SECTION 8.4 Preparing Solutions in the Laboratory

What do the effectiveness of a medicine, the safety of a chemical reaction, the cost of an industrial process, and the taste of a soft drink have in common? They all depend on a solution with a known concentration being carefully made. A solution with an accurate, known concentration is called a **standard solution**.

Key Terms

standard solution
volumetric flask

standard solution a solution with a known concentration

volumetric flask glassware that is used to make a liquid solution with an accurate volume

Preparing a Standard Aqueous Solution

There are two ways that an aqueous solution with a known concentration of solid solute can be prepared. You can dissolve a measured mass of pure solute in water and then dilute the solution to a known volume, or you can dilute a standard solution by adding a known volume of additional water.

Preparing a Standard Aqueous Solution from a Solid Solute

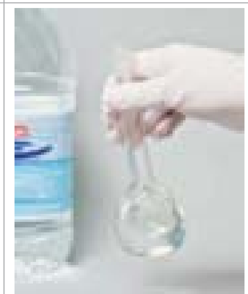
The basic procedure for preparing a standard aqueous solution with a solid solute is as follows:

1. Measure a mass of solute using a balance.
2. Dissolve the solute in water.
3. Add more water to dilute the solution to the required volume.
4. Mix the solution thoroughly.
5. Transfer the solution into a clean, dry, WHMIS-labelled container.

To make up a solution with a specific volume, chemists use a piece of special glassware called a volumetric flask. A **volumetric flask** is a pear-shaped glass container with a flat bottom and long neck. A *graduation mark* on the neck indicates the exact level to which the flask should be filled. Volumetric flasks are available in a variety of sizes, as shown in **Figure 8.20**. These flasks measure a fixed volume of solution to ±0.1 mL at a specified temperature, usually 20°C. If you were performing an experiment in which significant digits and error were important, the volume of solution in a 500 mL volumetric flask would be recorded as 500.0 mL ± 0.1 mL. **Table 8.7** on the next page describes how you can use a volumetric flask to prepare a standard aqueous solution.

Figure 8.20 Volumetric flasks are used for making solutions but not for storing them.
Identify *the features that the various flasks have in common.*

Table 8.7 Using a Volumetric Flask to Prepare a Standard Aqueous Solution

1. Place the known mass of solute in a clean beaker. Use distilled water to dissolve the solute completely.	
2. Rinse a clean volumetric flask of the required volume with a small quantity of distilled water. Discard the rinse water. Repeat the rinsing several times.	
3. Transfer the solution from the beaker to the volumetric flask using a funnel.	
4. Using a wash bottle, rinse the beaker with distilled water, and pour the rinse water into the volumetric flask. Repeat this rinsing several times.	
5. Using a wash bottle or a beaker, add distilled water to the volumetric flask until the level is just below the graduation mark. Then remove the funnel from the volumetric flask.	
6. View the neck of the volumetric flask straight on from the side, so that the graduation mark looks like a line, not an ellipse. Add distilled water, drop by drop, until the bottom of the *meniscus* (the curved surface of the solution) appears to touch the graduation mark.	

Calculating the Concentration of a Diluted Solution

A *stock solution* can be diluted to prepare a standard aqueous solution. A stock solution is usually a concentrated solution that is diluted before it is used. The key to understanding dilution is realizing that adding more solvent to a solution does not remove or add any particles of solute. The amount of solute is exactly the same before and after dilution, as illustrated in **Figure 8.21**.

The formula for molar concentration can be rearranged to give an expression for *n*, the amount of solute (in moles):

$$c = \frac{n}{V} \qquad n = cV$$

Thus, *n*, the amount of solute (in moles), is the product of *c*, the concentration (in moles per litre), and *V*, the volume of the solution (in litres). Since diluting a solution does not change *n*, the product of the molar concentration and volume before dilution equals the product of the molar concentration and volume after dilution:

$$c_1V_1 = c_2V_2$$

where c_1 and V_1 are the molar concentration and volume of the concentrated solution, and c_2 and V_2 are the molar concentration and volume of the diluted solution.

This dilution equation can be used to calculate quantities and concentrations when a stock solution is diluted. Often, the concentration of a stock solution is known to only two or three significant figures. Higher precision is usually possible when using a solid solute to prepare a standard solution.

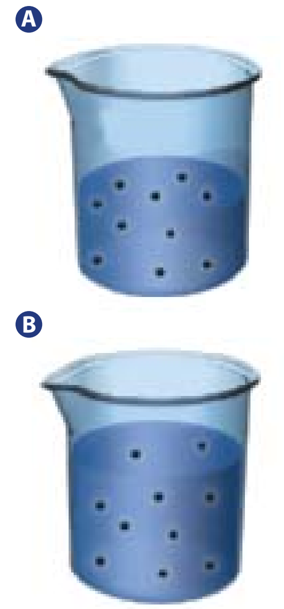


Figure 8.21 When a solution **(A)** is diluted, the volume of solvent increases **(B)**, but the number of solute particles remains the same.

Sample Problem

Diluting a Concentrated Solution

Problem

Your teacher has a stock solution of 12 mol/L hydrochloric acid. A class experiment requires 2.0 L of 0.10 mol/L hydrochloric acid. What volume of concentrated solution should be used to make the dilute solution for the experiment?

What Is Required?

You need to find the volume (V_1) of concentrated solution to be diluted.

What Is Given?

You know the initial concentration, c_1: 12 mol/L
You know the diluted concentration, c_2: 0.10 mol/L
You know the volume of the diluted solution, V_2: 2.0 L.

Plan Your Strategy	Act on Your Strategy
Write the dilution equation.	$c_1V_1 = c_2V_2$
Divide both sides of the equation by c_1 to isolate V_1.	$V_1 = \frac{c_2V_2}{c_1}$
Substitute the known quantities to calculate V_1, the volume of stock solution required.	$V_1 = \frac{0.10 \cancel{\text{ mol/L}} \times 2.0 \text{ L}}{12 \cancel{\text{ mol/L}}} = 0.017 \text{ L}$ Therefore, 0.017 L, or 17 mL, of the stock solution should be diluted to make the required dilute solution.

Check Your Solution

The units and number of significant digits are correct. The answer is reasonable: only a small volume of concentrated solution is needed because the dilute solution is much less concentrated than the stock solution.

Practice Problems

51. Suppose that you are given a stock solution of 1.50 mol/L ammonium sulfate, $(NH_4)_2SO_4(aq)$. What volume of the stock solution do you need to use to prepare each of the following solutions?

a. 50.0 mL of 1.00 mol/L $(NH_4)_2SO_4(aq)$

b. 200 mL of 0.800 mol/L $(NH_4)_2SO_4(aq)$

c. 250 mL of 0.300 mol/L $NH_4^+(aq)$

52. What is the concentration of the solution that is obtained by diluting 60.0 mL of 0.580 mol/L potassium hydroxide to each of the following volumes?

a. 350 mL

b. 180 mL

c. 3.00 L

53. What volume of a 1.60 mol/L stock solution of calcium chloride, $CaCl_2(aq)$, would you use to make 0.500 L of a 0.300 mol/L solution?

54. Water is added to 100 mL of 0.15 mol/L sodium nitrate, $NaNO_3(aq)$, to make 700 mL of diluted solution. Calculate the molar concentration of the diluted solution.

55. A solution is made by diluting 25 mL of 0.34 mol/L calcium nitrate, $Ca(NO_3)_2(aq)$, solution to 100 mL. Calculate the following concentrations for the solution:

a. the concentration of calcium nitrate

b. the concentration of nitrate ions

56. A laboratory stockroom has a stock solution of 90% (m/v) sulfuric acid, $H_2SO_4(aq)$. If a technician dilutes 50 mL of the stock solution to a final volume of 300 mL, what will be the new mass/volume percent concentration? (**Hint:** The dilution formula can be used for concentration expressed in any units, provided that the units remain the same.)

57. What volume of 1.25 mol/L potassium iodide solution can you make with 125 mL of 3.00 mol/L potassium iodide solution?

58. Hydrochloric acid is available as a stock solution with a concentration of 10 mol/L. If you need 1.0 L of 5.0 mol/L hydrochloric acid, what volume of stock solution should you measure out? Approximately how much distilled water will you need to make the dilution?

59. Write a procedure you could use to make each aqueous solution using a solid solute.

a. 50 mL of 0.25 mol/L silver nitrate, $AgNO_3(aq)$

b. 125 mL of 0.350 mol/L potassium carbonate, $K_2CO_3(aq)$

c. 400 mL of 0.200 mol/L potassium permanganate, $KMnO_4(aq)$

60. Outline a procedure for making each aqueous solution by diluting a stock solution.

a. 0.50 L of 1.0 mol/L sodium hydroxide, $NaOH(aq)$, using 17 mol/L sodium hydroxide

b. 150 mL of 0.300 mol/L ammonia, $NH_3(aq)$, using 6.0 mol/L ammonia

c. 1.75 L of 0.0675 mol/L ammonium bromide, $NH_4Br(aq)$, using 0.125 mol/L ammonium bromide

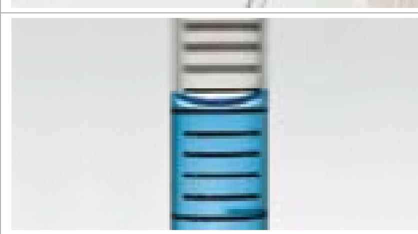
Figure 8.22 Volumetric and graduated pipettes accurately measure volumes.

Preparing a Standard Aqueous Solution by Diluting a Solution

Many of the solutions that are used in a chemistry laboratory are prepared by diluting a concentrated stock solution. You can use a graduated cylinder or a pipette to measure the volume of stock solution that will be diluted. A pipette is an instrument for measuring and transporting a volume of liquid. A pipette is more accurate than a graduated cylinder. There are different types and sizes of pipettes, as shown in **Figure 8.22**. The two most common types are the *volumetric* (or transfer) pipette and the *graduated* (or Mohr) pipette. A volumetric pipette, like a volumetric flask, has a single graduation mark on its stem. Volumetric pipettes are used for measuring common volumes, such as 5, 10, 25, or 50 mL. A graduated pipette can be used to measure any volume within the range of its graduation markings. Suction bulbs or pipette pumps are used for drawing liquid up into the pipette, as described in **Table 8.8**.

After a stock solution is measured with a pipette, the measured solution is placed in a volumetric flask. Water is then added to the flask, similar to the way water is added when preparing a standard aqueous solution using a solid solute. However, if a concentrated acid is being diluted, special safety precautions must be followed, as described on page 388.

Table 8.8 Using a Volumetric Pipette to Measure the Volume of a Stock Solution for Dilution

1. Make sure that the outside of the pipette, especially the tip, is dry. If not, wipe it with a paper towel.	
2. Squeeze the pipette bulb, and then place it over the top of the pipette. If using a pipette pump, place it over the top of the pipette.	
3. Rinse the pipette as follows. Place the tip of the pipette below the surface of the stock solution. Release the bulb carefully to draw up some liquid until the pipette is about half full. Remove the pipette bulb, invert the pipette, and drain the liquid into a beaker for waste. Repeat this rinsing two or three times.	
4. Fill the pipette with stock solution so that the level is past the graduation mark, but do not allow stock solution into the pipette bulb.	
5. Remove the pipette bulb, and quickly seal the top of the pipette with your finger or thumb.	
6. Remove the tip of the pipette from the stock solution. Lift your finger slightly, and let stock solution drain out slowly until the meniscus reaches the graduation mark. Wipe the tip of the pipette with a piece of paper towel.	
7. Move the pipette to the container into which you want to transfer the stock solution. Touch the tip of the pipette against the inside of the container, and release your finger to allow the liquid to drain. A small volume of liquid will remain inside the pipette. The pipette has been calibrated to allow for this volume of liquid. *Do not* force this liquid from the pipette.	

Suggested **Investigation**

Inquiry Investigation 8-D, Preparing and Diluting a Standard Solution

Learning Check

13. What is the advantage of preparing a standard solution from a solid solute rather than a stock solution?
14. Name two pieces of glassware that are used by chemists to prepare a solution with a known concentration.
15. Briefly describe two different ways to make 1.000 L of an aqueous solution with a known concentration.
16. Explain why the amount of solute is the same before and after dilution, but the concentration is less.
17. You are about to use a pipette to add 10.0 mL of 0.5 mol/L $CuSO_4(aq)$ to a beaker, when you see that the beaker contains a few drops of water. You previously rinsed the beaker using distilled water, but you did not dry the beaker. The amount of copper sulfate is important in the reaction you will be performing. Should you dry the beaker now or not worry about it? Explain your answer.
18. You need to make a solution that contains lead ions in a concentration of 0.002 g/L. The limit of accuracy of the balance you have is about 1 mg. How would you prepare the solution?

Safety Considerations When Diluting Acids

Some concentrated acids are dangerous. When diluting a concentrated acid, teachers, chemists, and lab technicians must follow strict safety procedures. A material safety data sheet (MSDS) is available for every hazardous chemical. An MSDS lists the properties of a chemical and the procedures for handling it safely.

A concentrated acid should always be diluted in a fume hood, such as the one shown in **Figure 8.23**, because breathing in the fumes causes acid to collect in the air passages and lungs. Rubber gloves are necessary to protect the hands, and a lab coat is necessary to protect clothing. Even a small splash of a concentrated acid will make a hole in fabric. Safety eyewear is also essential.

Mixing a strong, concentrated acid with water is a highly *exothermic* process—it releases a lot of heat. A concentrated acid is denser than water. When poured into water, such acids sink into the water and dissolve in solution. The heat that is generated is spread throughout the solution. As a result, this procedure is relatively safe. However, adding water to a concentrated acid is *not* safe. If water were added to a concentrated acid, the water would float on top of the solution. The heat generated could easily boil the solution at the acid-water boundary and splatter highly corrosive liquid. Also, the sudden change in temperature could crack the glassware, causing a dangerous spill. The rule when diluting concentrated acids is to add acid to water. You might remember this more easily with this memory aid: "add acid to water, like you oughter."

Figure 8.23 Proper safety precautions, such as working in a fume hood, must be taken whenever you use a concentrated acid.

STSE FEATURE

QUIRKS & QUARKS

with BOB MCDONALD

CBC

THIS WEEK ON QUIRKS & QUARKS

Antimony: The New Lead

Worldwide efforts to lower the level of lead in the atmosphere have been quite successful over the last 30 years. But now some scientists are worried about the level of another element: the metalloid antimony, Sb(s). The chemical processes in the human body do not use antimony. Antimony is toxic, with effects similar to those of arsenic. Dr. William Shotyk, an environmental geochemist at the University of Heidelberg in Germany, has been measuring the levels of lead and antimony in Europe and the Arctic. He has discovered that, while the level of lead has been dropping, the level of antimony has been increasing. Bob McDonald interviewed Dr. Shotyk to learn about antimony contamination in the environment.

Antimony, a shiny metalloid, is used as a catalyst to make PET, a plastic often used for drink bottles. A small amount of antimony remains in the plastic after manufacturing.

Useful but Dangerous

Antimony is present in many everyday products, including computers, batteries, and some types of glass. However, much of the antimony that is produced globally is used as a flame retardant in textiles and as a catalyst for making plastics. Some of these textiles and plastic products are incinerated when they are thrown out. Incineration releases tiny airborne particles of antimony compounds, which can travel thousands of kilometres. Dr. Shotyk thinks that these particles contribute to the rising level of antimony in arctic ice.

As well, Dr. Shotyk found that antimony leaches from polyethylene terephthalate (PET) bottles, which are commonly used for water and other drinks. The longer the water is in the bottle, the more antimony that is dissolved in the water. To eliminate this hazard, Japan is now using titanium as a catalyst for producing PET plastic bottles. Titanium is non-toxic and insoluble in water.

Related Career

Geochemists study the chemical composition of Earth. They also study the chemical processes that produce rocks, minerals, and soils, and they investigate the interactions of these processes with ground water, the oceans, and the atmosphere. Environmental geochemists study the links between the geochemical environment, pollutants, and the health of people, animals, and plants.

QUESTIONS

1. Describe the origins of antimony pollution.
2. Research the industrial life cycle of antimony. How is antimony produced? What processes and products is it used for? Can antimony be recycled?
3. Scientific research often involves a team of people, with different skills and education. List three careers related to geochemistry. Describe the skills and education required for each of these careers.

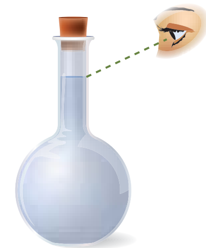
Section 8.4 REVIEW

Section Summary

- A standard solution can be made from a solid solute by using a volumetric flask.
- Stock solutions can be used to produce more dilute solutions.
- When a solution is diluted, the volumes and concentrations before and after dilution are related by the dilution equation: $c_1V_1 = c_2V_2$.
- The safe procedure for diluting a concentrated acid is to add the acid to water.

Review Questions

1. K/U Distinguish between a standard solution and a stock solution.
2. K/U Why should a hot solution never be poured into a volumetric flask?
3. T/I A solution is prepared by dissolving 25.4 g of copper(II) sulfate in a 1 L volumetric flask. Determine the molar concentration of this solution.
4. C Your class needs 4.0 L of aqueous sulfuric acid, H_2SO_4(aq), solution with a concentration of 0.10 mol/L. Outline a procedure that your teacher could use to make this solution from a stock solution of 12 mol/L aqueous sulfuric acid. Include any safety procedures that must be followed.
5. T/I What volume of 0.250 mol/L solution could you make with 55.9 g of potassium chloride, KCl(s)?
6. T/I Distilled water and 6.00 mol/L hydrochloric acid solution are mixed to produce 750 mL of a solution with a concentration of 2.00 mol/L. What volume of the hydrochloric acid solution is needed? Estimate the volume of water added.
7. T/I What mass of sodium acetate, $NaCH_3COO$(s), is needed to make 40.0 mL of a solution with a concentration of 1.25 mol/L?
8. T/I A chemical company accidentally released 475 L of a 5.50 mol/L solution of a toxic compound into a nearby stream. The stream flows into a small pond. What volume of water would the pond have to contain to dilute the compound to a safe concentration of 0.35 μmol/L? (1 μmol = 10^{-6} mol)
9. A A student makes the following errors while preparing a solution. Describe how each error affects the concentration of the resulting solution. Explain what the student should do to avoid the error.
   a. The student dissolves the solute in a beaker and transfers the solution to a volumetric flask, but forgets to rinse the beaker and add the rinse to the volumetric flask.
   b. The student looks at the graduation mark on the volumetric flask from above, as shown.



10. A A tanker car, carrying concentrated sulfuric acid, H_2SO_4(aq), jumps the train track. At the scene, the firefighters find that acid is leaking from the tanker car. Would it be safe for the firefighters to use water from their hoses to dilute the acid? What precautions should they take?
11. C A stock solution of 16 mol/L nitric acid, HNO_3(aq), is available. Describe a safe procedure for using this stock solution to make 2.0 L of 4.0 mol/L aqueous nitric acid solution.
12. T/I Hydrogen peroxide solution, H_2O_2(aq), is available with a concentration of 1.667 mol/L. When diluted to a concentration of 0.25 mol/L, the solution is used as a disinfectant. What volume of water should be added to 100 mL of the concentrated hydrogen peroxide solution to prepare the disinfectant?
13. A Describe how each of the following undesirable properties would affect the concentration of a standard solution, made from a solid solute.
   a. The solid contains unreactive impurities.
   b. The solid absorbs water vapour from the air.
   c. The solid slowly decomposes during storage.
14. C Potassium hydrogen phthalate (KHP) is a solid that is used to make a standard solution, which reacts with bases. Outline a procedure for making 250.0 mL of a 0.1000 mol/L aqueous solution of KHP. The molar mass of KHP is 204.2 g/mol.