1.5 Calculating Concentration

Figure A1.20: Some insect repellents contain 25% DEET. Health Canada regulates that there should be no more than 0.010 ppm of lead in drinking water. A lab technician determines that a solution of cobalt(II) nitrate has a concentration of 0.200 mol/L.

Three Methods for Communicating Concentration

You can sometimes determine the relative concentrations of solutions by observing their qualitative properties; but it is often very useful to know specifically how much solute is dissolved in a particular solvent. In science and technology, a variety of ways are used to communicate the concentration of a solution. The table "Expressing Concentration" summarizes three common ways to express concentrations.

EXPRESSING CONCENTRATION

	Symbol	Formula	Use	Used By
Percent by Volume	% *V/V*	$\frac{\text{mL of solute}}{\text{mL of solution}} \times 100\%$	communicating the volume of a liquid solute dissolved in the total volume of a solution	manufacturers of consumer products
Parts Per Million	ppm	$\frac{\text{g of solute}}{\text{g of solution}} \times 10^6$ ppm	communicating levels of a substance (like a pollutant) in very dilute aqueous solutions	agencies that set health and safety standards
Molar Concentration	*C*	$\frac{\text{mol of solute}}{\text{L of solution}}$	communicating the amount of moles of a pure substance dissolved in the total volume of a solution	scientists and lab technicians

In this lesson you will explore how and when to use these forms of communicating concentrations. By understanding how concentration is communicated, you should be better able to understand the labels of some of the consumer goods you purchase. You should also be able to make connections to environmental and scientific issues currently being debated.

Percent By Volume (% *V/V*)

Percent by volume is commonly used for liquids dissolved in liquids. This form of concentration is usually used for consumer products like drinks and cleaners. The equation for calculating percent by volume is as follows:

$$(\%\ V/V) = \frac{V_{\text{solute}}}{V_{\text{solution}}} \times 100\%$$

- volume of solute dissolved in the solution (mL) → V_{solute}
- percent by volume concentration of the solution → $(\%\ V/V)$
- total volume of the solution (mL) → V_{solution}

Example Problem 1.6

A hair product requires you to combine 20.0 mL of hydrogen peroxide with enough water to produce a solution with a total volume of 120.0 mL. Determine the percent by volume concentration of the solution.

Solution

$V_{\text{solute}} = 20.0\ \text{mL}$

$V_{\text{solution}} = 120.0\ \text{mL}$

$(\%\ V/V) = ?$

$$\begin{aligned}(\%\ V/V) &= \frac{V_{\text{solute}}}{V_{\text{solution}}} \times 100\% \\ &= \frac{20.0\ \cancel{\text{mL}}}{120.0\ \cancel{\text{mL}}} \times 100\% \\ &= 16.7\%\end{aligned}$$

The percentage by volume concentration of the solution is 16.7%.

Note: The rules of significant digits state that the final answer must be expressed to the same number of significant digits as the value with the least number of significant digits. Because the volume of the solute consists of only three significant digits, the final answer must consist of only three significant digits. For more information, refer to "Calculations with Significant Digits" on pages 534 to 536.

When problem-solving throughout this course, there are key points that you will want to remember:

- Mathematical solutions begin by listing the known and unknown values for this problem.
- The list of knowns and unknowns is used to choose the proper equation.
- The data, including units, is substituted into the equation.
- The final answer is expressed with the correct number of significant digits and with the proper units.

Sometimes, solving problems requires using algebra to rearrange the equation.

Example Problem 1.7

A mosquito repellent says that DEET makes up 45.0% of the total volume. If you have a 75-mL sample of this repellent, determine the volume of DEET within the sample.

Solution

List the knowns and the unknown.

$$(\%\ V/V) = 45.0\% \quad V_{\text{solution}} = 75\ \text{mL} \quad V_{\text{solute}} = ?$$

Rearrange the percent by volume equation so V_{solute} is isolated.

$$(\%\ V/V) = \frac{V_{\text{solute}}}{V_{\text{solution}}} \times 100\%$$

$$\frac{(\%\ V/V)}{100\%} = \frac{\frac{V_{\text{solute}}}{V_{\text{solution}}} \times \cancel{100\%}}{\cancel{100\%}} \quad \leftarrow \text{Divide both sides by } 100\%.$$

$$\frac{(\%\ V/V)}{100\%} = \frac{V_{\text{solute}}}{V_{\text{solution}}}$$

$$\frac{(\%\ V/V)}{100\%} \times V_{\text{solution}} = \frac{V_{\text{solute}}}{\cancel{V_{\text{solution}}}} \times \cancel{V_{\text{solution}}} \quad \leftarrow \text{Multiply both sides by } V_{\text{solution}}.$$

$$\frac{(\%\ V/V)}{100\%} \times V_{\text{solution}} = V_{\text{solute}} \quad \leftarrow V_{\text{solute}} \text{ is now isolated.}$$

Substitute the values into the equation.

$$\begin{aligned}V_{\text{solute}} &= \frac{(\%\ V/V)}{100\%} \times V_{\text{solution}} \\ &= \frac{45.0\%}{100\%} \times 75\ \text{mL} \\ &= 33.75\ \text{mL} \\ &= 34\ \text{mL} \quad \leftarrow \text{two significant digits}\end{aligned}$$

The repellent sample contains 34 mL of DEET.

It is not necessary to show all of the algebra in your solutions. Most students simply write the basic equation and then write the rearranged version on the next line.

$$(\%\ V/V) = \frac{V_{\text{solute}}}{V_{\text{solution}}} \times 100\%$$

$$\Downarrow$$

$$V_{\text{solute}} = \frac{(\%\ V/V)}{100\%} \times V_{\text{solution}}$$

The important thing to remember is that the second equation is simply a rearranged version of the basic equation; it is not a new equation.

Example Problem 1.8

Insecticidal soap is an environmentally friendly way to control insect pests on plants. A gardener needs a solution with a percent by volume concentration of insecticidal soap of 5.0%. If the total volume of the solution was 4000 mL, calculate the volume of insecticidal soap needed to make this solution.

Solution

$(\% \; V/V) = 5.0\%$

$V_{\text{solution}} = 4000 \text{ mL}$

$V_{\text{solute}} = ?$

$$(\% \; V/V) = \frac{V_{\text{solute}}}{V_{\text{solution}}} \times 100\%$$

$$\begin{aligned} V_{\text{solute}} &= \frac{(\% \; V/V)}{100\%} \times V_{\text{solution}} \\ &= \frac{5.0\%}{100\%} \times 4000 \text{ mL} \\ &= 200 \text{ mL} \\ &= 2.0 \times 10^{2} \text{ mL} \end{aligned}$$

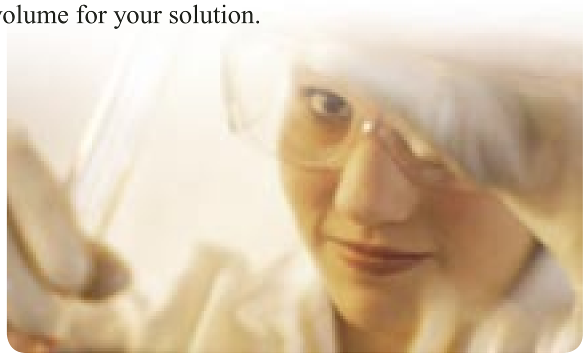
To make this solution, 2.0×10^{2} mL of insecticidal soap is needed.

Note: Because the percent by volume has the least number of significant digits (two), the final answer must be expressed with only two significant digits. To do this, in this case, scientific notation is required.

DID YOU KNOW?

If you combined 50 mL of ethanol with 50 mL of water, you get a solution with a volume of 95 mL. How can this be? The molecules of ethanol and the molecules of water do not directly stack on top of each other. Instead, the two liquids intermingle with each other and, thus, fill in some of the spaces between each other's molecules. This causes them to occupy less volume.

For this reason, if you are making a solution a specific concentration, you first need to measure the volume of your liquid solute; then you need to add a sufficient amount of solvent to produce a final total volume for your solution.



Practice

28. To make a hand cleaner, a technician mixes 30 mL of antiseptic with enough liquid soap to make 70 mL of solution. Determine the percent by volume concentration of the antiseptic in the hand cleaner.

29. A solution of rubbing alcohol is labelled 60% (*V/V*). Determine the volume of rubbing alcohol present in a 200-mL sample of the solution.

30. A bottle of insect repellent states that it has a DEET percent by volume concentration of 25%. If you just bought a 250-mL container of this product, what volume of DEET have you purchased?

Parts Per Million (ppm)

Parts per million is a unit of concentration used for very dilute solutions. You will often come across this unit when you are investigating situations involving very small amounts of substances in contaminated water systems or food. The table "Allowable Toxic Levels in Drinking Water" lists the current guidelines established by Canada Health for some toxic elements in your drinking water.

ALLOWABLE TOXIC LEVELS IN DRINKING WATER

Substance	Maximum Acceptable Concentration (ppm)
arsenic	0.025
chromium	0.050
fluoride	1.5
lead	0.010
mercury	0.001
uranium	0.02

The term *1 part per million* means "one part solute for every million parts of solution." The details of the equation used to calculate parts per million is as follows:

$$\text{parts per million} = \frac{m_{\text{solute}}}{m_{\text{solution}}} \times 10^{6} \text{ ppm}$$

mass of solute (g) → m_{solute}

parts per million concentration of the solution → parts per million

mass of solution (g) → m_{solution}

Remember that 1.000 mL of water has a mass of 1.000 g.

Example Problem 1.9

A 200-g sample from a bottle of water contains 5.4×10^{-3} g of mercury.

a. Calculate the concentration of mercury in the sample in parts per million.

b. Use the information in the table "Allowable Toxic Levels in Drinking Water" to determine if this water is safe to drink.

Solution

a. $m_{\text{solute}} = 5.4 \times 10^{-3}\ \text{g}$

$m_{\text{solution}} = 200\ \text{g}$

parts per million = ?

$$\begin{aligned}\text{parts per million} &= \frac{m_{\text{solute}}}{m_{\text{solution}}} \times 10^{6}\ \text{ppm}\\ &= \frac{5.4 \times 10^{-3}\ \cancel{\text{g}}}{200\ \cancel{\text{g}}} \times 10^{6}\ \text{ppm}\\ &= 27\ \text{ppm}\end{aligned}$$

The concentration of mercury in this sample is 27 ppm.

Calculator Tip: You will be required to perform the calculations that involve entering values in scientific notation into your calculator. For most calculators, this requires using a special key labelled EXP or EE. Pressing these keys includes the "×10" part of the scientific notation. So, you only need to enter the exponent.

Value	Keystrokes on Calculator
5.4×10^{-3}	[5] [·] [4] [EE] [(–)] [3]
$10^{6} = 1 \times 10^{6}$	[1] [EE] [6]

Consult the user's guide that came with your calculator for more information.

b. The mercury concentration in the water is well above the maximum acceptable concentration of 0.001 ppm. This water is not safe to drink.

Example Problem 1.10

Carbon monoxide, CO(g), is a deadly gas that takes the place of oxygen molecules and binds to hemoglobin in blood. If you are smoking, the concentration of carbon monoxide that reaches your lungs is approximately 200 ppm. Determine the mass of CO(g) that would be present in a sample of air having a mass of 9.6 g (approximately one breath). Express your answer in scientific notation.

Solution

parts per million = 200 ppm

$m_{\text{solution}} = 9.6\ \text{g}$

$m_{\text{solute}} = ?$

$$\text{parts per million} = \frac{m_{\text{solute}}}{m_{\text{solution}}} \times 10^{6}\ \text{ppm}$$

$$\begin{aligned}m_{\text{solute}} &= \frac{\text{parts per million}}{10^{6}\ \text{ppm}} \times m_{\text{solution}}\\ &= \frac{200\ \cancel{\text{ppm}}}{10^{6}\ \cancel{\text{ppm}}} \times 9.6\ \text{g}\\ &= 0.0019\ \text{g}\\ &= 1.9 \times 10^{-3}\ \text{g}\end{aligned}$$

There would be 1.9×10^{-3} g of CO(g) present.

Note: In Example Problem 1.10, the answer displayed on the calculator is not in scientific notation. To write the answer in scientific notation, follow these steps:

step 1: Move the decimal to the right until it is on the right side of the first non-zero digit.

0.00192

step 2: Round the number to the specific number of significant digits. In this case, round the value to two significant digits.

1.9

step 3: Insert the power of ten the value should be multiplied by. Because the decimal moved three places to the right, the exponent in the power of 10 is −3.

1.9×10^{-3}

Alternatively, many calculators can be set to automatically display answers in scientific notation. This is a very useful feature because it reduces errors.

On many calculators, using the MODE key automatically causes the answers to be displayed in scientific notation. Check the user's guide that came with your calculator to learn how to set this up.

DID YOU KNOW?

If you put 4 drops of ink into a rain barrel that holds 210 L of water, the concentration of the ink would be approximately 1 ppm.

Practice

31. A 250-g sample of water contains 8.30×10^{-3} g of lead.

   a. Calculate the concentration of lead in the sample of water in parts per million.

   b. Determine if this water is safe to drink.

32. Canadian law prevents the sale of fish for consumption containing more that 2.00 ppm of PCBs. A 227-g sample of fish is tested and found to contain the maximum allowable concentration of PCBs. Determine the mass of PCBs in this sample of fish.

33. It is considered unsafe to have more than 50.0 ppm of arsenic in drinking water. If you have a bottle of water containing 250 g of water with this level of arsenic, what mass of arsenic would you ingest?

Molar Concentration, *C* (mol/L)

Earlier in this chapter you saw how diagrams of the atomic structure of a water molecule can communicate that two hydrogen atoms covalently bond to one oxygen atom. If you were to break up this molecule, you would expect to get twice as many molecules of hydrogen gas, $H_2(g)$, as you would oxygen gas, $O_2(g)$. The difficulty is that any sample of water contains so many atoms of hydrogen and oxygen that it is impossible to count them individually. Technologists and scientists, who need to know the amount of the substance, have solved this problem by counting particles in a very large group called a **mole**.

mole: a specific amount of a substance that consists of 6.022×10^{23} particles

molar concentration (molarity): the amount of solute, in moles, per litre of solution

The mole is a very useful quantity because it enables technologists to combine the precise amounts of substances so that all of the reactants are completely converted into products in a chemical reaction. Since many reactions occur in solutions, concentrations within the scientific community are most often communicated using **molar concentration** or **molarity**. The molar concentration of a solution can be calculated using the following relationship:

$$C = \frac{n}{V}$$

n: number of moles of solute dissolved in the solution (mol)

V: total volume of the solution (L)

C: concentration of the solution (mol/L)

This technique is very useful because it communicates the number of molecules or ions of solute dissolved or dissociated in a specified volume of a solution.

Example Problem 1.11

A sample of water taken from a nearby lake is found to have 0.0035 mol of salt in a 100-mL solution. Determine the concentration of the salt in the lake.

Solution

$n = 0.0035 \text{ mol}$

$V = 100 \text{ }\cancel{\text{mL}} \times \dfrac{1 \text{ L}}{1000 \text{ }\cancel{\text{mL}}}$

$\quad = 0.100 \text{ L}$

Note: Because the volume of the solution must be in litres (L), convert the original volume using a conversion factor.

$C = ?$

$$\begin{aligned} C &= \frac{n}{V} \\ &= \frac{0.0035 \text{ mol}}{0.100 \text{ L}} \\ &= 0.035 \text{ mol/L} \\ &= 3.5 \times 10^{-2} \text{ mol/L} \end{aligned}$$

The concentration of the salt in the lake is 3.5×10^{-2} mol/L.

Throughout this course, when you record measurements or do calculations, you should always include the units. In Example Problem 1.11, the volume of the solution was given in millilitres (mL) instead of litres (L). It is essential that you communicate, in a clear and concise way, how to convert one unit into another. One of the best ways to do this is by using a **conversion factor**.

conversion factor: a fraction used to convert one set of units into another

Conversion factors offer a concise and consistent way to sort out units. Conversion factors not only keep your solutions organized, they help keep your thinking clear by giving you a reliable way to handle units in all situations. For more information, refer to "Conversion Factors" on page 532.

Molar Mass

Sometimes it is necessary to first calculate the number of moles using the mass of the sample and information from the periodic table to determine the **molar mass**. The equation for calculating the number of moles in a substance is as follows:

molar mass: the mass of 1 mol of a substance

$$n = \frac{m}{M}$$

- m: mass of the substance (g)
- n: number of moles of a substance (mol)
- M: molar mass of the substance (g/mol)

The process of finding the number of moles and then calculating the molar concentration is illustrated in Example Problem 1.12.

Example Problem 1.12

You dissolve 30.0 g of sodium sulfate, $Na_2SO_4(s)$, into 300 mL of water.

a. Determine the number of moles of sodium sulfate in this solution.

b. Calculate the molar concentration of this sodium sulfate solution.

Solution

a. First, determine the molar mass, M, of $Na_2SO_4(s)$.

11 Na sodium 22.99	16 S sulfur 32.06	8 O oxygen 16.00
Na^+ sodium	S^{2-} sulfide	O^{2-} oxide

$$\begin{aligned} M &= 2(M \text{ of Na}) + (M \text{ of S}) + 4(M \text{ of O}) \\ &= 2(22.99 \text{ g/mol}) + (32.06 \text{ g/mol}) + 4(16.00 \text{ g/mol}) \\ &= 142.04 \text{ g/mol} \end{aligned}$$

Now, calculate the number of moles.

$m = 30.0 \text{ g}$

$M = 142.04 \text{ g}$

$n = ?$

$$\begin{aligned} n &= \frac{m}{M} \\ &= \frac{30.0 \text{ g}}{142.04 \text{ g/mol}} \\ &= 0.211\,208\,110\,4 \\ &= 0.211 \text{ mol} \end{aligned}$$

The solution contains 0.211 mol of sodium sulfate.

b. $n = 0.211\,208\,110\,4 \text{ mol}$

$V = 300 \text{ }\cancel{\text{mL}} \times \dfrac{1 \text{ L}}{1000 \text{ }\cancel{\text{mL}}}$

$\quad = 0.300 \text{ L}$

$C = ?$

Note: Although the number of moles was rounded to three significant digits in part a., you should use the unrounded value in this calculation to get a more accurate answer to part b. Remember, the number of moles is still considered to have three significant digits in this calculation.

$$\begin{aligned} C &= \frac{n}{V} \\ &= \frac{0.211\,208\,110\,4 \text{ mol}}{0.300 \text{ L}} \\ &= 0.704 \text{ mol/L} \end{aligned}$$

The molar concentration of the sodium sulfate solution is 0.704 mol/L.

Practice

34. Determine the molar concentration for each solution.

a. 0.435 mol of sodium chloride, NaCl(s), dissolves in 200 mL of water.

b. 800 mL of water contains 0.674 mol of sodium hydroxide, NaOH(aq).

35. 30.0 g of NaCl(s) is added to water to make 800 mL of salt solution.

a. Use the periodic table on pages 554 and 555 to determine the number of moles in 30.0 g of NaCl(s).

b. Calculate the molar concentration of this salt solution.

36. In a science lab, 5.00 g of NaOH(s) is dissolved in 300 mL of water. What is the molar concentration of the resulting solution?

Standard Solutions

Technologists in a number of industries often need to make solutions with a specific concentration. In the field of health care, prescriptions can involve creams or liquids that require an exact amount of medicinal solute to be combined with the appropriate solvent. During manufacturing, specific solutions may have to be prepared. Each solution is an essential component, allowing for the precise control of a chemical reaction.

Why don't these facilities simply order the necessary solutions already mixed in the proper concentrations? As is the case with consumer goods, it is less expensive to ship highly concentrated solutions. Another reason is that sometimes the solutions need to be modified. This provides greater flexibility when it comes to mixing the specific solution needed for specific situations. Clearly, in many industries, technologists follow careful procedures to prepare **standard solutions**.

Making a standard solution requires practice and skill because the slightest error can cause the concentration of your standard solution to be less accurate. In the next investigation you will have an opportunity to produce a standard solution and a dilute solution.

standard solution: a solution having a precisely known concentration

Figure A1.21: In a number of industries, solutions need to be very specific.

Investigation

Developing Technological Skills with Solutions

Science Skills

✓ Performing and Recording

✓ Analyzing and Interpreting

CAUTION!

Use gloves, safety glasses, and a lab apron for this investigation.

Purpose

You will practise the skills for making a standard solution and for making a dilute solution.

Materials

- 50-mL beaker
- 2, 100-mL volumetric flasks
- anhydrous copper(II) sulfate, $CuSO_4$(s)
- distilled water
- eyedropper
- 10-mL volumetric pipette

Part A: Making a Standard Solution

In this part of the investigation you will make 100 mL of a 0.200 mol/L solution of copper(II) sulfate from anhydrous copper(II) sulfate.

Pre-Lab Analysis

1. Complete the following calculation to determine the number of moles of solute you will need for your solution:

$$V = 100\ \cancel{\text{mL}} \times \frac{1\ \text{L}}{1000\ \cancel{\text{mL}}}$$
$$= 0.100\ \text{L}$$
$$C = 0.200\ \text{mol/L}$$
$$n = ?$$

$$C = \frac{n}{V}$$
$$n = CV$$
$$= (\quad)(\quad)$$
$$= \boxed{\quad}$$

2. Complete the following calculation to determine the mass of the copper(II) sulfate, $CuSO_4$, you need.

$$n =$$
$$M = 1(M \text{ of Cu}) + 1(M \text{ of S}) + 4(M \text{ of O})$$
$$= (\quad) + (\quad) + 4(\quad)$$
$$= \boxed{\quad}$$
$$m = ?$$

$$n = \frac{m}{M}$$
$$m = nM$$
$$= (\quad)(\quad)$$
$$= \boxed{\quad}$$

Procedure

step 1: Measure the appropriate mass of solute, $CuSO_4(s)$, and place it into a small beaker.

step 2: Dissolve the solute in the beaker with as little distilled water as possible.

step 3: Carefully transfer the dissolved solute into a volumetric flask. Be sure to rinse your beaker with a little water, and add this rinse to the volumetric flask as well.

step 4: Carefully fill the volumetric flask until the top of the meniscus reaches the 100-mL line.

step 5: Use an eyedropper to add water until the bottom of the meniscus touches the 100-mL line. This is the key step. Do not overshoot the line. If you do overshoot, discard the solution and start over.

step 6: Stopper the volumetric flask. Firmly hold the stopper in place, and invert the flask 15 times to mix the solution.

step 7: Show the solution to your teacher to check the accuracy of your work. Keep your solution. It will be used in Part B of this investigation.

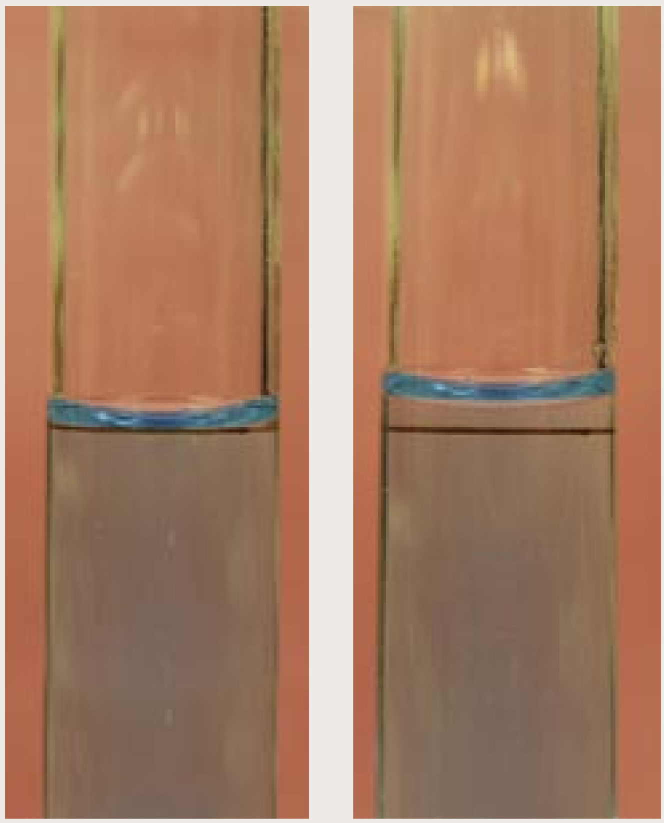


Figure A1.22: The correct measurement of 100 mL occurs when the bottom of the meniscus is even with the line on the volumetric flask. If the bottom of the meniscus is above the line on the volumetric flask, you have more than 100 mL of solution.

Part B: Diluting a Standard Solution

In this part of the investigation you will make 100 mL of a new solution that is a 10% dilution of your standard solution from Part A.

Procedure

step 1: Have your teacher demonstrate the proper technique for using a pipette.

step 2: Pipette 10 mL of your standard solution into another 100-mL volumetric flask.

step 3: Carefully fill the volumetric flask with water so the meniscus is just at the bottom of the 100-mL line.

step 4: Stopper the volumetric flask, and mix the contents of the flask by inverting and carefully shaking it.

step 5: Transfer the dilute solution to an appropriate storage container. Calculate the concentration of your dilute solution. Label the container with the name, chemical formula, and concentration. Also, indicate which WHMIS symbols should be placed on the label.

CAUTION!

Do not pour the remainder of your standard solution down the drain. Consult your teacher regarding the proper disposal of your solution.

Analysis

3. List the potential problems you may have encountered with each step of the procedure. Identify steps that could affect the accuracy of the concentration of your standard solution.

4. Are you confident that your standard solution is exactly 0.200 mol/L? Give a reason for your answer.

5. Do you think it would be easier or more difficult to make a standard solution that is colourless? Support your answer.

6. Explain the importance of knowing the exact concentration of a standard solution.

7. Explain how volumetric flasks and pipettes help you measure volumes with greater precision.

Evaluation

In this investigation you were instructed not to pour your standard solution down the drain. One reason for doing this is that once the water has evaporated, the crystals can be reconstituted and used by other classes. Another reason for not pouring the solutions down the drain has to do with the harmful effects of copper substances on the environment.

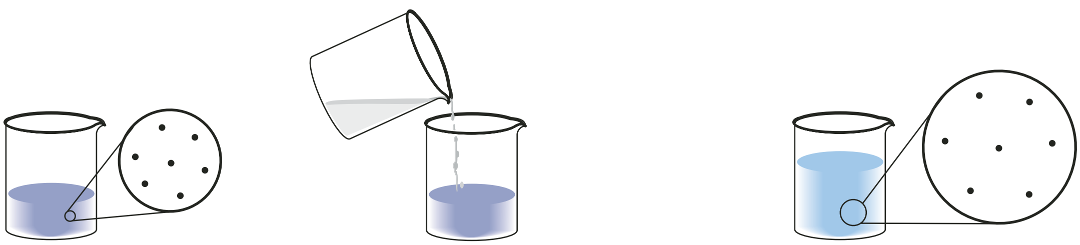
8. Use the Internet and other sources of information to determine the harmful effects of copper compounds released into the environment.

Diluting Solutions

Some chemical solutions are transported in concentrated form to save costs. It may be necessary to dilute such a solution to obtain a solution with a specifically desired concentration. There are also times when water is removed from a solution to make it more concentrated. In each case, the amount of solute is unchanged, but the amount of solvent changes.

Adding Solvent to a Solution

When solvent is added to a solution, the number of moles of solute, *n*, is unchanged.



initial solution

$C_i = \frac{n}{V_i}$

$n = C_i V_i$

number of moles of solute before dilution

final solution

$C_f = \frac{n}{V_f}$

number of moles of solute after dilution → $n = C_f V_f$

Since the number of moles of solute is constant,

initial concentration → $C_iV_i = C_fV_f$ ← final volume

initial volume; final concentration

Note: The final volume is the total volume of the solution, not the amount of solvent added.

Example Problem 1.13

You have 65.0 mL of a 0.759-mol/L solution of sodium chloride, NaCl(aq).

a. Calculate the final concentration of the solution if it is diluted to a final volume of 100.0 mL.
b. Calculate the final concentration of a solution prepared by adding 100.0 mL of water to the original solution.
c. How much water do you need to add to the original solution to obtain a solution with a concentration of 0.200 mol/L?
d. How much water needs to evaporate from the original solution to obtain a solution with a concentration of 0.890 mol/L?

Solution

a. $V_i = 65.0\text{ mL}$

$C_i = 0.759\text{ mol/L}$

$V_f = 100.0\text{ mL}$

$C_f = ?$

$$C_i V_i = C_f V_f$$
$$C_f = \frac{C_i V_i}{V_f} = \frac{(0.759\text{ mol/L})(65.0\text{ mL})}{100.0\text{ mL}} = 0.493\text{ mol/L}$$

← **Note:** There is no need to convert millilitres to litres because they cancel each other out.

The final concentration of the solution is 0.493 mol/L.

b. $V_i = 65.0\text{ mL}$

$C_i = 0.759\text{ mol/L}$

$V_f = 65.0\text{ mL} + 100.0\text{ mL} = 165.0\text{ mL}$

$C_f = ?$

$$C_i V_i = C_f V_f$$
$$C_f = \frac{C_i V_i}{V_f} = \frac{(0.759\text{ mol/L})(65.0\text{ mL})}{165.0\text{ mL}} = 0.299\text{ mol/L}$$

The final concentration of the solution is 0.299 mol/L.

c. $V_i = 65.0\text{ mL}$

$C_i = 0.759\text{ mol/L}$

$C_f = 0.200\text{ mol/L}$

$V_f = ?$

$V_{added} = ?$

$$C_i V_i = C_f V_f$$
$$V_f = \frac{C_i V_i}{C_f} = \frac{(0.759\text{ mol/L})(65.0\text{ mL})}{0.200\text{ mol/L}} = 246.675\text{ mL}$$

The amount added can be found by subtracting the initial volume from the final volume.

$$\begin{aligned} V_{added} &= V_f - V_i \\ &= 246.675\text{ mL} - 65.0\text{ mL} \\ &= 181.675\text{ mL} \\ &= 182\text{ mL} \end{aligned}$$

You need to add 182 mL of water.

continued on next page

d. $V_i = 65.0 \text{ mL}$

$C_i = 0.759 \text{ mol/L}$

$C_f = 0.890 \text{ mol/L}$

$V_f = ?$

$V_{evaporated} = ?$

$$C_i V_i = C_f V_f$$

$$V_f = \frac{C_i V_i}{C_f}$$

$$= \frac{(0.759 \cancel{\text{mol/L}})(65.0 \text{ mL})}{0.890 \cancel{\text{mol/L}}}$$

$$= 55.432\,584\,27 \text{ mL}$$

The amount evaporated can be found by subtracting the final volume from the initial volume.

$$V_{evaporated} = V_i - V_f$$

$$= 65.0 \text{ mL} - 55.432\,584\,27 \text{ mL}$$

$$= 9.567\,415\,73 \text{ mL}$$

$$= 9.6 \text{ mL}$$

The volume of water needed to evaporate is 9.6 mL.

Diluting Acids

In previous science courses you studied compounds that form solutions that turn blue litmus paper red because they produce hydrogen ions. These compounds are called **acids**.

acid: a substance that produces hydrogen ions when dissolved in water to form a conducting aqueous solution

Soft drinks, tomato sauce, and pickles are foods that are all slightly acidic. Acid content in food can be identified with a sour taste. While these products are relatively harmless, concentrated acids can be quite hazardous. Concentrated acids can cause acid burns on skin, blindness if splashed in the eyes, and death if swallowed.

The most common acid used in industry is sulfuric acid. In fact, more sulfuric acid is produced each year than any other industrial chemical. As you'll see in the next set of Practice questions, concentrated sulfuric acid is used in a wide variety of applications.

Safety Tip: When diluting an acid, always add the acid to the water in small amounts. The rearrangement of solute and solvent when an acid is diluted is exothermic and can be a safety risk.

Practice

Figure A1.23: A battery technician checks the concentration of sulfuric acid.

37. The battery is the primary source of electrical energy used in vehicles. Most automotive batteries produce electricity by using the chemical reaction between two different types of lead in a solution of sulfuric acid. This application is the reason why some people refer to sulfuric acid as battery acid. In one automotive battery, 360 mL of concentrated sulfuric acid, 17.8 mol/L, is combined with 640 mL of water to form the solution with the proper concentration.

a. Determine the total volume of the solution in the battery.

b. Calculate the molar concentration of the sulfuric acid solution in the battery.

c. Determine the percent by volume concentration of the sulfuric acid solution in the battery.

d. Consider your answers to questions 37.b. and 37.c. Which method of communicating concentration is likely used by scientists researching new designs for batteries, and which method is best for a brochure for customers explaining the features of a particular battery?

38. Sulfuric acid is used to make chlorine dioxide for bleaching in the pulp and paper industry. A technician in a pulp mill needs to make 275 L of a solution containing 4.25 mol/L of sulfuric acid.

a. Calculate the volume of concentrated sulfuric acid (17.8 mol/L) that the technician must measure to make the required solution.

b. Determine the volume of water needed to make the required solution.

39. Approximately two-thirds of all the sulfuric acid produced for industry is used in the production of fertilizers. Ammonium sulfate and potassium sulfate are both fertilizers that are manufactured using sulfuric acid. At a large fertilizer manufacturing plant, a technician begins to prepare some tests using a standard solution of sulfuric acid.

a. The technician measures out 2.50 L of a standard solution of sulfuric acid with a concentration of 10.0 mol/L. Determine the amount of water that must be added to create a solution with a concentration of 3.75 mol/L.

b. A large beaker contains 655 mL of a standard solution of sulfuric acid with a concentration of 10.0 mol/L. This beaker is placed in a fume hood where evaporation can occur. Determine the amount of water that would have to evaporate in order for the solution to have a concentration of 11.0 mol/L.

DID YOU KNOW?

Many natural compounds, such as the oils in onions, contain sulfur. When you slice an onion, a gas is released that rises upwards and combines with the water in your eyes. The result is that a dilute sulfuric acid solution forms in your eyes. In response to this irritation, your eyes automatically start to blink and tear to flush out the sulfuric acid.

Chemical Reactions and Electricity

If a vehicle's headlights are left on while the motor is shut off, the battery produces the electric current for the lights. The current is sustained by chemical reactions within the battery that decrease the concentration of sulfuric acid. If these reactions continue to the point that the sulfuric acid concentration drops below a critical level, the battery is said to be fully discharged or dead.

Figure A1.24: The voltage output of an automotive battery is checked.

When the engine is running, the vehicle's recharging system prevents this situation from occurring by supplying an electric current to the battery that flows in the opposite direction. As the electrons are forced into the battery, the chemical reactions are reversed, the concentration of sulfuric acid rises, and the battery is said to be fully charged.

The concentration of sulfuric acid in the battery is a good indicator of the state of charge of the battery. In the next chapter you will learn more about the role of electrons in chemical reactions and how all this relates to the batteries.

1.5 Summary

Having quantitative units for concentrations allows you to know specifically how much solute is dissolved in a solution. Percent by volume is a unit of concentration used to communicate what volume of liquid solute is dissolved in a solvent. Very dilute solutions are often expressed in parts per million (ppm). The method preferred by technologists and scientists is molar concentration (measured in mol/L). Volumetric flasks and pipettes are useful tools for making standard solutions. When you add more solvent to a solution, its volume is increased, thus lowering the concentration of the solvent and making it more dilute. The number of moles of solute dissolved in the solvent does not change. It is possible to calculate new volumes and concentrations when diluting or evaporating solvent from a solution.

1.5 Questions

Knowledge

1. Define the following.
   - a. mole
   - b. molar concentration
   - c. conversion factor
   - d. molar mass
   - e. parts per million concentration
   - f. percent by volume concentration
   - g. standard solution
   - h. volumetric flask
   - i. pipette
2. Describe why making quantitative measurements of the concentration of a solution is useful.
3. Explain why there are many different units to measure concentration.
4. Explain how each property listed changes as you add more solvent to the solution.
   - a. the concentration of the solution
   - b. the volume of the solution
   - c. the number of moles dissolved in the solution
5. Explain why it is necessary to make standard solutions.

Applying Concepts

6. A student takes 7.00 g of potassium permanganate, $KMnO_4(s)$, and dissolves it into 30.0 mL of water.
   - a. Calculate the concentration of the resulting solution in mol/L.
   - b. Calculate the concentration of the resulting solution in parts per million. (Remember, 30.0 mL of water is equal to 30.0 g of water.) Is this an appropriate way to communicate the concentration in this situation? Support your answer.
   - c. If the student pours the original solution into a jar that contains 250 mL of water, find the concentration of the resulting solution in the jar in mol/L.
   - d. If the student pours the original solute into a reservoir that contains 4.00×10^6 g of water, calculate the concentration of the resulting solution in parts per million. Is this an appropriate way to communicate the concentration in this situation? Support your answer.
7. A technician opens a jar that contains a concentrated disinfectant solution. The molar concentration of the disinfectant is 5.00 mol/L.
   - a. What volume of this disinfectant is required to make a 2.00-L hand-soap solution that has a disinfectant concentration of 0.400 mol/L?
   - b. If you take 20.0 mL of the disinfectant solution and add it to 150 mL of water, determine the percent by volume concentration of the resulting solution.
   - c. A 50.0-mL sample of the original disinfectant solution is left in an open container overnight in a fume hood. You notice in the morning that the volume of the solution is now 40.0 mL. Assuming that no disinfectant evaporated, calculate the new molar concentration of the solution.
8. Design a flowchart describing the specific steps needed to make a standard solution of copper(II) sulfate from anhydrous copper(II) sulfate crystals. Include the types of calculations and equipment you would use.
9. Each of the following three photographs shows a different method for communicating concentration. Provide a reason for the form of communication used in each photograph.

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Legend: t = top, m = middle, b = bottom, l = left, r = right

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