Background information:

Atomic and Molecular Weight

Everything in the world is made up of atoms. Think of atoms as the building blocks for larger structures. There are many different types of atoms (oxygen, carbon, hydrogen, etc.) that combine in specific ways to form molecules. A molecule of water is composed of two hydrogen atoms bound to an oxygen atom. Because an atom is composed of a set number of protons and neutrons, each type of atom has a unique weight. On the periodic table, this is listed as the atom's atomic weight. When atoms are combined into molecules, that molecule has a weight that is equal to the sum of its individual atoms.

Since an atom is extremely small, scientists are usually concerned with large groups of atoms and molecules. To simplify calculations, the unit of measurement mole was created. One mole is equal to the number of atoms in 12 grams of carbon, which has an atomic weight of 12. The mole was defined so that the mass of one mole of a substance is equal to the substance's molecular weight in grams. So one mole = $6.02214179(30)\times10^{23}$ molecules or atoms = molecular weight in grams. Using the mole allows scientists to talk about the number of atoms or molecules in a visible, measureable quantity.

Dilutions

Once we understand the concept of a mole, we can use this to perform a useful set of calculations to identify not only the amount of a chemical to use in making a solution but also in making dilutions. You may understand the concept of concentration. A concentration is the amount of a molecule in a specific volume. This could be grams of sodium chloride (table salt) in a liter of water. We can also calculate concentration with moles. One mole of sodium chloride in one liter of water is 1 molar NaCl. This is the molarity of the solution and abbreviated as M. A dilution is taking a specific amount of a solution and adding it to a larger volume. As an example, think of making a cup of Kool-Aid. Now take ½ of that cup and put it in a new cup. Then add water to fill up the new cup. You have now diluted the original cup of Kool-Aid by 2!

Here are some useful things to remember:

- molecular weight: how much 1 mole of molecules weighs
- molarity: the number of moles in a liter volume, M = mol/L
- equation for dilutions: M1V1 = M2V2, the concentration (or molarity) x volume of your original solution = the new concentration x new volume
    - In this case, the number of moles stays the same but the volume changes.
- 1 L (liter) = 1000 mL (milliliters), 1 kg = 1000 g, 1 g = 1000 mg and other related conversion factors

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Dimensional Analysis—How to Solve Calculations

A tip for doing these calculations is to use something called dimensional analysis. By lining up values with their units, the units can cancel out making understanding the calculation easier. A concentration would be written as

$$\frac{2\ \text{grams}}{1\ \text{liter}}$$

Since 1 liter = 1000 mL

Changing the concentration above to grams/mL:

$$\frac{2\ \text{grams}}{1\ \text{liter}} * \frac{1\ \text{liter}}{1000\ \text{mL}}$$

Since liter appears in the numerator and denominator of our calculation it cancels out and we can then cross out those units.

$$\frac{2\ \text{grams}}{1\ \cancel{\text{liter}}} * \frac{1\ \cancel{\text{liter}}}{1000\ \text{mL}}$$

Remember to save the numerical value next to the unit!! In the end, you must combine all the numerator values and divide by all the denominator values to get the correct answer!

Here's an example problem to show how to perform these calculations:

I have 20 grams (20 g) of solid with a molecular weight of 2 grams per mole. How many moles do I have?

$$20\ \text{grams} * \frac{1\ \text{mol}}{2\ \text{grams}} = \frac{20\ \text{grams}}{1} * \frac{1\ \text{mol}}{2\ \text{grams}} = 10\ \text{moles}$$

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Here's another example problem to show dimensional analysis in action:

How many grams NaCl (sodium chloride, table salt!) do you need to make 100 mL of a 2M solution? The molecular weight of NaCl is 58.4. This means there are 58.4 grams of NaCl.

Start with 2M written as: $\frac{2 \text{ mol}}{1 \text{ liter}}$

Convert to grams

$$\frac{2 \text{ mol}}{1 \text{ liter}} * \frac{58.4 \text{ grams}}{1 \text{ mol}} * \frac{1 \text{ liter}}{1000 \text{ mL}} =$$

To get the amount for 100 mL, divide by 10

$$\frac{2 \cancel{\text{mol}}}{1 \cancel{\text{liter}}} * \frac{58.4 \text{ grams}}{1 \cancel{\text{mol}}} * \frac{1 \cancel{\text{liter}}}{1000 \text{ mL}} = \frac{116.8 \text{ grams}}{1000 \text{ mL}} = \frac{11.68 \text{ grams}}{100 \text{ mL}}$$

Exercise overview 1: Kool-Aid concentration and serial dilutions

This series of problems is designed to teach the concepts of concentration and dilutions. By using Kool-Aid, watching the color fade in the solution provides a visual way to see what is happening in dilutions.

Materials:
1 packet Kool-Aid
5 50 mL conical tubes
calculator (optional)

Protocol and Questions:

1. Add the contents of one packet of Kool-Aid to a 50 mL conical tube and label it "Tube 1". Fill the tube to the 50 mL line with water.
Cap the tube and shake until the Kool-Aid goes into solution.
Why did you fill the tube to the 50 mL line as opposed to adding 50 mL of water?
____________displacement____

2. Look at the Kool-Aid packet.

How many grams are in the packet? _________

What is the total volume of your solution? __50 mL_____

What is the concentration of your Kool-Aid solution? ____________

The molecular weight of Kool-Aid is approximately 230.62 grams/mole.

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3. Take 5mL of the Kool-Aid solution and put it in a new 50mL tube. Label this "Tube 2".

Did the concentration in "Tube 1" change when you removed the 5mLs? ___no_________

Why or why not? __All of the solution is the same concentration____________________

4. Fill "Tube 2" to the 50mL line with deionized water. Compare "Tube 1" and "Tube 2" and record your observations. ____

____

Calculate the concentration of the Kool-Aid solution in "Tube 2" using the equation $M_1V_1 = M_2V_2$.

Concentration in "Tube 2" ____________

5. Repeat the dilution two more times by transferring 5mL from "Tube 2" to "Tube 3" and filling it to 50mL, then doing the same thing for "Tube 4". Compare the solutions in all 4 tubes.

What do you observe about them? ____

____

Can you tell which solution has the highest concentration? _yes, it is the darkest______

6. Add 4.5 grams of table salt (NaCl, molecular weight = 58.44 g/mol) to a new test tube. Label this tube "Tube 5". Fill the tube with water to the 50mL line and shake gently until the salt goes into solution. Visually compare your salt solution to your Kool-Aid solutions.

Based solely on your visual comparison, line up your solutions from the most concentrated to least concentration. Write down your order.

Highest __________________

____

____

____

Lowest __________________

Where did you place "Tube 5"? Why? ___________________________________

7. Calculate the Kool-Aid concentrations in each tube.

Concentration in “Tube 3” ____________

Concentration in “Tube 4” ____________

Calculate the concentration of the salt solution in “Tube 5”.

Concentration in “Tube 5” ____________

Based on your calculations, line up your solutions from the most to least concentrated.

Highest __________________

____

____

____

Lowest __________________

Did your prediction based solely on observation match the calculated concentrations?

Explain.____

____

Exercise overview 2: Nerds molarity and serial dilutions

This series of problems is designed to explain the concepts of moles and molarity. Each individual Nerd candy represents a mole of sugar. By transferring Nerds from one beaker to another and adjusting the “volume” in the beaker, students are simulating dilutions.

Materials:

Beaker Worksheet
16 “moles” (pieces) of Nerds candy
calculator (optional)

Protocol and Questions:

1. Place 16 moles of sugar (1 Nerd = 1mole) onto beaker 1 on your worksheet. Imagine adding 1 Liter of water to beaker 1. Using your pencil, shade beaker 1 to represent this volume.
How many moles are in beaker 1? ___16______

Use the example (on the beaker worksheet) to complete a moles / liter calculation to find the molarity of this solution, and record your answer under beaker 1.

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2. Transfer 1/2 of your solution to beaker 2 by moving moles and using an eraser to decrease the volume in beaker 1. In beaker 2, use your pencil to shade the volume transferred from beaker 1.

How many moles of nerds are left in beaker 1? __8__

What volume is left in beaker 1? _500 mL___

What is the molarity (moles / liter) in beaker 1? __16____

Did the molarity in beaker 1 change after you transferred 1/2 of your solution to beaker 2?

__no___

Explain your answer! _All of the solution is the same concentration____________

____

What is the molarity (moles / liter) of the nerd solution in beaker 2? ____16_________

3. Shade **beaker 2** to represent filling the beaker to 1 Liter with water. Re-calculate the molarity of the nerd solution in **beaker 2** and record your answer under beaker 2.

4. Transfer 1/2 of your nerd solution in beaker 2 to **beaker 3**. Using your pencil, shade beaker 3 to represent filling the beaker to 1 Liter with water. Calculate the Molarity of the nerd solution in **beaker 3**, and record your answer under beaker 3.

5. Transfer 1/2 of your nerd solution in beaker 3 to **beaker 4** and use your pencil to shade beaker 4 accordingly.

Oooops! You forgot to put away beaker 4 before going home last night. Evaporation has caused the volume in beaker 4 to go down to 125 mL! Use your eraser to represent the new volume in **beaker 4**.

Did you lose any nerd moles to evaporation? __no____

Explain your answer! __The water evaporates, but the nerds do not since their vapor pressure is too low.____

How many moles are in beaker 4? _____2_________

Calculate the Molarity of the nerd solution in beaker 4, and record your answer under beaker 4.