

Key Concepts

12.1 The Arithmetic of Equations

- A balanced chemical equation provides the same kind of quantitative information that a recipe does.
- Chemists use balanced chemical equations as a basis to calculate how much reactant is needed or product is formed in a reaction.
- A balanced chemical equation can be interpreted in terms of different quantities, including numbers of atoms, molecules, or moles; mass; and volume.
- Mass and atoms are conserved in every chemical reaction.

12.2 Chemical Calculations

- In chemical calculations, mole ratios are used to convert between moles of reactant and moles of product, between moles of reactants, or between moles of products.

- In a typical stoichiometric problem, the given quantity is first converted to moles. Then the mole ratio from the balanced equation is used to calculate the moles of the wanted substance. Finally, the moles are converted to any other unit of measurement related to the unit mole.

12.3 Limiting Reagent and Percent Yield

- In a chemical reaction, an insufficient quantity of any of the reactants will limit the amount of product that forms.
- The percent yield is a measure of the efficiency of a reaction performed in the laboratory.

Vocabulary

- actual yield (p. 372)
- excess reagent (p. 369)
- limiting reagent (p. 369)
- mole ratio (p. 359)
- percent yield (p. 372)
- stoichiometry (p. 354)
- theoretical yield (p. 372)

Key Equations

- mole-mole relationship for $aG \longrightarrow bW$:

$$x \text{ mol } G \times \frac{b \text{ mol } W}{a \text{ mol } G} = \frac{xb}{a} \text{ mol } W$$

- percent yield = $\frac{\text{actual yield}}{\text{theoretical yield}} \times 100\%$

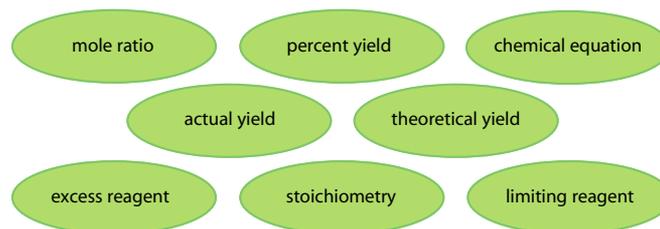
Organizing Information

Use these terms to construct a concept map that organizes the major ideas of this chapter.



Concept Map 12 Solve the Concept Map with the help of an interactive guided tutorial.

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Reviewing Content

12.1 The Arithmetic of Equations

36. Interpret each chemical equation in terms of interacting particles.
- $2\text{KClO}_3(s) \longrightarrow 2\text{KCl}(s) + 3\text{O}_2(g)$
 - $4\text{NH}_3(g) + 6\text{NO}(g) \longrightarrow 5\text{N}_2(g) + 6\text{H}_2\text{O}(g)$
 - $4\text{K}(s) + \text{O}_2(g) \longrightarrow 2\text{K}_2\text{O}(s)$
37. Interpret each equation in Problem 36 in terms of interacting numbers of moles of reactants and products.
38. Calculate and compare the mass of the reactants with the mass of the products for each equation in Problem 36. Show that each balanced equation obeys the law of conservation of mass.

12.2 Chemical Calculations

39. Explain the term *mole ratio* in your own words. When would you use this term?
40. Carbon disulfide is an important industrial solvent. It is prepared by the reaction of coke with sulfur dioxide.
- $$5\text{C}(s) + 2\text{SO}_2(g) \longrightarrow \text{CS}_2(l) + 4\text{CO}(g)$$
- How many moles of CS_2 form when 2.7 mol C reacts?
 - How many moles of carbon are needed to react with 5.44 mol SO_2 ?
 - How many moles of carbon monoxide form at the same time that 0.246 mol CS_2 forms?
 - How many mol SO_2 are required to make 118 mol CS_2 ?
41. Methanol (CH_3OH) is used in the production of many chemicals. Methanol is made by reacting carbon monoxide and hydrogen at high temperature and pressure.
- $$\text{CO}(g) + 2\text{H}_2(g) \longrightarrow \text{CH}_3\text{OH}(g)$$
- How many moles of each reactant are needed to produce 3.60×10^2 g CH_3OH ?
 - Calculate the number of grams of each reactant needed to produce 4.00 mol CH_3OH .
 - How many grams of hydrogen are necessary to react with 2.85 mol CO?
42. The reaction of fluorine with ammonia produces dinitrogen tetrafluoride and hydrogen fluoride.
- $$5\text{F}_2(g) + 2\text{NH}_3(g) \longrightarrow \text{N}_2\text{F}_4(g) + 6\text{HF}(g)$$

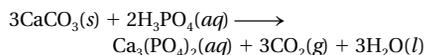
- If you have 66.6 g NH_3 , how many grams of F_2 are required for complete reaction?
 - How many grams of NH_3 are required to produce 4.65 g HF?
 - How many grams of N_2F_4 can be produced from 225 g F_2 ?
43. What information about a chemical reaction is derived from the coefficients in a balanced equation?
44. Lithium nitride reacts with water to form ammonia and aqueous lithium hydroxide.
- $$\text{Li}_3\text{N}(s) + 3\text{H}_2\text{O}(l) \longrightarrow \text{NH}_3(g) + 3\text{LiOH}(aq)$$
- What mass of water is needed to react with 32.9 g Li_3N ?
 - When the above reaction takes place, how many molecules of NH_3 are produced?
 - Calculate the number of grams of Li_3N that must be added to an excess of water to produce 15.0 L NH_3 (at STP).

12.3 Limiting Reagent and Percent Yield

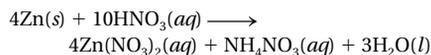
45. What is the significance of the limiting reagent in a reaction? What happens to the amount of any reagent that is present in an excess?
46. How would you identify a limiting reagent in a chemical reaction?
47. In a reaction chamber, 3.0 mol of aluminum is mixed with 5.3 mol Cl_2 and reacts. The reaction is described by the following balanced chemical equation.
- $$2\text{Al} + 3\text{Cl}_2 \longrightarrow 2\text{AlCl}_3$$
- Identify the limiting reagent for the reaction.
 - Calculate the number of moles of product formed.
 - Calculate the number of moles of excess reagent remaining after the reaction.
48. Heating an ore of antimony (Sb_2S_3) in the presence of iron gives the element antimony and iron(II) sulfide.
- $$\text{Sb}_2\text{S}_3(s) + 3\text{Fe}(s) \longrightarrow 2\text{Sb}(s) + 3\text{FeS}(s)$$
- When 15.0 g Sb_2S_3 reacts with an excess of Fe, 9.84 g Sb is produced. What is the percent yield of this reaction?

Understanding Concepts

49. Calcium carbonate reacts with phosphoric acid to produce calcium phosphate, carbon dioxide, and water.



- How many grams of phosphoric acid react with excess calcium carbonate to produce 3.74 g $\text{Ca}_3(\text{PO}_4)_2$?
 - Calculate the number of grams of CO_2 formed when 0.773 g H_2O is produced.
50. Nitric acid and zinc react to form zinc nitrate, ammonium nitrate, and water.



- How many atoms of zinc react with 1.49 g HNO_3 ?
- Calculate the number of grams of zinc that must react with an excess of HNO_3 to form 29.1 g NH_4NO_3 .

51. Hydrazine (N_2H_4) is used as rocket fuel. It reacts with oxygen to form nitrogen and water.



- How many liters of N_2 (at STP) form when 1.0 kg N_2H_4 reacts with 1.0 kg O_2 ?
 - How many grams of the excess reagent remain after the reaction?
52. When 50.0 g of silicon dioxide is heated with an excess of carbon, 32.2 g of silicon carbide is produced.



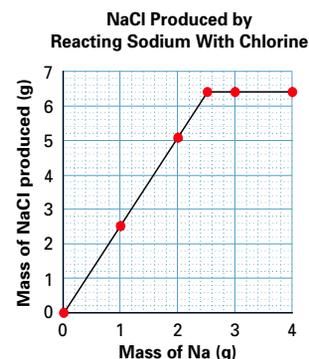
- What is the percent yield of this reaction?
 - How many grams of CO gas are made?
53. If the reaction below proceeds with a 96.8% yield, how many kilograms of CaSO_4 are formed when 5.24 kg SO_2 reacts with an excess of CaCO_3 and O_2 ?
- $$2\text{CaCO}_3(s) + 2\text{SO}_2(g) + \text{O}_2(g) \longrightarrow 2\text{CaSO}_4(s) + 2\text{CO}_2(g)$$

54. Ammonium nitrate will decompose explosively at high temperatures to form nitrogen, oxygen, and water vapor.

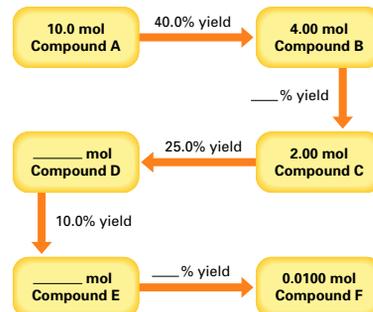


What is the total number of liters of gas formed when 228 g NH_4NO_3 is decomposed? (Assume STP.)

55. In an experiment, varying masses of sodium metal are reacted with a fixed initial mass of chlorine gas. The amounts of sodium used and the amounts of sodium chloride formed are shown on the following graph.

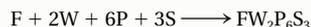


- Explain the general shape of the graph.
 - Estimate the amount of chlorine gas used in this experiment at the point where the curve becomes horizontal.
56. The manufacture of compound F requires five separate chemical reactions. The initial reactant, compound A, is converted to compound B, compound B is converted to compound C, and so forth. The diagram below summarizes the step-wise manufacture of compound F, including the percent yield for each step. Provide the missing quantities or missing percent yields. Assume that the reactant and product in each step react in a one-to-one mole ratio.



Critical Thinking

57. Given a certain quantity of reactant, you calculate that a particular reaction should produce 55 g of a product. When you perform the reaction, you find that you have produced 63 g of product. What is your percent yield? What could have caused a percent yield greater than 100%?
58. Would the law of conservation of mass hold in a net ionic equation? Explain.
59. A bicycle-built-for-three has a frame, two wheels, six pedals, and three seats. The balanced equation for this bicycle is

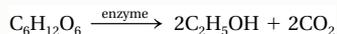


How many of each part are needed to make 29 bicycles-built-for-three?

- a. frames b. wheels
c. pedals d. seats

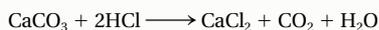


60. A car gets 9.2 kilometers to a liter of gasoline. Assuming that gasoline is 100% octane (C_8H_{18}), which has a density of 0.69 g/cm^3 , how many liters of air (21% oxygen by volume at STP) will be required to burn the gasoline for a 1250-km trip? Assume complete combustion.
61. Ethyl alcohol (C_2H_5OH) can be produced by the fermentation of glucose ($C_6H_{12}O_6$). If it takes 5.0 h to produce 8.0 kg of alcohol, how many days will it take to consume $1.0 \times 10^3 \text{ kg}$ of glucose? (An enzyme is used as a catalyst.)



Concept Challenge

62. A 1004.0-g sample of $CaCO_3$ that is 95.0% pure gives 225 L CO_2 at STP when reacted with an excess of hydrochloric acid.



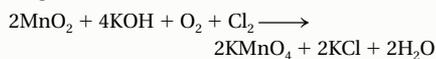
What is the density (in g/L) of the CO_2 ?

63. The white limestone cliffs of Dover, England, contain a large percentage of calcium carbonate ($CaCO_3$). A sample of limestone with a mass of 84.4 g reacts with an excess of hydrochloric acid to form calcium chloride.

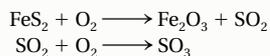


The mass of calcium chloride formed is 81.8 g. What is the percentage of calcium carbonate in the limestone?

64. For the reaction below there is a 100.0 g of each reactant available. Which reagent is the limiting reagent?



65. The equation for one of the reactions in the process of reducing iron ore to the metal is $Fe_2O_3(s) + 3CO(g) \longrightarrow 2Fe(s) + 3CO_2(g)$
- a. What is the maximum mass of iron, in grams, that can be obtained from 454 g (1.00 lb) of iron(III) oxide?
- b. What mass of CO is required to reduce the iron(III) oxide to iron metal?
66. SO_3 can be produced in the following two-step process:



Assuming that all the FeS_2 reacts, how many grams of SO_3 are produced when 20.0 g of the FeS_2 reacts with 16.0 g of O_2 ?

Cumulative Review

67. How many electrons, protons, and neutrons are in an atom of each isotope? (*Chapter 4*)
- titanium-47
 - tin-120
 - oxygen-18
 - magnesium-26
68. When comparing ultraviolet and visible electromagnetic radiation, which has (*Chapter 5*)
- a higher frequency
 - a higher energy
 - a shorter wavelength
69. Identify the larger atom of each pair. (*Chapter 6*)
- sodium and chlorine
 - arsenic and nitrogen
 - fluorine and cesium
70. Write electron dot formulas for the following atoms. (*Chapter 7*)
- Cs
 - Br
 - Ca
 - P
71. Which of these elements form ions with a $2+$ charge? (*Chapter 7*)
- potassium
 - sulfur
 - barium
 - magnesium
72. Distinguish among single, double, and triple covalent bonds. (*Chapter 8*)
73. Can a compound have both ionic and covalent bonds? Explain your answer. (*Chapter 8*)
74. How do you distinguish between a cation and an anion? (*Chapter 9*)
75. Name these ions. (*Chapter 9*)
- PO_4^{3-}
 - Al^{3+}
 - Se^{2-}
 - NH_4^+
76. Name each substance. (*Chapter 9*)
- SiO_2
 - K_2SO_4
 - H_2CO_3
 - MgS
77. Write the formula for each compound. (*Chapter 9*)
- aluminum carbonate
 - nitrogen dioxide
 - potassium sulfide
 - manganese(II) chromate
 - sodium bromide
78. What is the mass, in grams, of a molecule of benzene (C_6H_6)? (*Chapter 10*)
79. How many grams of beryllium are in 147 g of the mineral beryl ($\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$)? (*Chapter 10*)
80. What is the molecular formula of oxalic acid, molar mass 90 g/mol? Its percent composition is 26.7% C, 2.2% H, and 71.1% O. (*Chapter 10*)
81. How many moles is each of the following? (*Chapter 10*)
- 47.8 g KNO_3
 - 2.22 L SO_2 (at STP)
 - 2.25×10^{22} molecules PCl_3
82. Write a balanced chemical equation for each reaction. (*Chapter 11*)
- When heated, lead(II) nitrate decomposes to form lead(II) oxide, nitrogen dioxide, and molecular oxygen.
 - The complete combustion of isopropyl alcohol ($\text{C}_3\text{H}_7\text{OH}$) produces carbon dioxide and water vapor.
 - When a mixture of aluminum and iron(II) oxide is heated, metallic iron and aluminum oxide are produced.
83. Balance each equation. (*Chapter 11*)
- $\text{Ba}(\text{NO}_3)_2(\text{aq}) + \text{Na}_2\text{SO}_4(\text{aq}) \longrightarrow \text{BaSO}_4(\text{s}) + \text{NaNO}_3(\text{aq})$
 - $\text{AlCl}_3(\text{aq}) + \text{AgNO}_3(\text{aq}) \longrightarrow \text{AgCl}(\text{s}) + \text{Al}(\text{NO}_3)_3(\text{aq})$
 - $\text{H}_2\text{SO}_4(\text{aq}) + \text{Mg}(\text{OH})_2(\text{aq}) \longrightarrow \text{MgSO}_4(\text{aq}) + \text{H}_2\text{O}(\text{l})$
84. Write a net ionic equation for each reaction in Problem 83. (*Chapter 11*)
85. Identify the spectator ions in each reaction in Problem 83. (*Chapter 11*)
86. Write a balanced chemical equation for the complete combustion of ribose, $\text{C}_5\text{H}_{10}\text{O}_5$. (*Chapter 11*)

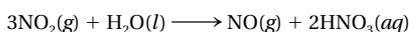
Standardized Test Prep

Test-Taking Tip

Anticipate the answer. Use what you know to predict what you think the answer should be. Then look to see if your answer, or one much like it, is given as an option.

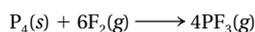
Select the choice that best answers each question or completes each statement.

1. Nitric acid is formed by the reaction of nitrogen dioxide with water.



How many moles of water are needed to react with 8.4 mol NO_2 ?

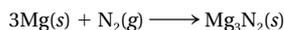
- a. 2.8 mol
 - b. 3.0 mol
 - c. 8.4 mol
 - d. 25 mol
2. Phosphorus trifluoride is formed from its elements.



How many grams of fluorine are needed to react with 6.20 g of phosphorus?

- a. 2.85 g
- b. 5.70 g
- c. 11.4 g
- d. 37.2 g

3. Magnesium nitride is formed in the reaction of magnesium metal with nitrogen gas.



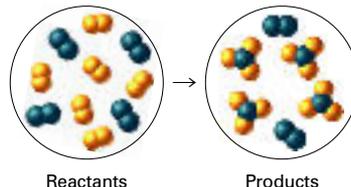
The reaction of 4.0 mol of nitrogen with 6.0 mol of magnesium produces

- a. 2.0 mol of Mg_3N_2 and 2.0 mol of excess N_2 .
- b. 4.0 mol of Mg_3N_2 and 1.0 mol of excess Mg.
- c. 6.0 mol of Mg_3N_2 and 3.0 mol of excess N_2 .
- d. no product because the reactants are not in the correct mole ratio.

Questions 4 and 5 involve the reaction between diatomic element P and diatomic element Q to form the compound P_3Q .



4. Write a balanced equation for the reaction between element P and element Q.
5. Based on the atomic windows below, identify the limiting reagent.



For each question there are two statements. Decide whether each statement is true or false. Then decide whether Statement II is a correct explanation for Statement I.

- | Statement I | Statement II |
|---|---|
| 6. Every stoichiometry calculation uses a balanced equation. | BECAUSE Every chemical reaction obeys the law of conservation of mass. |
| 7. A percent yield is always greater than 0% and less than 100%. | BECAUSE The actual yield in a reaction is never more than the theoretical yield. |
| 8. The amount of the limiting reagent left after a reaction is zero. | BECAUSE The limiting reagent is completely used up in a reaction. |
| 9. The coefficients in a balanced equation represent the relative masses of the reactants and products. | BECAUSE The mass of the reactants must equal the mass of the products in a chemical reaction. |
| 10. A mole ratio is always written with the larger number in the numerator. | BECAUSE A mole ratio will always be greater than 1. |