CONCENTRATION

- When you discuss a solution, you need to be aware of:
  - what materials are in the solution
  - how much of each material is in the solution

- CONCENTRATION is the amount of one substance compared to the others in a solution. This sounds vague, but that's because there are many different ways to specify concentration!

- We will discuss four different concentration units in CHM 111:

(1) MASS PERCENTAGE

$$= \frac{\text{mass solute}}{\text{mass solution}} \times 100\% \qquad \%\ ,\ \%\ w/w$$

(2) MOLARITY

$$= \frac{\text{moles solute}}{\text{L solution}} \qquad M \text{ or } \underline{M}$$

(3) MOLALITY

$$= \frac{\text{moles solute}}{\text{kg solvent}} \qquad m$$

(4) MOLE FRACTION

$$= \frac{\text{moles component A}}{\text{moles solution}} \qquad X_A$$

52 How would you prepare 455 grams of an aqueous solution that is 6.50% sodium sulfate by mass?

calculate mass solute

$$\text{mass }\% = \frac{\text{mass solute}}{\text{mass solution}} \times 100\%$$

mass % → 6.50%

mass solution → (455 g)

We know everything in this definition EXCEPT for the mass of solute (sodium sulfate). So, plug the knowns into the defintion and solve for the solute mass.

$$6.50 = \frac{\text{mass solute}}{455\text{ g}} \times 100$$

① × 455 g

② ÷ 100

$$\frac{6.50 \times 455\text{ g}}{100} = \text{mass solute} = 29.6\text{ g } Na_2SO_4$$

How much water? Since we know the total mass of the solution, just subtract the amount of sodium sulfate.

$$455\text{ g} - 29.6\text{ g} = 425.4\text{ g water}$$

Mix 29.6 g of sodium sulfate with 425.4 g of water to prepare this solution.

What's the MOLALITY and MOLE FRACTION OF SOLUTE of the previous solution?

29.6 g Na_2SO_4, 425.4 g water ← previous solution

$$m = \frac{\text{mol solute}}{\text{kg solvent}}$$

(1) Convert mass water to kg.

(2) Convert mass solute to moles (Use FW)

Na_2SO_4: Na : 2 x 22.99
S : 1 x 32.07
O : 4 x 16.00

142.05 g/mol

kg = 10^3 g

(1) $$425.4\text{ g } H_2O \times \frac{\text{kg}}{10^3\text{ g}} = 0.4254\text{ kg } H_2O$$

(2) $$29.6\text{ g } Na_2SO_4 \times \frac{\text{mol}}{142.05\text{ g}} = 0.208377\text{ mol } Na_2SO_4$$

$$m = \frac{0.208377\text{ mol } Na_2SO_4}{0.4254\text{ kg } H_2O} = \boxed{0.490\text{ m } Na_2SO_4}$$

29,6 g Na_2SO_4, 425,4 g water ← previous solution

$$X_{Na_2SO_4} = \frac{\text{mol } Na_2SO_4}{\text{total moles solution}}$$

① Find mol Na_2SO_4 (already done to find molality)

② Find mol H_2O by converting mass. Use FW

H_2O: H : 2 × 1,008
O : 1 × 16,00

18.016 g/mol

① 0.208377 mol Na_2SO_4 (see previous page)

② $425.4 \text{ g } H_2O \times \frac{\text{mol}}{18.016 \text{ g}} = 23.6123 \text{ mol } H_2O$

$$X_{Na_2SO_4} = \frac{0.208377 \text{ mol } Na_2SO_4}{0.208377 \text{ mol } Na_2SO_4 + 23.6123 \text{ mol } H_2O}$$

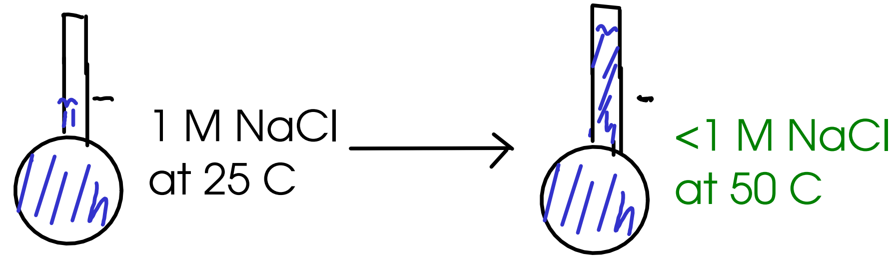
$= \boxed{0.00875}$

MOLARITY

- In the previous example, we converted between three of the four units that we discussed: mass percent, molality, and mole fraction.

- We didn't do MOLARITY, because the information given in the previous problem was not sufficient to determine molarity!

$$\underline{M} = \frac{\text{moles solute}}{\text{L solution}}$$



Molarity is based on VOLUME, while the other three units are based on MASS. (moles and mass can be directly converted)

Volume depends on TEMPERATURE!

- If you HEAT a solution, what happens to CONCENTRATION?

ex: 5.00 mol Na_2SO_4 in 1 L solution

5.00 mol Na_2SO_4: constant when heated

1 L solution: increases. (thermal expansion)

... the MOLAR CONCENTRATION decreases. (But the concentration in the other three units we discussed stays the same.)

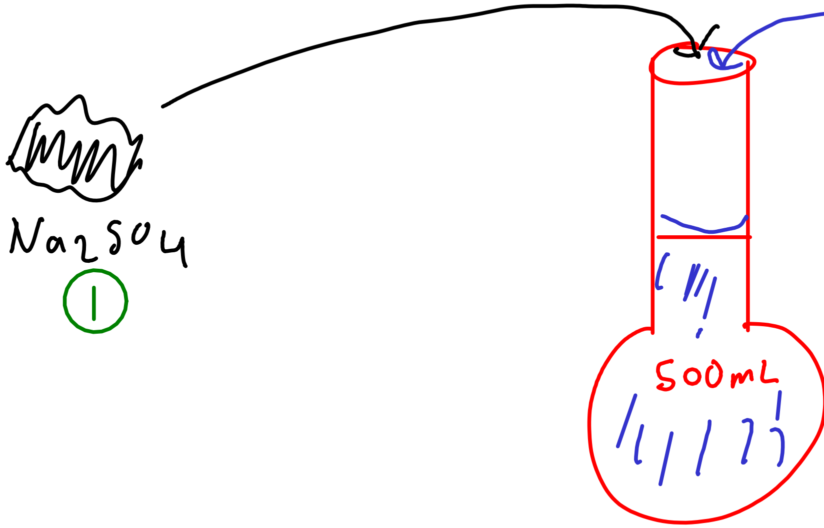
- If you COOL a solution, the MOLAR CONCENTRATION increases. (The other three units stay the same!)

... we use MOLARITY so much because it's easy to work with. It is easier to measure the VOLUME of a liquid solution than it is to measure mass.

Example: How would we prepare 500. mL of 0.500 M sodium sulfate in water?

Na_2SO_4: 142.05 g/mol

Dissolve the appropriate amount of sodium sulfate into enough water to make 500. mL of solution.



A VOLUMETRIC FLASK is a flask that is designed to precisely contain a certain volume of liquid.

VOLUMETRIC FLASKS are used to prepare solutions.

volumetric flask

Calculate the mass of sodium sulfate to put in the flask.

$$M = 0.500\ \text{mol/L} = \frac{\text{moles } Na_2SO_4}{\text{L solution}}\ ;\quad 0.500\ \text{mol/L} = \frac{\text{mol } Na_2SO_4}{0.500\ \text{L}}$$

$$\text{mol } Na_2SO_4 = (0.500\ \text{mol/L})(0.500\ \text{L}) = 0.250\ \text{mol } Na_2SO_4$$

$$0.250\ \text{mol } Na_2SO_4 \times \frac{142.05\ \text{g } Na_2SO_4}{\text{mol } Na_2SO_4} = 35.5\ \text{g } Na_2SO_4$$

Dissolve 35.5 g of sodium sulfate in enough water to make 500. mL solution

① ②

More on MOLARITY

To prepare a solution of a given molarity, you generally have two options:

1. Weigh out the appropriate amount of solute, then dilute to the desired volume with solvent (usually water)

2. Take a previously prepared solution of known concentration and DILUTE it with solvent to form a new solution — "stock solutions"

   - Use DILUTION EQUATION

The dilution equation is easy to derive with simple algebra.

$$M \times V$$

$$\frac{mol}{L} \times L = \text{moles solute}$$

... but when you dilute a solution, the number of moles of solute REMAINS CONSTANT. (After all, you're adding only SOLVENT)

$$M_1 V_1 = M_2 V_2$$

before diution — after dilution

Since the number of moles of solute stays the same, this equality must be true!

$$M_1V_1 = M_2V_2$$ ... the "DILUTION EQUATION"

M_1 = molarity of concentrated solution

V_1 = volume of concentrated solution

M_2 = molarity of dilute solution

V_2 = volume of dilute solution

The volumes don't HAVE to be in liters, as long as you use the same volume UNIT for both volumes!

Example: Take the 0.500 M sodium sulfate we discussed in the previous example and dilute it to make 150. mL of 0.333 M solution. How many mL of the original solution will we need to dilute?

$M_1V_1 = M_2V_2$ | $M_1 = 0.500\ M$, $V_1 = ???$ | $M_2 = 0.333\ M$, $V_2 = 150.\ mL$

$$(0.500\ M)V_1 = (0.333\ M)(150.\ mL)$$

V_1 = **99.9 mL of 0.500 M stock**

Take 99.9 mL of 0.500 M stock solution, and dilute it with enough water to make 150 mL total volume.

MOLARITY and the other concentration units

- To convert between molarity and the other three concentration units we've studied, you have to know more about the solution. For example:

molarity $\frac{\text{moles A}}{\text{L solution}}$ $\longrightarrow$ molality $\frac{\text{moles A}}{\text{kg solvent}}$

* To perform this conversion, you can assume a liter of solution, which will give you the number of moles present. But you've then got to have a way to convert the volume of SOLUTION to the mass of the SOLVENT. How?

* You need DENSITY (which depends on temperature). The density of the solution will allow you to find the total mass of the solution.

* If you subtract out the mass of the SOLUTE, then what you have left is the mass of the SOLVENT. Express that in kilograms, and you have all the information you need to find molality!

* You'll run into the same situation when you use any of the other mass or mole based units. DENSITY is required to go back and forth between MOLARITY and these units.

60 Example: If a solution is 0.688 m citric acid, what is the molar concentration (M) of the solution? The density of the solution is 1.049 g/mL

$H_3C_6H_5O_7$: 192.125 g/mol "CA"

$$\frac{0.688 \text{ mol CA}}{\text{kg solvent}} \rightarrow \frac{? \text{ mol CA}}{? \text{ L solution}}$$

molality (m) molarity (M)

1 - Assume we have 1 kg of solvent. This makes the number of moles of CA = 0.688 mol

2 - We need to FIND the VOLUME of the solution. We can use density to convert mass to volume, but we have to be careful. The mass we know right now is not the mass of the SOLUTION; it's the mass of the SOLVENT. We must find the MASS OF SOLUTE to find the mass of the solution.