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

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

mass % ↑ 6.50 %

mass solution ↑ 455 g

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

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

① × 455 g

② ÷ 100

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

How much water? Find by subtraction.

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

So, mix 29.6 g of 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

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

① Convert mass sodium sulfate to moles using formula weight.

② Convert mass water from grams to kilograms.

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

$$29.6 \text{ g } Na_2SO_4 \times \frac{\text{mol } Na_2SO_4}{142.05 \text{ g } Na_2SO_4} = 0.208377331 9 \text{ mol } Na_2SO_4 \; ①$$

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kg = 10^3 g

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

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

= **0.490 m Na_2SO_4**

29.6 g Na_2SO_4, 425 g water ← previous solution

$$X_{Na_2SO_4} = \frac{\text{mol solute } (Na_2SO_4)}{\text{mol solution } (Na_2SO_4 \text{ and water})} \quad \begin{matrix} (1) \\ (2) \end{matrix}$$

(1) Calculate moles sodium sulfate from the mass using formula weight. (We've already done that for the previous calculation of molality.)

(2) Find mol water by converting the mass of water to moles, then add in the mol sodium sulfate to find the mol of solution.

0.208373319 mol Na_2SO_4 (1) See previous page for calculation.

H_2O H : 2 x 1.008
O : 1 x 16.00

18.016 g H_2O = mol H_2O

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

mol solution = 0.208373319 mol Na_2SO_4 + 23.5901421 mol H_2O
= 23.79851943 mol

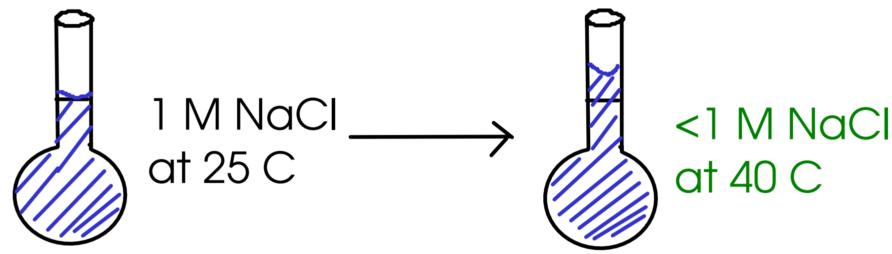
$$X_{Na_2SO_4} = \frac{0.208373319 \text{ mol } Na_2SO_4}{23.79851943 \text{ mol}} = \boxed{0.00876}$$

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!

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



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.)

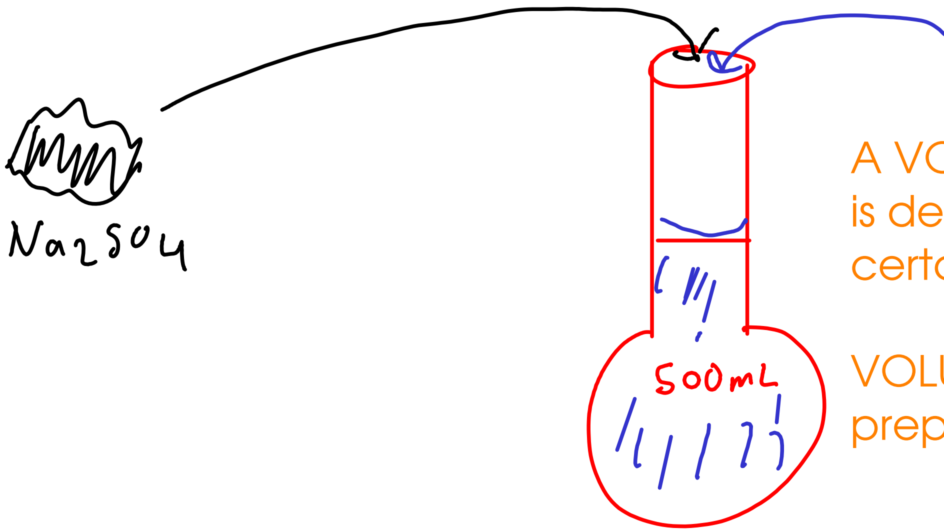
- If you COOL a solution, the MOLAR CONCENTRATION increases. (The other three units stay the same!)

... 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

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

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

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

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

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!

$$M_1 V_1 = M_2 V_2$$ ... 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 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?

$$M_1 V_1 = M_2 V_2$$

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

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

Take 99.9 mL of 0.500 M stock sodium sulfate solution and add water until the TOTAL VOLUME OF THE MIXTURE is 150. mL.

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.

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"

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

molality (definition) molarity (definition)

1 - ASSUME A BASIS of 1 kg of solvent. Each kilogram of solvent contains 0.688 mol of CA
2 - Find VOLUME OF SOLUTION. We know density of the solution, but we know only the mass of the SOLVENT (not the solution). To use the density, we need to convert the mol CA to mass, then add it to the mass of solvent - giving us the MASS OF SOLUTION.

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

mass solution = 1000 g solvent + 132.182 g CA = 1132.182 g solution

Find volume solution:

$$1132.182 \text{ g solution} \times \frac{\text{mL}}{1.049 \text{ g}} \times \frac{10^{-3}\text{ L}}{\text{mL}} = 1.079296473 \text{ L}$$

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

66 An aqueous solution is 8.50% ammonium chloride by mass. The density of the solution is 1.024 g/mL
Find: molality, mole fraction, molarity.

NH_4Cl : 53.491 g/mol H_2O: 18.016 g/mol

Find molality:

$$\frac{8.50\text{ g } NH_4Cl}{100\text{ g solution}} \longrightarrow \frac{\text{mol } NH_4Cl}{\text{kg } H_2O}$$

mass percent — molality

Find mol ammonium chloride:

$$8.50\text{ g } NH_4Cl \times \frac{\text{mol } NH_4Cl}{53.491\text{ g } NH_4Cl} = 0.1589052364\text{ mol } NH_4Cl$$

Find mass water:

$$100\text{ g solution} - 8.50\text{ g } NH_4Cl = 91.5\text{ g } H_2O = 0.0915\text{ kg } H_2O$$

Molality:

$$\frac{0.1589052364\text{ mol } NH_4Cl}{0.0915\text{ kg } H_2O} = \boxed{1.74\text{ m } NH_4Cl}$$

Mole fraction:

$$\frac{8.50\text{ g } NH_4Cl}{100\text{ g solution}} \longrightarrow \frac{\text{mol } NH_4Cl}{\text{mol } NH_4Cl + \text{mol } H_2O}$$

mass percent — mole fraction

We already know the moles ammonium chloride, so all we need to find is moles water. We found MASS WATER in the molality calculation, so we just need to convert that number to moles.

An aqueous solution is 8.50% ammonium chloride by mass. The density of the solution is 1.024 g/mL
Find: molality, mole fraction, molarity.

NH_4Cl : 53.491 g/mol H_2O: 18.016 g/mol

Find moles water:

$$91.5\,g\ H_2O \times \frac{mol\ H_2O}{18.016\,g\ H_2O} = 5.078818828\ mol\ H_2O$$

$$X_{NH_4Cl} = \frac{0.1589052364\ mol\ NH_4Cl}{0.1589052364\ mol\ NH_4Cl + 5.078818828\ mol\ H_2O}$$

$$= \boxed{0.0303}$$

(If we wanted Xwater, Xwater=1-Xammonium chloride)

Molarity:

$$\frac{8.50\,g\ NH_4Cl}{100\,g\ solution} \longrightarrow \frac{mol\ NH_4Cl}{L\ solution}$$

mass percent molarity

We already know mol ammonium chloride from previous work, so we need to calculate the volume of solution IN LITERS.

$$100\,g\ solution \times \frac{mL}{1.024\,g} \times \frac{10^{-3}\,L}{mL} = 0.09765625\ L\ solution$$

$$\frac{0.1589052364\ mol\ NH_4Cl}{0.09765625\ L\ solution} = \boxed{1.63\ \underline{M}\ NH_4Cl}$$