Math Tutor Calculating Percentage Composition

Chemists can analyze an unknown substance by determining its percentage composition by mass. Percentage composition is determined by expressing the mass of each element in a sample of the substance as a percentage of the mass of the whole sample. The results of this analysis can then be compared with the percentage composition of known compounds to determine the probable identity of the unknown substance.

Sample Problem

Determine the percentage composition of potassium chlorate, $KClO_3$.

First, calculate the molar mass of $KClO_3$. The formula shows you that one mole of $KClO_3$ consists of 1 mol K atoms, 1 mol Cl atoms, and 3 mol O atoms. Thus, the molar mass of $KClO_3$ is molar mass K + molar mass Cl + 3(molar mass O) = 39.10 g K + 35.45 g Cl + 3(16.00 g O).

$$\text{molar mass } KClO_3 = 122.55 \text{ g}$$

The percentage composition of $KClO_3$ is determined by calculating the percentage of the total molar mass contributed by each element.

$$\frac{\text{mass of element in 1 mol of compound}}{\text{molar mass of compound}} \times 100 = \text{\% element in compound}$$

$$\text{\% K in } KClO_3 = \frac{39.10 \text{ g K}}{122.55 \text{ g } KClO_3} \times 100 = 31.91\%$$

$$\text{\% Cl in } KClO_3 = \frac{35.45 \text{ g Cl}}{122.55 \text{ g } KClO_3} \times 100 = 28.93\%$$

$$\text{\% O in } KClO_3 = \frac{48.00 \text{ g O}}{122.55 \text{ g } KClO_3} \times 100 = 39.17\%$$

Determine the percentage of nitrogen in ammonium sulfate, $(NH_4)_2SO_4$.

Even though you want to find the percentage of only one element, you must calculate the molar mass of $(NH_4)_2SO_4$. To do that, examine the formula to find the number of moles of each element in the compound. The two ammonium groups, indicated by $(NH_4)_2$, contain 2 mol N and 8 mol H per mole of $(NH_4)_2SO_4$. The sulfate group, SO_4, contains 1 mol S and 4 mol O per mole of $(NH_4)_2SO_4$.

$$\begin{aligned}
2 \text{ mol N} &= 2 \times 14.01 \text{ g} = & 28.02 \text{ g}\\
8 \text{ mol H} &= 8 \times 1.01 \text{ g} = & 8.08 \text{ g}\\
1 \text{ mol S} &= 1 \times 32.06 = & 32.06 \text{ g}\\
4 \text{ mol O} &= 4 \times 16.00 = & 64.00 \text{ g}\\
\text{molar mass } (NH_4)_2SO_4 &= & 132.16 \text{ g}
\end{aligned}$$

Now, you can determine the percentage of nitrogen in the compound as follows.

$$\text{\% N in } (NH_4)_2SO_4 = \frac{28.02 \text{ g N}}{132.16 \text{ g } (NH_4)_2SO_4} \times 100 = 21.20\%$$

Practice

1. What is the percentage composition of sodium carbonate, Na_2CO_3?
2. What is the percentage of iodine in zinc iodate, $Zn(IO_3)_2$?

CHAPTER 7 Summary

BIG IDEA Chemical formulas represent the ratios of atoms in a chemical compound. Various rules are used to name ionic and covalent compounds.

SECTION 1 Chemical Names and Formulas

- A positive monatomic ion is identified simply by the name of the appropriate element. A negative monatomic ion is named by dropping parts of the ending of the element's name and adding *-ide* to the root.
- The charge of each ion in an ionic compound may be used to determine the simplest chemical formula for the compound.
- Binary compounds are composed of two elements.
- Binary ionic compounds are named by combining the names of the positive and negative ions.
- The old system of naming binary molecular compounds uses prefixes. The new system, known as the *Stock system*, uses oxidation numbers.

KEY TERMS

monatomic ion
binary compound
nomenclature
oxyanion
salt

SECTION 2 Oxidation Numbers

- Oxidation numbers are useful in naming compounds, in writing formulas, and in balancing chemical equations.
- Compounds containing elements that have more than one oxidation state are named by using the Stock system.
- Stock-system names and prefix-system names are used interchangeably for many molecular compounds.
- Oxidation number rules allow assignment of oxidation numbers to each element.
- By knowing oxidation numbers, we can name compounds without knowing whether they are ionic or molecular.

KEY TERMS

oxidation number
oxidation state

SECTION 3 Using Chemical Formulas

- Formula mass, molar mass, and percentage composition can be calculated from the chemical formula for a compound.
- The percentage composition of a compound is the percentage by mass of each element in the compound.
- Molar mass is used as a conversion factor between amount in moles and mass in grams of a given compound or element.

KEY TERMS

formula mass
percentage composition

SECTION 4 Determining Chemical Formulas

- An empirical formula shows the least whole-number ratio of atoms in a given compound.
- Empirical formulas indicate how many atoms of each element are combined in the simplest unit of a chemical compound.
- A molecular formula can be found from the empirical formula if the molar mass is measured.

KEY TERMS

empirical formula

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SECTION 1

Chemical Names and Formulas

REVIEWING MAIN IDEAS

1. **a.** What are monatomic ions?
b. Give three examples of monatomic ions.

2. How does the chemical formula for the nitrite ion differ from the chemical formula for the nitrate ion?

3. Using the periodic table, write the symbol of the ion typically formed by each of the following elements:
a. K
b. Ca
c. S
d. Cl
e. Ba
f. Br

4. Write the formula for and indicate the charge on each of the following ions:
a. sodium ion
b. aluminum ion
c. chloride ion
d. nitride ion
e. iron(II) ion
f. iron(III) ion

5. Name each of the following monatomic ions:
a. K^+
b. Mg^{2+}
c. Al^{3+}
d. Cl^-
e. O^{2-}
f. Ca^{2+}

6. Write formulas for the binary ionic compounds formed between the following elements. (Hint: See Sample Problem A.)
a. sodium and iodine
b. calcium and sulfur
c. zinc and chlorine
d. barium and fluorine
e. lithium and oxygen

7. Give the name of each of the following binary ionic compounds. (Hint: See Sample Problem B.)
a. KCl
b. $CaBr_2$
c. Li_2O
d. $MgCl_2$

8. Write the formulas for and give the names of the compounds formed by the following ions:
a. Cr^{2+} and F^-
b. Ni^{2+} and O^{2-}
c. Fe^{3+} and O^{2-}

9. What determines the order in which the component elements of binary molecular compounds are written?

10. Name the following binary molecular compounds according to the prefix system. (Hint: See Sample Problem D.)
a. CO_2
b. CCl_4
c. PCl_5
d. SeF_6
e. As_2O_5

11. Write formulas for each of the following binary molecular compounds. (Hint: See Sample Problem D.)
a. carbon tetrabromide
b. silicon dioxide
c. tetraphosphorus decoxide
d. diarsenic trisulfide

12. Distinguish between binary acids and oxyacids, and give two examples of each.

13. **a.** What is a salt?
b. Give two examples of salts.

14. Name each of the following acids:
a. HF
b. HBr
c. HNO_3
d. H_2SO_4
e. H_3PO_4

15. Give the molecular formula for each of the following acids:
a. sulfurous acid
b. chloric acid
c. hydrochloric acid
d. hypochlorous acid
e. perchloric acid
f. carbonic acid
g. acetic acid

PRACTICE PROBLEMS

16. Write formulas for each of the following compounds:
a. sodium fluoride
b. calcium oxide
c. potassium sulfide
d. magnesium chloride
e. aluminum bromide
f. lithium nitride
g. iron(II) oxide

17. Name each of the following ions:

a. NH_4^+
b. ClO_3^-
c. OH^-
d. SO_4^{2-}
e. NO_3^-
f. CO_3^{2-}
g. PO_4^{3-}
h. CH_3COO^-
i. HCO_3^-
j. CrO_4^{2-}

18. Write the formula and charge for each of the following ions:

a. ammonium ion
b. acetate ion
c. hydroxide ion
d. carbonate ion
e. sulfate ion
f. phosphate ion
g. copper(II) ion
h. tin(II) ion
i. iron(III) ion
j. copper(I) ion
k. mercury(I) ion
l. mercury(II) ion

SECTION 2

Oxidation Numbers

REVIEWING MAIN IDEAS

19. Name each of the following ions according to the Stock system:

a. Fe^{2+}
b. Fe^{3+}
c. Pb^{2+}
d. Pb^{4+}
e. Sn^{2+}
f. Sn^{4+}

20. Name each of the binary molecular compounds in item 11 by using the Stock system, when appropriate.

21. Write formulas for each of the following compounds:

a. phosphorus(III) iodide
b. sulfur(II) chloride
c. carbon disulfide
d. nitrogen(V) oxide

22. **a.** What are oxidation numbers?
b. What useful functions do oxidation numbers serve?

PRACTICE PROBLEMS

23. Name each of the following ionic compounds by using the Stock system:

a. NaCl
b. KF
c. CaS
d. $Co(NO_3)_2$
e. $FePO_4$
f. Hg_2SO_4
g. $Hg_3(PO_4)_2$

24. Assign oxidation numbers to each atom in the following compounds. (Hint: See Sample Problem E.)

a. HI
b. PBr_3
c. GeS_2
d. KH
e. As_2O_5
f. H_3PO_4

25. Assign oxidation numbers to each atom in the following ions. (Hint: See Sample Problem E.)

a. NO_3^-
b. ClO_4^-
c. PO_4^{3-}
d. $Cr_2O_7^{2-}$
e. CO_3^{2-}

SECTION 3

Using Chemical Formulas

REVIEWING MAIN IDEAS

26. **a.** Define *formula mass.*
b. In what unit is formula mass expressed?

27. What is meant by the molar mass of a compound?

PRACTICE PROBLEMS

28. Determine the formula mass of each of the following compounds or ions. (Hint: See Sample Problem F.)

a. glucose, $C_6H_{12}O_6$
b. calcium acetate, $Ca(CH_3COO)_2$
c. the ammonium ion, NH_4^+
d. the chlorate ion, ClO_3^-

29. Determine the number of moles of each type of monatomic or polyatomic ion in one mole of the following compounds. For each polyatomic ion, determine the number of moles of each atom present in one mole of the ion.

a. KNO_3
b. Na_2SO_4
c. $Ca(OH)_2$
d. $(NH_4)_2SO_3$
e. $Ca_3(PO_4)_2$
f. $Al_2(CrO_4)_3$

30. Determine the molar mass of each compound listed in item 29. (Hint: See Sample Problem G.)

31. Determine the number of moles of compound in each of the following samples. (Hint: See Sample Problem I.)
a. 4.50 g H_2O
b. 471.6 g $Ba(OH)_2$
c. 129.68 g $Fe_3(PO_4)_2$

32. Determine the percentage composition of each of the following compounds. (Hint: See Sample Problem J.)
a. NaCl
b. $AgNO_3$
c. $Mg(OH)_2$

33. Determine the percentage by mass of water in the hydrate $CuSO_4 \bullet 5H_2O$. (Hint: See Sample Problem K.)

SECTION 4

Determining Chemical Formulas

REVIEWING MAIN IDEAS

34. What three types of information can be used to find an empirical formula?

35. What is the relationship between the empirical formula and the molecular formula of a compound?

PRACTICE PROBLEMS

36. Determine the empirical formula of a compound containing 63.50% silver, 8.25% nitrogen, and 28.25% oxygen. (Hint: See Sample Problem L.)

37. Determine the empirical formula of a compound found to contain 52.11% carbon, 13.14% hydrogen, and 34.75% oxygen.

38. What is the molecular formula of the molecule that has an empirical formula of CH_2O and a molar mass of 120.12 g/mol?

39. A compound with a formula mass of 42.08 u is found to be 85.64% carbon and 14.36% hydrogen by mass. Find its molecular formula.

Mixed Review

REVIEWING MAIN IDEAS

40. Chemical analysis shows that citric acid contains 37.51% C, 4.20% H, and 58.29% O. What is the empirical formula for citric acid?

41. Name each of the following compounds by using the Stock system:
a. LiBr
b. $Sn(NO_3)_2$
c. $FeCl_2$
d. MgO
e. KOH
f. Fe_2O_3
g. $AgNO_3$
h. $Fe(OH)_2$
i. CrF_2

42. What is the mass in grams of each of the following samples?
a. 1.000 mol NaCl
b. 2.000 mol H_2O
c. 3.500 mol $Ca(OH)_2$
d. 0.625 mol $Ba(NO_3)_2$

43. Determine the formula mass and molar mass of each of the following compounds:
a. XeF_4
b. $C_{12}H_{24}O_6$
c. Hg_2I_2
d. CuCN

44. Write the chemical formulas for the following compounds:
a. aluminum fluoride
b. magnesium oxide
c. vanadium(V) oxide
d. cobalt(II) sulfide
e. strontium bromide
f. sulfur trioxide

45. How many atoms of each element are contained in a single formula unit of iron(III) formate, $Fe(CHO_2)_3 \bullet H_2O$? What percentage by mass of the compound is water?

46. Name each of the following acids, and assign oxidation numbers to the atoms in each:
a. HNO_2
b. H_2SO_3
c. H_2CO_3
d. HI

47. Determine the percentage composition of the following compounds:
a. NaClO
b. H_2SO_3
c. C_2H_5COOH
d. $BeCl_2$

48. Name each of the following binary compounds:

a. MgI_2
b. NaF
c. CS_2
d. N_2O_4
e. SO_2
f. PBr_3
g. $CaCl_2$
h. AgI

49. Assign oxidation numbers to each atom in the following molecules and ions:

a. CO_2
b. NH_4^+
c. MnO_4^-
d. $S_2O_3^{2-}$
e. H_2O_2
f. P_4O_{10}
g. OF_2

50. A 175.0 g sample of a compound contains 56.15 g C, 9.43 g H, 74.81 g O, 13.11 g N, and 21.49 g Na. What is the compound's empirical formula?

CRITICAL THINKING

51. Analyzing Information Sulfur trioxide is produced in the atmosphere through a reaction of sulfur dioxide and oxygen. Sulfur dioxide is a primary air pollutant. Analyze the formula for sulfur trioxide. Then, use your analysis to list all of the chemical information that you can.

52. Analyzing Data In the laboratory, a sample of pure nickel was placed in a clean, dry, weighed crucible. The crucible was heated so that the nickel would react with the oxygen in the air. After the reaction appeared complete, the crucible was allowed to cool, and the mass was determined. The crucible was reheated and allowed to cool. Its mass was then determined again to be certain that the reaction was complete. The following data were collected:

Mass of crucible	= 30.02 g
Mass of nickel and crucible	= 31.07 g
Mass of nickel oxide and crucible	= 31.36 g

Determine the following information based on the data given above:

Mass of nickel	=
Mass of nickel oxide	=
Mass of oxygen	=

Based on your calculations, what is the empirical formula for the nickel oxide?

USING THE HANDBOOK

53. Review the common reactions of Group 1 metals in the *Elements Handbook* (Appendix A), and answer the following questions:

a. Some of the Group 1 metals react with oxygen to form superoxides. Write the formulas for these compounds.
b. What is the charge on each cation for the formulas that you wrote in (a)?
c. How does the charge on the anion vary for oxides, peroxides, and superoxides?

54. Review the common reactions of Group 2 metals in the *Elements Handbook* (Appendix A), and answer the following questions:

a. Some of the Group 2 metals react with oxygen to form oxides. Write the formulas for these compounds.
b. Some of the Group 2 metals react with oxygen to form peroxides. Write the formulas for these compounds.
c. Some of the Group 2 metals react with nitrogen to form nitrides. Write the formulas for these compounds.
d. Most Group 2 elements form hydrides. What is hydrogen's oxidation state in these compounds?

55. Review the analytical tests for transition metals in the *Elements Handbook* (Appendix A), and answer the following questions:

a. Determine the oxidation state of each metal in the precipitates shown for cadmium, zinc, and lead.
b. Determine the oxidation state of each metal in the complex ions shown for iron, manganese, and cobalt.
c. The copper compound shown is called a *coordination compound*. The ammonia shown in the formula exists as molecules that do not have a charge. Determine copper's oxidation state in this compound.

56. Review the common reactions of Group 15 elements in the *Elements Handbook* (Appendix A), and answer the following questions:

a. Write formulas for each of the oxides listed for the Group 15 elements.

b. Determine nitrogen's oxidation state in the oxides listed in (a).

RESEARCH AND WRITING

57. Nomenclature Biologists who name newly discovered organisms use a system that is structured very much like the one used by chemists in naming compounds. The system used by biologists is called the *Linnaean system of binomial nomenclature*, after its creator, Carolus Linnaeus. Research this system in a biology textbook, and then note similarities and differences between the Linnaeus system and chemical nomenclature.

58. Common Chemicals Find out the systematic chemical name and write the chemical formula for each of the following common compounds:

a. baking soda
b. milk of magnesia
c. Epsom salts
d. limestone
e. lye
f. wood alcohol

ALTERNATIVE ASSESSMENT

59. Performance Assessment Your teacher will supply you with a note card that has one of the following formulas on it: $NaCH_3COO \bullet 3H_2O$, $MgCl_2 \bullet 6H_2O$, $LiC_2H_3O_2 \bullet 2H_2O$, or $MgSO_4 \bullet 7H_2O$. Design an experiment to determine the percentage of water by mass in the hydrated salt assigned to you. Be sure to explain what steps you will take to ensure that the salt is completely dry. If your teacher approves your design, obtain the salt and perform the experiment. What percentage of water does the salt contain?

60. Both ammonia, NH_3, and ammonium nitrate, NH_4NO_3, are used in fertilizers as a source of nitrogen. Which compound has the higher percentage of nitrogen? Research the physical properties of both compounds, and find out how each compound is manufactured and used. Explain why each compound has its own particular application. (Consider factors such as the cost of raw ingredients, the ease of manufacture, and shipping costs.)