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

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

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

$$\underset{\substack{\uparrow\\ 6.50\%}}{\text{mass \%}} = \frac{\text{mass solute}}{\underset{\substack{\uparrow\\ 455\,g}}{\text{mass solution}}} \times 100\%$$

We know everything in the definition of the unit EXCEPT the mass of the sulute (sodium sulfate), so we should calculate that using some basic algebra.

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

$\downarrow$ ① $\times 455\,g$ ② $\div 100$

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

How much water? Subtract ...

$$455\,g\ \text{solution} - 29.6\,g\ Na_2SO_4 = \boxed{425\,g\ \text{water}}$$

So, mix 29.6 g sodium sulfate with 425 grams water to prepare the solution.

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

29.6 g Na_2SO_4, 425 g water ← previous solution

$$m = \frac{\text{moles solute } (Na_2SO_4) \text{ ①}}{\text{kg solvent (water) ②}}$$

① Find moles solute: Convert mass sodium sulfate to moles using formula weight.

② Convert grams water to kg water.

Na_2SO_4: Na : 2 x 22.99

S : 1 x 32.07

O : 4 x 16.00

142.05 g Na_2SO_4 = mol Na_2SO_4

$$29.6\text{ g } Na_2SO_4 \times \frac{\text{mol } Na_2SO_4}{142.05\text{ g } Na_2SO_4} = 0.2083773319 \text{ mol } Na_2SO_4 \text{ ①}$$

kg = 10^3 g

$$425\text{ g } H_2O \times \frac{\text{kg}}{10^3\text{ g}} = 0.425\text{ kg} \text{ ②}$$

$$m = \frac{0.2083773319 \text{ mol } Na_2SO_4}{0.425\text{ kg}}$$

$$= \boxed{0.490\, m\ Na_2SO_4}$$

29.6 g Na_2SO_4, 425 g water ← previous solution

$$X_A = \frac{\text{mol A} \quad ①}{\text{total moles solution} \quad ②}$$

(A = Na_2SO_4)

① Calculate moles sodium sulfate from mass using formula weight. (We've already done this to find molality!)

② Find moles water from mass water using formula weight, then add to moles sodium sulfate.

0.20837773319 mol Na_2SO_4 ①

H_2O: H: 2 x 1.008
O: 1 x 16.00

18.016 g H_2O = mol H_2O

$$425 \text{ g } H_2O \times \frac{\text{mol } H_2O}{18.016 \text{ g } H_2O} = 23.5901421 \text{ mol } H_2O$$

$$\text{total} = 23.5901421 \text{ mol } H_2O + 0.20837773319 \text{ mol } Na_2SO_4$$

$$= 23.79851983 \text{ mol total } ②$$

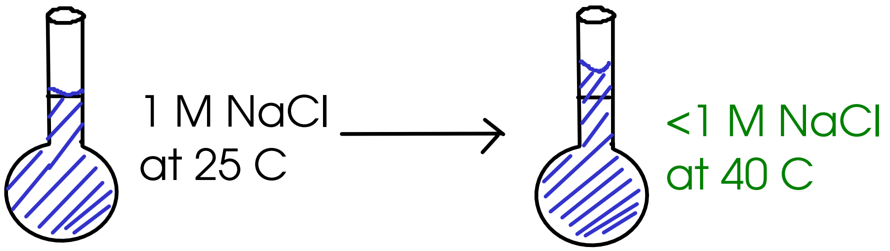
$$X_{Na_2SO_4} = \frac{0.20837773319 \text{ mol}}{23.79851983 \text{ mol}} = \boxed{0.00876}$$

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

constant when heated

increases. (thermal expansion)

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

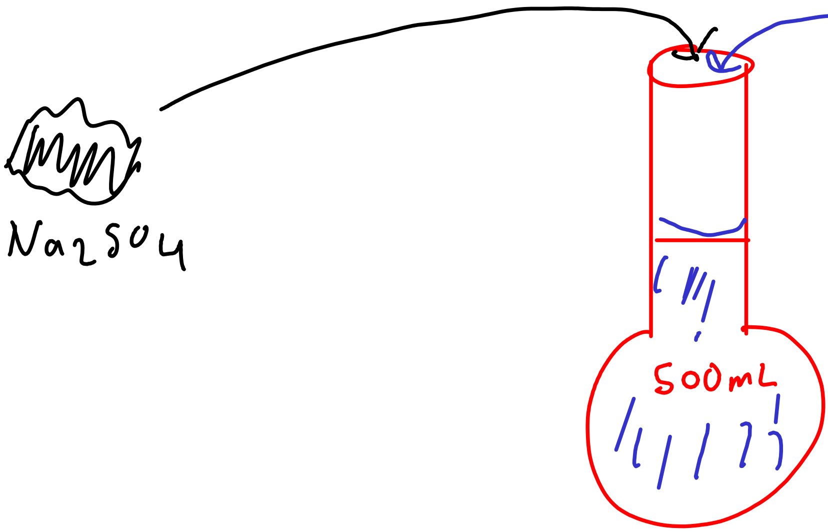
- If you COOL a solution, the MOLAR CONCENTRATION increases. (The other three units stay the same!)

... 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.

Na_2SO_4: (142.05 g/mol)

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

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



volumetric flask

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

VOLUMETRIC FLASKS are used to prepare solutions.

$$M = \frac{\text{mol } Na_2SO_4}{\text{L solution}};$$

$$0.500\,M = \frac{\text{mol } Na_2SO_4}{0.500\,L}$$

$$\text{mol } Na_2SO_4 = \left(0.500\,\frac{\text{mol } Na_2SO_4}{L}\right) \times 0.500\,L = 0.250 \text{ mol } Na_2SO_4$$

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

Weigh 35.5 grams sodium sulfate into a 500 mL volumetric flask, and add water to the mark.

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)"

"stock solution"

② Take a previously prepared solution of known concentration and DILUTE it with solvent to form a new solution

- 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)

$$M_1V_1 = M_2V_2$$

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

before
diution

after
dilution

$M_1V_1 = M_2V_2$ ... 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 ←(TOTAL VOLUME, NOT the volume water added!)

The volumes don't HAVE to be in liters, as long as you use the same volume UNIT for both V_1 and V_2

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?

$M_1V_1 = M_2V_2$

$M_1 = 0.500\,M$

$V_1 = ?$

$M_2 = 0.333\,M$

$V_2 = 150\,mL$

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

$$V_1 = \boxed{99.9\text{ mL of }0.500\,M\ Na_2SO_4}$$

Take 99.9 mL of 0.500 M stock solution and add it to a 150 mL volumetric flask. Then, add enough water to make 150 mL of solution.

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:

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

* 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.

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"

$$\frac{0.688 \text{ mol CA}}{\text{kg solvent}} \xrightarrow{\hspace{4em}} \frac{? \text{ mol CA}}{\text{L solution}}$$

molality definition

molarity definition

1 - ASSUME A BASIS of exactly 1 kg solvent. We know that each kg solvent contains 0.688 moles CA.

2 - Find volume of SOLUTION. We know the density of the solution, but we only know the mass of the SOLVENT. To get the mass of SOLUTION, we need to add in the citric acid mass. Find THAT by converting 0.688 moles CA to mass using its formula weight.

$$0.688 \text{ mol CA} \times \frac{192.125 \text{ g CA}}{\text{mol CA}} = 132.182 \text{ g CA}$$

$$\text{mass solution} = 1000 \text{ g solvent} + 132.182 \text{ g CA} = 1132.182 \text{ g}$$

Find volume.

$$1132.182 \text{ g solution} \times \frac{\text{mL}}{1.049 \text{ g}} = 1079.296473 \text{ mL}$$

$$= 1.079296473 \text{ L}$$

$$M = \frac{\text{mol CA}}{\text{L solution}} = \frac{0.688 \text{ mol CA}}{1.079296473 \text{ L}} = \boxed{0.637 \text{ M CA}}$$