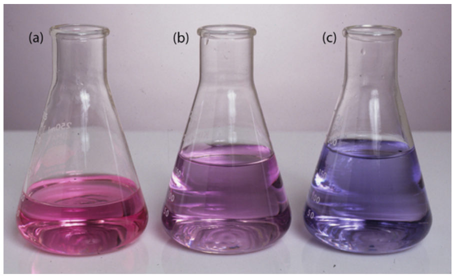
Titrations

Skills to Develop

- Perform and interpret titration calculations

A **titration** is a laboratory technique used to precisely measure molar concentration of an unknown solution using a known solution. The basic process involves adding a **standard solution** of one reagent to a known amount of the unknown solution of a different reagent. For instance, you might add a standard base solution to an mystery acid solution. As the addition takes place, the two reagents in the solutions, in this the acid and base, react. You also add an **indicator**, which is a molecule that changes color when the original reagent (the acid in the mystery solution, say) is completely consumed by reaction with the standard solution reagent. If you know exactly how much standard was added before the color change, you can calculate how many moles of the unknown were present at the beginning, and thus the concentration of the unknown.



Examples of solutions with an indicator added.

Many of the standard reagents you might use in the lab, especially HCl and NaOH, which are very common and important, are hard to prepare at precise concentration without titration. The reason is that HCl is purchased as a concentrated solution, which can vary a little in concentration because both the HCl and the water can evaporate. NaOH can be purchased as a solid, but it is **hygroscopic** which means that it absorbs water from the air. It can absorb so much water that it actually dissolves. For this reason, even if you buy it dry, once you open the bottle, it might start to absorb water, and it would be difficult to know when you measure it what % water it is. Thus, if you work in a biochemistry lab, for instance, you might want to control the pH of your solutions by adding a little bit of dilute HCl or NaOH, because chloride and sodium ions are very common and probably are already included in the solution, but you might want to know how concentrated your solutions are. To determine this, you would use a standard solution made of some easier-to-mass acid or base to titrate the solution you actually want to use. Once titrated, you could dilute it precisely to the concentration you want. Some other reagents you might want standard solutions of react with air; these you might also titrate if they have been waiting a long time so you know what the current concentration is.

Titrations might seem a little old-fashioned. Actually, the number of automated titration machines available (try a google search!) suggest that titrations are still very important in industry. One reason might be that titrations can be good for studying newly discovered molecules, for instance to measure the molecular weight and other properties that we will study more later.

Traditionally, you take a known mass or volume of the unknown solution and put it in a flask with the indicator. Then you add the standard solution in a buret, which is a special tube for adding solution slowly and measuring the volume added at the end. These days, it might be easier to use a plastic squeeze bottle instead of a buret. You put the standard solution in the squeeze bottle, get the mass of the bottle, do the titration, and then mass the bottle again. Now you know exactly how much standard was added!

Example 1

We have a solution of HCl whose concentration is known imprecisely (~2.5 M). (We made this solution in the previous section on molarity.) We want to determine the concentration more precisely. We have a solution of NaOH that is known to be 5.1079 M. We place 100.00 ml of the HCl solution in a flask with a drop of an indicator that will change color when the solution is no longer acidic. Then we add NaOH slowly until the indicator color changes. At this point, we have added 46.67 ml NaOH. Calculate the precise concentration of the HCl.

Solution

To answer, we need to know that the reaction is

$$HCl + NaOH \rightarrow NaCl + H_2O \tag{1}$$

So the ratio is 1 HCl:1 NaOH. We calculate the number of moles of NaOH added:

$$(5.1079\ mol/L)(46.67\ mL) = 238.4\ mmol \tag{2}$$

This is also the number of moles of HCl in the original 100.00 mL of solution, because the reaction ratio is 1:1. To calculate the concentration of the HCl solution, we just divide the number of moles of HCl by the volume.

$$(238.4\ mmol)/(100.00\ mL) = 2.384\ M \tag{3}$$

We could do this in one step using dimensional analysis:

$$(46.67\ \ mL\ \cancel{NaOH})\left(\frac{5.1079\ \ mol\ \cancel{NaOH}}{1000\ \ m\cancel{L}}\right)\left(\frac{1\ mol\ HCl}{1\ \ mol\ \cancel{NaOH}}\right)\left(\frac{1}{100.00\ mL}\right) = 2.384\ M \tag{4}$$

Now, we diluted 250 mL of the original stock solution to 1.00 L to make this solution. What is the concentration of the 10 M HCl, precisely? First we calculate the moles of HCl in the whole "2.5 M" solution, which is equal to the number of moles of HCl in quantity of stock solution ("10 M") that was used to make it (250ml).

$$(1.00\ \ L\ of\ \cancel{diluted\ solution})\left(\frac{2.384\ mol\ HCl}{1\ \ L\ of\ \cancel{diluted\ solution}}\right)\left(\frac{1}{0.250\ L\ of\ conc.\ \ solution}\right) = 9.536\ M \tag{5}$$

Why so low? HCl is a gas, and can evaporate out of solution. The stock solution must have been pretty old.

Contributors and Attributions

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