Molarity
How can the concentration of a solution be expressed quantitatively?

Why?
When you buy a bottle of a certain brand of lemonade you expect it to taste just as sweet as the last time you bought that kind of lemonade. Likewise, when doctors prescribe a certain ointment, they expect the concentration of medicine to be consistent. How do companies ensure their products taste or perform the same every time you purchase them? Many companies, including pharmaceutical companies, keep track of the concentration of a solution by measuring its molarity—a ratio of number of solute particles to the volume of solution. In this activity you will learn about molarity and how to represent concentration quantitatively.

Model 1 – Lemonade Mixtures*

Lemonade Solution 1

Lemonade Solution 2

*Both pitchers were filled with enough water (solvent) to provide 2 liters of solution.
Dissolved Lemonade Mix particle (solute) = •

1. Refer to Model 1.
   a. What is the solvent in this scenario?
      Water.
   b. What is the solute in this scenario?
      Lemonade Mix.
   c. What is a dissolved lemonade mix particle represented by?
      A black dot.

2. Circle the word that best completes each sentence below and justify your answer based on the diagrams in Model 1.
   a. Lemonade Solution 1 has (more/less/the same) volume of solution as 2. How do you know?
      Each pitcher is filled to 2 liters.
b. Lemonade Solution 1 has (moreless/the same) quantity of solute as Solution 2. Describe how you know in terms of number of particles.

"Fewer solute particles are drawn in the model."

3. Lemonade Solution 2 is considered to be [concentrated]**, and lemonade Solution 1 is considered to be [dilute]**. Examine the two pictures in Model 1. List two ways to differentiate a concentrated solution from a dilute solution.

The solution is darker and there are more solute particles.

4. A glass is filled with the concentrated lemonade solution from Model 1.

a. Is the solution in the glass the same concentration as the solution in the pitcher?

Yes.

b. Does the solution in the glass contain the same number of solute particles as the solution in the pitcher? If no, explain how your answer to part a can be true. Hint: Consider both amount of solute and amount of solvent.

"Concentration is not about the total solute, but the ratio of solute to solvent particles. The glass and the pitcher represent the same ratio of solute/solvent. The total number of solute particles does not matter."

5. Do the terms "concentrated" and "dilute" provide any specific information about the quantities of solute or solvent in a solution? Explain.

No—both concentrated and dilute are relative terms. They can only be used to compare solutions. No specific quantitative information is provided.
Model 2 – Chemical Solutions

**Dilute**

1 M CuCl₂ Solution
0.06 mole CuCl₂ in 0.06 L solution

\[
\frac{0.06 \text{ mole}}{0.06 \text{ L}} = 1 \text{ M}
\]

**Concentrated**

3 M CuCl₂ Solution
0.18 mole CuCl₂ in 0.06 L solution

\[
\frac{0.18 \text{ mole}}{0.06 \text{ L}} = 3 \text{ M}
\]

1 M Glucose Solution
0.06 mole glucose in 0.06 L solution

\[
\frac{0.06 \text{ mole}}{0.06 \text{ L}} = 1 \text{ M}
\]

3 M Glucose Solution
0.18 mole glucose in 0.06 L solution

\[
\frac{0.18 \text{ mole}}{0.06 \text{ L}} = 3 \text{ M}
\]

M = Molarity
“3 M” is read as “three molar”

3 M Glucose Solution
0.06 mole glucose in 0.02 L solution

\[
\frac{0.18 \text{ mole}}{0.06 \text{ L}} = 3 \text{ M}
\]

Molarity
6. List the beaker numbers for the solutions in Model 2 that are considered to be “concentrated.”
   Beakers 3, 4, and 5.

7. What does the letter “M” stand for in Model 2?
   Molarity.

8. Use the data in Model 2 to answer the questions below.
   a. Calculate the ratio of the moles of solute to liters of solution for each solution.
      
      \[
      \frac{\text{moles of solute}}{\text{liters of solution}} \quad \text{See Model 2 for calculations.}
      \]
   
   b. How does the ratio compare to the molarity of each solution?
      
      The ratio has the same numerical value in each case.

9. Write a mathematical equation to show how the molarity of a solution is calculated.
   
   \[
   \text{Molarity (M)} = \frac{\text{Moles of solute (n)}}{\text{Volume of solution in liters (L)}}
   \]

10. Which type of solution (dilute or concentrated) will have a larger molarity value?
    Concentrated.

11. Consider beakers 3–5 in Model 2. Circle the answer below for the quantity that is the same in all
    of the beakers that contain 3 M solutions.
    Number of moles of solute
    Volume of solution
    **Ratio of moles of solute to liters of solution**

12. Explain how beaker 5, with fewer moles of glucose, can have the same molarity as beaker 4.
    Beaker 5 also has fewer liters of solution. Beaker 5 has the same ratio of moles of solute to liters of solution
    as beaker 4 and thus both solutions have the same molarity.

13. Can molarity be determined by knowing either the number of moles alone or the volume of solution alone? Explain why or why not.
    No—both the number of moles and the volume of solution are needed to determine the concentration. Molarity is a ratio. A small volume of solution may have a high or low molarity depending on the number of particles present.
14. Calculate the molarity of a solution containing 1.5 moles of NaCl in 0.50 liters of solution. Show your work.

\[
\frac{1.5 \text{ moles } \text{NaCl}}{0.50 \text{ L solution}} = 3.0 \text{ M NaCl solution}
\]

15. Calculate the molarity of a solution containing 0.40 moles of acetic acid in 0.250 liters of solution. Show your work.

\[
\frac{0.40 \text{ moles CH}_3\text{COOH}}{0.250 \text{ L solution}} = 1.6 \text{ M CH}_3\text{COOH solution}
\]

16. A 0.5 M KCl solution contains 74.55 g of KCl (molar mass 74.55 g/mol) in 2000 mL of solution.

a. Does the ratio 74.55 g KCl/2000 ml provide the correct molarity for this solution?

No—that ratio is 0.0373, which is not the same as the stated molarity.

b. What units do the amount of solute and the volume of solution need to be in to obtain the molarity of 0.5 M? Show the calculation.

Solute needs to be in moles and volume needs to be in liters of solution.

\[
74.55 \text{ g} = 1 \text{ mole of KCl and 2000 mL} = 2 \text{ L}
\]

\[
\frac{1 \text{ mole KCl}}{2 \text{ L solution}} = 0.5 \text{ M KCl solution}
\]

17. Calculate the molarity of a solution containing 2.5 g of CuCl₂ in 1 L of solution. Show your work, including units.

\[
\frac{2.5 \text{ g CuCl}_2/(134.4 \text{ g/mol})}{1 \text{ L solution}} = 0.019 \text{ M CuCl}_2 \text{ solution}
\]

18. Consider the 3 M solutions in Model 2. What would a 3 M HCl picture look like if the beaker contained 100 mL? In the circle below, visually show the number of solute particles that would be present in any very small volume of the overall solution. (See Model 2 for examples.)

In a microscopically small volume of any 3 M solution, the number of particles (moles) of solute will always be the same.
Extension Questions

19. A student thinks that she can determine the concentration of a solution based on the darkness or color intensity of the solution alone. Based on the pictures in Model 2 describe why this student’s method will not always work.

Clear and colorless solutions like glucose look the same whether they are dilute or concentrated.

20. Calculate the molarity of a KCl solution if 37.3 g of KCl are dissolved in water to give a final solution volume of 500 mL. Show your work.

\[ \frac{37.3 \text{ g}}{74.55 \text{ g/mol}} = 0.500 \text{ moles KCl} \]

\[ 0.500 \text{ moles KCl/0.5 L solution} = 1 \text{ M KCl solution} \]

21. A student correctly determines that 17.1 grams of sucrose are needed to make 50 mL of a 1 M sucrose solution. When making this solution in lab, the student measured 50 mL of water and massed 17.1 grams of sucrose. The student then mixed the two together into a new beaker. The student’s resulting solution was not 1 M sucrose as intended. After the student mixed sucrose and water, the resulting solution was poured into a graduated cylinder and it read 62 mL.

a. What part of the molarity equation did the student overlook when mixing the solution?

The student overlooked the “liters of solution” part of the equation. The student measured the volume of the solvent used and not the final volume of the prepared (overall) solution.

b. What steps should the student take in lab to correctly prepare the 1 M solution?

In a beaker, dissolve 17.1 grams of sucrose in less than 50 mL of water. Transfer the dissolved sucrose solution to a graduated cylinder (or better yet, a volumetric flask) and add water until the total volume of solution is 50 mL.