PERCENTAGE COMPOSITION

- sometimes called "percent composition" or "percent composition by mass"
- the percentage of each element in a compound, expressed in terms of mass

Example: Find the percentage composition of ammonium nitrate.

NH_4NO_3 : N : 2 x 14.01 = 28.02

H : 4 x 1.008 = 4.032

O : 3 x 16.00 = 48.00

80.052 g NH_4NO_3 = 1 mol NH_4NO_3

These numbers are the masses of each element in a mole of the compound!

$$\%N: \frac{28.02\text{ g N}}{80.052\text{ g total}} \times 100\% = 35.0\%\ N$$

$$\%H: \frac{4.032\text{ g H}}{80.052\text{ g total}} \times 100\% = 5.0\%\ H$$

$$\%O: \frac{48.00\text{ g O}}{80.052\text{ g total}} \times 100\% = 60.0\%\ O$$

These should sum to approximately 100% (within roundoff error)

So far, we have

- looked at how to determine the composition by mass of a compound from a formula
- converted from MASS to MOLES (related to the number of atoms/molecules)
- converted from MOLES to MASS

Are we missing anything?

- What about SOLUTIONS, where the desired chemical is not PURE, but found DISSOLVED IN WATER?
- How do we deal with finding the moles of a desired chemical when it's in solution?

MOLAR CONCENTRATION *

- unit: MOLARITY (M): moles of dissolved substance per LITER of solution

dissolved substance

$$M = \text{molarity} = \frac{\text{moles of SOLUTE}}{\text{L SOLUTION}}$$

6.0 M HCl solution: $\frac{6.0 \text{ mol HCl}}{\text{L}}$

If you have 0.250 L (250 mL) of 6.0 M HCl, how many moles of HCl do you have? 6.0 mol HCl = L

$$0.250 \text{ L} \times \frac{6.0 \text{ mol HCl}}{\text{L}} = \boxed{1.5 \text{ mol HCl}}$$

*See SECTIONS 4.7 - 4.10 for more information about MOLARITY and solution calculations (p 154 - 162)

If you need 0.657 moles of hydrochloric acid, how many liters of 0.0555 M HCl do you need to measure out?

$$\frac{0.0555 \text{ mol HCl}}{\text{L}}$$

$$0.657 \text{ mol HCl} \times \frac{\text{L}}{0.0555 \text{ mol HCl}} = \boxed{11.8 \text{ L}}$$

11 800 mL

This is too large a volume for typical lab-scale work. So, we should pick a more concentrated solution.

What if we used 6.00 M HCl?

$$\frac{6.00 \text{ mol HCl}}{\text{L}}$$

$$0.657 \text{ mol HCl} \times \frac{\text{L}}{6.00 \text{ mol HCl}} = \boxed{0.110 \text{ L}}$$

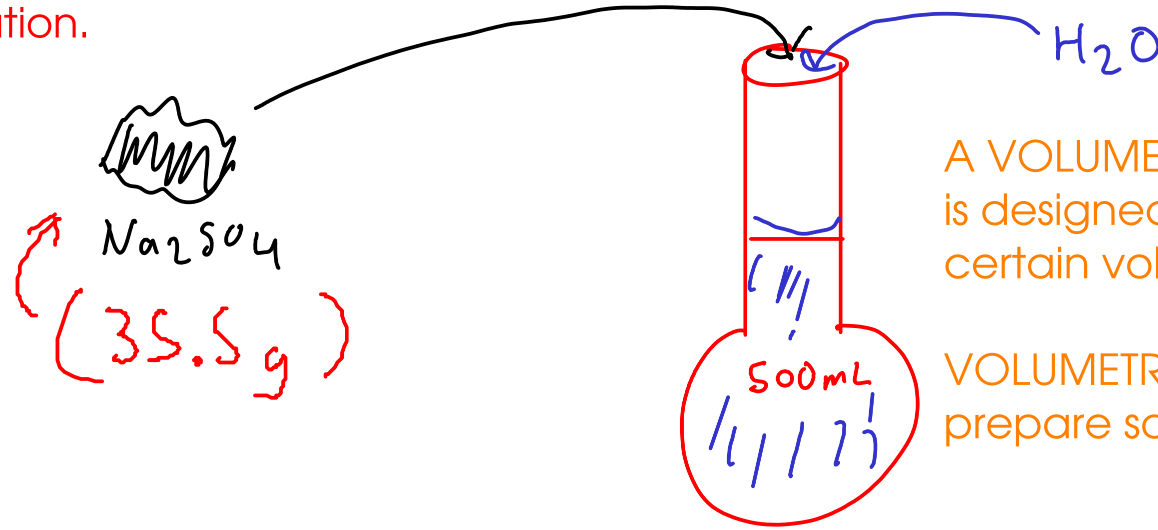
110 mL

110 mL is a reasonable lab volume. (Can be measured with 250 mL cylinder)

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

We want 0.500 M solution. We know the VOLUME we need to prepare, so we can use that volume and the desired concentration to find out how many MOLES of sodium sulfate we need. Then, we convert the moles sodium sulfate to mass using the formula weight.

$0.500 \text{ mol } Na_2SO_4 = L$ | $mL = 10^{-3} L$ | $142.05 \text{ g } Na_2SO_4 = \text{mol } Na_2SO_4$

$$500.\text{ mL} \times \frac{10^{-3}\text{ L}}{\text{mL}} \times \frac{0.500\text{ mol } Na_2SO_4}{\text{L}} \times \frac{142.05\text{ g } Na_2SO_4}{\text{mol } Na_2SO_4} = \boxed{35.5\text{ g } Na_2SO_4}$$

Put 35.5 g of sodium sulfate into an empty 500 mL volumetric flask, then fill the flask to the measuring line with distilled or deionized 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)

$$M_1V_1 = M_2V_2$$

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 volume of added solvent!

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?

$M_1 = 0.500\ M$ $M_2 = 0.333\ M$ $M_1V_1 = M_2V_2$

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

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

$$V_1 = \boxed{99.9\ mL}$$

So, to make the 0.333 M solution, we take 99.9 mL of 0.500 M sodium sulfate, and add enough water to it to make 150 mL of solution. (Ideally, use a 150 mL volumetric flask...)

CHEMICAL CALCULATIONS CONTINUED: REACTIONS

- Chemical reactions proceed on an ATOMIC basis, NOT a mass basis!

- To calculate with chemical reactions (i.e. use chemical equations), we need everything in terms of ATOMS ... which means MOLES of atoms

$$2Al(s) + 3Br_2(l) \longrightarrow 2AlBr_3(s)$$

coefficients are in terms of atoms and molecules!

2 atoms Al = 3 molecules Br_2 = 2 formula units $AlBr_3$

2 mol Al = 3 mol Br_2 = 2 mol $AlBr_3$

- To do chemical calculations, we need to:
  - Relate the amount of substance we know (mass or volume) to a number of moles
  - Relate the moles of one substance to the moles of another using the equation
  - Convert the moles of the new substance to mass or volume as desired

$$2\,Al(s) + 3\,Br_2(l) \longrightarrow 2\,AlBr_3(s)$$

* Given that we have 25.0 g of liquid bromine, how many grams of aluminum would we need to react away all of the bromine? How many grams of aluminum bromide would be produced?

1. Convert grams of bromine to moles: Need formula weight Br_2: $2 \times 79.90 = 159.80$

$159.80\text{ g } Br_2 = 1\text{ mol } Br_2$

$$25.0\text{ g } Br_2 \times \frac{1\text{ mol } Br_2}{159.80\text{ g } Br_2} = 0.15645\text{ mol } Br_2$$

2. Use the chemical equation to relate moles of bromine to moles of aluminum

$2\text{ mol Al} = 3\text{ mol } Br_2$

$$0.15645\text{ mol } Br_2 \times \frac{2\text{ mol Al}}{3\text{ mol } Br_2} = 0.10430\text{ mol Al}$$

3. Convert moles aluminum to mass: Need formula weight Al: 26.98

$26.98\text{ g Al} = 1\text{ mol Al}$

$$0.10430\text{ mol Al} \times \frac{26.98\text{ g Al}}{1\text{ mol Al}} = \boxed{2.81\text{ g Al}}$$

You can combine all three steps on one line if you like!

$$25.0\,g\,Br_2 \times \frac{1\,mol\,Br_2}{159.80\,g\,Br_2} \times \frac{2\,mol\,Al}{3\,mol\,Br_2} \times \frac{26.98\,g\,Al}{1\,mol\,Al} = \boxed{2.81\,g\,Al}$$

1 2 3

You can solve the second part of the question using CONSERVATION OF MASS - since there's only a single product and you already know the mass of all reactants.

$$\begin{array}{r} 25.0\,g\,Br_2 \\ +\ 2.81\,g\,Al \\ \hline 27.8\,g\,AlBr_3 \end{array}$$

But ...

...what would you have done to calculate the mass of aluminum bromide IF you had NOT been asked to calculate the mass of aluminum FIRST?

$$25.0\,g\,Br_2 \times \frac{1\,mol\,Br_2}{159.80\,g\,Br_2} \times \frac{2\,mol\,AlBr_3}{3\,mol\,Br_2} \times \frac{266.694\,g\,AlBr_3}{1\,mol\,AlBr_3} = 27.8\,g\,AlBr_3$$

1 convert mass bromine to moles

2 convert moles bromine to moles aluminum bromide

3 convert moles aluminum bromide to mass