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?

$$\text{mass}\,\% = \frac{\text{mass } Na_2SO_4}{\text{mass solution}} \times 100\%$$

Start any concentration calculation by writing out the DEFINITION of each concentration unit you're using...

6.50% ↑ (mass %)   455 g ↑ (mass solution)

We know everything in the definition except the mass of sodium sulfate, so we'll solve for the mass of sodium sulfate in the solution.

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

(1) ÷ 100
(2) × 455 g

$$29.575\text{ g} = \text{mass } Na_2SO_4 = 29.6\text{ g } Na_2SO_4$$

We also need to know how much water to add to the sodium sulfate...

$$455\text{ g solution} - 29.6\text{ g } Na_2SO_4 = 425.4\text{ g } H_2O \quad (425\text{ g } H_2O)$$

So, mix 29.6 g sodium sulfate with 425 grams water to make the 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

$$m = \frac{\text{mol } Na_2SO_4 \text{ (solute)}}{\text{kg } H_2O \text{ (solvent)}}$$

① 1 - Convert 29.6 grams sodium sulfdte to moles using formula weight.

② 2 - Convert 425.4 g water to kg.

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

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

② kg = 10^3 g

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

$$m = \frac{\text{mol } Na_2SO_4}{\text{kg } H_2O} = \frac{0.2083773319 \text{ mol } Na_2SO_4}{0.4254 \text{ kg } H_2O} = \boxed{0.490 \text{ m } Na_2SO_4}$$

29.6 g Na_2SO_4, 425.4 g water ← previous solution

$$X_{Na_2SO_4} = \frac{\text{mol } Na_2SO_4}{\text{mol } Na_2SO_4 + \text{mol } H_2O} \quad \begin{matrix} (1) \\ (2) \end{matrix}$$

1 - Convert mass sodium sulfate to moles using FORMULA WEIGHT. (We've already done this, so we'll just use the previous calculated value here.)

2 - Convert mass water (425.4 g) to moles water using formula weight, then add it to moles sodium sulfate.

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(1) 0.2083773319 mol Na_2SO_4

H_2O: H - 2 x 1.008
O - 1 x 16.00
18.016 g H_2O = mol H_2O

(2) $$425.4 \text{ g } H_2O \times \frac{\text{mol } H_2O}{18.016 \text{ g } H_2O} = 23.61234458 \text{ mol } H_2O$$

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

$$= \frac{0.2083773319 \text{ mol } Na_2SO_4}{0.2083773319 \text{ mol } Na_2SO_4 + 23.61234458 \text{ mol } H_2O}$$

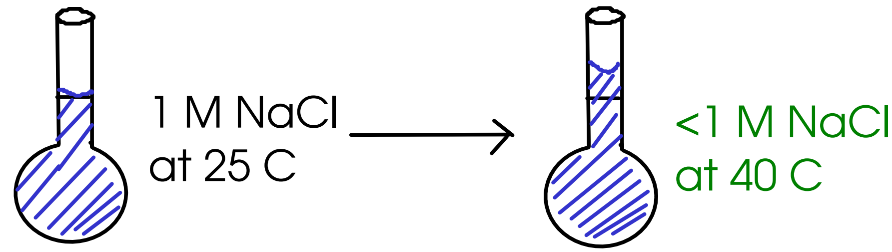
$$= \boxed{0.00875 = X_{Na_2SO_4}}$$

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!

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



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.)

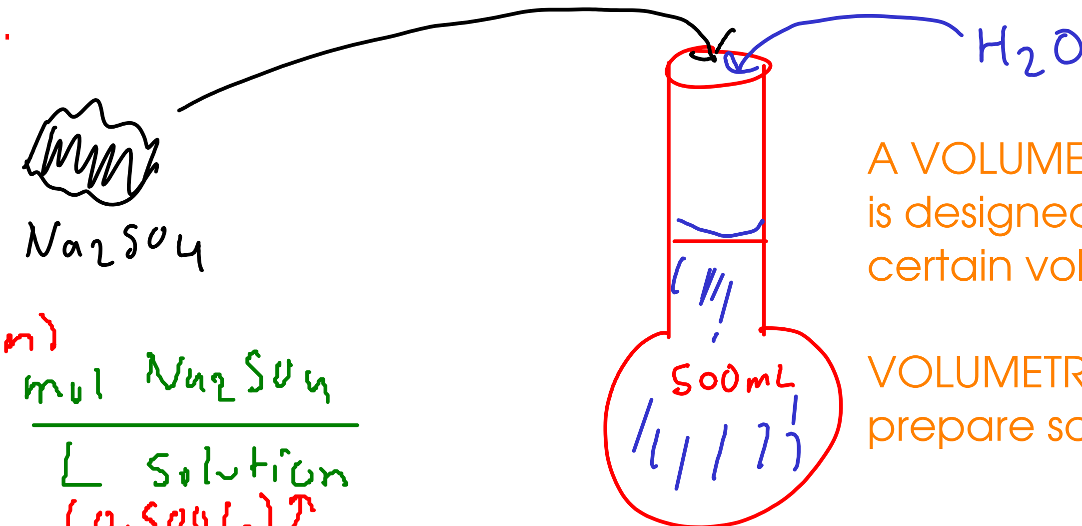
- If you COOL a solution, the MOLAR CONCENTRATION increases. (The other three units stay the same!)

... 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.

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.



$$\underset{(0.500\,M)}{M} = \frac{\text{mol } Na_2SO_4}{\underset{(0.500\,L)}{\text{L solution}}}$$

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.

$* 500\text{ mL} = 0.500\text{ L}$

Since we know everything in the definition except for moles sodium sulfate, let's calculate that first. Then convert to mass.

$$0.500\,\frac{\text{mol}}{\text{L}} = \frac{\text{mol } Na_2SO_4}{0.500\text{ L}} \quad ; \quad \text{mol } Na_2SO_4 = 0.250 \text{ mol } Na_2SO_4$$

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

To prepare the solution, add 35.5 grams sodium sulfate to a 500 mL volumetric flask, then dilute to the mark with distilled water.

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)

$$M_1 V_1 = M_2 V_2$$

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 ← (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?

$$M_1V_1 = M_2V_2$$

$M_1 = 0.500\ M$ $\quad$ $M_2 = 0.333\ M$

$V_1 = ?$ $\quad$ $V_2 = 150.\ mL$

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

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

Take 99.9 mL of 0.500 M sodium sulfate, then add enough water to make a total volume of 150 mL solution.