A. **Problems typically solved using the factor-label method (dimensional analysis)**

1. A water solution that is 15.0% sucrose by mass has a density of 1.059 g/mL. What mass of sucrose, in grams, is contained in 3.05 L of this solution?

2. A solution containing 12.0% sodium hydroxide by mass has a density of 1.131 g/mL. Sodium hydroxide has a density of 2.130 g/mL. What volume of the solution, in liters, must be used in an application requiring 1.00 kg of sodium hydroxide?

*3. A solution used to chlorinate a home swimming pool contains 7% chlorine by mass. An ideal chlorine level for the pool is one part per million (1 ppm). (Think of 1 ppm as being 1 g chlorine per million grams of water.) If you assume densities of 1.10 g/mL for the chlorine solution and 1.00 g/mL for the swimming pool water, what volume of the chlorine solution, in liters, is required to produce a chlorine level of 1 ppm in an 18,000-gallon swimming pool?

4. Magnesium metal can be extracted from seawater. Magnesium occurs in seawater to the extent of 1.4 g magnesium per kilogram of seawater. The annual production of magnesium in the United States is about $10^5$ tons (1 ton = 2000 lb, this is not metric tons). If all this magnesium were extracted from seawater, what volume of seawater, in m$^3$, would have to be processed? (Assume a density of 1.025 g/mL for seawater.)

5. A typical rate of deposit of dust ("dustfall") from unpolluted air is 10 tons (1 ton = 2000 lb, this is not metric tons) per square mile per month. What is this dustfall, expressed in mg per square meter per hour?

6. The volume of irrigation water is usually expressed in acre-feet. One acre-foot is a volume of water sufficient to cover 1 acre of land to a depth of 1 ft (640 acres = 1 m$^2$.) The principal lake in the California Water Project is Lake Oroville, whose water storage capacity is listed as $3.54 \times 10^6$ acre-feet. Express the volume of Lake Oroville in ft$^3$.

7. During a severe air pollution episode the concentration of lead in air was observed to be 3.01 µg Pb/m$^3$. How many Pb atoms would be present in a 0.500-L sample of this air (the approximate lung capacity of a human adult)?

8. The natural abundance of magnesium-24 is 78.99%. Determine the number of magnesium-24 atoms in one mole of magnesium produced from naturally occurring sources. Note: the % natural abundance of an isotope is the % of the total atoms of that isotope in the naturally occurring mixture, not the % of that isotope by mass.
*9. Deuterium, $^2\text{H}$, is sometimes used to replace ordinary $^1\text{H}$ atoms in chemical studies. The percent natural abundance of $^2\text{H}$ is 0.015%. What mass of hydrogen gas would have to be processed to extract 1.00 g of pure $^2\text{H}$ atoms? The mass of the $^2\text{H}$ isotope is 2.0140 u. (See note on question 8)

*10. The volume of seawater on Earth is about 330,000,000 mi$^3$. If seawater is 3.5% sodium chloride by mass and has a density of 1.03 g/mL, what is the approximate mass of sodium, in tons, in the seawater on Earth? (1 ton = 2000 lb.)

11. A typical adult body contains about 6 L of blood. The hemoglobin content of the blood is about 15.5 g/100 mL blood. The approximate molar mass of hemoglobin is 64,500 g/mol, and there are four iron (Fe) atoms in a hemoglobin molecule. Approximately how many Fe atoms are present in the blood of a typical adult?

12. The mineral spodumene has the formula Li$_2$O Al$_2$O$_3$·4SiO$_2$. Given that the percentage of lithium-6 atoms in naturally occurring lithium is 7.40%, how many lithium-6 atoms are present in a 426-g sample of spodumene? (See note on question 8)

B. Problems not just involving multiplication and division

*13. A pycnometer weighs 25.60 g empty and 35.55 g when filled with water at 20˚C. The density of water at 20˚C is 0.9982 g/mL. When 10.20 g lead is placed in the pycnometer and the pycnometer again filled with water at 20 ˚C, the total mass is 44.83 g. What is the density of the lead, in g/cm$^3$?

*14. An empty 3.00-L bottle weighs 1.70 kg. Filled with a certain wine it weighs 4.55 kg. The wine contains 11.0% ethyl alcohol by mass. How many ounces of ethyl alcohol are present in a 400-mL glass of this wine? (1 lb = 16 oz = 453.6 g.)

C. Problems combining a geometry formula with other conversions.

Some reference formulas:

volume of a cylinder = $\pi r^2h$

volume of a sphere = $\frac{4}{3} \pi r^3$

circumference of a circle = $2\pi r$

area of a circle = $\pi r^2$

15. A square piece of aluminum foil, 8.0 in. on a side, is found to weigh 1.863 g. What is the thickness of this foil, in mm? (The density of aluminum is 2.70 g/cm$^3$).

*16. The diameter of metal wire is often referred to by its American wire gauge number. A 16-gauge wire has a diameter of 0.05082 in. What length of wire, in meters, is there in a 1.00-lb. spool of 16-gauge copper wire? The density of copper is 8.92 g/cm$^3$. 
17. How many Cu atoms are present in a 1.00-m length of 20-gauge copper wire? (A 20 gauge wire has a diameter of 0.03196 in.; density of Cu = 8.92 g/cm³.)

D. Other problems where you might try setting up and solving an algebraic equation.

18. A Fahrenheit and a Celsius thermometer are immersed in the same medium, whose temperature is to be measured. At what Celsius temperature will the numerical reading on the Fahrenheit thermometer be?
   a) twice that on the Celsius thermometer?
   b) 200° more than that on the Celsius thermometer?

19. In each case, identify the element in question if
   a) the mass number of an atom is 234 and the atom has 60.0% more neutrons than protons.
   b) an ion with a 2+ charge has 10.0% more protons than electrons.

20. There are two naturally occurring isotopes of silver having the natural abundances: $^{107}$Ag, 51.84%; $^{109}$Ag, 48.16%. The mass of $^{107}$Ag is 106.905092 u. What is the mass of $^{109}$Ag to 4 significant figures?

*21. The two naturally occurring isotopes of nitrogen have masses of 14.0031 and 15.0001 u, respectively. Determine the percentage of nitrogen-15 atoms in naturally occurring nitrogen.

*22. The atomic mass of Bi is to be determined by converting the compound Bi(C$_6$H$_5$)$_3$ to Bi$_2$O$_3$. If 5.610 g Bi(C$_6$H$_5$)$_3$ yields 2.969 g Bi$_2$O$_3$, what is the atomic mass of Bi calculated from this data?

E. Empirical and molecular formula variations

23. The compound XF$_3$ consists of 65% F, by mass. What is the atomic mass of X?

24. Chlorophyll (essential to the process of photosynthesis) contains Mg to the extent of 2.72% by mass. Assuming one Mg atom per chlorophyll molecule, what is the molecular mass of chlorophyll?

*25. The metal M forms the sulfate M$_2$(SO$_4$)$_3$. An 0.738-g sample of this sulfate is converted to 1.511 g BaSO$_4$. What is the identity of M?

26. An alloy that melts at about the boiling point of water has Bi, Pb, and Sn atoms in the ratio 10:6:5, respectively. What is the mass of a sample of this alloy containing a total of one mole of atoms?

F. Stoichiometry

27. Balance the following equations by inspection.
   a) P$_2$H$_4$(l) → PH$_3$(g) + P$_4$(s)
   b) S$_2$Cl$_2$ + NH$_3$ → N$_2$S$_4$ + NH$_4$Cl + S$_8$
28. Write balanced equations to represent
   a) the complete combustion of benzoic acid, C₆H₅COOH

   b) the decomposition, by heating, of solid mercury (II) nitrate to produce
      pure liquid mercury, nitrogen dioxide gas, and oxygen gas.

   c) copper metal reacts with gaseous oxygen, carbon dioxide, and water to
      form green basic copper carbonate, Cu₂(OH)₂CO₃ (a reaction responsible
      for the formation of a green patina or coating on outdoor bronze statues).

   d) calcium dihydrogen phosphate reacts with sodium hydrogen carbonate
      (bicarbonate), producing calcium phosphate, sodium hydrogen phosphate,
      carbon dioxide, and water (the principle reaction occurring in the action
      of ordinary baking powder in the baking of cakes, bread, and biscuits).

29. Silver oxide decomposes at temperatures in excess of 300°C, yielding metallic
    silver and oxygen gas. A 3.13-g sample of impure silver oxide yields 0.187 g
    O₂(g). If one assumes that Ag₂O(s) is the only source of O₂(g), what is the
    percent, by mass, of Ag₂O in the sample?

30. NaBr, used to produce AgBr for use in photography, can itself be prepared
    through the reactions listed below. How much Fe, in kg, is consumed in the first
    step to produce 2.50 x 10³ kg NaBr in the third step?

    Fe + Br₂ → FeBr₂
    FeBr₂ + Br₂ → Fe₃Br₈  (not balanced)
    Fe₃Br₈ + Na₂CO₃ → NaBr + CO₂ + Fe₃O₄  (not balanced)

31. Azobenzene, an intermediate in the manufacture of dyes, can be prepared
    from nitrobenzene by reacting with triethylene glycol in the presence of
    Zn and KOH. In one reaction 0.10 L of nitrobenzene (d = 1.20 g/mL) and
    0.30 L of triethylene glycol (d = 1.12 g/mL) yielded 55 g azobenzene.
    What was the percent yield of this reaction?

    2 C₆H₅NO₂ + 4 C₆H₁₄O₄ → (C₆H₅N)₂ + 4 C₆H₁₂O₄ + 4 H₂O
                         nitrobenzene  triethylene        azobenzene
                                      glycol

G. Stoichiometry problems with two unknowns

32. A 2.05-g sample of an iron-aluminum alloy (ferroaluminum) is dissolved in
    excess HCl(aq) to produce 0.105 g H₂(g). What is the percent of aluminum by
    mass, of the ferroaluminum?

    Fe(s) + 2 HCl(aq) → FeCl₂(aq) + H₂(g)
    2 Al(s) + 6 HCl(aq) → 2 AlCl₃(aq) + 3 H₂(g)
33. A 0.155-g sample of an Al-Mg alloy reacts with an excess of HCl(aq) to produce 0.0163 g H₂. What is the percent Mg in the alloy?

34. The manufacture of ethyl alcohol, C₂H₅OH, yields diethyl ether, (C₂H₅)₂O as a by-product. The complete combustion of a 1.005-g sample of the product of this process yields 1.963 g CO₂. What must be the mass percents of C₂H₅OH and of (C₂H₅)₂O in this sample?

Answers to Problems

1. 484 g sucrose
2. 7.37 L solution
3. 0.9 L solution
4. 6 x 10⁷ m³ seawater
5. 4.9 mg/m² h
6. 1.54 x 10¹¹ ft³
7. 4.37 x 10¹² Pb atoms
8. 4.757 x 10²⁻³ Mg-24 atoms
9. 3.3 x 10³ g hydrogen
10. 2.2 x 10¹⁶ tons Na
11. 3 x 10²² Fe atoms
12. 1.02 x 10²³ Li-6 atoms
13. 11g/mL
14. 1.47 oz ethyl alcohol
15. 1.7 x 10⁻² mm
16. 38.8 m
17. 4.38 x 10⁻²² Cu atoms
18. a) 160°C  b) 210°C
19. (a) atom of ²³⁴Th, (b) Ti²⁺
20. 108.9μ
21. 0.36% ¹⁵N
22. 209 g/mol Bi
23. 31 amu X
24. 893 amu chlorophyll
25. Al (from calc. of its molar mass)
26. 186.98 g alloy
27. 86.6% Ag₂O
28. 509 kg Fe
29. 62% yield
30. 20% Al (.40g Al)
31. 90.8% C₂H₅OH and 9.2% (C₂H₅)₂O