**Solutions to: Solutions and Dilutions**

**Learning objectives**

Students should be able to:

**Content**
- Design a procedure for making a particular solution and assess the advantages of different approaches
- Choose the appropriate glassware to ensure the desired level of precision of a particular solution
- Convert between different concentration units (e.g., ppm to M)

**Process**
- Develop alternative pathways for diluting solutions (Information Processing)
- Design approaches for preparing solutions (Problem Solving)
- Infer chemical processes based on reactions (Critical Thinking)

**Prior knowledge**
- Types of glassware for preparing solutions, including graduated cylinders, pipettes, burets, and volumetric flasks
- Correct method for reading and dispensing from a graduated cylinder, pipette, buret, and volumetric flask
- Definitions of primary standard, secondary standard, calibration standard, accuracy and precision, ppm, molarity

**Further Reading**

Author(s): Mary Walczak (Shepherd)
Christine Dalton

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Solutions and Dilutions

Consider this…

Model 1. Shelby needs to make a 3.00 M acetic acid solution from an acetic acid standardized solution that is 15.0 M. The analytical equipment available to Shelby in the lab includes the volumetric flasks and pipettes shown below. Although several different size volumetric flasks are available, Shelby opts to use the 100-mL flask because it is both clean and dry.

Key Questions:

1. What size pipette does Shelby need to use to make 100 mL of 3.00 M acetic acid solution? Devise a general mathematical expression for calculating the concentration of the resulting solution.

\[ C_1V_1 = C_2V_2 \]

\[ (15 \text{ M})V_1 = (3 \text{ M})(100 \text{ mL}) \]

\[ V_1 = 20 \text{ mL} \]

2. The dilution factor (initial volume of solution/final volume of solution) is a way of expressing the extent to which a solution is diluted. What dilution factor is used to prepare the solution described in Q1?

\[ \frac{20 \text{ mL}}{100 \text{ mL}} = \frac{1}{5} \]

3. Shelby is not concerned about the dryness of the pipettes. Explain, based on proper pipetting techniques and your laboratory experiences, exactly how Shelby should use the pipette. Why does proper lab technique eliminate the need for dry pipettes?
Shelby could rinse the pipette with small amounts of the concentrated solution three times to ensure that only droplets of that solution are in the pipette before measuring out solution to transfer.

4. Was it necessary for the volumetric flask to be dry? Discuss as a group and explain your answer and reasoning in a grammatically complete sentence.

No, because water is added to dilute the concentrated solution. Therefore, the flask needs only to be clean and contain only water.

5. Assign different volumetric flasks to group members. For each size flask, determine the volume necessary to prepare that volume of a 3.00 M acetic acid solution from the 15.0 M standard solution. Determine the dilution factor used to prepare any of these solutions. Check your group’s answers by comparing with other groups. Resolve any differences.

As shown in the table below, three combinations of pipette/volumetric flask give a final solution concentration of 3 M: 20 mL into 100 mL; 10 mL into 50 mL; 5 mL into 25 mL. The dilution factor for all of these options is the same: 1/5.

<table>
<thead>
<tr>
<th>stock</th>
<th>desired</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 M</td>
<td>3 M</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>pipette size</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 mL</td>
</tr>
<tr>
<td>500 mL</td>
</tr>
<tr>
<td>250 mL</td>
</tr>
<tr>
<td>100 mL</td>
</tr>
<tr>
<td>50 mL</td>
</tr>
<tr>
<td>25 mL</td>
</tr>
</tbody>
</table>

6. Suppose Shelby’s supervisor said to make 250 mL of 3.00 M acetic acid solution. How would you suggest Shelby prepare this solution?

\[ C_1 V_1 = C_2 V_2 \]
\[(15 \ M) V_1 = (3 \ M)(250 \ mL)\]
\[ V_1 = 50 \ mL \]

Shelby does not have a 50-mL pipette available to make this solution. Multiple pipette deliveries are required. Any combination that gives a
total of 50 mL of the 15 M solution works. The best choice is to use the 25-
mL pipette twice because that is the fewest number of transfers (see Rules
of Thumb, below).

7. Shelby’s supervisor asked for 100 mL of a 2.00 M acetic acid solution. Could Shelby
prepare this from the 15.0 M standard solution using the available glassware in Model 1? If
so, how? If not, what other glassware might Shelby want to use?

\[ C_1V_1 = C_2V_2 \]
\[ (15 \, M)V_1 = (2 \, M)(100 \, mL) \]
\[ V_1 = 13.33 \, mL \]

Shelby does not have a pipette that delivers 13.33 mL! Using 10 mL gives a
1.5 M solution and 15 mL gives 2.25 M. If the concentration must be
precisely 2.00 M, the solution must be prepared gravimetrically.

Consider this…

Making Solutions: Rules-of-Thumb
- Graduated cylinders are considerably less accurate and precise than glass transfer pipettes.
- Dilution in one step is better than two.
- Larger glassware has less relative uncertainty.
- Measuring (Mohr) pipettes are less precise than glass transfer pipettes.
- Waste handling is expensive.
- Glassware is designed to hold a specific volume only at a stated temperature.

Key Questions.
8. Considering the “rules-of-thumb” listed above, circle the glassware in each pair above that will provide the lower uncertainty.

9. Under what conditions is it advantageous to use the smaller volumetric flask in the center panel above? When is the larger flask the optimum choice? Compare answers with group members and arrive at a consensus.

It is advantageous to use the smaller volumetric flask in the center panel when the reagents and/or waste handling are expensive. Making less solution will reduce these costs. The larger flask is better in situations when precision is vitally important, because it has a lower relative uncertainty.

Consider this….

Model 2. Reagan is doing an atomic absorption experiment that requires a set of zinc standards in the 0.4-1.6 ppm range. A 1000 ppm Zn solution was prepared by dissolving the necessary amount of solid Zn(NO$_3$)$_2$ in water. The standards can be prepared by diluting the 1000 ppm Zn solution. Table 1 shows one possible set of serial dilutions (stepwise dilution of a solution) that Reagan could perform to make the necessary standards. Solution A was prepared by diluting 5.00 mL of the 1000 ppm Zn standard to 50.00 mL. Solutions C-E are called “calibration standards” because they will be used to calibrate the atomic absorption spectrometer.

Table 1. Dilutions of Zinc Solutions.

<table>
<thead>
<tr>
<th>Solution</th>
<th>Zinc Solution Concentration (ppm Zn)</th>
<th>Volume used (mL)</th>
<th>Diluted Volume (mL)</th>
<th>Solution Concentration (ppm Zn)</th>
<th>Solution Concentration (ppm Zn(NO$_3$)$_2$)</th>
<th>Solution Concentration (M Zn(NO$_3$)$_2$)</th>
<th>Solution Concentration (M Zn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1000</td>
<td>5.00</td>
<td>50.00</td>
<td>1.00 x 10$^2$</td>
<td>2.90 x 10$^2$</td>
<td>1.53 x 10$^{-3}$</td>
<td>1.53 x 10$^{-3}$</td>
</tr>
<tr>
<td>B</td>
<td>Solution A</td>
<td>5.00</td>
<td>100.00</td>
<td>5.00</td>
<td>14.0</td>
<td>7.65 x 10$^{-5}$</td>
<td>7.65 x 10$^{-5}$</td>
</tr>
<tr>
<td>C</td>
<td>Solution B</td>
<td>5.00</td>
<td>50.00</td>
<td>0.500</td>
<td>1.00</td>
<td>7.65 x 10$^{-6}$</td>
<td>7.65 x 10$^{-6}$</td>
</tr>
<tr>
<td>D</td>
<td>Solution B</td>
<td>10.00</td>
<td>50.00</td>
<td>1.000</td>
<td>3.000</td>
<td>1.529 x 10$^{-5}$</td>
<td>1.529 x 10$^{-5}$</td>
</tr>
<tr>
<td>E</td>
<td>Solution B</td>
<td>25.00</td>
<td>100.00</td>
<td>1.250</td>
<td>4.000</td>
<td>1.911 x 10$^{-5}$</td>
<td>1.911 x 10$^{-5}$</td>
</tr>
</tbody>
</table>
Key Questions.

10. Using your general scheme for calculating the concentration of diluted solutions devised in key question 1, calculate the resulting concentration (ppm Zn) for each solution A-E above. Enter your answers into the diagram at the right and into the boxes in Table 1. Verify answers provided in Table 1.

\[ C_1V_1 = C_2V_2 \]

Since the standard is 1000 ppm Zn, the straightforward dilution calculation suffices.

11. The atomic mass of Zn is 65.4094 amu and the molar mass of Zn(NO₃)₂ is 189.4194 amu. Devise a scheme to calculate the solution concentrations in units of ppm Zn(NO₃)₂. Calculate the resulting solution concentrations in ppm Zn(NO₃)₂ for Solutions A-E. Enter your results in Table 1.

Here the concentrations must be converted to ppm Zn(NO₃)₂ before using the dilution equation.

\[
\frac{1000 \text{ ppm Zn}}{65.409 \text{ g Zn}} \times \frac{1 \text{ mole Zn(NO₃)₂}}{189.419 \text{ g Zn(NO₃)₂}} = 2896 \text{ ppm Zn(NO₃)₂}
\]

12. Devise a scheme to calculate the solution concentrations in units of molarity (M Zn(NO₃)₂) and (M Zn). Calculate the resulting solution concentrations in M Zn(NO₃)₂ and M Zn for Solutions A-E. Enter your results in Table 1.

\[
\frac{1000 \text{ g Zn}}{10^6 \text{ g solution}} \times \frac{mole \ Zn}{65.409 \text{ g Zn}} \times \frac{1 \text{ g solution}}{1 \text{ mL solution}} \times \frac{1000 \text{ mL}}{L} = 1.529 \times 10^{-2} \text{ M Zn}
\]

\[
\frac{1000 \text{ g Zn}}{10^6 \text{ g solution}} \times \frac{mole \ Zn(NO₃)₂}{65.409 \text{ g Zn}} \times \frac{1 \text{ mole Zn(NO₃)₂}}{1 \text{ mole Zn}} \times \frac{1 \text{ g solution}}{1 \text{ mL solution}} \times \frac{1000 \text{ mL}}{L} = 1.529 \times 10^{-2} \text{ M Zn(NO₃)₂}
\]
13. Compare the solution concentrations expressed as ppm Zn and ppm Zn(NO\(_3\))\(_2\). Compare the concentrations expressed as M Zn and M Zn(NO\(_3\))\(_2\).

Which units allow easy conversion between chemical species (e.g., Zn and Zn(NO\(_3\))\(_2\))? 

The solution concentrations expressed as ppm Zn and ppm Zn(NO\(_3\))\(_2\) are not numerically equivalent. The Molarity concentrations, however, do not depend on the compound of interest (i.e., Zn or Zn(NO\(_3\))\(_2\)). The difference is due to ppm being based on *mass* of analyte (i.e., Zn or Zn(NO\(_3\))\(_2\)), which is different in the two cases. For molarity, the concentration is based on the number of *moles* of analyte, which is the same for Zn or Zn(NO\(_3\))\(_2\).

Which units express concentrations in numbers with easily expressed magnitudes?

The solution concentrations expressed as ppm Zn and ppm Zn(NO\(_3\))\(_2\) are easily expressed numbers for solutions in this concentration range.

Suppose you have an analyte for which you don’t know the molar mass. Which concentration units would you use?

**Molarity concentrations** require the use of molar mass, so if that quantity is unknown ppm must be used.

14. For the concentrations involved in this particular experiment, which set of units is most convenient? Explain your reasoning.

Concentrations expressed as ppm Zn or Zn(NO\(_3\))\(_2\) are more convenient than molarity. The scientific notation required for molarity is more cumbersome than the larger numbers for ppm. One should be careful, however, to correctly express significant figures!

15. Write a laboratory procedure for the preparation of Solution B from Solution A for Reagan to carry out.

Clean a 5.00-mL pipette and a 50.00-mL volumetric flask. Transfer a small amount (~30 mL) of the 1000 ppm Zn solution to a clean, dry beaker. Draw a small portion of this Zn solution into the pipette and use it to rinse the inside surfaces of the pipette. Discard the rinsing into a waste beaker. Repeat the rinsing procedure twice more with the 1000 ppm Zn solution. Fill the 5.00-mL pipette with 1000 ppm Zn solution. Transfer this portion of solution into the volumetric flask. Let the pipette drain and touch the side of the pipette to the inside neck of the volumetric flask to remove any drop clinging to the tip. Add deionized water to the volumetric flask so that the solution level is near, but not over, the line on the neck. Stopper and invert the flask to mix. Adjust the solution level so the meniscus is at
the line on the neck by adding more deionized water. Stopper the flask again and invert to mix. Properly label the volumetric flask.

16. Although only 50 mL of each calibration standard (Solutions C-E) are needed for the experiment, Reagan made 100 mL of Solution E. Give a rationale for this decision.

The dilution factor required to prepare solution E is ¼. Twelve and a half mL of Solution B is required to prepare 50 mL of this solution. Since Reagan has no 12.5-mL pipette, the solution was doubled in volume so the 25.00-mL pipette could be used.

17. Suppose Reagan made an error in preparing Solution A and ended up with a 100.5 ppm Zn solution. What is the impact of this error on Solutions B-E?

If Solution A really had a concentration of 100.5 ppm Zn, the subsequent dilutions to prepare solutions B-E would result in solutions with the following concentrations: 5.025, 0.0503, 1.005, 1.256 ppm Zn.

Consider this…

Model 3. Alternatively, Reagan could prepare the same calibration standards by first preparing a 50 ppm standard and then diluting this standard to make the three calibration standards, as shown at the right. The advantage to this approach is that only one dilution of the 1000 ppm Zn standard is needed before preparing the calibration standards.

Key Questions.

18. Brainstorm ideas about how the 50 ppm standard can be prepared. As a group, come to a consensus on a dilution scheme to prepare this standard and explain the rationale behind choosing this particular method.

The required dilution factor to prepare a 50 ppm Zn standard from the 1000 ppm Zn standard is 1/20. This can be achieved in several ways using the available volumetric glassware. The following combinations work: 5 mL to 100 mL and 25 mL
to 500 mL. In this case it is not likely that 500 mL of this standard will be required to prepare the three calibration standards. Therefore, the 5 mL to 100 mL dilution is the better choice.

19. Divide the calibration standards, Solutions C, D, and E, among group members. For each calibration standard, determine how the 50 ppm standard could be diluted using the laboratory equipment from Model 1 to prepare the solution. The calibration standard concentrations are the same as in Model 2 Solutions C, D and E.

In order to make the same concentration calibration standards (0.50, 1.00, and 1.25 ppm Zn), the required dilution factors for the 50 ppm standard are 1/100, 1/50 and 1/40, respectively. Given the available glassware, the solutions can be prepared as follows:

Solution C (0.50 ppm Zn): 5 mL to 500 mL
Solution D (1.00 ppm Zn): 10 mL to 500 mL
Solution E (1.25 ppm Zn): 12.5 mL to 500 mL*

*Solution E can not readily be prepared since there is no 12.5 mL pipette. If a 1000-mL volumetric flask is available, Solution E could be prepared by using a 25.00-mL pipette.

20. Compare the dilution schemes of Models 2 and 3. Which is the better method in terms of the following parameters:
   a. time
   b. error
   c. waste generation
   d. amount of glassware requiring cleaning

   Based on your answers, which model is better and why?

   a. Time: Model 3 is faster since one fewer solution is made.
   b. Error: Model 3 is better because larger sized volumetric flasks are used. The same size pipettes are used in both models.
   c. Waste generation: Model 2 is better since smaller volumes of solutions are made.
   d. Glassware: Model 3 is slightly better because one fewer volumetric flask must be cleaned.

   Overall, Model 3 is the better choice in all respects except waste generation. Unless waste is an overwhelming concern, choose Model 3.
21. Reagan decides another calibration standard is needed between 0.5 and 1.0 ppm. Using Model 2 or 3 (whichever you decided was better in Q20), how would you make a 0.75 ppm Zn calibration standard (Solution F)?

A dilution factor of $0.75/50 = 3/200 = 1/66.66$ is required. This solution can be prepared by diluting 15.00 mL of the 50 ppm solution to 1000 mL. Alternatively, if the solutions of Model 2 are used, 15 mL of Solution B (5 ppm Zn) can be diluted to 100 mL to give a 0.75 ppm Zn solution.

22. List important considerations when developing a procedure to make a solution.

- dilution factors, concentration units, available glassware, desired level of precision

23. Explain the process of designing an experiment in which calibration standards (solutions used to calibrate an instrument) must be made from a standard solution.

A solution of known concentration (standard solution) is diluted to prepare a set of calibration standards. The desired concentration range for the calibration standards must be known. Dilution factors can be calculated by comparing the target concentrations with the standard concentration. Combinations of volumetric glassware (pipettes and volumetric flasks) are selected to give the desired dilution factors. The solutions are then prepared by diluting pipetted volumes of the standard in volumetric flasks.