CHAPTER 6 Review

Reflecting on Chapter 6

Summarize this chapter in the format of your choice. Here are a few ideas to use as guidelines:

- Determine the mass percent of each element in a compound.
- Predict the empirical formula of a compound using the periodic table, and test your prediction through experimentation.
- Use experimental data to determine the empirical (simplest) formula of a compound.
- Use the molar mass and empirical formula of a compound to determine the molecular (actual) formula of the compound.
- Determine experimentally the percent by mass of water in a hydrate. Use this information to determine its molecular formula.
- Explain how a carbon-hydrogen combustion analyzer can be used to determine the mass percent of carbon, hydrogen, and oxygen in a compound.

Reviewing Key Terms

For each of the following terms, write a sentence that shows your understanding of its meaning.

anhydrous

carbon-hydrogen combustion analyzer

empirical formula

forensic scientists

hydrate

law of definite proportions

mass percent

molecular formula

percentage composition

Knowledge/Understanding

1. When determining the percentage composition of a compound from its formula, why do you base your calculations on a one mole sample?
2. The main engines of the space shuttle burn hydrogen and oxygen, with water as the product. Is this synthetic (human-made) water the same as water found in nature? Explain.
3. **(a)** What measurements need to be taken during a carbon-hydrogen combustion analysis?
   (b) Acetylene, C_2H_2, and benzene, C_6H_6, both have the same empirical formula. How would their results compare in a carbon-hydrogen combustion analysis? Explain your answer.
4. If you know the molar mass of a substance, and the elements that make up the substance, can you determine its molecular formula? Explain your answer.

Inquiry

5. A 5.00 g sample of borax (sodium tetraborate decahydrate, $Na_2B_4O_7{\cdot}10H_2O$) was thoroughly heated to remove all the water of hydration. What mass of anhydrous sodium tetraborate remained?
6. Determine the percentage composition of each compound.
   (a) freon-12, CCl_2F_2
   (b) white lead, $Pb_3(OH)_2(CO_3)_2$
7. **(a)** What mass of water is present in 25.0 g of $MgCl_2{\cdot}2H_2O$?
   (b) What mass of manganese is present in 5.00 g of potassium permanganate, $KMnO_4$?
8. Silver nitrate, $AgNO_3$, can be used to test for the presence of halide ions in solution. It combines with the halide ions to form a silver halide precipitate. In medicine, it is used as an antiseptic and an antibacterial agent. Silver nitrate drops are placed in the eyes of newborn babies to protect them against an eye disease.
   (a) Calculate the mass percent of silver in silver nitrate.
   (b) What mass of pure silver is contained in 2.00×10^2 kg of silver nitrate?
9. Barium sulfate, $BaSO_4$, is opaque to X-rays. For this reason, it is sometimes given to patients before X-rays of their intestines are taken. What mass of barium is contained in 45.8 g of barium sulfate?
10. Bismuth nitrate, $Bi(NO_3)_2$, is used in the production of some luminous paints. How many grams of pure bismuth are in a 268 g sample of bismuth nitrate?
11. The molar mass of a compound is approximately 121 g. The empirical formula of the

compound is CH_2O. What is the molecular formula of the compound?

12. A complex organic compound, with the name 2,3,7,8-tetrachlorodibenza-para-dioxin, belongs to a family of toxic compounds called *dioxins*. The empirical formula of a certain dioxin is $C_6H_2OCl_2$. If the molar mass of this dioxin is 322 g/mol, what is its molecular formula?

13. A student obtains an empirical formula of $C_1H_{2.67}$ for a gaseous compound.
- **(a)** Why is this not a valid empirical formula?
- **(b)** Use the student's empirical formula to determine the correct empirical formula.

14. Progesterone, a hormone, is made up of 80.2% carbon, 10.18% oxygen, and 9.62% hydrogen. Determine the empirical formula of progesterone.

15. An inorganic salt is composed of 17.6% sodium, 39.7% chromium, and 42.8% oxygen. What is the empirical formula of this salt?

16. What is the empirical formula of a compound that contains 67.6% mercury, 10.8% sulfur, and 21.6% oxygen?

17.
- **(a)** An inorganic salt is made up of 38.8% calcium, 20.0% phosphorus, and 41.2% oxygen. What is the empirical formula of this salt?
- **(b)** On further analysis, each formula unit of this salt is found to contain two phosphate ions. Predict the molecular formula of this salt.

18. Capsaicin is the compound that is responsible for the "hotness" of chili peppers. Chemical analysis reveals capsaicin to contain 71.0% carbon, 8.60% hydrogen, 15.8% oxygen, and 4.60% nitrogen.
- **(a)** Determine the empirical formula of capsaicin.
- **(b)** Each molecule of capsaicin contains one atom of nitrogen. What is the molecular formula of capsaicin?

19. A compound has the formula X_2O_5, where X is an unknown element. The compound is 44.0% oxygen by mass. What is the identity of element X?

20. A 1.254 g sample of an organic compound that contains only carbon, hydrogen, and oxygen reacts with a stream of chlorine gas, $Cl_{2(g)}$. After the reaction, 4.730 g of HCl and 9.977 g of CCl_4 are obtained. Determine the empirical formula of the organic compound.

21. A 2.78 g sample of hydrated iron(II) sulfate, $FeSO_4 \cdot xH_2O$, was heated to remove all the water of hydration. The mass of the anhydrous iron(II) sulfate was 1.52 g. Calculate the number of water molecules associated with each formula unit of $FeSO_4$.

22. Citric acid is present in citrus fruits. It is composed of carbon, hydrogen, and oxygen. When a 0.5000 g sample of citric acid was subjected to carbon-hydrogen combustion analysis, 0.6871 g of carbon dioxide and 0.1874 g of water were produced. Using a mass spectrometer, the molar mass of citric acid was determined to be 192 g/mol.
- **(a)** What are the percentages of carbon, hydrogen, and oxygen in citric acid?
- **(b)** What is the empirical formula of citric acid?
- **(c)** What is the molecular formula of citric acid?

23. Methanol, CH_3OH (also known as methyl alcohol), is a common laboratory reagent. It can be purchased at a hardware store under the name "methyl hydrate" or "wood alcohol." If 1.00 g of methanol is subjected to carbon-hydrogen combustion analysis, what masses of carbon dioxide and water are produced?

24. Copper can form two different oxides: copper(II) oxide, CuO, and copper(I) oxide, Cu_2O. Suppose that you find a bottle labelled "copper oxide" in the chemistry prep room. You call this mystery oxide Cu_xO. Design an experiment to determine the empirical formula of Cu_xO. Assume that you have a fully equipped chemistry lab at your disposal. Keep in mind the following information:
- Both CuO and Cu_2O react with carbon to produce solid copper and carbon dioxide gas:
  $$Cu_xO_{(s)} + C_{(s)} \rightarrow Cu_{(s)} + CO_{2(g)}$$
  This reaction proceeds with strong heating.
- Carbon reacts with oxygen to produce carbon dioxide gas:
  $$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$$
  This reaction also proceeds with strong heating.
- Carbon is available in the form of activated charcoal.

(a) State at least one safety precaution that you would take.
(b) State the materials required, and sketch your apparatus.
(c) Outline your procedure.
(d) What data do you need to collect?
(e) State any assumptions that you would make.

25. Magnesium sulfate, $MgSO_4$, is available as anhydrous crystals or as a heptahydrate. Assume that you are given a bottle of $MgSO_4$, but you are not sure whether or not it is the hydrate.
(a) What method could you use, in a laboratory, to determine whether this is the hydrate?
(b) If it is the hydrate, what results would you expect to see?
(c) If it is the anhydrous crystals, what results would you expect to see?

Communication

26. Draw a concept map to relate the following terms: molar mass of an element, molar mass of a compound, percentage composition, empirical formula, and molecular formula. Use an example for each term.

27. Draw a schematic diagram of a carbon-hydrogen combustion analyzer. Write a few sentences to describe each stage of the analysis as dimethyl ether, C_2H_6O, passes through the apparatus.

Making Connections

28. For many years, tetraethyl lead, $Pb(C_2H_5)_4$, a colourless liquid, was added to gasoline to improve engine performance. Over the last 20 years it has been replaced with non-lead-containing additives due to health risks associated with exposure to lead. Tetraethyl lead was added to gasoline up to 2.0 mL per 3.8 L (1.0 US gallon) of gasoline.
(a) Calculate the mass of tetraethyl lead in 1.0 L of gasoline. The density of $Pb(C_2H_5)_4$ is 1.653 g/mL.
(b) Calculate the mass of elemental lead in 1.0 L of gasoline.

29. Natron is the name of the mixture of salts that was used by the ancient Egyptians to dehydrate corpses before mummification. Natron is composed of Na_2CO_3, $NaHCO_3$, NaCl, and $CaCl_2$. The Na_2CO_3 absorbs water from tissues to form $Na_2CO_3 \cdot 7H_2O$.
(a) Name the compound $Na_2CO_3 \cdot 7H_2O$.
(b) Calculate the mass percent of water in $Na_2CO_3 \cdot 7H_2O$.
(c) What mass of anhydrous Na_2CO_3 is required to dessicate (remove all the water) from an 80 kg body that is 78% water by mass?

30. Imagine that you are an analytical chemist at a pharmaceutical company. One of your jobs is to determine the purity of the acetylsalicylic acid (ASA), $C_9H_8O_4$. ASA is prepared by reacting salicylic acid (SA), $C_7H_6O_3$, with acetic anhydride, $C_4H_6O_3$. Acetic acid, $C_2H_3O_2H$, is also produced

$$\underset{\text{SA}}{C_7H_6O_3} + \underset{\text{acetic anhydride}}{C_4H_6O_3} \rightarrow \underset{\text{ASA}}{C_9H_8O_4} + \underset{\text{acetic acid}}{C_2H_3O_2H}$$

ASA often contains unreacted SA. Since it is not acceptable to sell ASA contaminated with SA, one of your jobs is to analyze the ASA to check purity. Both ASA and SA are white powders.
(a) You analyze a sample that you believe to be pure ASA, but which is actually contaminated with some SA. How will this affect the empirical formula that you determine for the sample?
(b) Another sample contains ASA contaminated with 0.35 g SA. The mass of the sample is 5.73 g. What empirical formula will you obtain?

Answers to Practice Problems and Short Answers to Section Review Questions:

Practice Problems: **1.** 36% Ca; 64% Cl **2.** 48.1% Ni; 16.9% P; 35.0% O **3.** 39.5% C; 7.8% H; 52.7% O **4.** 26.6% K; 35.4% Cr; 38.0% O **5.(a)** 63.65% N **(b)** 13.24% N **(c)** 35.00% N **(d)** 22.23% N **6.** 2.06% H; 32.69% S; 62.25% O **7.** 47.47% O **8.(a)** 63.19% Mn; 36.81% O **(b)** 158 g **9.** NH_3 **10.** Li_2O **11.** BF_3 **12.** SCl **13.** Cr_2O_3 **14.** P_2O_5 **15.** $Na_2Cr_2O_7$ **16.** $C_{12}H_{14}O_3$ **17.** C_4H_{10} **18.** $C_2H_2O_4$ **19.** $C_{18}H_{21}NO_3$ **20.** $C_{15}H_{12}O_3$ **21.** C_5H_{12}; 83.3% C; 16.7% H. **22.** $C_{21}H_{30}O_5$ **23.** 50.9% **24.** 5 **25.** 4

Section Review: **6.1:** **3.** 3.05 g **4.** 11.3 g **5.** 17.1 g. **7.** Na^+ **6.2:** **2.** $C_8H_8O_3$ **3.(a)** Cl_2O_7 **(b)** $SiCl_4$ **4.** CH_2O **6.** $C_9H_{17}O$ **7.** $C_{11}H_{14}O_2$ **8.(a)** $FeC_{10}H_{10}$ **(b)** Yes. **6.3:** **2.** $C_4H_6O_6$ **4.(a)** C_2H_3O **(b)** Double **5.** $C_{12}H_{10}O_2$ **6.4:** **1.** Yes **2.** 488 g **4.** No **6.** 6 **7.(a)** CH_2O **(b)** $C_6H_{12}O_6$ **8.(a)** CH_2 **(b)** $CH_{12}H_2$