The Science of Chemistry

Section: Describing Matter

1. What is the density of a block of marble that occupies 310 cm³ and has a mass of 853 g?
2. Diamond has a density of 3.26 g/cm³. What is the mass of a diamond that has a volume of 0.350 cm³?
3. What is the volume of a sample of liquid mercury that has a mass of 76.2 g, given that the density of mercury is 13.6 g/mL?
4. What is the density of a sample of ore that has a mass of 74.0 g and occupies 20.3 cm³?
5. Find the volume of a sample of wood that has a mass of 95.1 g and a density of 0.857 g/cm³?
6. Express a length of 16.45 m in centimeters.
7. Express a length of 16.45 m in kilometers.
8. Express a mass of 0.014 mg in grams.
9. Complete the following conversion:
   \[ 10.5 \text{ g} = \underline{\text{______}} \text{ kg} \]
10. Complete the following conversion:
    \[ 1.57 \text{ km} = \underline{\text{______}} \text{ m} \]
11. Complete the following conversion:
    \[ 3.54 \mu\text{g} = \underline{\text{______}} \text{ g} \]
12. Complete the following conversion:
    \[ 3.5 \text{ mol} = \underline{\text{______}} \mu\text{mol} \]
13. Complete the following conversion:
    \[ 1.2 \text{ L} = \underline{\text{______}} \text{ mL} \]
14. Complete the following conversion:
    \[ 358 \text{ cm}^3 = \underline{\text{______}} \text{ m}^3 \]
15. Complete the following conversion:
    \[ 548.6 \text{ mL} = \underline{\text{______}} \text{ cm}^3 \]
16. What is the density of an 84.7 g sample of an unknown substance if the sample occupies 49.6 cm³?
17. What volume would be occupied by 7.75 g of a substance with a density of 1.70766 g/cm³?
18. Express a time period of exactly 1 day in terms of seconds. Try to write out all the equalities needed to solve this problem.
19. How many centigrams are there in 6.25 kg?
20. Polycarbonate plastic has a density of 1.2 g/cm³. A photo frame is constructed from two 3.0 mm sheets of polycarbonate. Each sheet measures 28 cm by 22 cm. What is the mass of the photo frame?
21. Find the volume of a cube that is 3.23 cm on each edge.
22. Calculate the density of a 17.982 g object that occupies 4.13 cm³.

Matter and Energy

Section: Measurements and Calculations in Chemistry

1. Determine the specific heat of a material if a 35.0 g sample absorbed 48.0 J as it was heated from 293 K to 313 K.
2. A piece of copper alloy with a mass of 85.0 g is heated from 30.0 °C to 45.0 °C. In the process, it absorbs 523 J of energy as heat.
   a. What is the specific heat of this copper alloy?
   b. How much energy will the same sample lose if it is cooled to 25.0 °C?
3. The temperature of a 74.0 g sample of material increases from 15.0 °C to 45.0 °C when it absorbs 2.00 kJ of energy as heat. What is the specific heat of this material?
4. How much energy is needed to raise the temperature of 5.00 g of gold \((c_p = 0.129 \text{ J/(g} \cdot \text{K)})\) by 25.0 °C?
5. Energy in the amount of 420 J is added to a 35.0 g sample of water \((c_p = 4.18 \text{ J/(g} \cdot \text{K)})\) at a temperature of 10.0 °C. What will be the final temperature of the water?
6. What mass of liquid water \((c_p = 4.18 \text{ J/(g} \cdot \text{K)})\) at room temperature (25°C) can be raised to its boiling point with the addition of 24.0 kJ of energy?
7. How much energy would be absorbed as heat by 75 g of iron \((c_p = 0.449 \text{ J/(g\(\cdot\)K)})\) when heated from 295 K to 301 K?

**Atoms and Moles**

**Section: Structure of Atoms**

1. How many protons, electrons, and neutrons are in an atom of bromine-80?
2. Write the nuclear symbol for carbon-13.
3. Write the hyphen notation for the element that contains 15 electrons and 15 neutrons.
4. How many protons, electrons, and neutrons are in an atom of carbon-13?
5. Write the nuclear symbol for oxygen-16.
6. Write the hyphen notation for the element whose atoms contains 7 electrons and 9 neutrons.

**Section: Counting Atoms**

7. What is the mass in grams of 2.25 mol of the element iron, Fe?
8. What is the mass in grams of 0.375 mol of the element potassium, K?
9. What is the mass in grams of 0.0135 mol of the element sodium, Na?
10. What is the mass in grams of 16.3 mol of the element nickel, Ni?
11. What is the mass in grams of 3.6 mol of the element carbon, C?
12. What is the mass in grams of 0.733 mol of the element chlorine, Cl?
13. How many moles of calcium, Ca, are in 5 g of calcium?
14. How many moles of gold, Au, are in \(3.6 \times 10^{-10}\) g of gold?
15. How many moles of copper, Cu, are in 3.22 g of copper?
16. How many moles of lithium, Li, are in \(2.72 \times 10^{-4}\) g of lithium?
17. How many moles of lead, Pb, are in \(1.5 \times 10^{12}\) atoms of lead?
18. How many moles of tin, Sn, are in 2500 atoms of tin?

19. How many atoms of aluminum, Al, are in 2.75 mol of aluminum?
20. How many moles of carbon, C, are in \(2.25 \times 10^{22}\) atoms of carbon?
21. How many moles of oxygen, O, are in \(2 \times 10^6\) atoms of oxygen?
22. How many atoms of sodium, Na, are in 3.8 mol of sodium?
23. What is the mass in grams of \(7.5 \times 10^{15}\) atoms of nickel, Ni?
24. How many atoms of sulfur, S, are in 4 g of sulfur?
25. What mass of gold, Au, contains the same number of atoms as 9.00 g of aluminum, Al?
26. What is the mass in grams of \(5 \times 10^9\) atoms of neon, Ne?
27. How many atoms of carbon, C, are in 0.02 g of carbon?
28. What mass of silver, Ag, contains the same number of atoms as 10 g of boron, B?
29. How many moles of atoms are there in \(3.25 \times 10^{5}\) g Pb?
30. How many moles of atoms are there in 150 g S?

**The Mole and Chemical Composition**

**Section: Avogadro’s Number and Mole Conversions**

1. What is the mass in grams of 3.25 mol \(\text{Fe}_2(\text{SO}_4)_3\)?
2. How many moles of molecules are there in 250 g of hydrogen nitrate, \(\text{HNO}_3\)?
3. How many molecules of aspirin, \(\text{C}_9\text{H}_8\text{O}_4\), are there in a 100 mg tablet of aspirin?
4. What is the mass in grams of 3.04 mol of ammonia vapor, \(\text{NH}_3\)?
5. Calculate the mass of 0.257 mol of calcium nitrate, \(\text{Ca(NO}_3)_2\).
6. How many moles are there in 6.60 g of \((\text{NH}_4)_2\text{SO}_4\)?
7. How many moles are there in 4.50 kg of \(\text{Ca(OH)}_2\)?
8. How many molecules are there in 25.0 g of H₂SO₄?
9. How many molecules are there in 125 g of sugar, C₁₂H₂₂O₁₁?
10. What is the mass in grams of 6.25 mol of copper(II) nitrate?
11. How many moles are there in 3.82 g of SO₂?
12. How many moles are there in 4.15 × 10⁻³ g of C₆H₁₂O₆?
13. How many moles are there in 77.1 g of Cl₂?
14. How many molecules are there in 3.82 g of SO₂?
15. How many molecules are there in 4.15 × 10⁻³ g of C₆H₁₂O₆?
16. Determine the number of moles in 4.50 g of H₂O?
17. Determine the number of moles in 471.6 g of Ba(OH)₂?
18. Determine the number of moles in 129.68 g of Fe₃(PO₄)₂?
19. What is the mass in grams of 1.00 mol NaCl?
20. What is the mass in grams of 2.00 mol H₂O?
21. What is the mass in grams of 3.500 mol Ca(OH)₂?
22. What is the mass in grams of 0.6250 mol Ba(NO₃)₂?

Section: Relative Atomic Mass and Chemical Formulas

23. Find the formula mass for the following: H₂SO₄.
24. Find the formula mass for the following: Ca(NO₃)₂.
25. Find the formula mass for the following: PO₄³⁻.
26. Find the formula mass for the following: MgCl₂.
27. Find the formula mass for the following: Na₂SO₃.
28. Find the formula mass for the following: HClO₃.
29. Find the formula mass for the following: MnO₄⁻.
30. Find the formula mass for the following: C₂H₆O.
31. Find the molar mass for the following: Al₂S₃.
32. Find the molar mass for the following: NaNO₃.
33. Find the molar mass for the following: Ba(OH)₂.
34. Find the molar mass for the following: K₂SO₄.
35. Find the molar mass for the following: (NH₄)₂CrO₄.
36. Determine the formula mass of the following: calcium acetate, Ca(CH₃COO)₂.
37. Determine the molar mass of the following: glucose, C₆H₁₂O₆.
38. Determine the molar mass of the following: calcium acetate, Ca(CH₃COO)₂.
39. Determine the molar mass of the following: the ammonium ion, NH₄⁺.
40. Determine the molar mass of the following: the chlorate ion, ClO₃⁻.
41. Determine the molar mass of XeF₄.
42. Determine the molar mass of C₁₂H₄₂O₆.
43. Determine the molar mass of Hg₂I₂.
44. Determine the molar mass of CuCN.
45. Determine the formula mass of the following: the ammonium ion, NH₄⁺.
46. Determine the formula mass of the following: the chlorate ion, ClO₃⁻.

Section: Formulas and Percentage Composition

47. Calculate the percentage composition of lead (II) chloride, PbCl₂.
48. Calculate the percentage composition of barium nitrate, Ba(NO₃)₂.
49. Find the mass percentage of water in ZnSO₄•7H₂O.
50. a. Magnesium hydroxide is 54.87% oxygen by mass. How many grams of oxygen are in 175 g of the compound?
   b. How many moles of oxygen is this?
51. Calculate the percent composition of sodium nitrate, NaNO₃.
52. Calculate the percent composition of silver sulfate, Ag₂SO₄.
53. What is the mass percentage of water in the hydrate CuSO₄•5H₂O?
54. a. Zinc chloride, ZnCl₂ is 52.02% chlorine by mass. What mass of chlorine is contained in 80.3 g of ZnCl₂?
   b. How many moles of Cl is this?
55. A compound is found to contain 63.52% iron and 36.48% sulfur. Find its empirical formula.
56. Determine the formula mass and molar mass of ammonium carbonate, (NH₄)₂CO₃.
   a. The formula mass is ________
   b. The molar mass is ________
57. Calculate the percent composition of (NH₄)₂CO₃.
58. A compound is found to contain 36.48% Na, 25.41% S, and 38.11% O. Find its empirical formula.
59. Calculate the percent composition of sodium chloride, NaCl.
60. Calculate the percent composition of silver nitrate, AgNO₃.
61. Calculate the percent composition of magnesium hydroxide, Mg(OH)₂.
62. What is the mass percentage of water in the hydrate CuSO₄•5H₂O?
63. Determine the percent composition for NaClO.
64. Determine the percent composition for H₂SO₃.
65. Determine the percent composition for C₂H₅COOH.
66. Determine the percent composition for BeCl₂.
67. a. A compound is found to contain 54.5% carbon, 9.1% hydrogen, and 36.4% oxygen. Determine the simplest formula.
   b. The molar mass of a compound is 88.1 g. What is the molecular formula if the simplest formula is C₃H₄O?
68. Find the empirical formula of a compound found to contain 26.56% potassium, 35.41% chromium, and the remainder oxygen.
69. Analysis of 20.0 g of a compound containing only calcium and bromine indicates that 4.00 g of calcium are present. What is the empirical formula of the compound formed?
70. A compound is analyzed and found to contain 36.70% potassium, 33.27% chlorine, and 30.03% oxygen. What is the empirical formula of the compound?
71. Determine the empirical formula of the compound that contains 17.15% carbon, 1.44% hydrogen, and 81.41% fluorine.
72. A 60.00 g sample of tetraethyl-lead, a gasoline additive, is found to contain 38.43 g lead, 17.83 g carbon, and 3.74 g hydrogen. Find its empirical formula.
73. A 100.00 g sample of an unidentified compound contains 29.84 g sodium, 67.49 g chromium, and 72.67 g oxygen. What is the compound's empirical formula?
74. A compound is found to contain 53.70% iron and 46.30% sulfur. Find its empirical formula.
75. Analysis of a compound indicates that it contains 1.04 g K, 0.70 g Cr, and 0.86 g O. Find its empirical formula.
76. If 4.04 g of N combine with 11.46 g of O to produce a compound with the formula mass of 108.0 amu, what is the molecular formula of this compound?
77. Determine the empirical formula of a compound containing 63.50% silver, 8.25% nitrogen, and the remainder oxygen.
78. Determine the empirical formula of a compound found to contain 52.11% carbon, 13.14% hydrogen, and 34.75% oxygen.
79. Chemical analysis of citric acid shows that it contains 37.51% C, 4.20% H, 58.29% O. What is its empirical formula?

80. 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 its empirical formula?

81. 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?

82. Determine the molecular formula of the compound with an empirical formula of CH and a formula mass of 78.110 amu.

83. A sample compound with a formula mass of 34.00 amu is found to consist of 0.44 g H and 6.92 g O. Find its molecular formula.

84. The empirical formula for trichloroisocyanuric acid, the active ingredient in many household bleaches, is OCNCI. The molar mass of this compound is 232.41 g/mol. What is the molecular formula of trichloroisocyanuric acid?

85. Determine the molecular formula of a compound with an empirical formula of NH2 and a formula mass of 32.06 amu.

86. The molar mass of a compound is 92 g/mol. Analysis of a sample of the compound indicates that it contains 0.606 g N and 1.390 g O. Find its molecular formula.

87. What is the molecular formula of the molecule that has an empirical formula of CH2O and a molar mass of 120.12 g/mol?

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

**Stoichiometry**

**Section: Calculating Quantities in Reactions**

1. A seashell, composed largely of calcium carbonate, is placed in a solution of HCl. As a result, 1500 mL of dry CO2 gas at STP is produced. The other products are CaCl2 and H2O. Based on this information, how many grams of CaCO3 are consumed in the reaction?

2. Acid precipitation is the term generally used to describe rain or snow that is more acidic than normal. One cause of acid precipitation is the formation of sulfuric and nitric acids from various sulfur and nitrogen oxides produced in volcanic eruptions, forest fires, and thunderstorms. In a typical volcanic eruption, for example, $3.50 \times 10^8$ kg of SO2 may be produced. If this amount of SO2 were converted to H2SO4 according to the two-step process given below, how many kilograms of H2SO4 would be produced from such an eruption?

   $\text{SO}_2 + \frac{1}{2}\text{O}_2 \rightarrow \text{SO}_3$

   $\text{SO}_3 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_4$

3. Solid iron(III) hydroxide decomposes to produce iron(III) oxide and water vapor. If 0.750 L of water vapor is produced at STP, how many grams of iron(III) oxide are produced?

   a. How many grams of iron(III) hydroxide were used?
   
   b. How many grams of iron(III) oxide are produced?

4. Balance the following chemical equation.

   $\text{Mg(s)} + \text{O}_2(g) \rightarrow \text{MgO(s)}$

   Then, based on the quantity of reactant or product given, determine the corresponding quantities of the specified reactants or products, assuming that the system is at STP.
a. How many moles of MgO are produced from 22.4 L O2?
b. How many moles of MgO are produced from 11.2 L O2?
c. How many moles of MgO are produced from 1.40 L O2?

5. Assume that 8.50 L of I2 are produced using the following reaction that takes place at STP: 

\[ \text{KI(aq)} + \text{Cl}_2(g) \rightarrow \text{KCl(aq)} + \text{I}_2(g) \]

Balance the equation before beginning your calculations.

a. How many moles of I2 are produced?
b. How many moles of KI were used?
c. How many grams of KI were used?

6. Suppose that 650 mL of hydrogen gas are produced through a replacement reaction involving solid iron and sulfuric acid, H2SO4, at STP.

How many grams of iron(II) sulfate are also produced?

Section: Limiting Reactants and Percentage Yield

7. Methanol, CH3OH, is made by causing carbon monoxide and hydrogen gases to react at high temperature and pressure. If 450 mL of CO and 825 mL of H2 are mixed,

a. Which reactant is present in excess?
b. How much of that reactant remains after the reaction?
c. What volume of CH3OH is produced, assuming the same pressure?

Causes of Change

Section: Using Enthalpy

1. When 1 mol of methane is burned at constant pressure, \(-890 \text{ kJ/mol}\) of energy is released as heat. If a 3.2 g sample of methane is burned at constant pressure, what will be the value of \(\Delta H\)? (Hint: Convert the grams of methane to moles. Also make sure your answer has the correct sign for an exothermic process.)

2. How much energy is needed to raise the temperature of a 55 g sample of aluminum from 22.4°C to 94.6°C? The specific heat of aluminum is 0.897 J/(g·K).

3. 3500 J of energy are added to a 28.2 g sample of iron at 20°C. What is the final temperature of the iron in kelvins? The specific heat of iron is 0.449 J/(g·K).

Section: Changes in Enthalpy During Reactions

4. The combustion of methane gas, CH4, forms CO2(g) + H2O(l). Calculate the energy as heat produced by burning 1 mol of the methane gas.

5. Calculate \(\Delta H\) for the following reaction:

\[ 2\text{N}_2(g) + 5\text{O}_2(g) \rightarrow 2\text{N}_2\text{O}_5(g) \]

Use the following data in your calculation:

\[
\begin{align*}
\text{H}_2(g) + \frac{1}{2}\text{O}_2(g) & \rightarrow \text{H}_2\text{O}(l) \\
\Delta H_f^0 &= -285.8 \text{ kJ/mol} \\
\text{N}_2\text{O}_5(g) + \text{H}_2\text{O}(l) & \rightarrow 2\text{NHO}_3(l) \\
\Delta H &= -76.6 \text{ kJ/mol} \\
\frac{1}{2}\text{N}_2(g) + \frac{3}{2}\text{O}_2(g) + \frac{1}{2}\text{H}_2(g) & \rightarrow \text{HNO}_3(l) \\
\Delta H_f^0 &= -174.1 \text{ kJ/mol}
\end{align*}
\]

6. Calculate the enthalpy of formation of butane, C4H10, using the following balanced chemical equation and information. Write out the solution according to Hess’s law.

\[ \text{C}(s) + \frac{3}{2}\text{O}_2(g) \rightarrow \text{CO}_2(g) \]

\(\Delta H_f^0 = -393.5 \text{ kJ/mol}\)

\[ \text{H}_2(g) + \frac{1}{2}\text{O}_2(g) \rightarrow \text{H}_2\text{O}(l) \]

\(\Delta H_f^0 = -285.8 \text{ kJ/mol}\)

\[ 4\text{CO}_2(g) + 5\text{H}_2\text{O}(l) \rightarrow \text{C}_4\text{H}_{10}(g) + \frac{13}{2}\text{O}_2(g) \]

\(\Delta H = 2877.6 \text{ kJ/mol}\)

7. Calculate the enthalpy of combustion of 1 mol of nitrogen, N2, to form NO2.

8. Calculate the enthalpy of formation for 1 mol sulfur dioxide, SO2, from its elements, sulfur and oxygen. Use the balanced chemical equation and the following information.

\[ \text{S}(s) + \frac{3}{2}\text{O}_2(g) \rightarrow \text{SO}_3(g) \]

\(\Delta H = -395.2 \text{ kJ/mol}\)

\[ 2\text{SO}_2(g) + \text{O}_2(g) \rightarrow 2\text{SO}_3(g) \]

\(\Delta H = -198.2 \text{ kJ/mol}\)
9. Use enthalpy data given after the question to calculate the enthalpy of reaction for each of the following. Solve each by combining the known thermochemical equations.

a. \( \text{CaCO}_3(s) \rightarrow \text{CaO}(s) + \text{CO}_2(g) \)

   **Given:**
   
   \[
   \begin{align*}
   2\text{CaCO}_3(s) & \rightarrow 2\text{Ca}(s) + 2\text{C}(s) + 3\text{O}_2(g) \\
   \Delta H & = 2413.8 \text{ kJ/mol} \\
   2\text{Ca}(s) + \text{O}_2(g) & \rightarrow 2\text{CaO}(s) \\
   \Delta H & = -1269.8 \text{ kJ/mol} \\
   \text{C}(s) + \text{O}_2(g) & \rightarrow \text{CO}_2(g) \\
   \Delta H & = -393.5 \text{ kJ/mol} \\
   \text{CaCO}_3(s) & \rightarrow \text{CaO}(s) + \text{CO}_2(g) \\
   \Delta H & = -1269.8 \text{ kJ/mol} \\
   \text{C}(s) + \text{O}_2(g) & \rightarrow \text{CO}_2(g) \\
   \Delta H & = -393.5 \text{ kJ/mol} \\
   \end{align*}
   \]

   **Verify the result by using the general chemical equations using the known thermochemical equations.**

b. \( \text{C}_6\text{H}_6(l) + \text{O}_2(g) \rightarrow \text{H}_2\text{O}(l) \)

   **Given:**
   
   \[
   \begin{align*}
   \text{C}_6\text{H}_6(l) & \rightarrow 6\text{C}(s) + 3\text{H}_2(g) \\
   \Delta H & = -49.08 \text{ kJ/mol} \\
   \text{C}(s) + \text{O}_2(g) & \rightarrow \text{CO}_2(g) \\
   \Delta H & = -393.5 \text{ kJ/mol} \\
   \text{H}_2(g) + \frac{1}{2} \text{O}_2(g) & \rightarrow \text{H}_2\text{O}(l) \\
   \Delta H & = -285.8 \text{ kJ/mol} \\
   \end{align*}
   \]

10. Calculate the enthalpies for reactions in which ethane, \( \text{C}_2\text{H}_6 \), are the respective reactants and \( \text{CO}_2(g) \) and \( \text{H}_2\text{O}(l) \) are the products in each. Solve each by combining the known thermochemical equations using the \( \Delta H \) values given below. Verify the result by using the general equation for finding enthalpies of reaction from enthalpies of formation.

a. \( \text{C}_2\text{H}_6(g) + \text{O}_2(g) \rightarrow \text{H}_2\text{O}(l) \)

   **Given:**
   
   \[
   \begin{align*}
   \text{C}_2\text{H}_6(g) & \rightarrow 2\text{C}(s) + 3\text{H}_2(g) \\
   \Delta H & = 83.8 \text{ kJ/mol} \\
   \text{C}(s) + \text{O}_2(g) & \rightarrow \text{CO}_2(g) \\
   \Delta H & = -393.5 \text{ kJ/mol} \\
   \text{H}_2(g) + \frac{1}{2} \text{O}_2(g) & \rightarrow \text{H}_2\text{O}(l) \\
   \Delta H & = -285.8 \text{ kJ/mol} \\
   \end{align*}
   \]

b. \( \text{C}_6\text{H}_6(g) + \text{O}_2(g) \rightarrow \text{H}_2\text{O}(l) \)

   **Given:**
   
   \[
   \begin{align*}
   \text{C}_6\text{H}_6(l) & \rightarrow 6\text{C}(s) + 3\text{H}_2(g) \\
   \Delta H & = -49.08 \text{ kJ/mol} \\
   \text{C}(s) + \text{O}_2(g) & \rightarrow \text{CO}_2(g) \\
   \Delta H & = -393.5 \text{ kJ/mol} \\
   \text{H}_2(g) + \frac{1}{2} \text{O}_2(g) & \rightarrow \text{H}_2\text{O}(l) \\
   \Delta H & = -285.8 \text{ kJ/mol} \\
   \end{align*}
   \]

11. The enthalpy of formation of ethanol, \( \text{C}_2\text{H}_5\text{OH} \), is \(-277 \text{ kJ/mol} \) at 298.15 K. Calculate the enthalpy of combustion of one mole of ethanol from the information given below, assuming that the products are \( \text{CO}_2(g) \) and \( \text{H}_2\text{O}(l) \).

   \[
   \begin{align*}
   \text{C}_2\text{H}_5\text{OH}(l) & \rightarrow 2\text{C}(s) + 3\text{H}_2 + \frac{1}{2} \text{O}_2(g) \\
   \Delta H & = -(-277 \text{ kJ/mol}) \\
   \text{C}(s) + \text{O}_2(g) & \rightarrow \text{CO}_2(g) \\
   \Delta H & = -393.5 \text{ kJ/mol} \\
   \text{H}_2(g) + \frac{1}{2} \text{O}_2(g) & \rightarrow \text{H}_2\text{O}(l) \\
   \Delta H & = -285.8 \text{ kJ/mol} \\
   \end{align*}
   \]

12. The enthalpy of formation for sulfur dioxide gas is \(-0.2968 \text{ kJ/(mol} \cdot \text{K})\). Calculate the amount of energy given off in kJ when 30 g of \( \text{SO}_2(g) \) is formed from its elements.

13. Predict the sign of \( \Delta S \) for each of the following reactions:

   a. the thermal decomposition of solid calcium carbonate
   \[
   \text{CaCO}_3(s) \rightarrow \text{CaO}(s) + \text{CO}_2(g) \\
   \Delta S \]

   b. the oxidation of \( \text{SO}_2 \) in air
   \[
   2\text{SO}_2(g) + \text{O}_2(g) \rightarrow 2\text{SO}_3(g) \\
   \Delta S \]

14. Calculate the value of \( \Delta G \) for the reaction below, given the values of \( \Delta H \) and \( \Delta S \). The temperature is 298 K.

   \[
   \text{Cu}_2\text{S}(s) + \text{S}(s) \rightarrow 2\text{CuS}(s) \\
   \Delta H = -26.7 \text{ kJ/mol} \\
   \Delta S = -0.0197 \text{ kJ/(mol} \cdot \text{K}) \\
   \]

15. Will the reaction in item 14 be spontaneous at 298 K?
16. Predict whether the value of $\Delta S$ for each of the following reactions will be greater than, less than, or equal to zero.
   a. $3\text{H}_2(g) + \text{N}_2(g) \rightarrow 2\text{NH}_3(g)$
   b. $2\text{Mg}(s) + \text{O}_2(g) \rightarrow 2\text{MgO}(s)$
   c. $\text{C}_6\text{H}_{12}\text{O}_6(s) + 6\text{O}_2(g) \rightarrow 6\text{CO}_2(g) + 6\text{H}_2\text{O}(g)$
   d. $\text{KNO}_3(s) \rightarrow \text{K}^+(aq) + \text{NO}_3^-(aq)$

17. Based on the following values, compute $\Delta G$ values for each reaction and predict whether the reaction will occur spontaneously.
   a. $\Delta H = 125 \text{ kJ/mol}, T = 293 \text{ K}$,
      $\Delta S = 0.035 \text{ kJ/(mol} \cdot \text{K})$
   b. $\Delta H = -85.2 \text{ kJ/mol}, T = 400 \text{ K}$,
      $\Delta S = 0.125 \text{ kJ/(mol} \cdot \text{K})$
   c. $\Delta H = -275 \text{ kJ/mol}, T = 773 \text{ K}$,
      $\Delta S = 0.45 \text{ kJ/(mol} \cdot \text{K})$

18. The $\Delta S$ for the reaction shown, at 298.15 K, is 0.003 $\text{ kJ/(mol} \cdot \text{K})$. Calculate the $\Delta G$ for this reaction, and determine whether it will occur spontaneously at 298.15 K.

   $\text{C}(s) + \text{O}_2(g) \rightarrow \text{CO}_2(g) + 393.51 \text{ kJ/mol}$

19. When graphite reacts with hydrogen at 300K, $\Delta H$ is $-74.8 \text{ kJ/mol}$ and $\Delta S$ is $-0.0809 \text{ kJ/(mol} \cdot \text{K})$. Will this reaction occur spontaneously?

20. The thermite reaction used in some welding applications has the following enthalpy and entropy changes at 298.15 K. Assuming $\Delta S$ and $\Delta H$ are constant, calculate $\Delta G$ at 448 K.

   $\text{Fe}_2\text{O}_3(s) + 2\text{Al}(s) \rightarrow 2\text{Fe}(s) + \text{Al}_2\text{O}_3(s)$
   $\Delta H = -851.5 \text{ kJ/mol}$
   $\Delta S = -0.0385 \text{ kJ/(mol} \cdot \text{K})$

21. Calculate the change in enthalpy for the following reaction.

   $4\text{FeO}(s) + \text{O}_2(g) \rightarrow 2\text{Fe}_2\text{O}_3(s)$

   Use the following enthalpy data.

   $\text{FeO}(s) \rightarrow \text{Fe}(s) + \frac{1}{2} \text{O}_2(g)$
   $\Delta H = 272 \text{ kJ/mol}$

   $2\text{Fe}(s) + \frac{3}{2} \text{O}_2(g) \rightarrow 2\text{Fe}_2\text{O}_3(g)$
   $\Delta H = -824.2 \text{ kJ/mol}$
the surface, the pressure is 201 kPa; at 20.4 m below the surface, the pressure is 301 kPa; and so forth. Given the volume of a balloon is 3.5 L at STP and that the temperature of the water remains the same, what is the volume 51 m below the water’s surface?

14. The piston of an internal combustion engine compresses 450 mL of gas. The final pressure is 15 times greater than the initial pressure. What is the final volume of the gas, assuming constant temperature?

15. A helium-filled balloon contains 125 mL of gas at a pressure of 0.974 atm. What volume will the gas occupy at standard pressure?

16. A weather balloon with a volume of 1.375 L is released from Earth’s surface at sea level. What volume will the balloon occupy at an altitude of 20.0 km, where the air pressure is 10 kPa?

17. A sample of helium gas has a volume of 200 mL at 0.96 atm. What pressure, in atm, is needed to reduce the volume to 50 mL?

18. A certain mass of oxygen was collected over water when potassium chlorate was decomposed by heating. The volume of the oxygen sample collected was 720 mL at 25°C and a barometric pressure of 755 torr. What would the volume of the oxygen be at STP? (Hint: First calculate the partial pressure of the oxygen. Then use the combined gas law.)

19. Use Boyle’s law to solve for the missing value in the following:
   \[ P_1 = 350 \text{ torr}, \quad V_1 = 200 \text{ mL}, \quad P_2 = 700 \text{ torr}, \quad V_2 = ? \]

20. Use Boyle’s law to solve for the missing value in the following:
   \[ P_1 = 0.75 \text{ atm}, \quad V_2 = 435 \text{ mL}, \quad P_2 = \text{0.48 atm}, \quad V_1 = ? \]

21. Use Boyle’s law to solve for the missing value in the following:
   \[ V_1 = 2.4 \times 10^3 \text{ mL}, \quad P_2 = 180 \text{ mm Hg}, \quad V_2 = 1.8 \times 10^3 \text{ mL}, \quad P_1 = ? \]

22. The pressure exerted on a 240 mL sample of hydrogen gas at constant temperature is increased from 0.428 atm to 0.724 atm. What will the final volume of the sample be?

23. A flask containing 155 cm³ of hydrogen was collected under a pressure of 22.5 kPa. What pressure would have been required for the volume of the gas to have been 90 cm³, assuming the same temperature?

24. A gas has a volume of \( V_1 = 450 \text{ mL} \). If the temperature is held constant, what volume would the gas occupy if the pressure \( P_2 = 2P_1 \)?

25. What volume would the gas occupy if the pressure \( P_2 = 0.25P_1 \)?

26. A sample of oxygen that occupies \( 1.00 \times 10^6 \text{ mL} \) at 575 mm Hg is subjected to a pressure of 1.25 atm. What will be the final volume of the sample if the temperature is held constant?

27. A helium-filled balloon has a volume of 2.75 L at 20°C. The volume of the balloon decreases to 2.46 L after it is placed outside on a cold day.
   a. What is the outside temperature in K?
   b. What is the outside temperature in °C?

28. A gas at 65°C occupies 4.22 L. At what Celsius temperature will the volume be 3.87 L, assuming the same pressure?

29. A certain quantity of gas has a volume of 0.75 L at 298 K. At what temperature, in degrees Celsius, would this quantity of gas be reduced to 0.50 L, assuming constant pressure?

30. A balloon filled with oxygen gas occupies a volume of 5.5 L at 25°C. What volume will the gas occupy at 100°C?

31. A sample of nitrogen gas is contained in a piston with a freely moving cylinder. At 0°C, the volume of the gas is 375 mL. To what temperature must the gas be heated to occupy a volume of 500 mL?

32. Use Charles’s law to solve for the missing value in the following:
   \[ V_1 = 80 \text{ mL}, \quad T_1 = 27°C, \quad T_2 = 77°C, \quad V_2 = ? \]

33. Use Charles’s law to solve for the missing value in the following:
   \[ V_1 = 125 \text{ L}, \quad V_2 = 85 \text{ L}, \quad T_2 = 127°C, \quad T_1 = ? \]
34. Use Charles's law to solve for the missing value in the following:

\[ T_1 = -33°C, \quad V_2 = 54 \text{ mL}, \quad T_2 = 160°C, \quad V_1 = ? \]

35. A sample of air has a volume of 140 mL at 67°C. At what temperature will its volume be 50 mL at constant pressure?

36. At standard temperature, a gas has a volume of 275 mL. The temperature is then increased to 130°C, and the pressure is held constant. What is the new volume?

37. An aerosol can contains gases under a pressure of 4.5 atm at 20°C. If the can is left on a hot sandy beach, the pressure of the gases increases to 4.8 atm. What is the Celsius temperature on the beach?

38. Before a trip from New York to Boston, the pressure in an automobile tire is 1.8 atm at 293 K. At the end of the trip, the pressure gauge reads 1.9 atm. What is the new Celsius temperature of the air inside the tire? (Assume tires with constant volume.)

39. At 120°C, the pressure of a sample of nitrogen is 1.07 atm. What will the pressure be at 205°C, assuming constant volume?

40. A sample of helium gas has a pressure of 1.2 atm at 22°C. At what Celsius temperature will the helium reach a pressure of 2 atm?

41. An empty aerosol-spray can at room temperature (20°C) is thrown into an incinerator where the temperature reaches 500°C. If the gas inside the empty container was initially at a pressure of 1.0 atm, what pressure did it reach inside the incinerator? Assume the gas was at constant volume and the can did not explode.

42. The temperature within an automobile tire at the beginning of a long trip is 25°C. At the conclusion of the trip, the tire has a pressure of 1.8 atm. What is the final Celsius temperature within the tire if its original pressure was 1.75 atm?

43. A sample of gas in a closed container at a temperature of 100°C and a pressure of 3.0 atm is heated to 300°C. What pressure does the gas exert at the higher temperature?

44. A sample of hydrogen at 47°C exerts a pressure of 0.329 atm. The gas is heated to 77°C at constant volume. What will its new pressure be?

45. To what temperature must a sample of nitrogen at 27°C and 0.625 atm be taken so that its pressure becomes 1.125 atm at constant volume?

46. The pressure on a gas at −73°C is doubled, but its volume is held constant. What will the final temperature be in degrees Celsius?

**Section: Molecular Composition of Gases**

47. Quantitatively compare the rates of effusion for the following pairs of gases at the same temperature and pressure.

a. Hydrogen and nitrogen
b. Fluorine and chlorine

48. Some hydrogen gas is collected over water at 20°C. The levels of water inside and outside the gas-collection bottle are the same. The partial pressure of hydrogen is 742.5 torr. What is the barometric pressure at the time the gas is collected?

49. What is the volume, in liters, of 0.100 g of C₂H₂F₄ vapor at 0.928 atm and 22.3°C?

50. What is the molar mass of a 1.25 g sample of gas that occupies a volume of 1.00 L at a pressure of 0.961 atm and a temperature of 27.0°C?

51. What pressure, in atmospheres, is exerted by 0.325 mol of hydrogen gas in a 4.08 L container at 35°C?

52. A gas sample occupies 8.77 L at 20.0°C. What is the pressure, in atmospheres, given that there are 1.45 mol of gas in the sample?

53. A 2.07 L cylinder contains 2.88 mol of helium gas at 22°C. What is the pressure in atmospheres of the gas in the cylinder?

54. A tank of hydrogen gas has a volume of 22.9 L and holds 14.0 mol of the gas at 12°C. What is the reading on the pressure gauge in atmospheres?

55. A sample that contains 4.38 mol of a gas at 250.0 K has a pressure of 0.857 atm. What is the volume?
56. How many liters are occupied by 0.909 mol of nitrogen at 125°C and 0.901 atm pressure?

57. A reaction yields 0.00856 mol of O₂ gas. What volume in mL will the gas occupy if it is collected at 43.0°C and 0.926 atm pressure?

58. A researcher collects 0.00909 mol of an unknown gas by water displacement at a temperature of 16.0°C and 0.873 atm pressure (after the partial pressure of water vapor has been subtracted). What volume of gas in mL does the researcher have?

59. How many grams of carbon dioxide gas are there in a 45.1 L container at 34.0°C and 1.04 atm?

60. What is the mass, in grams, of oxygen gas in a 12.5 L container at 45.0°C and 7.22 atm?

61. A sample of carbon dioxide with a mass of 0.30 g was placed in a 250 mL container at 400.0 K. What is the pressure exerted by the gas?

62. What mass of ethene gas, C₂H₄, is contained in a 15.0 L tank that has a pressure of 4.40 atm at a temperature of 305 K?

63. NH₃ gas is pumped into the reservoir of a refrigeration unit at a pressure of 4.45 atm. The capacity of the reservoir is 19.4 L. The temperature is 24.0°C. What is the mass of the gas in g?

64. What is the molar mass of a gas if 0.427 g of the gas occupies a volume of 125 mL at 20.0°C and 0.980 atm?

65. What is the density of a sample of ammonia gas, NH₃, if the pressure is 0.928 atm and the temperature is 63.0°C?

66. The density of a gas was found to be 2.0 g/L at 1.50 atm and 27.0°C. What is the molar mass of the gas?

67. What is the density of argon gas, Ar, at a pressure of 551 torr and a temperature of 25.0°C?

68. A chemist determines the mass of a sample of gas to be 3.17 g. Its volume is 942 mL at a temperature of 14.0°C and a pressure of 1.09 atm. What is the molar mass of the gas?

69. The density of dry air at sea level (1 atm) is 1.225 g/L at 15.0°C. What is the average molar mass of the air?

70. How many liters of gaseous carbon monoxide at 27.0°C and 0.247 atm can be produced from the burning of 65.5 g of carbon according to the following equation?

\[
2C(s) + O₂(g) \rightarrow 2CO(g)
\]

71. Calculate the pressure, in atmospheres, exerted by each of the following.
   a. 2.50 L of HF containing 1.35 mol at 320 K
   b. 4.75 L of NO₂ containing 0.860 mol at 300 K
   c. 750 mL of CO₂ containing 2.15 mol at 57.0°C

72. Calculate the volume, in liters, occupied by each of the following.
   a. 2.00 mol of H₂ at 300.0 K and 1.25 atm
   b. 0.425 mol of NH₃ at 37.0°C and 0.724 atm
   c. 4.00 g of O₂ at 57.0°C and 0.888 atm

73. Determine the number of moles of gas contained in each of the following.
   a. 1.25 L at 250 K and 1.06 atm
   b. 0.800 L at 27.0°C and 0.925 atm
   c. 750 mL at –50.0°C and 0.921 atm

74. Find the mass of each of the following.
   a. 5.60 L of O₂ at 1.75 atm and 250 K
   b. 3.50 L of NH₃ at 0.921 atm and 27.0°C
   c. 0.125 mL of SO₂ at 0.822 atm and –53.0°C

75. Find the molar mass of each gas measured at the specified conditions.
   a. 0.650 g occupying 1.12 L at 280 K and 1.14 atm
   b. 1.05 g occupying 2.35 L at 37.0°C and 0.840 atm
   c. 0.432 g occupying 750 mL at –23.0°C and 1.03 atm

76. If the density of an unknown gas is 3.20 g/L at –18.0°C and 2.17 atm, what is the molar mass of this gas?

77. One method of estimation the temperature of the center of the sun is based on the assumption that the center consists of gases that have an average molar mass of 2.00 g/mol. If the density of the center of the sun is 1.40 g/cm³ at a pressure of 1.30 × 10⁹ atm, calculate the temperature in degrees Celsius.
78. Three of the primary components of air are carbon dioxide, nitrogen, and oxygen. In a sample containing a mixture of only these gases at exactly one atmosphere pressure, the partial pressures of carbon dioxide and nitrogen are given as $P_{\text{CO}_2} = 0.285 \text{ torr}$ and $P_{\text{N}_2} = 593.525 \text{ torr}$. What is the partial pressure of oxygen?

79. Determine the partial pressure of oxygen collected by water displacement if the water temperature is $20.0 ^\circ \text{C}$ and the total pressure of the gases in the collection bottle is 730 torr. $P_{\text{H}_2\text{O}}$ at 20.0 °C is equal to 17.5 torr.

80. A sample of hydrogen effuses through a porous container about 9.00 times faster than an unknown gas. Estimate the molar mass of the unknown gas.

81. Compare the rate of effusion of carbon dioxide with that if hydrogen chloride at the same temperature and pressure.

82. If a molecule of neon gas travels at an average of 400 m/s at a given temperature, estimate the average speed of a molecule of butane gas, C$_4$H$_{10}$, at the same temperature.

83. Nitrogen effused through a pinhole 1.7 times as fast as another gaseous element at the same conditions. Estimate the other element’s molar mass.

84. Determine the molecular mass ratio of two gases whose rates of diffusion have a ratio of 16:0:1.

85. Estimate the molar mass of a gas that effuses at 1.60 times the effusion rate of carbon dioxide.

86. List the following gases in order of increasing average molecular velocity at 25°C: H$_2$O, He, HCl, BrF, and NO$_2$.

87. What is the ratio of the average velocity of hydrogen molecules to that of neon atoms at the same temperature and pressure?

88. At a certain temperature and pressure, chlorine molecules have an average velocity of 0.0380 m/s. What is the average velocity of sulfur dioxide molecules under the same conditions?

89. A sample of helium effuses through a porous container 6.50 times faster than does unknown gas X. What is the molar mass of the unknown gas?

90. How many liters of H$_2$ gas at STP can be produced by the reaction of 4.60 g of Na and excess water, according to the following equation? $2\text{Na}(s) + 2\text{H}_2\text{O}(l) \rightarrow \text{H}_2(g) + 2\text{NaOH}(aq)$

91. How many grams of Na are needed to react with H$_2$O to liberate 400 mL H$_2$ gas at STP?

92. What volume of oxygen gas in liters can be collected at 0.987 atm pressure and 25.0°C when 30.6 g of KClO$_3$ decompose by heating, according to the following equation? $2\text{KClO}_3(s) \xrightarrow{\Delta} 2\text{KCl}(s) + 3\text{O}_2(g)$

93. What mass of sulfur must be used to produce 12.6 L of gaseous sulfur dioxide at STP according to the following equation? $\text{S}_8(s) + 8\text{O}_2(g) \rightarrow 8\text{SO}_2(g)$

94. How many grams of water can be produced from the complete reaction of 3.44 L of oxygen gas, at STP, with hydrogen gas?

95. Aluminum granules are a component of some drain cleaners because they react with sodium hydroxide to release both energy and gas bubbles, which help clear the drain clog. The reaction is $2\text{NaOH}(aq) + 2\text{Al}(s) + 6\text{H}_2\text{O}(l) \rightarrow 2\text{NaAl(OH)}_4(aq) + 3\text{H}_2(g)$ What mass of aluminum would be needed to produce 4.00 L of hydrogen gas at STP?

96. What volume of chlorine gas at 38.0°C and 1.63 atm is needed to react completely with 10.4 g of sodium to form NaCl?

97. Air bags in cars are inflated by the sudden decomposition of sodium azide, NaN$_3$, by the following reaction. $2\text{NaN}_3(s) \rightarrow 3\text{N}_2(g) + 2\text{Na}(s)$ What volume of N$_2$ gas, measured at 1.30 atm and 87.0°C, would be produced by the reaction of 70.0 g of NaN$_3$?

98. Assume that 5.60 L of H$_2$ at STP react with CuO according to the following equation: $\text{CuO}(s) + \text{H}_2(g) \rightarrow \text{Cu}(s) + \text{H}_2\text{O}(g)$ How many moles of H$_2$ react?
99. A modified Haber process for making ammonia is conducted at 550°C and 250 atm. If 10.0 kg of nitrogen (the limiting reactant) is used and the process goes to completion, what volume of ammonia is produced?

100. When liquid nitroglycerin, C₃H₅(NO₃)₃, explodes, the products are carbon dioxide, nitrogen, oxygen, and water vapor. If 500.0 g of nitroglycerin explode at STP, what is the total volume, at STP, for all the gases produced?

101. The principal source of sulfur on Earth is deposits of free sulfur occurring mainly in volcanically active regions. The sulfur was initially formed by the reaction between the two volcanic vapors SO₂ and H₂S to form H₂O(l) and S₈(s). What volume of SO₂, at 0.961 atm and 22.0°C, was needed to form a sulfur deposit of 4.50 × 10⁵ kg on the slopes of a volcano in Hawaii?

102. What volume of H₂S, at 0.961 atm and 22.0°C, was needed to form a sulfur deposit of 4.50 × 10⁵ kg on the slopes of a volcano in Hawaii?

103. A 3.25 g sample of solid calcium carbide, CaC₂, reacted with water to produce acetylene gas, C₂H₂, and aqueous calcium hydroxide. If the acetylene was collected over water at 17.0°C and 0.974 atm, how many milliliters of acetylene were produced?

104. Assume that 13.5 g of Al react with HCl according to the following equation, at STP: Al(s) + HCl(aq) → AlCl₃(aq) + H₂(g) Remember to balance the equation first.
   a. How many moles of Al react?
   b. How many moles of H₂ are produced?
   c. How many liters of H₂ at STP are produced?

4. What is the molarity of a solution composed of 6.250 g of HCl in 0.3000 L of solution?

5. 5.00 grams of sugar, C₁₂H₂₂O₁₁, are dissolved in water to make 1.00 L of solution. What is the concentration of this solution expressed as molarity?

6. Suppose you wanted to dissolve 40.0 g NaOH in enough H₂O to make 6.00 L of solution. You want to calculate the molarity, M, of the resulting solution.
   a. What is the molar mass of NaOH?
   b. What is the molarity of this solution?

7. What is the molarity of a solution of 14.0 g of NH₄Br in enough H₂O to make 150 mL of solution?

8. Suppose you wanted to produce 1.00 L of a 3.50 M solution of H₂SO₄. How many grams of solute are needed to make this solution?

9. How many grams of solute are needed to make 2.50 L of a 1.75 M solution of Ba(NO₃)₂?

10. How many moles of NaOH are contained in 65.0 mL of a 2.20 M solution of NaOH in H₂O?

11. A solution is made by dissolving 26.42 g of (NH₄)₂SO₄ in enough H₂O to make 50.00 mL of solution.
   a. What is the molar mass of (NH₄)₂SO₄?
   b. What is the molarity of this solution?

12. Suppose you wanted to find out how many milliliters of 1.0 M AgNO₃ are needed to provide 168.88 of pure AgNO₃.
   a. What is the molar mass of AgNO₃?
   b. How many mL of solution are needed?

13. Na₂SO₄ is dissolved in water to make 450 mL of a 0.250 M solution.
   a. What is the molar mass of Na₂SO₄?
   b. How many moles of Na₂SO₄ are needed?

14. Citric acid is one component of some soft drinks. Suppose that a 2.00 L solution is made from 150 mg of citric acid, C₆H₈O₇.
   a. What is the molar mass of C₆H₈O₇?
   b. What is the molarity of citric acid in the solution?
15. Suppose you wanted to know how many grams of KCl would be left if 350 mL of a 6.0 M KCl solution were evaporated to dryness.
   a. What is the molar mass of KCl?
   b. How many grams of KCl would remain?

16. Sodium metal reacts violently with water to form NaOH and release hydrogen gas. Suppose that 10.0 g of Na reacts completely with 1.00 L of water, and the final volume of the system is 1.00 L.

   \[2\text{Na(s)} + 2\text{H}_2\text{O(l)} \rightarrow 2\text{NaOH(aq)} + \text{H}_2(g)\]

   a. What is the molar mass of NaOH?
   b. What is the molarity, M, of the NaOH solution formed by the reaction?

Section: Physical Properties of Solutions

17. Given 0.01 m aqueous solutions of each of the following, arrange the solutions in order of increasing change in the freezing point of the solution.
   a. NaI
   b. CaCl_2
   c. K_3PO_4
   d. C_6H_12O_6 (glucose)

Chemical Equilibrium

Section: Systems at Equilibrium

1. At equilibrium a mixture of N_2, H_2, NH_3 gas at 500℃ is determined to consist of 0.602 mol/L of N_2, 0.420 mol/L of H_2, and 0.113 mol/L of NH_3. What is the equilibrium constant for the reaction N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) at this temperature?

2. The reaction AB_2C(g) \rightleftharpoons B_2(g) + AC(g) reached equilibrium at 900 K in a 5.00 L vessel. At equilibrium 0.0840 mol of AB_2C, 0.0350 mol of B_2, and 0.0590 mol of AC were detected. What is the equilibrium constant at this temperature for this system?

3. At equilibrium at 1.0 L vessel contains 20.00 mol of H_2, 18.00 mol of CO_2, 12.00 mol of H_2O, and 5.900 mol of CO at 427℃. What is the value of K_eq for the following reaction?

   \[\text{CO}_2(g) + \text{H}_2(g) \rightleftharpoons \text{CO(g)} + \text{H}_2\text{O(g)}\]

4. A reaction between gaseous sulfur dioxide and oxygen gas to produce gaseous sulfur trioxide takes place at 600℃. At that temperature, the concentration of SO_2 is found to be 1.50 mol/L, the concentration of O_2 is 1.25 mol/L, and the concentration of SO_3 is 3.50 mol/L. Using the balanced chemical equation, calculate the equilibrium constant for this system.

5. At equilibrium at 2500 K, [HCl] = 0.0625 and [H_2] = [Cl_2] = 0.00450 for the reaction

   \[\text{H}_2(g) + \text{Cl}_2(g) \rightleftharpoons 2\text{HCl(g)}\]

   Find the value of K_{eq}.

6. An equilibrium mixture at 435℃ is found to consist of 0.00183 mol/L of H_2, 0.00313 mol/L of I_2, and 0.0177 mol/L of HI. Calculate the equilibrium constant, K_{eq}, for the reaction H_2(g) + I_2(g) \rightleftharpoons 2HI(g).

7. For the reaction

   \[\text{H}_2(g) + \text{I}_2(g) \rightleftharpoons 2\text{HI(g)}\]

   at 425℃, calculate [HI], given [H_2] = [I_2] = 0.000479 and K_{eq} = 54.3.

8. At 25℃, an equilibrium mixture of gases contains 0.00640 mol/L PCl_3, 0.0250 mol/L Cl_2, and 0.00400 mol/L PCl_5. What is the equilibrium constant for the following reaction?

   \[\text{PCl}_5(g) \rightleftharpoons \text{PCl}_3(g) + \text{Cl}_2(g)\]

9. At equilibrium a 2 L vessel contains 0.360 mol of H_2, 0.110 mol of Br, and 37.0 mol of HBr. What is the equilibrium constant for the reaction at this temperature?

   \[\text{H}_2(g) + \text{Br}_2(g) \rightleftharpoons 2\text{HBr(g)}\]

10. Calculate the solubility-product constant, K_{sp}, of lead(II) chloride, PbCl_2, which has a solubility of 1.00 g/100.0 g H_2O at a temperature other than 25℃.

11. 5.00 g of Ag_2SO_4 will dissolve in 1.00 L of water. Calculate the solubility product constant for this salt.
12. What is the value of $K_{sp}$ for tin(II) sulfide, given that its solubility is $5.2 \times 10^{-12}$ g/100.0 g water?

13. Calculate the solubility product constant for calcium carbonate, given that it has a solubility of $5.3 \times 10^{-5}$ g/L of water.

14. Calculate the solubility of cadmium sulfide, CdS, in mol/L, given the $K_{sp}$ value as $8.0 \times 10^{-27}$.

15. Determine the concentration of strontium ions in saturated solution of strontium sulfate, SrSO$_4$, if the $K_{sp}$ is $3.2 \times 10^{-7}$.

16. What is the solubility in mol/L of manganese(II) sulfide, MnS, given that its $K_{sp}$ value is $2.5 \times 10^{-13}$?

17. Calculate the concentration of Zn$^{2+}$ in saturated solution of zinc sulfide, ZnS, given that $K_{sp}$ of zinc sulfide equals $1.6 \times 10^{-24}$.

18. What is the value of $K_{sp}$ for Ag$_2$SO$_4$ if 5.40 g is soluble in 1.00 L of water?

19. Calculate the concentration of Hg$^{2+}$ ions in a saturated solution of HgS(s). $K_{sp}$ is $1.6 \times 10^{-52}$.

20. At 25°C, the value of $K_{eq}$ is $1.7 \times 10^{-13}$ for the following reaction.

$$\text{N}_2\text{O}(g) + \frac{1}{2}\text{O}_2(g) \rightleftharpoons 2\text{NO}(g)$$

It is determined that $[\text{N}_2\text{O}] = 0.0035$ mol/L and $[\text{O}_2] = 0.0027$ mol/L. Using this information, what is the concentration of NO(g) at equilibrium?

21. Tooth enamel is composed of the mineral hydroxyapatite, Ca$_5$(PO$_4$)$_3$OH, which has a $K_{sp}$ of $6.8 \times 10^{-37}$. The molar solubility of hydroxyapatite is $2.7 \times 10^{-5}$ mol/L. When hydroxyapatite is reacted with fluoride, the OH$^-$ is replaced with the F$^-$ ion on the mineral, forming fluorapatite, Ca$_5$(PO$_4$)$_3$F. (The latter is harder and less susceptible to caries.) The $K_{sp}$ of fluorapatite is $1 \times 10^{-66}$. Calculate the solubility of fluorapatite in water. Given your calculations, can you support the fluoridation of drinking water? Your answer must be within ± 0.5%.

### Acids and Bases

#### Section: Acidity, Basicity and pH

1. Identify the following as being true of acidic or basic solutions at 25°C:
   $[\text{H}_3\text{O}^+] = 1.0 \times 10^{-3}$ M

2. Identify the following as being true of acidic or basic solutions at 25°C:
   $[\text{OH}^-] = 1.0 \times 10^{-4}$ M

3. Identify the following as being true of acidic or basic solutions at 25°C:
   pH = 5

4. Identify the following as being true of acidic or basic solutions at 25°C:
   pH = 8

5. The pH of a hydrochloric acid solution for cleaning tile is 0.45. What is the $[\text{H}_3\text{O}^+]$ in the solution?

6. A Ca(OH)$_2$ solution has a pH of 8.
   a. Determine $[\text{H}_3\text{O}^+]$ for the solution.
   b. Determine $[\text{OH}^-]$.
   c. Determine $[\text{Ca(OH)}_2]$.

7. Determine the pH of the following solution:
   $1 \times 10^{-3}$ M HCl.

8. Determine the pH of the following solution:
   $1 \times 10^{-5}$ M HNO$_3$.

9. Determine the pH of the following solution:
   $1 \times 10^{-4}$ M NaOH.

10. Determine the pH of the following solution:
    $1 \times 10^{-2}$ M KOH.

11. The pH of a solution is 10.
   a. What is the concentration of hydroxide ions in the solution?
   b. If the solution is Sr(OH)$_2$(aq), what is its molarity?

12. Determine the hydronium ion concentration in a solution that is $1 \times 10^{-4}$ M HCl.

13. Determine the hydronium ion concentration in a solution that is $1 \times 10^{-4}$ M HCl.

14. Determine the hydronium ion concentration in a solution that is $1 \times 10^{-3}$ M HNO$_3$.

15. Determine the hydronium ion concentration in a solution that is $1 \times 10^{-3}$ M HNO$_3$.  

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16. Determine the hydroxide ion concentration in a solution that is $3 \times 10^{-2}$ M NaOH.

17. Determine the hydronium ion concentration in a solution that is $3.00 \times 10^{-2}$ M NaOH.

18. a. Determine the hydroxide ion concentration in a solution that is $1 \times 10^{-4}$ M Ca(OH)$_2$.
   b. Determine the hydronium ion concentration in a solution that is $1 \times 10^{-4}$ M Ca(OH)$_2$.

19. a. Determine the [H$_3$O$^+$] in a 0.01 M solution of HClO$_4$.
   b. Determine the [OH$^-$] in a 0.01 M solution of HClO$_4$.

20. An aqueous solution of Ba(OH)$_2$ has a [H$_3$O$^+$] of $1 \times 10^{-11}$ M.
   a. What is the [OH$^-$]?
   b. What is the molarity of Ba(OH)$_2$ in the solution?

Section: Neutralization and Titration

21. If 20 mL of 0.01 M aqueous HCl is required to neutralize 30 mL of an aqueous solution of NaOH, determine the molarity of the NaOH solution.

Reaction Rates

Section: How Can Reaction Rates Be Explained?

1. A reaction involving reactants A and B is found to occur in the one-step mechanism: 2A + B $\rightarrow$ A$_2$B. Write the rate law for this reaction, and predict the effect of doubling the concentration of either reactant on the overall reaction rate.

2. A chemical reaction is expressed by the balanced chemical equation A + 2B $\rightarrow$ C. Using the data below, determine the rate law for the reaction.
   Experiment # 1. initial [A] = 0.2 M initial [B] = 0.2 M initial rate of formation of C = 0.0002 M/min
   Experiment # 2. initial [A] = 0.2 M initial [B] = 0.4 M initial rate of formation of C = 0.0008 M/min
   Experiment # 3. initial [A] = 0.4 M initial [B] = 0.4 M/min initial rate of formation of C = 0.0016 M/min

3. A particular reaction is found to have the following rate law.
   $R = k[A][B]^2$
   How is the rate affected if
   a. the initial concentration of A is cut in half?
   b. the initial concentration of B is tripled?
   c. the initial concentration of A is doubled, but the concentration of B is cut in half?

Oxidation, Reduction, and Electrochemistry

Section: Oxidation-Reduction Reactions

1. Name the following acid: HNO$_2$

2. Assign oxidation numbers to each atom in H$_2$SO$_3$.

3. Assign oxidation numbers to each atom in H$_2$CO$_3$.

4. Assign oxidation numbers to each atom in HI.

5. Assign oxidation numbers to each atom in CO$_2$.

6. Assign oxidation numbers to each atom in NH$_4^+$.

7. Assign oxidation numbers to each atom in MnO$_4^-$.

8. Assign oxidation numbers to each atom in S$_2$O$_3^{2-}$.

9. Assign oxidation numbers to each atom in H$_2$O$_2$.

10. Assign oxidation numbers to each atom in P$_4$O$_{10}$.

11. Assign oxidation numbers to each atom in OF$_2$.

12. Assign oxidation numbers to each atom in SO$_3$.

13. Determine the oxidation state of the metal in CdS.

14. Determine the oxidation state of the metal in ZnS.
15. Determine the oxidation state of the metals in PbCrO₄.
16. Determine the oxidation state of the metal in Fe(SCN)²⁺.
17. Determine the oxidation state of the metal in MnO₄⁻.
18. Determine the oxidation state of the metals in CoCl₂.
19. Determine the oxidation state of the metal in [Cu(NH₃)₄](OH)₂.
20. Determine the oxidation state of the nitrogen in N₂O₃.
21. Determine the oxidation state of the nitrogen in N₂O₅.
22. Which of the following equations represent redox reactions?
   a. 2KNO₃(s) → 2KNO₂(s) + O₂(g)
   b. H₂(g) + CuO(s) → Cu(s) + H₂O(l)
   c. NaOH(aq) + HCl(aq) → NaCl(aq) + H₂O(l)
   d. H₂(g) + Cl₂(g) → 2HCl(g)
   e. SO₃(g) + H₂O(l) → H₂SO₄(aq)
23. Identify if the following reactions are redox or nonredox:
   a. 2NH₄Cl(aq) + Ca(OH)₂(aq) → 2NH₃(aq) + 2H₂O(l) + CaCl₂(aq)
   b. 2HNO₃(aq) + 3H₂S(g) → 2NO(g) + 4H₂O(l) + 3S(s)
   c. [Be(H₂O)₄]²⁺(aq) + H₂O(l) → H₃O⁺(aq) + [Be(H₂O)₃OH]⁺(aq)

Nuclear Chemistry

Section: Atomic Nuclei and Nuclear Stability

1. The mass of a ²⁰Ne atom is 19.992 44 amu. Calculate the mass defect.
2. The mass of a ⁷Li atom is 7.016 00 amu. Calculate its mass defect.
3. Calculate the nuclear binding energy of one lithium-6 atom. The measured atomic mass of lithium-6 is 6.015 amu.
19. Balance the nuclear equation:
\[ ^{32}_{15}\text{P} + \_\_\_ \rightarrow ^{32}_{15}\text{P} \]  
20. Balance the nuclear equation:
\[ ^{236}_{92}\text{U} \rightarrow ^{94}_{36}\text{Kr} + \_\_\_ + ^{1}_{0}\text{n} \]  

**Section: Uses of Nuclear Chemistry**

21. The Environmental Protection Agency and health officials nationwide are concerned about the levels of radon gas in homes. The half-life of the radon-222 isotope is 3.8 days. If a sample of gas taken from a basement contains 4.38 \( \mu \)g of radon-222, how much radon will remain in the sample after 15.2 days?  

22. Uranium-238 decays through alpha decay with a half-life of \( 4.46 \times 10^9 \) years. How long would it take for 7/8 of a sample of uranium-238 to decay?  

23. The half-life of carbon-14 is 5715 years. How long will it be until only half of the carbon-14 in a sample remains?  

24. The half-life of iodine-131 is 8.040 days. What percentage of an iodine-131 sample will remain after 40.2 days?  

25. The half-life of plutonium-239 is 24 110 years. Of an original mass of 100 g, how much remains after 96 440 years?  

26. The half-life of thorium-227 is 18.72 days. How many days are required for three-fourths of a given amount to decay?  

27. The half-life of protactinium-234 is 6.69 hours. What fraction of a given amount remains after 26.76 hours?  

28. How many milligrams remain of a 15 mg sample of radium-226 after 6396 years? The half life of radium-226 is 1599 years.  

29. After 4797 years, how much of an original 0.25 g of radium-226 remains? Its half-life is 1599 years.  

30. The half-life of radium-224 is 3.66 days. What was the original mass of radium-224 if 0.05 g remains after 7.32 days?