Concentration Quantitatively

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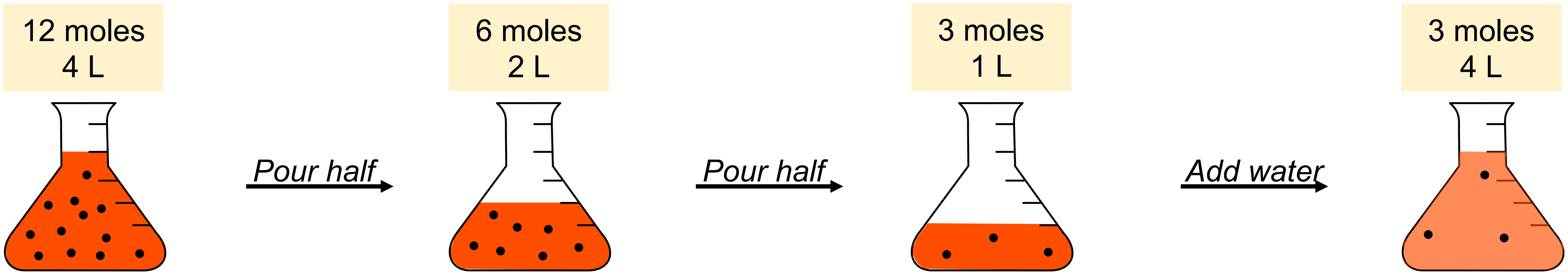
CHEMISTRY 161
FALL 2019

www.mioy.org/chem161

MOLARITY (M): Concentration of solution

$$\text{Concentration} = \frac{\text{moles of solute}}{\text{Volume (L) of solution}} \quad ; \quad \text{M} = \frac{\text{mol}}{\text{L}}$$

Think about what concentration means before getting into the math.



$\text{M} = \frac{12\ \text{mol}}{4\ \text{L}} = 3\ \text{M}$ $\quad$ $\text{M} = \frac{6\ \text{mol}}{2\ \text{L}} = 3\ \text{M}$ $\quad$ $\text{M} = \frac{3\ \text{mol}}{1\ \text{L}} = 3\ \text{M}$ $\quad$ $\text{M} = \frac{3\ \text{mol}}{4\ \text{L}} = 0.75\ \text{M}$

Each black dot represents a mole (the quantity/amount)

What is a ppm?

A ppm (part per million) is a unit of concentration. Specifically, it is:

$$1 \text{ ppm} = \frac{1 \text{ mg solute}}{1 \text{ kg solution}}$$

A molar (M or mol/L) is a unit of concentration as well. If a solution of NaCl is 0.80 M, we say:

$$0.80 \text{ M NaCl} = \frac{0.80 \text{ mol NaCl}}{1 \text{ L}}$$

Likewise, a solution of NaCl that is 0.80 ppm is:

$$0.80 \text{ ppm NaCl} = \frac{0.80 \text{ mg NaCl}}{1 \text{ kg water}}$$

We can convert between the two units of concentration using the density of water and the molar mass of NaCl:

$$0.80 \text{ ppm NaCl} = \frac{0.80 \text{ mg NaCl}}{1 \text{ kg water}} \times \frac{1 \text{ kg}}{1000 \text{ g}} \times \frac{1 \text{ g water}}{1 \text{ mL water}} \times \frac{1000 \text{ mL}}{1 \text{ L}} \times \frac{1 \text{ g}}{1000 \text{ mg}} \times \frac{1 \text{ mol NaCl}}{58.44 \text{ g NaCl}} = 1.4 \times 10^{-5} \frac{\text{mol}}{\text{L}} \text{ NaCl}$$

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NaOH = 39.99 g/mol

KCl = 74.55 g/mol

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Collect the molar masses of NaOH and KCl:

NaOH = 39.99 g/mol

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Let's assume you have 10 g of each solute and 1 L of solution.

We can determine the concentration (molarity) of each solution then:

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$$10\text{ g NaOH} \times \frac{1\text{ mol}}{39.99\text{ g}} = 0.25\text{ mol NaOH}$$

$$[\text{NaOH}] = \frac{\#\text{ moles}}{\text{Volume (L)}} = \frac{0.25\text{ mol NaOH}}{1\text{ L}} = 0.25\text{ M}$$

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Because NaOH has a smaller molar mass, we have more moles of NaOH → greater concentration/molarity.

Consider separate solutions of NaOH and KCl made by dissolving 125.0 g of each solute in 250.0 mL of solution.
Calculate the concentration of each solution.

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$$125.0\ \text{g NaOH} \times \frac{1\ \text{mol}}{39.99\ \text{g}} = 3.125_8\ \text{mol NaOH}$$

$$125.0\ \text{g KCl} \times \frac{1\ \text{mol}}{74.55\ \text{g}} = 1.676_7\ \text{mol KCl}$$

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$$[\text{NaOH}] = \frac{\#\text{ moles}}{\text{Volume (L)}} = \frac{3.125_8 \text{ mol NaOH}}{0.2500 \text{ L}} = 12.50 \text{ M}$$

$$[\text{KCl}] = \frac{\#\text{ moles}}{\text{Volume (L)}} = \frac{1.676_7 \text{ mol KCl}}{0.2500 \text{ L}} = 6.707 \text{ M}$$

Because NaOH has a smaller molar mass, we have <u>more</u> moles of NaOH → greater concentration/molarity.

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We can find out by setting up the expression for molarity and solving for the # of moles:

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$$\mathrm{V} = 0.032_8\ \mathrm{L}$$

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$$0.800\text{ M} = \frac{0.026_3\text{ mol NaOH}}{V}$$

$$V = 0.032_8\text{ L}$$

Step 3:

Find the amount of water needed to dilute this sample:

$$\left(75.0\text{ mL}\times\frac{1\text{ L}}{1000\text{ mL}}\right) - 0.032_8\text{ L} = 0.042\text{ L water}$$

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Alternative solution:

You can use the following equation to solve for the volume (V_2) of the 0.800 M solution (M_2) that would contain the same number of moles as 75 mL (V_1) of the 0.35 M solution (M_1):

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$$M_1V_1 = M_2V_2$$
$$(0.35\text{ M})(75.0\text{ mL}) = (0.800\text{ M})V_2$$
$$V_2 = 0.032_8\text{ L}$$

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Find the amount of water needed to dilute this sample:

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We can make 75.0 mL of a 0.35 M NaOH solution by taking 0.033 L of a 0.800 M NaOH solution and diluting it with 0.042 L of water.

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So, first determine how many moles are in your original solution:

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$$0.82\text{ M} = \frac{0.26_3\text{ mol HI}}{\text{V}}$$

$$\text{V} = 0.32\text{ L} = 320\text{ mL}$$

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$$M_1V_1 = M_2V_2$$

$$(0.50\ \mathrm{M})(525\ \mathrm{mL}) = (0.82\ \mathrm{M})V_2$$

$$V_2 = 320\ \mathrm{L}$$

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$$\mathrm{x_1} = 0.33\ \mathrm{mol\ HCl}$$

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$$x_2 = 0.17\text{ mol HCl}$$

$$n_{\text{HCl}} = x_1 + x_2$$

$$= 0.33\text{ mol} + 0.17\text{ mol}$$

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$$n_{\mathrm{HCl}} = x_1 + x_2$$

$$= 0.33\ \mathrm{mol} + 0.17\ \mathrm{mol}$$

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And the total volume is 220 mL + 405 mL = 625 mL.

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$$[\mathrm{HCl}]_2 = \frac{\#\ \mathrm{moles}}{\mathrm{Volume\ (L)}}$$

$$0.42\ \mathrm{M} = \frac{\mathrm{x_2\ mol}}{405\ \mathrm{mL} \times \frac{1\ \mathrm{L}}{1000\ \mathrm{mL}}}$$

$$\mathrm{x_2} = 0.17\ \mathrm{mol\ HCl}$$

$$\mathrm{n_{HCl}} = \mathrm{x_1} + \mathrm{x_2} = 0.33\ \mathrm{mol} + 0.17\ \mathrm{mol}$$

$$\mathrm{n_{HCl}} = 0.50\ \mathrm{mol\ HCl}$$

And the total volume is 220 mL + 405 mL = 625 mL.

So we can find the new concentration now:

I mix 220 mL of 1.5 M HCl solution with 405 mL of 0.42 M HCl solution. What is the new volume and concentration of this solution?

From our definition of concentration, we know that we need to find the total number of moles and the total volume of the new solution.

We can start by finding the number of moles in solution 1, solution 2, and the total:

$$[\mathrm{HCl}]_1 = \frac{\#\ \mathrm{moles}}{\mathrm{Volume\ (L)}}$$

$$1.5\ \mathrm{M} = \frac{x_1\ \mathrm{mol}}{220\ \mathrm{mL} \times \frac{1\ \mathrm{L}}{1000\ \mathrm{mL}}}$$

$$x_1 = 0.33\ \mathrm{mol\ HCl}$$

$$[\mathrm{HCl}]_2 = \frac{\#\ \mathrm{moles}}{\mathrm{Volume\ (L)}}$$

$$0.42\ \mathrm{M} = \frac{x_2\ \mathrm{mol}}{405\ \mathrm{mL} \times \frac{1\ \mathrm{L}}{1000\ \mathrm{mL}}}$$

$$x_2 = 0.17\ \mathrm{mol\ HCl}$$

$$n_{\mathrm{HCl}} = x_1 + x_2$$

$$= 0.33\ \mathrm{mol} + 0.17\ \mathrm{mol}$$

$$n_{\mathrm{HCl}} = 0.50\ \mathrm{mol\ HCl}$$

And the total volume is 220 mL + 405 mL = 625 mL.

So we can find the new concentration now:

$$[\mathrm{HCl}] = \frac{0.50\ \mathrm{mol\ HCl}}{62_5\ \mathrm{mL} \times \frac{1\ \mathrm{L}}{1000\ \mathrm{mL}}} = 8.0 \times 10^{-7}\ \mathrm{M}$$

I mix 220 mL of 1.5 M HCl solution with 405 mL of 0.42 M HCl solution. What is the new volume and concentration of this solution?

From our definition of concentration, we know that we need to find the total number of moles and the total volume of the new solution.

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$$\mathrm{x_1} = 0.33\ \mathrm{mol\ HCl}$$

$$[\mathrm{HCl}]_2 = \frac{\#\ \mathrm{moles}}{\mathrm{Volume\ (L)}}$$

$$0.42\ \mathrm{M} = \frac{\mathrm{x_2\ mol}}{405\ \mathrm{mL} \times \frac{1\ \mathrm{L}}{1000\ \mathrm{mL}}}$$

$$\mathrm{x_2} = 0.17\ \mathrm{mol\ HCl}$$

$$\mathrm{n_{HCl}} = \mathrm{x_1} + \mathrm{x_2} = 0.33\ \mathrm{mol} + 0.17\ \mathrm{mol}$$

$$\mathrm{n_{HCl}} = 0.50\ \mathrm{mol\ HCl}$$

And the total volume is 220 mL + 405 mL = 625 mL.

So we can find the new concentration now:

$$[\mathrm{HCl}] = \frac{0.50\ \mathrm{mol\ HCl}}{62_5\ \mathrm{mL} \times \frac{1\ \mathrm{L}}{1000\ \mathrm{mL}}} = 0.80\ \mathrm{M}$$

Q: Does that make sense?

I mix 220 mL of 1.5 M HCl solution with 405 mL of 0.42 M HCl solution. What is the new volume and concentration of this solution?

From our definition of concentration, we know that we need to find the total number of moles and the total volume of the new solution.

We can start by finding the number of moles in solution 1, solution 2, and the total:

$$[\mathrm{HCl}]_1 = \frac{\#\ \mathrm{moles}}{\mathrm{Volume\ (L)}}$$

$$1.5\ \mathrm{M} = \frac{x_1\ \mathrm{mol}}{220\ \mathrm{mL} \times \frac{1\ \mathrm{L}}{1000\ \mathrm{mL}}}$$

$$x_1 = 0.33\ \mathrm{mol\ HCl}$$

$$[\mathrm{HCl}]_2 = \frac{\#\ \mathrm{moles}}{\mathrm{Volume\ (L)}}$$

$$0.42\ \mathrm{M} = \frac{x_2\ \mathrm{mol}}{405\ \mathrm{mL} \times \frac{1\ \mathrm{L}}{1000\ \mathrm{mL}}}$$

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$$n_{\mathrm{HCl}} = x_1 + x_2$$

$$= 0.33\ \mathrm{mol} + 0.17\ \mathrm{mol}$$

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And the total volume is 220 mL + 405 mL = 625 mL.

So we can find the new concentration now:

$$[\mathrm{HCl}] = \frac{0.50\ \mathrm{mol\ HCl}}{62_5\ \mathrm{mL} \times \frac{1\ \mathrm{L}}{1000\ \mathrm{mL}}} = 0.80\ \mathrm{M}$$

Q: Does that make sense?

A: Yes! We diluting our HCl by mixing a greater amount of low concentration HCl into a higher concentration.