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CHEMFILE MINI-GUIDE TO PROBLEM SOLVING

Concentration of Solutions

There are three principal ways to express solution concentration in chemistry—percentage by mass, molarity, and molality.

The following table compares these three ways of stating solution concentration. Examining the method of preparation of the three types may help you understand the differences among them.

	Symbol	Meaning	How to prepare
Percentage	%	Grams solute per 100 g of solution	**5%:** Dissolve 5 g of solute in 95 g solvent.
Molarity	M	Moles solute per liter of solution	**5 M:** Dissolve 5 mol of solute in solvent and add solvent to make 1 L of solution.
Molality	*m*	Moles solute per kilogram of solvent	**5 *m*:** Dissolve 5 mol of solute in 1 kg of solvent.

PERCENTAGE CONCENTRATION

You will find percentages of solutes stated on the labels of many commercial products, such as household cleaners, liquid pesticide solutions, and shampoos. If your sink becomes clogged, you might buy a bottle of drain opener whose label states that it is a 2.4% sodium hydroxide solution. This means that the bottle contains 2.4 g of NaOH for every 100 g of solution.

Computing percentage concentration is very much like computing percentage composition (see Chapter 6). Both involve finding the percentage of a single component of a multicomponent system. In each type of percentage calculation, the mass of the important component (in percentage concentration, the solute) is divided by the total mass of the system and multiplied by 100 to yield a percentage. In percentage concentration, the solute is the important component, and the total mass of the system is the mass of the solute plus the mass of the solvent.

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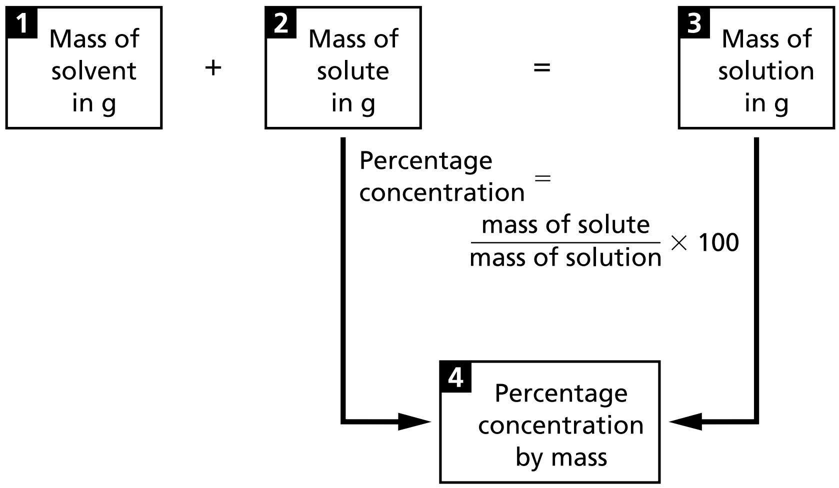
General Plan for Solving Percentage Concentration Problems



SAMPLE PROBLEM 1

What is the percentage by mass of a solution made by dissolving 0.49 g of potassium sulfate in 12.70 g of water?

SOLUTION

1. *ANALYZE*

- *What is given in the problem?* — the mass of solvent, and the mass of solute, K_2SO_4
- *What are you asked to find?* — the concentration of the solution expressed as a percentage by mass

Items	Data
Mass of solvent	12.70 g H_2O
Mass of solute	0.49 g K_2SO_4
Concentration (% by mass)	? %

2. *PLAN*

- *What step is needed to calculate the concentration of the solution as a percentage by mass?* — Divide the mass of solute by the mass of the solution and multiply by 100.

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1 Mass of water in g + **2** Mass of K_2SO_4 in g = **3** Mass of K_2SO_4 solution in g

$$\text{percentage concentration} = \frac{\text{solute mass}}{\text{solution mass}} \times 100$$

4 Percentage K_2SO_4 by mass

$$\text{percentage concentration} = \frac{\overset{given}{g\ K_2SO_4}}{\underset{given}{g\ K_2SO_4} + \underset{given}{g\ H_2O}} \times 100$$

3. *COMPUTE*

$$\text{percentage concentration} = \frac{0.49\ g\ K_2SO_4}{0.49\ g\ K_2SO_4 + 12.70\ g\ H_2O} \times 100 = 3.7\%\ K_2SO_4$$

4. *EVALUATE*

- *Are the units correct?* Yes; percentage K_2SO_4 was required.
- *Is the number of significant figures correct?* Yes; the number of significant figures is correct because the data had a minimum of two significant figures.
- *Is the answer reasonable?* Yes; the computation can be approximated as $0.5/13 \times 100 = 3.8\%$.

PRACTICE

1. What is the percentage concentration of 75.0 g of ethanol dissolved in 500.0 g of water? *ans:* 13.0% ethanol
2. A chemist dissolves 3.50 g of potassium iodate and 6.23 g of potassium hydroxide in 805.05 g of water. What is the percentage concentration of each solute in the solution? *ans:* 0.430% KIO_3, 0.765% KOH
3. A student wants to make a 5.00% solution of rubidium chloride using 0.377 g of the substance. What mass of water will be needed to make the solution? *ans:* 7.16 g H_2O
4. What mass of lithium nitrate would have to be dissolved in 30.0 g of water in order to make an 18.0% solution? *ans:* 6.59 g $LiNO_3$

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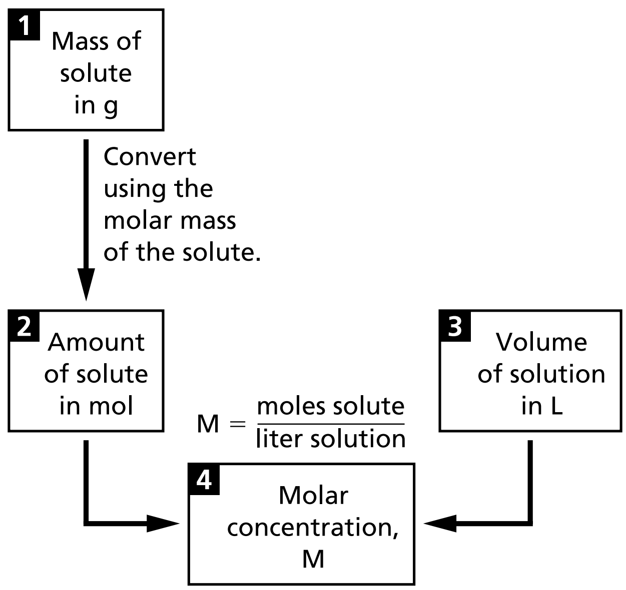
MOLARITY

Molarity is the most common way to express concentration in chemistry. Molarity is the number of moles of solute per liter of solution and is given as a number followed by a capital M. A 2 M solution of nitric acid contains 2 mol of HNO_3 per liter of solution. As you know, substances react in mole ratios. Knowing the molar concentration of a solution allows you to measure a number of moles of a dissolved substance by measuring the volume of solution.

General Plan for Solving Molarity Problems



SAMPLE PROBLEM 2

What is the molarity of a solution prepared by dissolving 37.94 g of potassium hydroxide in some water and then diluting the solution to a volume of 500.00 mL?

SOLUTION

1. *ANALYZE*

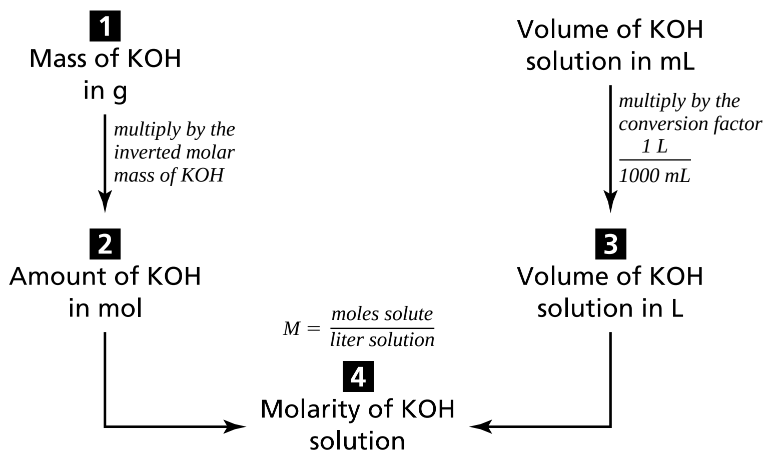
• *What is given in the problem?*	the mass of the solute, KOH, and the final volume of the solution
• *What are you asked to find?*	the concentration of the solution expressed as molarity

Items	Data
Mass of solute	37.94 g KOH
Moles of solute	? mol KOH
Molar mass of solute*	56.11 g/mol
Volume of solution	500.00 mL
Concentration (molarity)	? M

* determined from the periodic table

2. *PLAN*

- *What steps are needed to calculate the concentration of the solution as molarity?* Determine the amount in moles of solute; calculate the moles per liter of solution.



$$\overset{given}{\text{g KOH}} \times \overset{\frac{1}{\text{molar mass of KOH}}}{\frac{1 \text{ mol KOH}}{56.11 \text{ g KOH}}} = \text{mol KOH}$$

$$\overset{given}{\text{mL solution}} \times \frac{1 \text{ L}}{1000 \text{ mL}} = \text{L solution}$$

$$\frac{\overset{calculated\ above}{\text{mol KOH}}}{\underset{calculated\ above}{\text{L solution}}} = \text{M solution}$$

3. *COMPUTE*

$$37.94 \text{ g KOH} \times \frac{1 \text{ mol KOH}}{56.11 \text{ g KOH}} = 0.6762 \text{ mol KOH}$$

$$500.00 \text{ mL solution} \times \frac{1 \text{ L}}{1000 \text{ mL}} = 0.500\ 00 \text{ L solution}$$

$$\frac{0.6762 \text{ mol KOH}}{0.500\ 00 \text{ L solution}} = 1.352 \text{ M}$$

4. *EVALUATE*

- *Are the units correct?* — Yes; units canceled to give moles KOH per liter of solution.
- *Is the number of significant figures correct?* — Yes; the number of significant figures is correct because the data had a minimum of four significant figures.
- *Is the answer reasonable?* — Yes; note that 0.6762 mol is approximately 2/3 mol and 0.500 00 L is 1/2 L. Thus, the calculation can be estimated as (2/3)/(1/2) = 4/3, which is very close to the result.

PRACTICE

1. Determine the molarity of a solution prepared by dissolving 141.6 g of citric acid, $C_3H_5O(COOH)_3$, in water and then diluting the resulting solution to 3500.0 mL. *ans:* 0.2106 M

2. What is the molarity of a salt solution made by dissolving 280.0 mg of NaCl in 2.00 mL of water? Assume the final volume is the same as the volume of the water. *ans:* 2.40 M

3. What is the molarity of a solution that contains 390.0 g of acetic acid, CH_3COOH, dissolved in enough acetone to make 1000.0 mL of solution? *ans:* 6.494 M

SAMPLE PROBLEM 3

An analytical chemist wants to make 750.0 mL of a 6.00 M solution of sodium hydroxide. What mass of NaOH will the chemist need to make this solution?

SOLUTION

1. *ANALYZE*

- *What is given in the problem?* — the identity of the solute, the total volume of solution, and the molarity of the solution
- *What are you asked to find?* — the mass of solute to dissolve

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Items	**Data**
Mass of solute	**?** g NaOH
Molar mass of solute	40.00 g/mol
Moles of solute	**?** mol NaOH
Volume of solution	750.0 mL
Concentration (molarity)	6.00 M

2. *PLAN*

- *What steps are needed to calculate the mass of solute needed?*

  Determine the amount in moles needed for the solution required, and convert to grams by multiplying by the molar mass of the solute.

3. *COMPUTE*

Molarity of NaOH solution × Volume of NaOH solution in L = Amount of NaOH in mol

Volume of NaOH solution in mL → *multiply by the conversion factor $\frac{1\ L}{1000\ mL}$* → Volume of NaOH solution in L

Amount of NaOH in mol → *multiply by the molar mass of NaOH* → Mass of NaOH in g

$$\overset{given}{\text{mL solution}} \times \frac{1\ \text{L}}{1000\ \text{mL}} = \text{L solution}$$

$$\overset{given}{\frac{\text{mol NaOH}}{\text{L solution}}} \times \overset{calculated\ above}{\text{L solution}} \times \overset{molar\ mass\ of\ NaOH}{\frac{40.00\ \text{g NaOH}}{1\ \text{mol NaOH}}} = \text{g NaOH}$$

$$750.0\ \cancel{\text{mL}}\ \text{solution} \times \frac{1\ \text{L}}{1000\ \cancel{\text{mL}}} = 0.7500\ \text{L solution}$$

$$\frac{6.00\ \cancel{\text{mol NaOH}}}{\cancel{\text{L solution}}} \times 0.7500\ \cancel{\text{L solution}} \times \frac{40.00\ \text{g NaOH}}{1\ \cancel{\text{mol NaOH}}}$$

$$= 180.\ \text{g NaOH}$$

4. *EVALUATE*

- *Are the units correct?*

  Yes; units canceled to give grams of NaOH.

- *Is the number of significant figures correct?*

  Yes; the number of significant figures is correct because the data had a minimum of three significant figures.

- *Is the answer reasonable?* Yes; the calculation can be estimated as $(3/4) \times (6)(40) = (3/4) \times 240 = 180$.

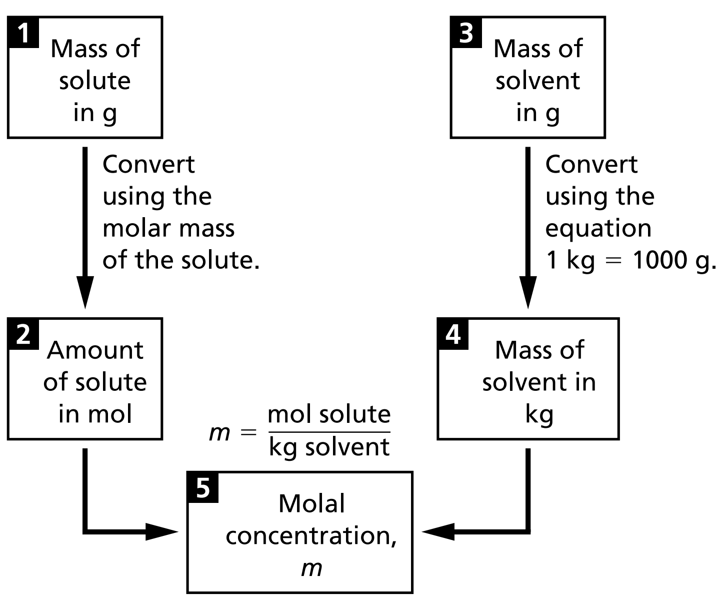
PRACTICE

1. What mass of glucose, $C_6H_{12}O_6$, would be required to prepare 5.000×10^3 L of a 0.215 M solution? *ans:* 1.94×10^5 g
2. What mass of magnesium bromide would be required to prepare 720. mL of a 0.0939 M aqueous solution? *ans:* 12.4 g
3. What mass of ammonium chloride is dissolved in 300. mL of a 0.875 M solution? *ans:* 14.0 g

MOLALITY

Molality is the amount in moles of solute per kilogram of solvent and is given by a number followed by an italic lowercase *m*. A 5 *m* aqueous solution of glucose contains 5 mol of $C_6H_{12}O_6$ per kilogram of water. Molal concentration is important primarily in working with colligative properties of solutions, which you will do in Chapter 16.

General Plan for Solving Molality Problems



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SAMPLE PROBLEM 4

Determine the molal concentration of a solution containing 81.3 g of ethylene glycol, $HOCH_2CH_2OH$, dissolved in 166 g of water.

SOLUTION

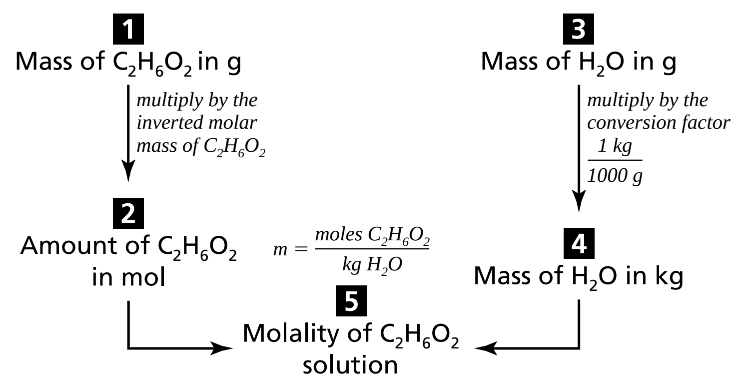
1. *ANALYZE*

- *What is given in the problem?* — the mass of ethylene glycol dissolved, and the mass of the solvent, water
- *What are you asked to find?* — the molal concentration of the solution

Items	Data
Mass of solute	81.3 g ethylene glycol
Molar mass of solute	62.08 g/mol ethylene glycol
Moles of solute	**?** mol ethylene glycol
Mass of solvent	166 g H_2O
Concentration (molality)	**?** m

2. *PLAN*

- *What steps are needed to calculate the molal concentration of the ethylene glycol solution?* — Determine the amount of solute in moles and the mass of solvent in kilograms; calculate the moles of solute per kilogram of solvent.



$$\underset{given}{\text{g } C_2H_6O_2} \times \overset{\frac{1}{\text{molar mass of } C_2H_6O_2}}{\frac{1 \text{ mol } C_2H_6O_2}{62.08 \text{ g } C_2H_6O_2}} = \text{mol } C_2H_6O_2$$

$$\overset{given}{\text{g } H_2O} \times \frac{1 \text{ kg}}{1000 \text{ g}} = \text{kg } H_2O$$

$$\frac{\overset{calculated\ above}{\text{mol } C_2H_6O_2}}{\underset{calculated\ above}{\text{kg } H_2O}} = m\ C_2H_6O_2 \text{ solution}$$

3. *COMPUTE*

$$81.3 \text{ g } C_2H_6O_2 \times \frac{1 \text{ mol } C_2H_6O_2}{62.08 \text{ g } C_2H_6O_2} = 1.31 \text{ mol } C_2H_6O_2$$

$$166 \text{ g } H_2O \times \frac{1 \text{ kg}}{1000 \text{ g}} = 0.166 \text{ kg } H_2O$$

$$\frac{1.31 \text{ mol } C_2H_6O_2}{0.166 \text{ kg } H_2O} = 7.89\ m$$

4. *EVALUATE*

- *Are the units correct?* — Yes; units canceled to give moles $C_2H_6O_2$ per kilogram of solvent.
- *Is the number of significant figures correct?* — Yes; the number of significant figures is correct because the data had a minimum of three significant figures.
- *Is the answer reasonable?* — Yes; because 1.31 mol is approximately 4/3 mol and 0.166 kg is approximately 1/6 kg, the calculation can be estimated as (4/3)/(1/6) = 24/3 = 8, which is very close to the result.

PRACTICE

1. Determine the molality of a solution of 560 g of acetone, CH_3COCH_3, in 620 g of water. *ans:* 16 *m*

2. What is the molality of a solution of 12.9 g of fructose, $C_6H_{12}O_6$, in 31.0 g of water? *ans:* 2.31 *m*

3. How many moles of 2-butanol, $CH_3CHOHCH_2CH_3$, must be dissolved in 125 g of ethanol in order to produce a 12.0 *m* 2-butanol solution? What mass of 2-butanol is this? *ans:* 1.50 mol 2-butanol
111 g 2-butanol

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ADDITIONAL PROBLEMS

1. Complete the table below by determining the missing quantity in each example. All solutions are aqueous. Any quantity that is not applicable to a given solution is marked NA.

Solution made	Mass of solute used	Quantity of solution made	Quantity of solvent used
a. 12.0% $KMnO_4$	**?** g $KMnO_4$	500.0 g	**?** g H_2O
b. 0.60 M $BaCl_2$	**?** g $BaCl_2$	1.750 L	NA
c. 6.20 *m* glycerol, $HOCH_2CHOHCH_2OH$	**?** g glycerol	NA	800.0 g H_2O
d. **?** M $K_2Cr_2O_7$	12.27 g $K_2Cr_2O_7$	650. mL	NA
e. **?** *m* $CaCl_2$	288 g $CaCl_2$	NA	2.04 kg H_2O
f. 0.160 M NaCl	**?** g NaCl	25.0 mL	NA
g. 2.00 *m* glucose, $C_6H_{12}O_6$	**?** g glucose	**?** g solution	1.50 kg H_2O

2. How many moles of H_2SO_4 are in 2.50 L of a 4.25 M aqueous solution?

3. Determine the molal concentration of 71.5 g of linoleic acid, $C_{18}H_{32}O_2$, in 525 g of hexane, C_6H_{14}.

4. You have a solution that is 16.2% sodium thiosulfate, $Na_2S_2O_3$, by mass.

a. What mass of sodium thiosulfate is in 80.0 g of solution?

b. How many moles of sodium thiosulfate are in 80.0 g of solution?

c. If 80.0 g of the sodium thiosulfate solution is diluted to 250.0 mL with water, what is the molarity of the resulting solution?

5. What mass of anhydrous cobalt(II) chloride would be needed in order to make 650.00 mL of a 4.00 M cobalt(II) chloride solution?

6. A student wants to make a 0.150 M aqueous solution of silver nitrate, $AgNO_3$ and has a bottle containing 11.27 g of silver nitrate. What should be the final volume of the solution?

7. What mass of urea, NH_2CONH_2, must be dissolved in 2250 g of water in order to prepare a 1.50 *m* solution?

8. What mass of barium nitrate is dissolved in 21.29 mL of a 3.38 M solution?

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9. Describe what you would do to prepare 100.0 g of a 3.5% solution of ammonium sulfate in water.

10. What mass of anhydrous calcium chloride should be dissolved in 590.0 g of water in order to produce a 0.82 *m* solution?

11. How many moles of ammonia are in 0.250 L of a 5.00 M aqueous ammonia solution? If this solution were diluted to 1.000 L, what would be the molarity of the resulting solution?

12. What is the molar mass of a solute if 62.0 g of the solute in 125 g of water produce a 5.3 *m* solution?

13. A saline solution is 0.9% NaCl. What masses of NaCl and water would be required to prepare 50. L of this saline solution? Assume that the density of water is 1.000 g/mL and that the NaCl does not add to the volume of the solution.

14. A student weighs an empty beaker on a balance and finds its mass to be 68.60 g. The student weighs the beaker again after adding water and finds the new mass to be 115.12 g. A mass of 4.08 g of glucose is then dissolved in the water. What is the percentage concentration of glucose in the solution?

15. The density of ethyl acetate at 20°C is 0.902 g/mL. What volume of ethyl acetate at 20°C would be required to prepare a 2.0% solution of cellulose nitrate using 25 g of cellulose nitrate?

16. Aqueous cadmium chloride reacts with sodium sulfide to produce bright-yellow cadmium sulfide. Write the balanced equation for this reaction and answer the following questions.

a. How many moles of $CdCl_2$ are in 50.00 mL of a 3.91 M solution?

b. If the solution in (a) reacted with excess sodium sulfide, how many moles of CdS would be formed?

c. What mass of CdS would be formed?

17. What mass of H_2SO_4 is contained in 60.00 mL of a 5.85 M solution of sulfuric acid?

18. A truck carrying 22.5 kL of 6.83 M aqueous hydrochloric acid used to clean brick and masonry has overturned. The authorities plan to neutralize the acid with sodium carbonate. How many moles of HCl will have to be neutralized?

19. A chemist wants to produce 12.00 g of barium sulfate by reacting a 0.600 M $BaCl_2$ solution with excess H_2SO_4, as shown in the reaction below. What volume of the $BaCl_2$ solution should be used?

$$BaCl_2 + H_2SO_4 \rightarrow BaSO_4 + 2HCl$$

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20. Many substances are hydrates. Whenever you make a solution, it is important to know whether or not the solute you are using is a hydrate and, if it is a hydrate, how many molecules of water are present per formula unit of the substance. This water must be taken into account when weighing out the solute. Something else to remember when making aqueous solutions from hydrates is that once the hydrate is dissolved, the water of hydration is considered to be part of the solvent. A common hydrate used in the chemistry laboratory is copper sulfate pentahydrate, $CuSO_4 \cdot 5H_2O$. Describe how you would make each of the following solutions using $CuSO_4 \cdot 5H_2O$. Specify masses and volumes as needed.

a. 100. g of a 6.00% solution of $CuSO_4$

b. 1.00 L of a 0.800 M solution of $CuSO_4$

c. a 3.5 *m* solution of $CuSO_4$ in 1.0 kg of water

21. What mass of calcium chloride hexahydrate is required in order to make 700.0 mL of a 2.50 M solution?

22. What mass of the amino acid arginine, $C_6H_{14}N_4O_2$, would be required to make 1.250 L of a 0.00205 M solution?

23. How much water would you have to add to 2.402 kg of nickel(II) sulfate hexahydrate in order to prepare a 25.00% solution?

24. What mass of potassium aluminum sulfate dodecahydrate, $KAl(SO_4)_2 \cdot 12H_2O$, would be needed to prepare 35.00 g of a 15.00% $KAl(SO_4)_2$ solution? What mass of water would be added to make this solution?