Preparing Solutions

8.4

What do the effectiveness of a medicine, the safety of a chemical reaction, and the cost of an industrial process have in common? They all depend on solutions that are made carefully with known concentrations. A solution with a known concentration is called a **standard solution**. There are two ways to prepare an aqueous solution with a known concentration. You can make a solution by dissolving a measured mass of pure solute in a certain volume of solution. Alternatively, you can dilute a solution of known concentration.

Section Preview/ Specific Expectations

In this section, you will

- **prepare** solutions by dissolving a solid solute and then diluting a concentrated solution
- **communicate** your understanding of the following terms: *standard solution, volumetric flask*

Using a Volumetric Flask

A **volumetric flask** is a pear-shaped glass container with a flat bottom and a long neck. Volumetric flasks like the ones shown in Figure 8.19 are used to make up standard solutions. They are available in a variety of sizes. Each size can measure a fixed volume of solution to ±0.1 mL at a particular temperature, usually 20˚C. When using a volumetric flask, you must first measure the mass of the pure solute. Then you transfer the solute to the flask using a funnel, as shown in Figure 8.20. At this point, you add the solvent (usually water) to dissolve the solute, as in Figure 8.21. You continue adding the solvent until the bottom of the meniscus appears to touch the line that is etched around the neck of the flask. See Figure 8.22. This is the volume of the solution, within ±0.1 mL. If you were performing an experiment in which significant digits and errors were important, you would record the volume of a solution in a 500 mL volumetric flask as 500.0 mL ±0.1 mL. Before using a volumetric flask, you need to rinse it several times with a small quantity of distilled water and discard the washings. *Standard solutions are never stored in volumetric flasks*. Instead, they are transferred to another bottle that has a secure stopper or cap.

Figure 8.19 These volumetric flasks, from left to right, contain solutions of chromium(III) salts, iron(III) salts, and cobalt(II) salts.

Figure 8.20 Transfer a known mass of solid solute into the volumetric flask. Alternatively, dissolve the solid in a small volume of solvent. Then add the liquid to the flask.

Figure 8.21 Add distilled water until the flask is about half full. Swirl the mixture around in order to dissolve the solute completely. Rinse the beaker that contained the solute with solvent. Add the rinsing to the flask.

Figure 8.22 Add the rest of the water slowly. When the flask is almost full, add the water drop by drop until the bottom of the meniscus rests at the etched line.

Diluting a Solution

You can make a less concentrated solution of a known solution by adding a measured amount of additional solvent to the standard solution. The number of molecules, or moles, of solute that is present remains the same before and after the dilution. (See Figure 8.23.)

To reinforce these ideas, read through the Sample Problem below. Then try the Practice Problems that follow.

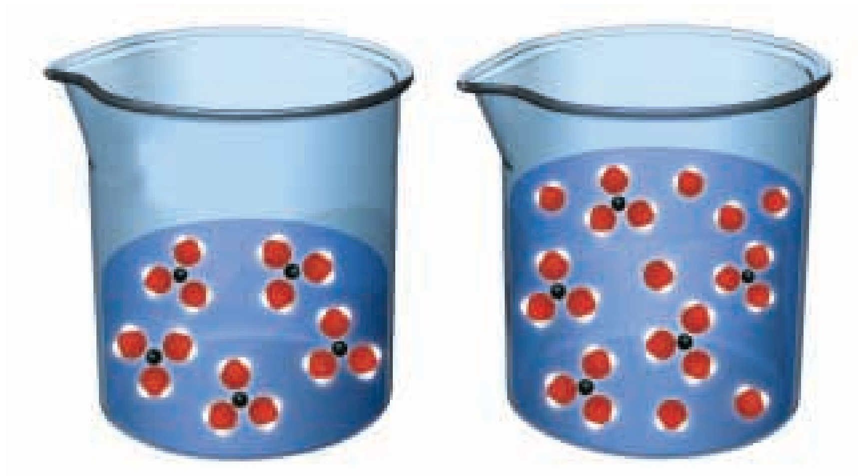

Figure 8.23 When a solution is diluted, the volume increases. However, the amount of solute remains the same.

Sample Problem

Diluting a Standard Solution

Problem

For a class experiment, your teacher must make 2.0 L of 0.10 mol/L sulfuric acid. This acid is usually sold as an 18 mol/L concentrated solution. How much of the concentrated solution should be used to make a new solution with the correct concentration?

What Is Required?

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

What Is Given?

Initial concentration = 18 mol/L
Concentration of diluted solution = 0.10 mol/L
Volume of diluted solution = 2.0 L

Plan Your Strategy

Note: Amount of solute (mol) after dilution = Amount of solute (mol) before dilution

Step 1 Calculate the amount of solute (in mol) that is needed for the final dilute solution.

Step 2 Calculate the volume of the concentrated solution that will provide the necessary amount of solute.

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FROM PAGE 320

Act on Your Strategy

Step 1 Calculate the amount of solute that is needed for the final dilute solution.

$$\text{Molar concentration (in mol/L)} = \frac{\text{Amount of solute (in mol)}}{\text{Volume of solution (in L)}}$$

$$\therefore \text{Amount of solute} = \text{Molar concentration} \times \text{Volume of solution}$$

For the final dilute solution,

$$\begin{aligned}\text{Amount of solute} &= 0.10 \text{ mol/L} \times 2.0 \text{ L} \\ &= 0.20 \text{ mol}\end{aligned}$$

Step 2 Calculate the volume of the original concentrated solution that is needed.

Rearrange and use the molar concentration equation. Substitute in the amount of solute you calculated in step 1.

$$\begin{aligned}\text{Volume of solution (in L)} &= \frac{\text{Amount of solute (in mol)}}{\text{Molar concentration (in mol/L)}} \\ &= \frac{0.20 \cancel{\text{ mol}}}{18 \cancel{\text{ mol}}/\text{L}} \\ &= 0.011 \text{ L}\end{aligned}$$

Therefore, 0.011 L, or 11 mL, of the concentrated 18 mol/L solution should be used to make 2.0 L of 0.10 mol/L sulfuric acid.

Check Your Solution

The units are correct. The final solution must be much less concentrated. Thus, it is reasonable that only a small volume of concentrated solution is needed.

Practice Problems

25. Suppose that you are given a solution of 1.25 mol/L sodium chloride in water, $NaCl_{(aq)}$. What volume must you dilute to prepare the following solutions?

(a) 50 mL of 1.00 mol/L $NaCl_{(aq)}$

(b) 200 mL of 0.800 mol/L $NaCl_{(aq)}$

(c) 250 mL of 0.300 mol/L $NaCl_{(aq)}$

26. What concentration of solution is obtained by diluting 50.0 mL of 0.720 mol/L aqueous sodium nitrate, $NaNO_{3(aq)}$, to each volume?

(a) 120 mL **(b)** 400 mL **(c)** 5.00 L

27. A solution is prepared by adding 600 mL of distilled water to 100 mL of 0.15 mol/L ammonium nitrate. Calculate the molar concentration of the solution. Assume that the volume quantities can be added together.

Now that you understand how to calculate standard solutions and dilution, it is time for you to try it out for yourself. In the following investigation, you will prepare and dilute standard solutions.

Investigation 8-C

SKILL FOCUS
- Initiating and planning
- Performing and recording
- Analyzing and interpreting

Estimating Concentration of an Unknown Solution

Copper(II) sulfate, $CuSO_4$, is a soluble salt. It is sometimes added to pools and ponds to control the growth of fungi. Solutions of this salt are blue in colour. The intensity of the colour increases with increased concentration. In this investigation, you will prepare copper(II) sulfate solutions with known concentrations. Then you will estimate the concentration of an unknown solution by comparing its colour intensity with the colour intensities of the known solutions.

Copper(II) sulfate pentahydrate is a *hydrate*. Hydrates are ionic compounds that have a specific amount of water molecules associated with each ion pair.

Question

How can you estimate the concentration of an unknown solution?

Part 1 Making Solutions with Known Concentrations

Safety Precautions

- Copper(II) sulfate is poisonous. Wash your hands at the end of this investigation.
- If you spill any solution on your skin, wash it off immediately with copious amounts of cool water.

Materials

graduated cylinder
6 beakers
chemical balance
stirring rod
copper(II) sulfate pentahydrate, $CuSO_4{\cdot}5H_2O$
distilled water
labels or grease marker

Procedure

1. With your partner, develop a method to prepare 100 mL of 0.500 mol/L aqueous $CuSO_4{\cdot}5H_2O$ solution. Include the water molecules that are hydrated to the crystals, as given in the molecular formula, in your calculation of the molar mass. Show all your calculations. Prepare the solution.
2. Save some of the solution you prepared in step 1, to be tested in Part 2. Use the rest of the solution to make the dilutions in steps 3 to 5. Remember to label the solutions.
3. Develop a method to dilute part of the 0.500 mol/L $CuSO_4$ solution, to make 100 mL of 0.200 mol/L solution. Show your calculations. Prepare the solution.
4. Show your calculations to prepare 100 mL of 0.100 mol/L solution, using the solution you prepared in step 3. (You do not need to describe the method because it will be similar to the method you developed in step 3. Only the volume diluted will be different.) Prepare the solution.
5. Repeat step 4 to make 100 mL of 0.050 mol/L $CuSO_4$, by diluting part of the 0.100 mol/L solution you made. Then make 50 mL of 0.025 mol/L solution by diluting part of the 0.050 mol/L solution.

Part 2 Estimating the Concentration of an Unknown Solution

Materials

paper towels
6 clean, dry, identical test tubes
medicine droppers
5 prepared solutions from Part 1
10 mL of copper(II) sulfate, $CuSO_4$, solution with an unknown concentration

Procedure

1. You should have five labelled beakers containing $CuSO_4$ solutions with the following concentrations: 0.50 mol/L, 0.20 mol/L, 0.10 mol/L, 0.05 mol/L, and 0.025 mol/L. Your teacher will give you a sixth solution of unknown concentration. Record the letter or number that identifies this solution.
2. Label each test tube, one for each solution. Pour a sample of each solution into a test tube. The height of the solution in the test tubes should be the same. Use a medicine dropper to add or take away solution as needed. (Be careful not to add water, or a solution of different concentration, to a test tube.)
3. The best way to compare colour intensity is by looking down through the test tube. Wrap each test tube with a paper towel to stop light from entering the side. Arrange the solutions of known concentration in order.
4. Place the solutions over a diffuse light source such as a lightbox. Compare the colour of the unknown solution with the colours of the other solutions.
5. Use your observations to estimate the concentration of the unknown solution.

6. Pour the solutions of $CuSO_4$ into a beaker supplied by your teacher. Wash your hands.

Analysis

1. Describe any possible sources of error for Part 1 of this investigation.
2. What is your estimate of the concentration of the unknown solution?

Conclusion

3. Obtain the concentration of the unknown solution from your teacher. Calculate the percentage error in your estimate.

Applications

4. Use your estimated concentration of the unknown solution to calculate the mass of $CuSO_4 \cdot 5H_2O$ that your teacher would need to prepare 500 mL of this solution.
5. If your school has a spectrometer or colorimeter, you can measure the absorption of light passing through the solutions. By measuring the absorption of solutions of copper(II) sulfate with different concentrations, you can draw a graph of absorption against concentration.

Figure 8.24 **When diluting acid, always add the acid to the water—never the reverse. Rubber gloves, a lab coat, and safety goggles or a face shield protect against acid splashes.**

Diluting Concentrated Acids

The acids that you use in your investigations are bought as concentrated standard solutions. Sulfuric acid is usually bought as an 18 mol/L solution. Hydrochloric acid is usually bought as a 12 mol/L solution. These acids are far too dangerous for you to use at these concentrations. Your teacher dilutes concentrated acids, following a procedure that minimizes the hazards involved.

Concentrated acids should be diluted in a fume hood because breathing in the fumes causes acid to form in air passages and lungs. Rubber gloves must be used to protect the hands. A lab coat is needed to protect clothing. Even small splashes of a concentrated acid will form holes in fabric. Safety goggles, or even a full-face shield, are essential.

Mixing a strong, concentrated acid with water is a very exothermic process. A concentrated acid is denser than water. Therefore, when it is poured into water, it sinks into the solution and mixes with the solution. The heat that is generated is spread throughout the solution. This is the only safe way to mix an acid and water. If you added water to a concentrated acid, the water would float on top of the solution. The heat generated at the acid-water layer could easily boil the solution and splatter highly corrosive liquid. The sudden heat generated at the acid-water boundary could crack the glassware and lead to a very dangerous spill. Figure 8.24 illustrates safety precautions needed to dilute a strong acid.

Section Wrap-up

In this section, you learned how to prepare solutions by dissolving a solid solute and then diluting a concentrated solution. In the next chapter, you will see how water is used as a solvent in chemistry laboratories. Many important reactions take place in water. You will also learn more about water pollution and water purification.

Section Review

1. I What mass of potassium chloride, KCl, is used to make 25.0 mL of a solution with a concentration of 2.00 mol/L?

2. I A solution is prepared by dissolving 42.5 g of silver nitrate, $AgNO_3$ in a 1 L volumetric flask. What is the molar concentration of the solution?

3. I The solution of aqueous ammonia that is supplied to schools has a concentration of 14 mol/L. Your class needs 3.0 L of a solution with a concentration of 0.10 mol/L.
   (a) What procedure should your teacher follow to make up this solution?
   (b) Prepare an instruction sheet or a help file for your teacher to carry out this dilution.

4. I 47.9 g of potassium chlorate, $KClO_3$, is used to make a solution with a concentration of 0.650 mol/L. What is the volume of the solution?

5. I Water and 8.00 mol/L potassium nitrate solution are mixed to produce 700 mL of a solution with a concentration of 6.00 mol/L. What volumes of water and potassium nitrate solution are used?