.32. a. This model contains three atoms of two different elements (H and O). Therefore, the model is of H_2O.

b. This model represents a crystal that contains two different elements in a 1:1 ratio (K^+ and Cl^-). Therefore, the model represents the ionic compound, KCl.

c. This model contains six atoms, four of which are the same (H), and two others (C and O). Therefore, the model is of CH_3OH.

d. This model contains four atoms of two different elements (N and H). Therefore, the model is of NH_3.

2.33. A potassium-39 atom in this case would contain 19 protons and 20 neutrons. If the charge of the proton were twice that of an electron, it would take twice as many electrons as protons, or 38 electrons, to maintain a charge of zero.

2.34. a. Since the mass of an atom is not due only to the sum of the masses of the protons, neutrons, and electrons, when you change the element in which you are basing the amu, the mass of the amu must change as well.

b. Since the amount of material that makes up a hydrogen atom doesn't change, when the amu gets larger, as in this problem, the hydrogen atom must have a smaller mass in amu.

2.35. a. $2Li + Cl_2 \rightarrow 2LiCl$

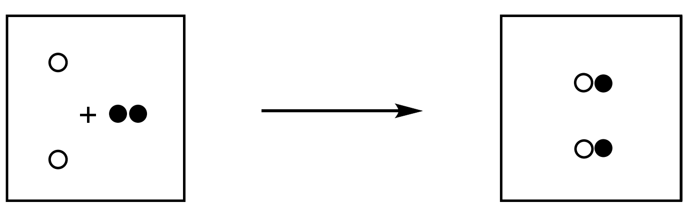
b. $16Na + S_8 \rightarrow 8Na_2S$

c. $2Al + 3I_2 \rightarrow 2AlI_3$

d. $3Ba + N_2 \rightarrow Ba_3N_2$

e. $12V + 5P_4 \rightarrow 4V_3P_5$

2.36.

a. 

b. $2A + B_2 \rightarrow 2AB$

c. Some possible real elements with formula B_2 are F_2, Cl_2, Br_2, and I_2.

■ SOLUTIONS TO PRACTICE PROBLEMS

Note on significant figures: If the final answer to a solution needs to be rounded off, it is given first with one nonsignificant figure, and the last significant figure is underlined. The final answer is then rounded to the correct number of significant figures. In multistep problems, intermediate answers are given with at least one nonsignificant figure; however, only the final answer has been rounded off.

2.37. a. Helium b. Hydrogen c. Palladium d. Strontium

2.38. a. Beryllium b. Silver c. Silicon d. Carbon

2.39. a. K b. S c. Fe d. Mn

2.40. a. Cu b. Ca c. Hg d. Sn

2.41. The mass of the electron is found by multiplying the two values:

$$1.602 \text{ x } 10^{-19} \text{ C} \times \frac{5.64 \times 10^{-12} \text{ kg}}{1 \text{ C}} = 9.0\underline{3}5 \times 10^{-31} \text{ kg} = 9.04 \times 10^{-31} \text{ kg}$$

2.42. The mass of the fluorine atom is found by multiplying the two values:

$$1.602 \times 10^{-19} \text{ C} \times \frac{1.97 \times 10^{-7} \text{ kg}}{1 \text{ C}} = 3.1\underline{5}5 \times 10^{-26} \text{ kg} = 3.16 \times 10^{-26} \text{ kg}$$

2.43. The isotope of atom A is the atom with 18 protons, atom C; the atom that has the same mass number as atom A (37) is atom D.

2.44. The isotope of atom A is the atom with 32 protons, atom D; the atom that has the same mass number as atom A (71) is atom B.

2.45. Each isotope of chlorine (atomic number 17) has 17 protons. Each neutral atom will also have 17 electrons. The number of neutrons for Cl-35 is 35 – 17 = 18 neutrons. The number of neutrons for Cl-37 is 37 – 17 = 20 neutrons.

2.46. Each isotope of nitrogen (atomic number 7) has seven protons. Each neutral atom will also have seven electrons. The number of neutrons for N-14 is 14 – 7 = 7 neutrons. The number of neutrons for N-15 is 15 – 7 = 8 neutrons.

2.47. The element with 11 protons in its nucleus is sodium (Na). The mass number = 11 + 12 = 23. The notation for the nucleus is ${}^{23}_{11}\text{Na}$.

2.48. The element with 34 protons in its nucleus is selenium (Se).
The mass number = 34 + 45 = 79. The notation for the nucleus is ${}^{79}_{34}\text{Se}$.

2.49. Since the atomic ratio of nitrogen to hydrogen is 1:3, divide the atomic weight of N by one-third of the atomic weight of hydrogen to find the relative atomic weight of N.

$$\frac{\text{Atomic weight of N}}{\text{Atomic weight of H}} = \frac{7.933 \text{ g}}{1/3 \text{ x } 1.712 \text{ g}} = \frac{13.9\underline{0}1 \text{ g N}}{1 \text{ g H}} = \frac{13.90}{1}$$

2.50. Since the atomic ratio of hydrogen to sulfur is 2:1, divide the atomic weight of S by one-half of the atomic weight of hydrogen to find the relative atomic weight of S.

$$\frac{\text{Atomic weight of S}}{\text{Atomic weight of H}} = \frac{9.330\text{ g}}{1/2 \text{ x } 0.587\text{ g}} = \frac{31.\underline{7}8\text{ g S}}{1\text{ g H}} = \frac{31.8}{1}$$

2.51. Multiply each isotopic mass by its fractional abundance, and then sum:

$$\begin{array}{llcl} \text{X-63:} & 62.930 \times 0.6909 & = & 43.4\underline{7}83 \\ \text{X-65:} & 64.928 \times 0.3091 & = & \underline{20.0692} \\ & & & 63.5\underline{4}75 \quad = 63.55\text{ amu} \end{array}$$

The element is copper, atomic weight 63.546 amu.

2.52. Multiply each isotopic mass by its fractional abundance, and then sum:

$$\begin{array}{lcl} 49.9472 \times 0.002500 & = & 0.124868 \\ 50.9440 \times 0.9975 & = & \underline{50.81664} \\ & = & 50.9\underline{4}150 \quad = 50.94\text{ amu} \end{array}$$

The atomic weight of this element is 50.94 amu. The element is vanadium (V).

2.53. Multiply each isotopic mass by its fractional abundance, and then sum:

$$\begin{array}{lcl} 38.964 \times 0.9326 & = & 36.3\underline{3}78 \\ 39.964 \times 1.00 \times 10^{-4} & = & 0.00399\underline{6}4 \\ 40.962 \times 0.0673 & = & \underline{2.75674} \\ & = & 39.0\underline{9}853 \quad = 39.10\text{ amu} \end{array}$$

The atomic weight of this element is 39.10 amu. The element is potassium (K).

2.54. Multiply each isotopic mass by its fractional abundance, and then sum:

$$\begin{array}{lcl} 27.977 \times 0.9221 & = & 25.7\underline{9}8 \\ 28.976 \times 0.0470 & = & 1.3\underline{6}2 \\ 29.974 \times 0.0309 & = & \underline{0.9262} \\ & = & 28.0\underline{8}6 \quad = 28.09\text{ amu} \end{array}$$

The atomic weight of this element is 28.09 amu. The element is silicon (Si).

2.55. According to the picture, there are 20 atoms, 5 of which are brown and 15 of which are green. Using the isotopic masses in the problem, the atomic weight of element X is

$$\frac{5}{20}(23.02\text{ amu}) + \frac{15}{20}(25.147\text{ amu}) = 5.75\underline{5} + 18.86\underline{0}2 = 24.61\underline{5}2 = 24.615\text{ amu}$$

2.56. According to the picture, there are 24 atoms, 8 of which are blue and 16 of which are orange. Using the isotopic masses in the problem, the atomic weight of element X is

$$\frac{8}{24}(47.621\text{ amu}) + \frac{16}{24}(51.217\text{ amu}) = 15.87\underline{3}7 + 34.14\underline{4}7 = 50.01\underline{8}4 = 50.018\text{ amu}$$

2.57. a. C: Group 4A, Period 2; nonmetal

b. Po: Group 6A, Period 6; metal

c. Cr: Group 6B, Period 4; metal

d. Mg: Group 2A, Period 3; metal

e. B: Group 3A, Period 2; metalloid

2.58. a. V: Group 5B, Period 4; metal

b. Rb: Group 1A, Period 5; metal

c. B: Group 3A, Period 2; metalloid

d. I: Group 7A, Period 5; nonmetal

e. He: Group 8A, Period 1; nonmetal

2.59. a.Tellurium b. Aluminum

2.60. a. Bismuth b. Beryllium

2.61. Examples are:

a. O (oxygen)

b. F (fluorine)

c. Fe (iron)

d. Ce (cerium)

2.62. Examples are:

a. Ti (titanium)

b. Li (lithium)

c. S (sulfur)

d. U (uranium)

2.63. They are different in that the solid sulfur consists of S_8 molecules, whereas the hot vapor consists of S_2 molecules. The S_8 molecules are four times as heavy as the S_2 molecules. Hot sulfur is a mixture of S_8 and S_2 molecules, but at high enough temperatures only S_2 molecules are formed. Both hot sulfur and solid sulfur consist of molecules with only sulfur atoms.

2.64. They are different in that the solid phosphorus consists of P_4 molecules, whereas the hot vapor consists of P_2 molecules. The P_4 molecules are twice as heavy as the P_2 molecules. Hot phosphorus is a mixture of P_4 and P_2 molecules above the boiling point, but at high temperatures only P_2 molecules are formed. Both solid phosphorus and phosphorus vapor consist of molecules with only phosphorus atoms.

2.65. The number of nitrogen atoms in the 4.19-g sample of N_2O is

$$5.73 \times 10^{22}\ N_2O \text{ molecules} \times \frac{2 \text{ N atoms}}{1\ N_2O \text{ molecule}} = 1.1\underline{4}6 \times 10^{23} \text{ N atoms} = 1.15 \times 10^{23} \text{ N atoms}$$

The number of nitrogen atoms in 2.67 g of N_2O is

$$2.67 \text{ g } N_2O \times \frac{1.146 \times 10^{23} \text{ N atoms}}{4.19 \text{ g } N_2O} = 7.3\underline{0}3 \times 10^{22} \text{ N atoms} = 7.30 \times 10^{22} \text{ N atoms}$$

2.66. Since each HNO_3 molecule contains one N atom, in 4.30×10^{22} HNO_3 molecules there are 4.30 x 10^{22} N atoms. The number of oxygen atoms in 61.0 g of HNO_3 is obtained as follows.

$$61.0 \text{ g } HNO_3 \times \frac{4.30 \times 10^{22}\ HNO_3 \text{ molecules}}{4.50 \text{ g } HNO_3} \times \frac{3 \text{ O atoms}}{1\ HNO_3 \text{ molecule}}$$

$$= 1.7\underline{4}9 \times 10^{24} \text{ O atoms} = 1.75 \times 10^{24} \text{ O atoms}$$

2.67. $1.2 \times 10^{23} \text{ H atoms} \times \frac{1\ NH_3 \text{ molecule}}{3 \text{ H atoms}} = 4.0 \times 10^{22}\ NH_3 \text{ molecules}$

2.68. $4.2 \times 10^{23} \text{ H atoms} \times \frac{1\ C_2H_5OH \text{ molecule}}{6 \text{ H atoms}} = 7.0 \times 10^{22}\ C_2H_5OH \text{ molecules}$

2.69. a. N_2H_4
b. H_2O_2
c. C_3H_8O
d. PCl_3

2.70. a. $C_3H_8O_3$
b. Si_2H_6
c. NH_3O
d. SF_4

2.71. a. PCl_5
b. NO_2
c. $C_3H_6O_2$

2.72. a. H_2SO_4
b. C_6H_6
c. C_3H_6O

2.73. $\frac{1 \text{ Fe atom}}{1\ Fe(NO_3)_2 \text{ unit}} \times \frac{1\ Fe(NO_3)_2 \text{ unit}}{2\ NO_3^- \text{ ions}} \times \frac{1\ NO_3^- \text{ ion}}{3 \text{ O atoms}} = \frac{1 \text{ Fe atom}}{6 \text{ O atoms}} = \frac{1}{6}$

Thus, the ratio of iron atoms to oxygen atoms is one Fe atom to six O atoms.

2.74. $$\frac{1\ PO_4^{3-}\ \text{ion}}{1\ (NH_4)_3PO_4\ \text{unit}} \times \frac{4\ \text{O atoms}}{1\ PO_4^{3-}\ \text{ion}} \times \frac{1\ (NH_4)_3PO_4\ \text{unit}}{3\ NH_4^+\ \text{units}} \times \frac{1\ NH_4^+\ \text{unit}}{1\ \text{N atom}} = \frac{4\ \text{O atoms}}{3\ \text{N atoms}} = \frac{4}{3}$$

Thus, the ratio of oxygen atoms to nitrogen atoms is four O atoms to three N atoms.

2.75. a. $Fe(CN)_3$

b. K_2CO_3

c. Li_3N

d. Ca_3P_2

2.76. a. Co_3N_2

b. $(NH_4)_3PO_4$

c. Na_2SO_3

d. $Fe(OH)_3$

2.77. a. Na_2SO_4: sodium sulfate (Group 1A forms only 1+ cations.)

b. Na_3N: sodium nitride (Group 2A forms only 1+ cations.)

c. CuCl: copper(I) chloride (Group 1B forms 1+ and 2+ cations.)

d. Cr_2O_3: chromium(III) oxide (Group 6B forms numerous oxidation states.)

2.78. a. CaO: calcium oxide (Group 2A forms only 2+ cations.)

b. Mn_2O_3: manganese(III) oxide (Group 7B forms numerous oxidation states.)

c. NH_4HCO_3: ammonium bicarbonate or ammonium hydrogen carbonate.

d. $Cu(NO_3)_2$: copper(II) nitrate (Group 1B forms 1+ and 2+ cations.)

2.79. a. Iron(III) phosphate: $FePO_4$ (Phosphate is in Table 2.6.)

b. Potassium sulfide: K_2S (Group 1A ions form 1+ cations and sulfide is in Table 2.4)

c. Magnesium carbonate: $MgCO_3$ (Group 2A ions form 2+ cations; carbonate is in Table 2.6.)

d. Manganese(II) sulfite: $MnSO_3$ (Sulfite is in Table 2.6.)

2.80. a. Sodium thiosulfate: $Na_2S_2O_3$ (The $S_2O_3^{2-}$ is in Table 2.6.)

b. Copper(II) hydroxide: $Cu(OH)_2$ (Two OH^- ions must be used to balance Cu^{2+}.)

c. Calcium hydrogen carbonate: $Ca(HCO_3)_2$ (The HCO_3^- ion is in Table 2.6.)

d. Chromium(III) phosphide: CrP (Both ions have charges of 3-.)

2.81. a. Molecular

b. Ionic

c. Molecular

d. Ionic

2.82. a. Molecular
b. Molecular
c. Molecular
d. Ionic

2.83. a. Hydrogen iodide
b. Diphosphorus pent(a)oxide
c. Arsenic trihydride
d. Chlorine dioxide

2.84. a. Dinitrogen difluoride
b. Carbon tetrafluoride
c. Dinitrogen pent(a)oxide
d. Tetr(a)arsenic hex(a)oxide

2.85. a. NBr_3
b. XeF_6
c. CO
d. Cl_2O_5

2.86. a. P_2O_5
b. NO_2
c. N_2F_4
d. BF_3

2.87. a. Selenium trioxide
b. Disulfur dichloride
c. Carbon monoxide

2.88. a. Nitrogen trifluoride
b. Diphosphorus tetrahydride
c. Oxygen difluoride

2.89. a. Sulfurous acid: H_2SO_3
b. Hyponitrous acid: $H_2N_2O_2$
c. Disulfurous acid: $H_2S_2O_5$
d. Arsenic acid: H_3AsO_4

2.90. a. Selenous acid: H_2SeO_3

b. Chlorous acid: $HClO_2$

c. Hypoiodous acid: HIO

d. Nitric acid: HNO_3

2.91. $Na_2SO_4 \bullet 10H_2O$ is sodium sulfate decahydrate.

2.92. $NiSO_4 \bullet 6H_2O$ is nickel(II) sulfate hexahydrate.

2.93. Iron(II) sulfate heptahydrate is $FeSO_4 \bullet 7H_2O$.

2.94. Cobalt(II) chloride hexahydrate is $CoCl_2 \bullet 6H_2O$.

2.95. $$1\ Ca(NO_3)_2 \times \frac{6\text{ O atoms}}{1\ Ca(NO_3)_2\text{ unit}} + 1\ Na_2CO_3 \times \frac{3\text{ O atoms}}{1\ Na_2CO_3\text{ unit}} = 9\text{ O atoms}$$

2.96. $$2\ PbO \times \frac{1\text{ O atom}}{1\text{ PbO unit}} + 2\ SO_2 \times \frac{2\text{ O atoms}}{1\ SO_2\text{ unit}} = 6\text{ O atoms}$$

The equation is not balanced as written. There are currently only 2 oxygen atoms on the left side.

2.97. a. Balance: $Sn + NaOH \rightarrow Na_2SnO_2 + H_2$

If Na is balanced first by writing a 2 in front of NaOH, the entire equation is balanced.

$$Sn + 2NaOH \rightarrow Na_2SnO_2 + H_2$$

b. Balance: $Al + Fe_3O_4 \rightarrow Al_2O_3 + Fe$

First balance O (it appears once on each side) by writing a 3 in front of Fe_3O_4 and a 4 in front of Al_2O_3:

$$Al + 3Fe_3O_4 \rightarrow 4Al_2O_3 + Fe$$

Now balance Al against the 8 Al's on the right and Fe against the 9 Fe's on the left:

$$8Al + 3Fe_3O_4 \rightarrow 4Al_2O_3 + 9Fe$$

c. Balance: $CH_3OH + O_2 \rightarrow CO_2 + H_2O$

First balance H (it appears once on each side) by writing a 2 in front of H_2O:

$$CH_3OH + O_2 \rightarrow CO_2 + 2H_2O$$

To avoid fractional coefficients for O, multiply the equation by 2:

$$2CH_3OH + 2O_2 \rightarrow 2CO_2 + 4H_2O$$

Finally, balance O by changing $2O_2$ to "$3O_2$"; this balances the entire equation:

$$2CH_3OH + 3O_2 \rightarrow 2CO_2 + 4H_2O$$

d. Balance: $P_4O_{10} + H_2O \rightarrow H_3PO_4$

First balance P (it appears once on each side) by writing a 4 in front of H_3PO_4:

$$P_4O_{10} + H_2O \rightarrow 4H_3PO_4$$

Finally, balance H by writing a 6 in front of H_2O; this balances the entire equation:

$$P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$$

e. Balance: $PCl_5 + H_2O \rightarrow H_3PO_4 + HCl$

First balance Cl (it appears once on each side) by writing a 5 in front of HCl:

$$PCl_5 + H_2O \rightarrow H_3PO_4 + 5HCl$$

Finally, balance H by writing a 4 in front of H_2O; this balances the entire equation:

$$PCl_5 + 4H_2O \rightarrow H_3PO_4 + 5HCl$$

2.98. a. Balance: $Ca_3(PO_4)_2 + H_3PO_4 \rightarrow Ca(H_2PO_4)_2$

First balance Ca (appears only once on each side) by writing a 3 in front of $Ca(H_2PO_4)_2$;

$$Ca_3(PO_4)_2 + H_3PO_4 \rightarrow 3Ca(H_2PO_4)_2$$

Finally, balance P by writing a 4 in front of H_3PO_4; this balances the entire equation:

$$Ca_3(PO_4)_2 + 4H_3PO_4 \rightarrow 3Ca(H_2PO_4)_2$$

b. Balance: $MnO_2 + HCl \rightarrow MnCl_2 + Cl_2 + H_2O$

First balance O (appears only once on each side) by writing a 2 in front of H_2O:

$$MnO_2 + HCl \rightarrow MnCl_2 + Cl_2 + 2H_2O$$

Finally, balance H and Cl by writing a 4 in front of HCl to balance the entire equation:

$$MnO_2 + 4HCl \rightarrow MnCl_2 + Cl_2 + 2H_2O$$

c. Balance: $Na_2S_2O_3 + I_2 \rightarrow NaI + Na_2S_4O_6$

First balance S by writing a 2 in front of $Na_2S_2O_3$:

$$2Na_2S_2O_3 + I_2 \rightarrow NaI + Na_2S_4O_6$$

Finally, balance Na by writing a 2 in front of NaI; this balances the entire equation:

$$2Na_2S_2O_3 + I_2 \rightarrow 2NaI + Na_2S_4O_6$$

d. Balance: $Al_4C_3 + H_2O \rightarrow Al(OH)_3 + CH_4$

First balance Al with a 4 in front of $Al(OH)_3$, and balance C with a 3 in front of CH_4:

$$Al_4C_3 + H_2O \rightarrow 4Al(OH)_3 + 3CH_4$$

Finally, balance H and O with a 12 in front of H_2O; this balances the entire equation:

$$Al_4C_3 + 12H_2O \rightarrow 4Al(OH)_3 + 3CH_4$$

e. Balance: $NO_2 + H_2O \rightarrow HNO_3 + NO$

First balance H with a 2 in front of HNO_3:

$$NO_2 + H_2O \rightarrow 2HNO_3 + NO$$

Finally, balance N with a 3 in front of NO_2; this balances the entire equation:

$$3NO_2 + H_2O \rightarrow 2HNO_3 + NO$$

2.99. Balance: $Ca_3(PO_4)_2(s) + H_2SO_4(aq) \rightarrow CaSO_4(s) + H_3PO_4(aq)$

Balance Ca first with a 3 in front of $CaSO_4$:

$$Ca_3(PO_4)_2(s) + H_2SO_4(aq) \rightarrow 3CaSO_4(s) + H_3PO_4(aq)$$

Next, balance the P with a 2 in front of H_3PO_4:

$$Ca_3(PO_4)_2(s) + H_2SO_4(aq) \rightarrow 3CaSO_4(s) + 2H_3PO_4(aq)$$

Finally, balance the S with a 3 in front of H_2SO_4; this balances the equation:

$$Ca_3(PO_4)_2(s) + 3H_2SO_4(aq) \rightarrow 3CaSO_4(s) + 2H_3PO_4(aq)$$

2.100. Balance: $Na(s) + H_2O(l) \rightarrow NaOH(aq) + H_2(g)$

Balance H first with a 2 in front of H_2O and NaOH:

$$Na + 2H_2O \rightarrow 2NaOH + H_2$$

Then, balance Na with a 2 in front of Na; this balances the equation:

$$2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$$

2.101. Balance: $NH_4Cl(aq) + Ba(OH)_2(aq) \rightarrow NH_3(g) + BaCl_2(aq) + H_2O(l)$

Balance O first with a 2 in front of H_2O:

$$NH_4Cl + Ba(OH)_2 \rightarrow NH_3 + BaCl_2 + 2H_2O$$

Balance H with a 2 in front of NH_4Cl and a 2 in front of NH_3; this balances the equation:

$$2NH_4Cl(aq) + Ba(OH)_2(aq) \xrightarrow{\Delta} 2NH_3(g) + BaCl_2(aq) + 2H_2O(l)$$

2.102. Balance: $PbS(s) + PbSO_4(s) \rightarrow Pb(l) + SO_2(g)$

Balance S first with a 2 in front of SO_2:

$$PbS + PbSO_4 \rightarrow Pb + 2SO_2$$

Balance Pb with a 2 in front of Pb; this balances the equation:

$$PbS(s) + PbSO_4(s) \xrightarrow{\Delta} 2Pb(l) + 2SO_2(g)$$

■ SOLUTIONS TO GENERAL PROBLEMS

2.103. Calculate the ratio of oxygen for 1 g (fixed amount) of nitrogen in both compounds:

$$\text{A:} \quad \frac{2.755 \text{ g O}}{1.206 \text{ g N}} = \frac{2.28\underline{4}4 \text{ g O}}{1 \text{ g N}} \qquad \text{B:} \quad \frac{4.714 \text{ g O}}{1.651 \text{ g N}} = \frac{2.85\underline{5}2 \text{ g O}}{1 \text{ g N}}$$

Next, find the ratio of oxygen per gram of nitrogen for the two compounds.

$$\frac{\text{g O in B/1 g N}}{\text{g O in A/1 g N}} = \frac{2.85\underline{5}2 \text{ g O}}{2.28\underline{4}4 \text{ g O}} = \frac{1.24\underline{9}8 \text{ g O}}{1 \text{g O}}$$

B contains 1.25 times as many O atoms as A does (there are five O's in B for every four O's in A).

2.104. Calculate the ratio of oxygen for 1 g (fixed amount) of sulfur in both compounds:

$$\text{A:} \quad \frac{1.811 \text{ g O}}{1.210 \text{ g S}} = \frac{1.49\underline{6}6 \text{ g O}}{1 \text{ g S}} \qquad \text{B:} \quad \frac{1.779 \text{ g O}}{1.783 \text{ g S}} = \frac{0.997\underline{7}5 \text{ g O}}{1 \text{ g S}}$$

Next, find the ratio of oxygen per gram of sulfur for the two compounds.

$$\frac{\text{g O in A/1 g S}}{\text{g O in B/1 g S}} = \frac{1.49\underline{6}6 \text{ g O}}{0.997\underline{7}5 \text{ g O}} = \frac{1.49\underline{9}9 \text{ g O}}{1 \text{g O}}$$

A contains 1.50 times as many O atoms as B (there are three O's in A for every two O's in B).

2.105. The smallest difference is between -4.80×10^{-19} C and -6.40×10^{-19} C and is equal to -1.60×10^{-19} C. If this charge is equivalent to one electron, the number of excess electrons on a drop may be found by dividing the negative charge by the charge of one electron.

$$\text{Drop 1:} \quad \frac{-4.80 \times 10^{-19} \text{ C}}{-1.60 \times 10^{-19} \text{ C}} = 3.0\underline{0} \cong 3 \text{ electrons}$$

$$\text{Drop 2:} \quad \frac{-6.40 \times 10^{-19} \text{ C}}{-1.60 \times 10^{-19} \text{ C}} = 4.0\underline{0} \cong 4 \text{ electrons}$$

$$\text{Drop 3:} \quad \frac{-9.60 \times 10^{-19} \text{ C}}{-1.60 \times 10^{-19} \text{ C}} = 6.0\underline{0} \cong 6 \text{ electrons}$$

$$\text{Drop 4:} \quad \frac{-1.28 \times 10^{-18} \text{ C}}{-1.60 \times 10^{-19} \text{ C}} = 8.0\underline{0} \cong 8 \text{ electrons}$$

2.106. The smallest difference in charge for the oil drop is $-1.85 \text{ x } 10^{-19}$; assume this is the fundamental unit of negative charge. Use this to divide into each drop's charge:

$$\text{Drop 1:} \quad \frac{-5.55 \times 10^{-19} \text{ C}}{-1.85 \times 10^{-19} \text{ C}} = 3.\underline{0} \cong 3 \text{ electrons}$$

$$\text{Drop 2:} \quad \frac{-9.25 \times 10^{-19} \text{ C}}{-1.85 \times 10^{-19} \text{ C}} = 5.\underline{0} \cong 5 \text{ electrons}$$

$$\text{Drop 3:} \quad \frac{-1.11 \times 10^{-18} \text{ C}}{-1.85 \times 10^{-19} \text{ C}} = 6.\underline{0} \cong 6 \text{ electrons}$$

Drop 4: $\dfrac{-1.48 \times 10^{-18}\ \mathrm{C}}{-1.85 \times 10^{-19}\ \mathrm{C}} = 8.\underline{0} \cong 8$ electrons

2.107. For the Eu atom to be neutral, the number of electrons must equal the number of protons, so a neutral europium atom has 63 electrons. The 3+ charge on the Eu^{3+} indicates there are three more protons than electrons, so the number of electrons is 63 – 3 = 60.

2.108. For the Cs atom to be neutral, the number of electrons must equal the number of protons, so a neutral cesium atom has 55 electrons. The 1+ charge on the Cs^{+} indicates there is one more proton than electrons, so the number of electrons is 55 – 1 = 54.

2.109. The number of protons = mass number – number of neutrons = 81 – 46 = 35. The element with Z = 35 is bromine (Br).

The ionic charge = number of protons – number of electrons = 35 – 36 = –1.

Symbol: ${}^{81}_{35}\mathrm{Br}^{-}$.

2.110. The number of protons = mass number – number of neutrons = 74 – 51 = 23. The element with Z = 23 is vanadium (V).

The ionic charge = number of protons – number of electrons = 23 – 18 = +5.

Symbol: ${}^{74}_{23}\mathrm{V}^{5+}$.

2.111. The sum of the fractional abundances must equal 1. Let y equal the fractional abundance of ^{151}Eu. Then the fractional abundance of ^{153}Eu equals $(1 - y)$. We write one equation in one unknown:

Atomic weight = 151.9641 = 150.9196y + 152.9209$(1 - y)$

-0.9598 = -2.0013 y

$$y = \frac{-0.9568}{-2.0013} = 0.478\underline{0}9$$

The fractional abundance of ^{151}Eu = 0.478$\underline{0}$9 = 0.4781.

The fractional abundance of ^{153}Eu = 1 – 0.478$\underline{0}$9 = 0.521$\underline{9}$1 = 0.5219.

2.112. As in the previous problem, the sum of the fractional abundances must equal 1. Thus, the abundance of one isotope can be expressed in terms of the other. Let y equal the fractional abundance of Ag-107. Then the fractional abundance of Ag-109 equals $(1 - y)$. We can write one equation in one unknown:

Atomic weight = 107.87 = 106.91y + 108.90$(1 - y)$

107.87 = 108.90 – 1.99y

$$y = \frac{108.90 - 107.87}{1.99} = 0.51\underline{7}58$$

The fractional abundance of Ag-107 = 0.51$\underline{7}$58 = 0.518.

The fractional abundance of Ag-109 = 1 – 0.51$\underline{7}$58 = 0.48$\underline{2}$41 = 0.482.

2.113. a. Bromine, Br

b. Hydrogen, H

c. Niobium, Nb

d. Fluorine, F

2.114. a. Bromine, Br

b. Mercury, Hg

c. Aluminum, Al

d. Potassium, K

2.115. a. Chromium(III) ion

b. Lead(IV) ion

c. Titanium(II) ion

d. Copper(II) ion

2.116. a. Manganese(II) ion

b. Nickel(II) ion

c. Cobalt(II) ion

d. Iron(III) ion

2.117. All possible ionic compounds: Na_2SO_4, NaCl, $CoSO_4$, and $CoCl_2$.

2.118. All possible ionic compounds: MgS, $Mg(NO_3)_2$, Cr_2S_3, and $Cr(NO_3)_3$.

2.119. a. Tin(II) phosphate

b. Ammonium nitrite

c. Magnesium hydroxide

d. Nickel(II) sulfite

2.120. a. Copper(II) nitrite

b. Ammonium phosphide

c. Potassium sulfite

d. Mercury(II) nitride

2.121. a. Hg_2S [Mercury(I) exists as the polyatomic Hg_2^{2+} ion (Table 2.6).]

b. $Co_2(SO_3)_3$

c. $(NH_4)_2Cr_2O_7$

d. AlF_3

2.122. a. H_2O_2

b. $Mg_3(PO_4)_2$

c. Pb_3P_4

d. $CaCO_3$

2.123. a. Arsenic tribromide

b. Hydrogen telluride (dihydrogen telluride)

c. Diphosphorus pent(a)oxide

d. Silicon dioxide

2.124. a. Chlorine tetrafluoride

b. Carbon disulfide

c. Phosphorus trifluoride

d. Sulfur hexafluoride

2.125. a. Balance the C and H first:

$$C_2H_6 + O_2 \rightarrow 2CO_2 + 3H_2O$$

Avoid a fractional coefficient for O on the left by doubling all coefficients except O_2's, and then balance the O's:

$$2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$$

b. Balance the P first:

$$P_4O_6 + H_2O \rightarrow 4H_3PO_3$$

Then balance the O (or H), which also gives the H (or O) balance:

$$P_4O_6 + 6H_2O \rightarrow 4H_3PO_3$$

c. Balancing the O first is the simplest approach. (Starting with K and Cl and then proceeding to O will cause the initial coefficient for $KClO_3$ to be changed in balancing O last.)

$$4KClO_3 \rightarrow KCl + 3KClO_4$$

d. Balance the N first:

$$(NH_4)_2SO_4 + NaOH \rightarrow 2NH_3 + H_2O + Na_2SO_4$$

Then balance the Na, followed by O; this also balances the H:

$$(NH_4)_2SO_4 + 2NaOH \rightarrow 2NH_3 + 2H_2O + Na_2SO_4$$

e. Balance the N first:

$$2NBr_3 + NaOH \rightarrow N_2 + NaBr + HOBr$$

Note that NaOH and HOBr each have one O and that NaOH and NaBr each have one Na; thus the coefficients of all three are equal; from $2NBr_3$, this coefficient must be $6Br/2 = 3$:

$$2NBr_3 + 3NaOH \rightarrow N_2 + 3NaBr + 3HOBr$$

2.126. a. Balance the Na first:

$$2NaOH + H_2CO_3 \rightarrow Na_2CO_3 + H_2O$$

Then balance the H; this also balances the O:

$$2NaOH + H_2CO_3 \rightarrow Na_2CO_3 + 2H_2O$$

b. Balance the Cl with a 4 in front of the HCl; then balance the O's with a 2 in front of H_2O:

$$SiCl_4 + 2H_2O \rightarrow SiO_2 + 4HCl$$

c. Balance the O first with an 8 in front of CO; then balance the C with an 8 in front of C:

$$Ca_3(PO_4)_2 + 8C \rightarrow Ca_3P_2 + 8CO$$

d. Balance the O by multiplying O_2 by 3 and doubling both products to give a total of six O's on both sides of the equation:

$$H_2S + 3O_2 \rightarrow 2SO_2 + 2H_2O$$

Then balance H and S with a 2 in front of H_2S:

$$2H_2S + 3O_2 \rightarrow 2SO_2 + 2H_2O$$

e. Since the reaction has two N's on the left and one N on the right, try a tentative N-balancing by writing a 2 in front of NO_2:

$$N_2O_5 \rightarrow 2NO_2 + O_2$$

Now there are five O's on the left and six O's on the right. Balance the O's with a ½ in front of O_2; this gives

$$N_2O_5 \rightarrow 2NO_2 + \tfrac{1}{2}\, O_2$$

Because it is customary to balance chemical equations with whole number coefficients, multiplying each of the reactant and product coefficients by 2 yields the desired result:

$$2N_2O_5 \rightarrow 4NO_2 + O_2$$

2.127. Let: x = number of protons. Then $1.55x$ is the number of neutrons. Since the mass number is 235, you get

$$235 = x + 1.55x = 2.55x$$

Thus, $x = 92.\underline{1}57$, or 92. The element is uranium (U). Since the ion has a +4 charge, there are 88 electrons.

2.128. Let: x = number of protons. Then $1.30x$ is the number of neutrons. Since the mass number is 85, you get

$$85 = x + 1.30x = 2.30x$$

Thus, $x = 36.95$, or 37. The element is rubidium (Rb). Since the ion has a +1 charge, there are 36 electrons.

2.129. The average atomic weight would be

Natural carbon: $12.011 \times 1/2$	=	$6.00\underline{5}500$
Carbon-13: $13.00335 \times 1/2$	=	$\underline{6.501675}$
Average	=	$12.50\underline{7}175$

The average atomic weight of the sample is 12.507 amu.

2.130. The average atomic weight would be

Natural chlorine: $35.4527 \times 1/2 = 17.7263500$

Chlorine-35: $34.96885 \times 1/2 = \underline{17.4844250}$

Average $= 35.2107750$

The average atomic weight of the sample is 35.2108 amu.

2.131. The provisional name for element 117 is ununseptium. The name is arrived at by replacing each of the digits of the atomic number with a root, *un* for 1 and *sept* for 7, and then adding the suffice *–ium*.

2.132. The target element was Bk-249 and the beam element was Ca-48.

■ SOLUTIONS TO STRATEGY PROBLEMS

2.133. SO_3, sulfur trioxide; NO_2, nitrogen dioxide; PO_4^{3-}, phosphate ion;

N_2, nitrogen; $Mg(OH)_2$, magnesium hydroxide

2.134. The unknown metal, M, is a cation with a 2+ charge. An example is magnesium.

2.135. The name of the product is aluminum oxide. The reaction is

$$4Al(s) + 3O_2(g) \rightarrow 2Al_2O_3(s)$$

2.136. $4NH_3(g) + 5O_2(g) \rightarrow 4NO(g) + 6H_2O(l)$

2.137. $(0.7721)(37.24 \text{ amu}) + (1 - 0.7721)(x) = 37.45 \text{ amu}$

$$x = \frac{37.45 - (0.7721)(37.24)}{(1 - 0.7721)} = 38.\underline{1}61 \text{ amu} = 38.2 \text{ amu}$$

2.138. Sulfur has atomic number 16, so S^{2+} has 16 minus 2 or 14 electrons, which is the number of neutrons in the unknown ion. The number of protons is 27 minus 14 = 13, which is the atomic number, so the element is aluminum. The number of electrons is 13 – 3 = 10.

2.139. $6.5 \times 10^{20} \text{ formula units } CaCl_2 \times \frac{3 \text{ ions}}{1 \text{ formula unit}} = 1.95 \times 10^{21} \text{ ions}$

2.140. $MgCO_3$, magnesium carbonate

Mg_3N_2, magnesium nitride

$Cr_2(CO_3)_3$, chromium(III) carbonate

CrN, chromium(III) nitride

2.141. SO_3, sulfur trioxide

HNO_2, nitrous acid

Mg_3N_2, magnesium nitride

$HI(aq)$, hydroiodic acid

$Cu_3(PO_4)_2$, copper(II) phosphate

$CuSO_4 \bullet 5H_2O$, copper(II) sulfate pentahydrate

2.142. HIO_3, iodic acid

$NaIO_4$, sodium periodate

$Mg(IO_2)_2$, magnesium iodite

$Fe(IO_2)_3$, iron(III) iodite

2.143. a. An aqueous solution of lead(II) chloride is mixed with an aqueous solution of sodium sulfide to form an aqueous solution of sodium chloride and a lead(II) sulfide precipitate.

b. When gaseous sulfur trioxide is passed into liquid water an aqueous solution of sulfuric acid is formed.

c. Graphite is combusted in an oxygen atmosphere to form gaseous carbon dioxide.

d. Gaseous hydrogen iodide forms when hydrogen gas and gaseous iodine are mixed.

2.144. $Cl_2(g) + 2K(s) \rightarrow 2KCl(s)$

2.145. Each $^1H_2{}^{16}O$ molecule contains 8 neutrons, 10 protons, and 10 electrons.

\# neutrons in 6.0×10^{23} molecules = $8 \times (6.0 \times 10^{23}) = 4.8 \times 10^{24}$ neutrons

\# protons in 6.0×10^{23} molecules = $10 \times (6.0 \times 10^{23}) = 6.0 \times 10^{24}$ protons

Because the water molecules are neutrally charged there must also be 6.0×10^{24} electrons.

2.146. a. hydrogen chloride

b. hydrobromic acid

c. hydrogen fluoride

d. nitric acid

2.147. We are told that a ^{238}U nucleus decays by emitting a ^4He atom while the remaining subatomic particles remain intact. In equation form, we can write this as follows:

$$^{238}_{92}U \rightarrow {}^{4}_{2}He + {}^{y}_{z}X$$

Such nuclear decay processes must follow conservation laws. In this regard, the total mass number of the reactants must equal that of the products. It follows that if 238 = 4 + y, then y = 234. Likewise, the total atomic number of the reactants must equal that of the products. Again, if 92 = 2 + z, then z = 90. The symbol for the other nuclide being produced in this decay process is $^{234}_{90}Th$. Thorium (Th) is produced.

2.148. $2\ H_3PO_4(aq) + 3\ Mg(OH)_2(s) \rightarrow 6\ H_2O(l) + Mg_3(PO_4)_2(s)$

■ SOLUTIONS TO CAPSTONE PROBLEMS

2.149. The spheres occupy a diameter of 2 × 1.86 Å = 3.72 Å. The line of sodium atoms would stretch a length of

$$\text{Length} = \frac{3.72\ \text{Å}}{1\ \text{Na atom}} \times 2.619 \times 10^{22}\ \text{Na atoms} = 9.7\underline{4}2 \times 10^{22}\ \text{Å}$$

Now, convert this to miles.

$$9.7\underline{4}2 \times 10^{22}\ \text{Å} \times \frac{10^{-10}\ \text{m}}{1\ \text{Å}} \times \frac{1\ \text{mile}}{1.609 \times 10^{3}\ \text{m}} = 6.0\underline{5}5 \times 10^{9}\ \text{miles} = 6.06 \times 10^{9}\ \text{miles}$$

2.150. The spheres occupy a diameter of 2 × 0.99 Å = 1.98 Å. The line of chlorine atoms would stretch a length of

$$\text{Length} = \frac{1.98\ \text{Å}}{1\ \text{Cl atom}} \times \frac{1.699 \text{ x } 10^{22}\ \text{Cl atoms}}{1.000\ \text{g Cl}} \times 0.\underline{5}\ \text{g Cl} = \underline{1}.682 \times 10^{22}\ \text{Å}$$

Now, convert this to miles.

$$\underline{1}.682 \times 10^{22}\ \text{Å} \times \frac{10^{-10}\ \text{m}}{1\ \text{Å}} \times \frac{1\ \text{mile}}{1.609 \times 10^{3}\ \text{m}} = \underline{1}.045 \times 10^{9}\ \text{miles} = 1 \times 10^{9}\ \text{miles}$$

2.151. $NiSO_4{\bullet}7H_2O(s) \rightarrow NiSO_4{\bullet}6H_2O(s) + H_2O(g)$

[8.753 g] = [8.192 g + (8.753 − 8.192 = 0.561 g)]

The 8.192 g of $NiSO_4{\bullet}6H_2O$ must contain 6 × 0.561 = 3.366 g H_2O.

Mass of anhydrous $NiSO_4$ = 8.192 g $NiSO_4{\bullet}6H_2O$ – 3.366 g $6H_2O$ = 4.826 g $NiSO_4$

2.152. The formula for cobalt(II) sulfate heptahydrate is $CoSO_4{\bullet}7H_2O$ and the formula for cobalt(II) sulfate monohydrate is $CoSO_4{\bullet}H_2O$. The equation for the described heating process is

$CoSO_4{\bullet}7H_2O(s) \rightarrow CoSO_4{\bullet}H_2O(s) + 6H_2O(g)$

Using the law of conservation of mass with the data provided,

[3.548 g heptahydrate] = [2.184 g monohydrate + (3.548 − 2.184 = 1.364 g H_2O)]

Mass of one H_2O unit per 3.548 g of $CoSO_4{\bullet}7H_2O$ = 1.364 g ÷ 6 = 0.22733 g

Mass of anhydrous $CoSO_4$ = 2.184 g $CoSO_4{\bullet}H_2O$ – 0.22733 g H_2O = 1.95$\underline{6}$7 g = 1.957 g $CoSO_4$

2.153. $$\text{Mass of O} = 0.6015\ \text{L} \times \frac{1.330\ \text{g O}}{1\ \text{L}} = 0.799\underline{9}95\ \text{g} = 0.8000\ \text{g oxygen}$$

$$15.999\ \text{amu O} \times \frac{3.177\ \text{g X}}{0.799\underline{9}95\ \text{g O}} = 63.5\underline{3}6\ \text{amu X} = 63.54\ \text{amu}$$

The atomic weight of X is 63.54 amu; X is copper.

2.154. Mass of Cl = $0.4810 \text{ L} \times \frac{2.948 \text{ g Cl}}{1 \text{ L}} = 1.41\underline{7}99 \text{ g} = 1.418 \text{ g chlorine}$

$$35.45 \text{ amu Cl} \times \frac{4.315 \text{ g X}}{1.41\underline{7}99 \text{ g Cl}} = 107.\underline{8}8 \text{ amu X} = 107.9 \text{ amu}$$

The atomic weight of X is 107.9 amu; X is silver.

2.155.

(a) For the first species, since the net charge is zero, the number of protons in the nucleus (and the atomic number of the nucleus) equals the number of electrons, 32. The element's name and symbol are, respectively, germanium and Ge, i.e., a metalloid found in Group/family 4A. With the mass number being the number of protons (32) and neutrons in the nucleus, the number neutrons in the nucleus equals 73 – 32 = 41. Hence, the complete symbol for the charge-neutral particle would be ${}^{73}_{32}\text{Ge}$.

For the second species, we gather a large amount of information from the symbol given for the particle. "I" is the symbol for iodine, a nonmetal halogen associated with Group 7A. The left handed subscript indicates both the number of protons in the nucleus (53) and the atomic number (53). The upper right superscript indicates a charge of 1-; thus, the electron count (54) is one higher than the proton count (53). With the mass number (131) equaling the number of neutrons plus protons (53), the number of neutrons in the particle equals 131-53 = 78.

These results are summarized in the following table:

Name or Group # of Element	Element Name	Metal, Metalloid Or Nonmetal?	Symbol (example ${}^{31}_{15}P^{3-}$)	Mass Number	Atomic Number	Number of ${}^{1}_{0}n$ in Nucleus	Number of ${}^{1}_{1}p^{+}$ in Nucleus	Number of e^-	Net Charge
Group 4A	germanium	metalloid	${}^{73}_{32}\text{Ge}$	73	32	41	32	32	0
Halogen Group 7A	iodine	nonmetal	${}^{131}_{53}I^{-}$	131	53	78	53	54	1-

(b) For the first species, we are given the atomic number, 34, which also equals the number of protons in the nucleus (34). The element is selenium, a nonmetal Group 6A chalcogen. Since the particle has a charge of 2-, it must have two more electrons (36) associated with the particle. With the mass number (80) equaling the number of neutrons (46) plus the number of protons (34), the complete symbol for the ion would be ${}^{80}_{34}\text{Se}^{2-}$.

For the second species, we have a 2+ charged ion; hence, there must be two more protons (56) than electrons (54) associated with the particle. Since the proton count equals the atomic number (56), the element is barium (Ba), an alkaline earth metal of Group 2A. Noting the mass number of 138 equals the number of protons (56) plus neutrons, 82 (=138-56) neutrons are in the nucleus. Hence, the complete symbol for the ion would be ${}^{138}_{56}\text{Ba}^{2+}$.

These results are summarized in the following table:

Name or Group # of Element	Element Name	Metal, Metalloid Or Nonmetal?	Symbol (example $^{31}_{15}P^{3-}$)	Mass Number	Atomic Number	Number of $^{1}_{0}n$ in Nucleus	Number of $^{1}_{1}p^{+}$ in Nucleus	Number of e^-	Net Charge
Chalcogen Group 6A	selenium	Nonmetal	$^{80}_{34}Se^{2-}$	80	34	46	34	36	2-
Alkaline Earth Metal Group 2A	barium	Metal	$^{138}_{56}Ba^{2+}$	138	56	82	56	54	2+

2.156. The term "molecule" is used for $CH_3CH_2CH_2OH$ because only covalent bonding forces are holding nonmetal atoms together to yield a distinctly unique molecular structure. The term "formula unit" is used for $Pb_3(PO_4)_4{\cdot}6H_2O$ to account for the extended presence of ionic bonding forces holding lead(IV) cations and phosphate anions together. This does not disallow the concurrent presence of covalent bonding forces which allow the phosphate ions and hydrate water molecules to be viewed semi-independently. The distinction becomes clearer if the dehydrated form of $Pb_3(PO_4)_4{\cdot}6H_2O$ is considered, i.e., $Pb_3(PO_4)_4$. In the crystalline form, this ionic substance could be represented in an infinite number of ways, e.g., $Pb_3(PO_4)_4$, $(Pb_3(PO_4)_4)_2$, $(Pb_3(PO_4)_4)_8$, $(Pb_3(PO_4)_4)_{50,000,000}$, etc. Because an ionic crystal is viewed as a broadly extended array of ions, and not as distinct molecules, the general rule is to present ionic substances using their simplest, or empirical formula, which is often referred to as a formula unit.

Each of the 4 molecules of $CH_3CH_2CH_2OH$ contain 12 atoms and each of the 5 formula units of $Pb_3(PO_4)_4{\cdot}6H_2O$ contain 41 atoms. This yields a total of 253 atoms:

$$4\ CH_3CH_2CH_2OH \text{ molecules x } \frac{12 \text{ atoms}}{1 \text{ molecule}} + 5\ Pb_3(PO_4)_4{\bullet}6H_2O \text{ f.u.} \times \frac{41 \text{ atoms}}{1 \text{ f.u.}} = 253 \text{ atoms}$$

In terms of proton count, 12 C atoms each contain 6 protons, 92 H atoms each contain 1 proton, 114 O atoms each contain 8 protons, 15 Pb atoms each contain 82 protons, and 20 P atoms each contain 15 protons. This results in 2606 protons in the mixture.

As for the electron count, since the substances are electrically neutral, there must be the same number of electrons as protons. Hence, there are 2606 electrons in the mixture.

To determine the theoretical maximum number of O_3 molecules that could be made from the mixture, it is useful to first determine the number of O atoms present:

$$4\ CH_3CH_2CH_2OH \text{ molecules x } \frac{1 \text{ O atom}}{1 \text{ molecule}} + 5\ Pb_3(PO_4)_4{\bullet}6H_2O \text{ f.u.} \times \frac{22 \text{ O atoms}}{1 \text{ f.u.}} = 114 \text{ O atoms}$$

With each O_3 molecule containing three O atoms, 114 O atoms would yield 38 O_3 molecules:

$$114 \text{ O atoms x } \frac{1\ O_3 \text{ molecule}}{3 \text{ O atoms}} = 38\ O_3 \text{ molecules}$$

The chemical symbol for potassium is K. Since neither of the two substances in the sample have K in their formulas, we conclude there are no K atoms in the mixture.

Because the sample contains 5 formula units of $Pb_3(PO_4)_4{\bullet}6H_2O$, with each containing 3 lead atoms, there are 15 Pb atoms in the mixture.

The correct name of $Pb_3(PO_4)_4{\bullet}6H_2O$ is lead(IV) phosphate hexahydrate.

The oxoanion present in $Pb_3(PO_4)_4{\bullet}6H_2O$ is the phosphate ion which corresponds to the phosphoric acid, H_3PO_4.

2.157. (a) It is easiest to initially write a combustion equation with only oxygen as the reactant as follows:

$$C_{11}H_7S + O_2 \rightarrow CO_2 + H_2O + SO_2$$

Balancing the carbon atoms requires the placement of a coefficient of 11 in front of the CO_2. Likewise, the sulfur atoms are balanced by placing an appropriate coefficient (1 in this case) in front of the SO_2:

$$C_{11}H_7S + O_2 \rightarrow 11\ CO_2 + H_2O + SO_2$$

Next, we attempt to balance the hydrogen atoms but quickly realize the only way to do so would require placement of a fractional coefficient in front of H_2O. To sidestep this, the portions of the equation that have already been addressed are multiplied by 2:

$$2\ C_{11}H_7S + O_2 \rightarrow 22\ CO_2 + H_2O + 2\ SO_2$$

We can now easily see that 14 reacting H atoms would produce 7 water product molecules:

$$2\ C_{11}H_7S + O_2 \rightarrow 22\ CO_2 + 7\ H_2O + 2\ SO_2$$

At this stage the only remaining element to be balanced is oxygen. With 55 oxygen atoms on the product side, we need an equal number on the reactant side. Recognizing every ½ of an O_2 molecule is equivalent to 1 oxygen atom, placement of a coefficient of 55/2 in front of O_2 completes the balancing:

$$2\ C_{11}H_7S + 55/2\ O_2 \rightarrow 22\ CO_2 + 7\ H_2O + 2\ SO_2$$

Again, it is easier to modify the equation such that only integer coefficients are present by once again multiplying by 2:

$$4\ C_{11}H_7S + 55\ O_2 \rightarrow 44\ CO_2 + 14\ H_2O + 4\ SO_2$$

Careful inspection of this equation will show that it is balanced but we have yet to include the nitrogen that also moves through the combustion system. To achieve the desired result, we add 3.76 times as many N_2 molecules as oxygen molecules, and being generally inert, we include the N_2 on the product side as well. That is,

$$4\ C_{11}H_7S + 55\ O_2 + 55(3.76)\ N_2 \rightarrow 44\ CO_2 + 14\ H_2O + 4\ SO_2 + 55(3.76)\ N_2$$

(b) In the case of 120% stoichiometric combustion, we need only to multiply the O_2 and N_2 coefficients by 1.20, and also remember to include the excess O_2 on the product side:

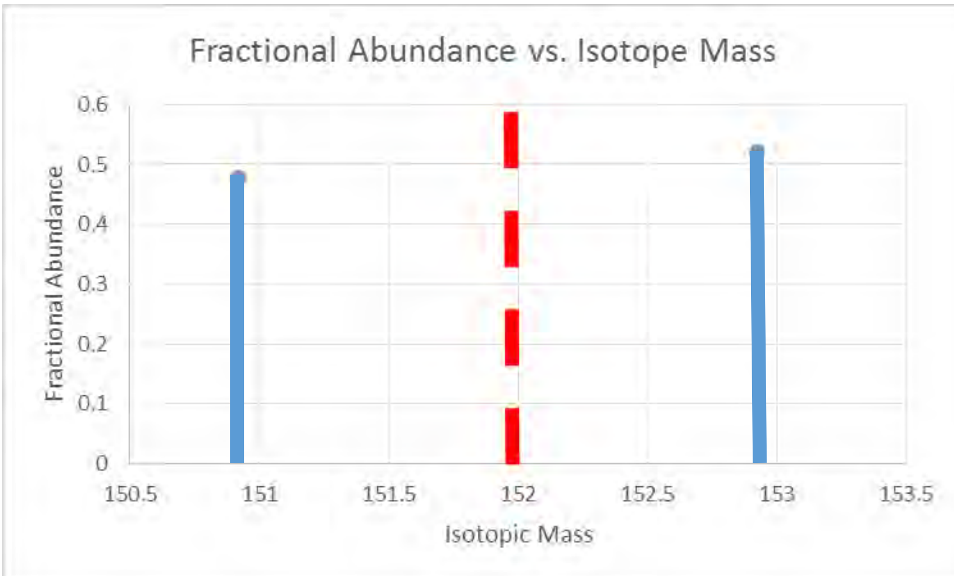
$$4\ C_{11}H_7S + 55(1.20)\ O_2 + 55(3.76)(1.20)\ N_2$$
$$\rightarrow 44\ CO_2 + 14\ H_2O + 4\ SO_2 + 55(3.76)(1.20)\ N_2 + 55(0.20)\ O_2$$

Further simplification yields the following equation:

$$4\ C_{11}H_7S + 66\ O_2 + 248.16\ N_2 \rightarrow 44\ CO_2 + 14\ H_2O + 4\ SO_2 + 248.16\ N_2 + 11\ O_2$$

2.158. (a) See the solution to problem 2.111. There it is shown that the fractional abundance of ^{151}Eu = $0.478\underline{0}9 = 0.4781$, and the fractional abundance of ^{153}Eu = $1 - 0.478\underline{0}9 = 0.521\underline{9}1 = 0.5219$.

(b) See the graph below:



In a mass spectrometer experiment, the two blue solid lines would appear in the mass spectrum of an elemental europium sample. In contrast, it is the x-value of the dotted red line which is presented in the periodic table of atomic weights for europium.

2.159. Although there are ways to solve this problem, the approach here utilizes dimensional analysis to first determine the number of graduating students required to piece together the atomic gold strings ascending to the top of the flagpole as follows:

$$172 \text{ ft} \times \frac{12 \text{ in}}{1 \text{ ft}} \times \frac{2.54 \text{ cm}}{1 \text{ in}} \times \frac{1 \text{ m}}{100 \text{ cm}} \times \frac{10^{12} \text{ pm}}{1 \text{ m}} \times \frac{1 \text{ Au atom}}{348 \text{ pm}} \times \frac{1 \text{ graduate}}{1 \times 10^{7} \text{ Au atoms}} = 1.506 \times 10^{4} \text{ graduates}$$

Noting each class year produces 250 graduates, the number of years required to accomplish the stated goal is readily calculated as follows:

$$1.506 \times 10^{4} \text{ graduates} \times \frac{1 \text{ year}}{250 \text{ graduates}} = 60.3 \text{ years}$$

With the class of 2018 being the inaugural group to begin the process, the class of 2019 would be the second year and so forth. Counting forward, the 60$^{\text{th}}$ year would be the class of 2077. Since this class would still come shy of the top of the flagpole, one more year would be required to attach the extended length of atomic gold strings to the top of the flagpole. Thus, the class of 2078 would be the class recognized for finally achieving the initial goal.

2.160. A:

(a) Complete combustion of an organic compound such as $C_5H_{10}O$ refers to its reaction with oxygen (O_2) to produce CO_2 and H_2O. We first balance the carbon atoms by recognizing that each molecule of $C_5H_{10}O$ much produce 5 molecules of CO_2:

$$C_5H_{10}O + \_\_\_\_ O_2 \rightarrow 5\, CO_2 + \_\_\_\_ H_2O$$

Next, we balance the hydrogen atoms by recognizing each molecule of $C_5H_{10}O$ must produce 5 molecules of H_2O:

$$C_5H_{10}O + \_\_\_\_ O_2 \rightarrow 5\, CO_2 + 5\, H_2O$$

Counting up the oxygen atoms on the product side, we see there are 15 of them. Therefore, we must have 15 oxygen atoms on the reactant side. With one oxygen atom supplied by $C_5H_{10}O$, it is readily observed the other 14 oxygen atoms must be supplied by 7 oxygen molecules:

$$C_5H_{10}O + 7\ O_2 \rightarrow 5\ CO_2 + 5\ H_2O$$

A careful count of all atoms of each type will show that this reaction is now balanced.

(b) To approach this reaction requires a bit of nomenclature regarding the formula for lead(IV) nitride. The name lead(IV) refers to the Pb^{4+} ion while nitride refers to the N^{3-} ion. Combining these two ions to form an electrically neutral species results in the formula for Pb_3N_4. This gives us another clue to the reaction being considered:

$$Pb(s) + \_\_\_\_\_ \rightarrow Pb_3N_4$$

Considering there is only one other assumed reactant, the most likely candidate is nitrogen gas:

$$Pb(s) + \_\_\_\_\_N_2 \rightarrow Pb_3N_4$$

This reaction is finally balanced by direct inspection:

$$3\ Pb(s) + 2\ N_2 \rightarrow Pb_3N_4$$

B:

(a) Complete combustion of an organic compound such as $C_8H_{18}O_2$ refers to its reaction with oxygen (O_2) to produce CO_2 and H_2O. We first balance the carbon atoms by recognizing that each molecule of $C_8H_{18}O_2$ much produce 8 molecules of CO_2:

$$C_8H_{18}O_2 + \_\_\_\_O_2 \rightarrow 8\ CO_2 + \_\_\_\_H_2O$$

Next, we balance the hydrogen atoms by recognizing each molecule of $C_8H_{18}O_2$ must produce 9 molecules of H_2O:

$$C_8H_{18}O_2 + \_\_\_\_O_2 \rightarrow 8\ CO_2 + 9\ H_2O$$

Counting up the oxygen atoms on the product side, we see there are 25 of them. Therefore, we must have 25 oxygen atoms on the reactant side. With two oxygen atoms supplied by $C_8H_{18}O_2$, it is readily apparent the other 23 oxygen atoms must be supplied by 11.5 (or 23/2) oxygen molecules:

$$C_8H_{18}O_2 + \frac{23}{2}O_2 \rightarrow 8\ CO_2 + 9\ H_2O$$

Multiplying all of the coefficients by 2 provides a balanced reaction with integer coefficients:

$$2\ C_8H_{18}O_2 + 23\ O_2 \rightarrow 16\ CO_2 + 18\ H_2O$$

(b) To approach this reaction requires some nomenclature regarding the formula for mercury(I) phosphide, i.e., a compound composed the Hg_2^{2+} ion and the P^{3-} ion. To be electrically neutral, the relevant formula would be $(Hg_2)_3P_2$. Placing this into the skeleton equation provided yields the following:

$$\_\_\_\_\_\_\_ + \_\_\_\_\_P_4 \rightarrow (Hg_2)_3P_2$$

Assuming mercury, Hg, to be the only other assumed reactant, the reaction skeleton is further constructed:

$$\_\_\_\_\_\_Hg + \_\_\_\_\_P_4 \rightarrow (Hg_2)_3P_2$$

Since each formula unit of $(Hg_2)_3P_2$ contains 2 phosphorus atoms, the P_4: $(Hg_2)_3P_2$ ratio must be 1:2 in the final balanced reaction, that is:

$$\_\_\_\_\_\_ Hg + P_4 \rightarrow 2\ (Hg_2)_3P_2$$

Considering mercury to be monatomic, and the fact that each formula unit of $(Hg_2)_3P_2$ associates with 6 Hg atoms, simple inspection provides the final balanced reaction as follows:

$$12\ Hg + P_4 \rightarrow 2\ (Hg_2)_3P_2$$

PART II

Features of the Text

In the preface to the first edition, we wrote, “Scientists delve into the molecular machinery of the biological cell and examine bits of material from the planets of the solar system. In these endeavors chemistry is fundamental. The challenge for the instructors of introductory chemistry is to capture the excitement of these discoveries while giving students a solid understanding of the basic principles and facts. The challenge for the students is to be receptive to a new way of thinking, which will allow them to be caught up in the excitement of discovery.” From the very first edition, our aim has always been to help instructors capture the excitement of chemistry and to teach students to “think chemistry.” Here are some of the features of the text that we feel are especially important in achieving these goals.

Chapter Opening

Each chapter begins with a photo related to the content of the chapter. Under this photo on the chapter-opening page is the *Contents and Concepts* section. This feature outlines the main sections of the chapter and briefly previews the key concepts and relationships among topics, providing an outline for students’ reading and studying. You can use this yourself to quickly survey a chapter to see how it corresponds to your course plan and to see what deletions or changes of order you might wish to make. You can refer students to *Contents and Concepts* when you inform them of these deletions or changes.

After the opening page, we begin each chapter with a *chapter theme*—something specific that reveals the real-world relevance of the chapter topic. For example, we open Chapter 2, *Atoms, Molecules, and Ions,* with a discussion of sodium, chlorine, and sodium chloride. This chapter theme then leads naturally into a series of questions (for instance, “How do we explain the differences in properties of different forms of matter?”) that we answer later in the chapter.

Vocabulary

Chemists use words in a precise way, and it is important that students develop a chemistry vocabulary that allows them to read and communicate the subject effectively. When a new, important word is introduced in the text, we flag it by putting it in boldface type. The definition of the word will generally accompany it in the same sentence in italic type. For example, in Section 3.8, which discusses limiting reactants, we have the sentence: “The **limiting reactant** (or **limiting reagent**) is *the reactant that is entirely consumed when a reaction goes to completion.”* All these boldfaced words are collected at the end of each chapter in the list of *Important Terms* (opposite the *Learning Objectives* in *A Checklist for Review).* They also appear in the *Glossary* at the end of the book.

Problem-Solving Approach

Learning chemistry requires the students’ active participation. For this purpose, we have included two types of in-chapter problems in which we ask students to participate by trying to do problems that exemplify the material they have just read.

First are *Exercises,* which ask the student to solve a problem closely related to the previous text discussion. Most of these (unless fairly simple) are preceded by *Examples* that lead the student through the problem-solving process for a similar problem. Our goal is to help the student learn the problem-solving skills important to absorbing the ideas presented. We believe that problem-solving is not a skill a student is born with; it requires models showing how it is done, and it requires practice.

Each *Example* consistently uses our three-part problem-solving process: a *Problem Strategy,* a *Solution,* and an *Answer Check.* By providing every Example with this three-part process (Problem Strategy, Solution, Answer Check), we hope to help students develop their problem-solving skills: *think* how to proceed, *solve* the problem, *check* the answer. The Problem Strategy outlines the process that one typically works through in solving such a problem. Then the student is led through the step-by-step worked-out Solution. Finally the student is confronted with an Answer Check: Is this answer reasonable in terms of the general knowledge I have of the problem? This final phase of problem solving is a critical step often overlooked by students. Only consistent answer checking can lead to reliable results. Having worked through an example, the student can work the related Exercise on his or her own. For additional practice, similar end-of-chapter *Practice Problems* are identified at the end of the Exercise. The *General Problems* at the end of the chapter are similar to the Practice Problems, but are not keyed to the text Exercises.

We also have yet another level of support for students in this problem-solving process. In every example, we have a *Gaining Mastery Toolbox.* At the beginning of each Toolbox we state the “big idea” involved in this Example problem (the *Critical Concept*). Under this Critical Concept, we list prior topics needed to solve this problem (the *Solution Essentials).*

While we believe in the importance of this coherent Example/Exercise approach, we also think it is necessary to have students expand their understanding of the concepts. For this purpose we introduced a second type of in-chapter problem, *Concept Checks.* We have written these to force students to think about the concepts involved rather than to focus on the final result or numerical answer—or to try to fit the problem to a memorized algorithm. We want students to begin each problem by asking, “What are the chemical concepts that apply here?” Many of these problems involve visualizing a molecular situation since visualization is such a critical part of learning and understanding modern chemistry. For additional practice, similar types of end-of-chapter problems are provided, the *Conceptual Problems.*

Emphasis on Molecular Concepts

Molecular concepts are central to modern chemistry, and we have focused our presentation at the molecular level. We start building the molecular “story” in Chapter 1 (in the very first section), and by Chapter 2 we have developed the molecular view and have integrated it into the problem-solving apparatus as well as into the text discussions. We continue in the following chapters to use the molecular view to strengthen chemical concepts. Most students are strongly visual in their learning, so we have used colorful molecular models liberally in these discussions. We have introduced electrostatic potential maps where pedagogically relevant to show how electron density changes across a molecule. This is especially helpful for visually demonstrating things such as acid-base behavior.

Chapter Essays

We have two types of "boxed" essays to showcase chemistry as a modern science. One of these is the series of *A Chemist Looks At* essays, which cover up-to-date issues of science and technology. We have chosen topics that will engage students' interest and at the same time highlight the chemistry involved. Icons are used to describe the content area (materials, environment, daily life, frontiers, and life science) being discussed. The essays show students that chemistry is a vibrant, constantly changing science that has relevance for our modern world. The essay "Gecko Toes, Sticky but not Tacky," for example, describes the van der Waals forces used by gecko toes and their possible applications to the development of infinitely reusable tape or robots that can climb walls.

Also with this edition, we continue our *Instrumental Methods* essays. These essays demonstrate the importance of sophisticated instruments for modern chemistry by focusing on instrumental methods used by research chemists, such as mass spectroscopy or nuclear magnetic resonance. Although short, these essays provide students with a level of detail to pique the students' interest in this subject.

We recognize that classroom and study times are very limited and that it can be difficult to integrate this material into the course. For that reason, we have included two questions based upon each *A Chemist Looks At* or *Instrumental Methods* essay. These questions, given at the end of the General Problems, promote the development of scientific writing skills, another area that often gets neglected in packed general chemistry courses. It is our hope that having brief essay questions ready to assign will allow both students and instructors to value the importance of this content and make it easier to incorporate it into their curricula. You might want to tell students that you may have similar questions on your exams as a way to ensure that students read the essays.

A Checklist for Review

This portion of the end-of-chapter material consists of three parts:

1. **Summary of Facts and Concepts.** This summary presents a verbal review of the chapter. A student can use each chapter summary as a way to review by trying to flesh out each statement as he or she reads along.
2. **Learning Objectives and Important Terms.** The Learning Objectives and Important Terms for each chapter section are given in table form, with the learning objectives listed on the left side and the important terms on the right side. Each Learning Objective describes words introduced, concepts discussed, and problem-solving skills introduced (noting Example numbers). The Important Terms is a list of all boldface terms in the text. Both the Learning Objectives and Important Terms can be used as a way to view the structure of the chapter and can be used as a comprehensive review.
3. **Key Equations.** Many chapters introduce one or more mathematical equations used in problem-solving. Within the chapter, the key equations are shaded in color. They are listed in this section for review.

Questions and Problems

After the Checklist for Review the chapter consists of a series of sections of questions and problems that offer a variety of types and difficulty.

Self-Assessment and Review Questions

The Review Questions at the beginning of each of these sections are straightforward and can be used by a student to test his or her understanding of the chapter ideas. On the basis of student feedback, we developed conceptually focused multiple-choice questions to provide students with a quick opportunity for self-assessment. As they are intended primarily for self-study, these questions have been included at the end of the *Self-Assessment and Review Questions* section. However, since multiple-choice questions are commonly included on exams, instructors may wish to assign them as homework or additional practice. Four of these questions are included in each chapter and answered in the back of the book. Solutions to all Self-Assessment and Review Questions are included in the *Student* and *Complete Solutions Manuals*.

Concept Explorations

While we have included them in the end-of-chapter material, *Concept Explorations* are unlike any of the other end-of-chapter problems. These multi-part, multi-step problems are carefully structured activities developed to help students explore important chemical concepts—the key ideas in general chemistry—and confront common misconceptions or gaps in learning. Often deceptively simple, Concept Explorations ask probing questions to test the students' understanding. Because we feel strongly that, to develop a lasting conceptual understanding, students must think about questions in an unfamiliar way without jumping quickly to solutions and answer them without formulas or algorithms (or even a calculator), we have purposely not included their answers in the *Student Solutions Manual*. As Concept Explorations are ideally used in an interactive classroom situation, we have reformatted them into workbook-style in-class handouts with space for written answers (available as printable PDFs on the student and instructor websites) to facilitate their use in small groups. There are two Concept Explorations per chapter in the first nineteen chapters. (Their use is discussed in more detail in Part VIII Concept Explorations: What Are They? See also Part IX Concept Explorations: A List of Concepts and Misconceptions.)

Conceptual Problems

These problems have the same intent as the in-chapter *Concept Checks.* They are meant to aid the student in learning the underlying concepts. In these, we ask students questions that require them to think and to solve problems by first asking: "What are the chemical concepts that apply here?" These questions are phrased to force a thoughtful answer rather than allow the student to apply a memorized algorithm. Solutions to these appear in the *Complete Solutions Manual*.

Practice Problems

A student can obtain practice with the problem-solving skills exemplified by the in-chapter examples by working through similar *Practice Problems* available at the ends of the chapters. These problem sets are divided into segments by topic heading. The problems are in matched pairs, and answers to all odd-numbered problems appear at the end of the book. Solutions to these odd-numbered problems appear in the *Student Solutions Manual*; solutions to all problems appear in the *Complete Solutions Manual*.

General Problems

These problems are similar to the *Practice Problems,* but have not been divided by topic or keyed to related exercises. Each section ends with the boxed essay-related questions, each of which is color-coded to refer to a type of *A Chemist Looks at* essay (life science, red; materials, brown; environment, green; frontiers, purple; daily life, orange) or *Instrumental Methods* essay (blue-green) on which it is based. Odd-numbered problems and the even-numbered problems that follow are similar; answers to all odd-numbered problems except the essay questions are given in the back of the book. Solutions to these odd-numbered problems appear in the *Student Solutions Manual*; solutions to all problems appear in the *Complete Solutions Manual*.

Strategy Problems

In addition to confronting common misconceptions, we also recognized a need to challenge students to build a conceptual understanding rather than simply memorizing the algorithm from the matched pair and then applying it to a similar problem to get a solution. The *Strategy Problems* have been written to extend students' problem-solving skills beyond those developed in the Practice and General Problems and to increase the level of rigor in the text. To work a Strategy Problem, students will need to think about the problem (which might involve several concepts or problem-solving skills from the chapter), then solve it on their own without a similar problem from which to model their answer. For this reason, we have chosen explicitly not to include the answers to the Strategy Problems in the *Student Solutions Manual*; solutions to all problems appear in the *Complete Solutions Manual.*

Capstone Problems

These are challenging problems that require students to combine skills, strategies, and concepts from different sections within a chapter, and from previous chapters, allowing students to test their ability to integrate skills. Solutions to the odd-numbered problems appear in the *Student Solutions Manual*; solutions to all problems appear in the *Complete Solutions Manual*.

2. Isotopes and Mass Spectrometry

Time: 45 minutes

Required chemicals and solutions: None

Other required materials:

Metric ruler, 1/student if possible

Special note: None

Connections: Mass spectrometry has been used to identify substances in the exhaled breath of patients to help with medical diagnoses.

Date: ____________________
Course/Section: ____________________
Instructor: ____________________

Student name: ____________________
Team members: ____________________

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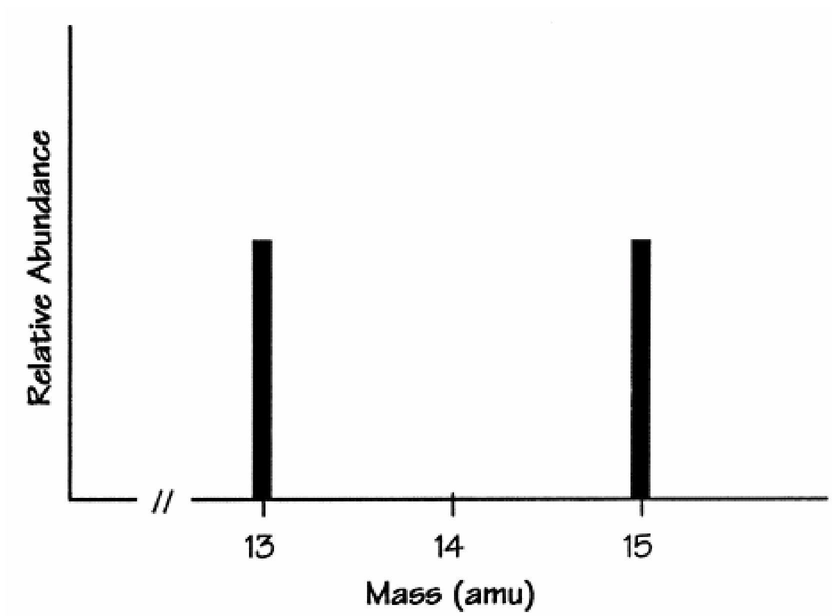
Isotopes and Mass Spectrometry

Prelaboratory Assignment

1. Suppose the mass spectrum of a hypothetical monatomic element X contains a signal at mass number 13 and another of identical height at mass number 15.

   a. Sketch the mass spectrum. Make sure each axis is properly labeled.



   b. How many isotopes are present? Why?

   Because there are two signals for this monatomic element, there must be two isotopes. One has mass number 13, and the other has mass number 15.

c. What are the fractional abundances of the isotopes? Why?

Because the signals have equal heights, the fractional abundances must be equal. Each one is 0.50.

2. a. Devise a *general* method for determining the fractional abundances of two or more isotopes from a mass spectrum. Your method must include some means of measuring the signals. You must state the type of measuring device that you will need to apply your method. You must also indicate how you will use the measurements to obtain the fractional abundances.

The heights of all signals will be measured with a metric ruler. These heights will be added together. The fractional abundance of an isotope will be equal to the height of its signal, divided by the sum of the heights of all of the signals.

b. Test your method by determining the fractional abundances of neon's isotopes from the mass spectrum in Figure 2.1. When you compare your results to known abundances, remember to take the precision of the measurements into account.

Mass Number	Measurement with Units
20	**6.75 cm**
21	**0.03 cm**
22	**0.70 cm**

Calculation:

6.75 cm + 0.03 cm + 0.70 cm = 7.48 cm

Fractional abundance of isotope with

mass number 20: 6.75/7.48 = 0.902

mass number 21: 0.03/7.48 = 0.004

mass number 22: 0.70/7.48 = 0.094

Comments:

The agreement between these results and the known fractional abundances is excellent, as shown in the following comparison:

Mass Number	Known	Calculated
20	0.9051	0.902
21	0.0027	0.004
22	0.0922	0.094

3. a. Explain fragmentation in a mass spectrometer.

A molecule may fragment after a collision with a high-energy electron in the mass spectrometer. If this occurs, the mass spectrum will contain signals that are due to fragments of molecules, as well as a signal due to an unfragmented molecule.

b. How will fragmentation affect the mass spectrum of hydrogen chloride? Explain carefully.

The mass spectrum is expected to consist of signals due to unfragmented $H^{35}Cl^+$ and $H^{37}Cl^+$ as well as those for $^{35}Cl^+$ and $^{37}Cl^+$.

Date: ____________________
Course/Section: ____________________
Instructor: ____________________

Student name: ________________________
Team members: ________________________

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Isotopes and Mass Spectrometry

Results

1. *Mercury peaks*

Mass Number	Measurement with Units
198	2.29 cm
199	3.80 cm
200	5.25 cm
201	2.95 cm
202	6.70 cm
204	1.45 cm

2. *Hydrogen chloride, HCl, peaks*

Mass Number	Formula	Measurement with Units
35	$^{35}Cl^{+}$	1.09 cm
36	$H^{35}Cl^{+}$	6.72 cm

37	**$^{37}Cl^{+}$**	**0.41 cm**
38	**$H^{37}Cl^{+}$**	**2.14 cm**

3. *Hydrogen bromide, HBr, peaks*

Mass Number	Formula	Measurement with Units
79	$^{79}Br^+$	**3.01 cm**
80	$H^{79}Br^+$	**6.78 cm**
81	$^{81}Br^+$	**2.95 cm**
82	$H^{81}Br^+$	**6.61 cm**

How many isotopes of bromine are indicated? Explain.

There are two isotopes because there are signals for $^{79}Br^+$ and $^{81}Br^+$ as well as those for $H^{79}Br^+$ and $H^{81}Br^+$.

4. *Bromine, Br_2, peaks (optional)*

Mass Number	Formula	Measurement with Units
79	$^{79}Br^+$	**4.08 cm**
81	$^{81}Br^+$	**4.08 cm**
158	$^{79}Br^{79}Br^+$	**3.35 cm**
160	$^{79}Br^{81}Br^+$	**6.71 cm**
162	$^{81}Br^{81}Br^+$	**3.35 cm**

Questions

1. Calculate the fractional abundances of the isotopes of mercury, chlorine, and bromine.

Hg:

2.29 cm + 3.80 cm + 5.25 cm + 2.95 cm + 6.70 cm + 1.45 cm

= 22.44 cm

Fractional abundance for mass no. 198: 2.29/22.44 = 0.102

199: 3.80/22.44 = 0.169

200: 5.25/22.44 = 0.234

201: 2.95/22.44 = 0.131

202: 6.70/22.44 = 0.299

204: 1.45/22.44 = 0.065

Cl from HCl:

Using the largest signals: 6.72 cm + 2.14 cm = 8.86 cm

Fractional abundance for mass no. 35: 6.72/8.86 = 0.758
37: 2.14/8.86 = 0.242

Br from HBr:

Using the largest signals: 6.78 cm + 6.61 cm = 13.39 cm

Fractional abundance for mass no. 79: 6.78/13.39 = 0.506
81: 6.61/13.39 = 0.494

2. Calculate the atomic weight of mercury, chlorine, and bromine from your data. Use mass numbers rather than exact masses. Compare your results to the actual atomic weights of these elements, and comment on any discrepancies.

Hg:

(198)(0.102) + (199)(0.169) + (200)(0.234)
+ (201)(0.131) + (202)(0.299) + (204)(0.065)
= 200.6 (known: 200.59)

Cl:

(35)(0.758) + (37)(0.242) = 35.5 (known: 35.453)

Br:

(79)(0.506) + (81)(0.494) = 80.0 (known: 79.904)

The agreement between the calculated and known values is excellent.

3. (Optional) Why does the mass spectrum of Br_2 contain three signals whose heights are almost in the ratio of 1:2:1? What are the origins of these signals? It may help to suppose that the fractional abundances of the isotopes are exactly equal. Then think about the probability of combining the various isotopes of bromine atoms into diatomic molecules. Finally, why does the spectrum contain two other signals of roughly equal height? What are the origins of these signals?

To explain the 1:2:1 ratio of the signals at mass numbers 158, 160, and 162, we assume that the fractional abundances of ^{79}Br and ^{81}Br are exactly equal (each with 0.50). Consider a ^{79}Br atom. It has an equal probability of encountering another ^{79}Br atom (to form ^{79}Br^{79}Br) or an ^{81}Br atom (to form ^{79}Br^{81}Br) because the fractional abundances of the two isotopes are equal.

Next, consider an ^{81}Br atom. It has equal probability of meeting another ^{81}Br atom (to form ^{81}Br^{81}Br) or a ^{79}Br atom (to form ^{81}Br^{79}Br, which is the same as ^{79}Br^{81}Br). Because there are two ways to get ^{79}Br^{81}Br but only one way to get ^{79}Br^{79}Br and only one way to get ^{81}Br^{81}Br, the probability of finding these molecules should be in the ratio of 1:2:1.

Finally, the signals at mass numbers 79 and 81 are due to $^{79}Br^+$ and $^{81}Br^+$. They have equal heights (or close to it) because their fractional abundances are equal (or close to it).

Name: ______________________ Partner(s): ______________________
Instructor: ______________________ Date: ______________________

CHAPTER 2

Concept Explorations

2.25. Average Atomic Mass

Part 1: Consider the four identical spheres below, each with a mass of 2.00 g.

Calculate the average mass of a sphere in this sample.

Part 2: Now consider a sample that consists of four spheres, each with a different mass: blue mass is 2.00 g, red mass is 1.75 g, green mass is 3.00 g, and yellow mass is 1.25 g.

a. Calculate the average mass of a sphere in this sample.

b. How does the average mass for a sphere in this sample compare with the average mass of the sample that consisted just of the blue spheres? How can such different samples have their averages turn out the way they did?

Part 3: Consider two jars. One jar contains 100 blue spheres, and the other jar contains 25 each of red, blue, green, and yellow colors mixed together.

a. If you were to remove 50 blue spheres from the jar containing just the blue spheres, what would be total mass of spheres left in the jar? (Note that the masses of the spheres are given in Part 2.)

b. If you were to remove 50 spheres from the jar containing the mixture (assume you get a representative distribution of colors), what would be the total mass of spheres left in the jar?

c. In the case of the mixture of spheres, does the average mass of the spheres *necessarily* represent the mass of an individual sphere in the sample?

d. If you had 80.0 grams of spheres from the blue sample, how many spheres would you have?

e. If you had 60.0 grams of spheres from the mixed-color sample, how many spheres would you have? What assumption did you make about your sample when performing this calculation?

Part 4: Consider a sample that consists of three green spheres and one blue sphere. The green mass is 3.00 g, and the blue mass is 1.00 g.

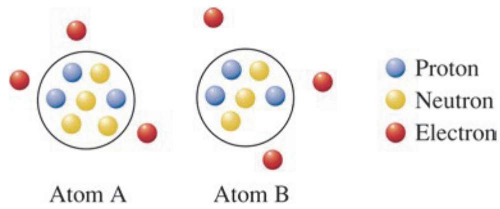
a. Calculate the *fractional abundance* of each sphere in the sample.

b. Use the fractional abundance to calculate the average mass of the spheres in this sample.

c. How are the ideas developed in this Concept Exploration related to the atomic masses of the elements?

2.26 Model of the Atom

Consider the following depictions of two atoms, which have been greatly enlarged so you can see the subatomic particles.



a. How many protons are present in atom A?

b. What is the significance of the number of protons depicted in atom A or any atom?

c. Can you identify the real element represented by the drawing of atom A? If so, what element does it represent?

d. What is the charge on element A? Explain how you arrived at your answer.

e. Write the nuclide symbol of atom A.

f. Write the atomic symbol and the atomic number of atom B.

g. What is the mass number of atom B? How does this mass number compare with that of atom A?

h. What is the charge on atom B?

i. Write the nuclide symbol of element B.

j. Draw pictures like those above of ${}^{6}_{3}Li^{+}$ and ${}^{6}_{3}Li^{-}$ atoms. What are the mass number and atomic number of each of these atoms?

k. Consider the two atoms depicted in this problem and the two that you just drew. What is the total number of lithium isotopes depicted? How did you make your decision?

l. Is the mass number of an isotope of an atom equal to the mass of the isotope of the atom? Be sure to explain your answer.