

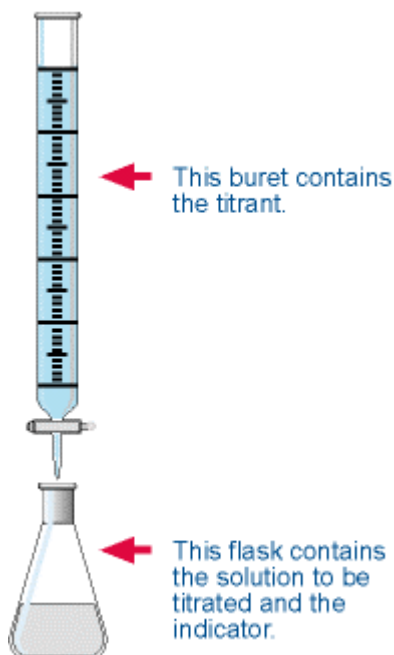
Acid-Base Titrations

Molarities of acidic and basic solutions can be used to convert back and forth between moles of solutes and volumes of their solutions, but how are the molarities of these solutions determined? This section describes a procedure called titration, which can be used to find the molarity of a solution of an acid or a base.

In **titration**, one solution (solution #1) is added to another solution (solution #2) until a chemical reaction between the components in the solutions has run to completion. Solution #1 is called the **titrant**, and we say that it is used to **titrate** solution #2. The completion of reaction is usually shown by a change of color caused by a substance called an **indicator**.

A typical titration proceeds in the following way. A specific volume of the solution to be titrated (solution #2) is poured into an Erlenmeyer flask (see figure below). For example, 25.00 mL of a nitric acid solution of unknown concentration might be added to a 250 mL Erlenmeyer flask.

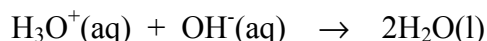
A solution of a substance that reacts with the solute in solution #2 is added to a buret. (A **buret** is a laboratory instrument used to add measured volumes of solutions to other containers.) This solution in the buret, which has a known concentration, is the titrant. The buret is set up over the Erlenmeyer flask so the titrant can be added in a controlled manner to the solution to be titrated. For example, a 0.115 M NaOH solution might be added to a buret, which is set up over the Erlenmeyer flask containing the nitric acid solution.



Setup for a Typical Titration In a typical titration, the titrant in the buret is added to the solution in the Erlenmeyer flask until the indicator changes color to show that the reaction is complete.

An indicator is added to the solution being titrated. The **indicator** is a substance that changes color when the reaction is complete. In our example, phenolphthalein, which is a commonly used acid-base indicator, is added to the nitric acid solution in the Erlenmeyer flask. Phenolphthalein has two chemical forms. In acidic conditions, it is in the acid form, which is colorless. In basic conditions, an H^+ ion is removed from each phenolphthalein molecule, converting it to its base form, which is red.

The titrant is slowly added to the solution being titrated until the indicator changes color, showing that the reaction is complete. This stage in the procedure is called the **endpoint**. In our example, the NaOH solution is slowly added from the buret until the mixture in the Erlenmeyer flask changes from colorless to red. The OH^- ions in the NaOH solution react with the H_3O^+ ions in the HNO_3 solution.



As long as there are excess H_3O^+ ions in the solution, the solution stays acidic, the phenolphthalein stays mostly in the acid form, and the solution is colorless. When enough NaOH solution is added to react with all of the H_3O^+ ions, the reaction is complete. When a small amount of extra NaOH solution is added, perhaps one drop, there will be an excess of hydroxide ions, OH^- , in solution. These react with the phenolphthalein molecules, changing them from the acid form to the base form. Because the base form is red, the solution turns red, telling us that the reaction is complete (or just slightly beyond complete).

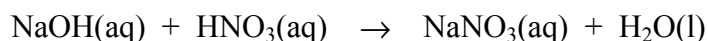
The volume of titrant added from the buret is measured. For our example, let's assume that 18.3 mL of 0.115 M NaOH has been added. The following setup shows how the molarity of the nitric acid solution can be calculated from this data.

$$\begin{aligned} \frac{? \text{ mol HNO}_3}{1 \text{ L HNO}_3 \text{ soln}} &= \frac{18.3 \text{ mL NaOH soln}}{25.00 \text{ mL HNO}_3 \text{ soln}} \left(\frac{10^3 \text{ mL}}{1 \text{ L}} \right) \left(\frac{0.115 \text{ mol NaOH}}{10^3 \text{ mL NaOH soln}} \right) \left(\frac{1 \text{ mol HNO}_3}{1 \text{ mol NaOH}} \right) \\ &= \frac{0.0842 \text{ mol HNO}_3}{1 \text{ L HNO}_3 \text{ soln}} \text{ or } \mathbf{0.0842 \text{ M HNO}_3} \end{aligned}$$

The first step is to clearly identify the units that you want. Molarity describes the number of moles of solute per liter of solution so we start by identifying that we want moles of HNO_3 over 1 L HNO_3 solution.

Because molarity is a ratio of two units, we begin our calculation with a ratio of two units. Knowing that we want volume of HNO_3 solution on the bottom when we are done, we place 25.00 mL HNO_3 solution on the bottom at the start. We place 18.3 mL NaOH solution on the top of our ratio, giving us the ratio of two units overall that we want.

We convert milliliters of HNO_3 solution to liters of HNO_3 solution using the relationship between milliliters and liters to convert milliliters. The last two conversion factors convert from amount of one substance in a chemical reaction (mL NaOH solution) to amount of another substance in the reaction (mol HNO_3). Thus, this is an equation stoichiometry problem that requires at its core the conversion of moles of NaOH to moles of HNO_3 using the molar ratio for the reaction between them.



In order to use the molar ratio to convert from moles of NaOH to moles of HNO₃, we need to convert from volume of NaOH solution to moles of NaOH using the molarity as a conversion factor.

The following is a sample study sheet for titration problems.

Study Sheet for Acid-Base Titration Problems

Tip-off - You will be given the volume of a solution of an acid or base (the titrant – solution #1) necessary to react completely with a given volume of solution being titrated (solution #2). You will also be given the molarity of the titrant (solution #1). You will be asked to calculate the molarity of solution #2.

General Procedure - You can use the following steps.

- Use the dimensional analysis process, with the following general format.

$$\frac{? \text{ mol \#2}}{1 \text{ L \#2 soln}} = \frac{(\text{given}) (\text{volume unit \#1}) \#1}{(\text{given}) (\text{volume unit \#2}) \#2} \left(\frac{--- (\text{volume unit \#2})}{--- \text{L}} \right) \left(\frac{--- \text{L (or mL)}}{--- (\text{volume unit \#1})} \right) \left(\frac{(\text{number from molarity}) \text{ mol \#1}}{1 \text{ L (or } 10^3 \text{ mL) \#1 soln}} \right) \left(\frac{(\text{coef. \#2}) \text{ mol \#2}}{(\text{coef. \#1}) \text{ mol \#1}} \right)$$

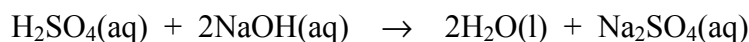
- * The first conversion factor is only necessary if you are not given liters of #2. (Because you are usually given milliliters, this conversion factor often converts from milliliters to liters.)
- * The second conversion factor is only necessary if you are not given either milliliters or liters of #1. (You are usually given milliliters, so if you use the form of the molarity conversion factor that includes “10³ mL #1 soln”, this conversion factor is not necessary.)
- * The coefficients in the final conversion factor come from the balanced equation for the reaction.

- Complete the calculation in the usual way.

General Procedure - See Example.

EXAMPLE – Calculating Molarity from Titration Data: Titration reveals that 11.6 mL of 3.0 M sulfuric acid are required to neutralize the sodium hydroxide in 25.00 mL of NaOH solution. What is the molarity of the NaOH solution?

Solution:



$$\begin{aligned} \frac{? \text{ mol NaOH}}{1 \text{ L NaOH soln}} &= \frac{11.6 \text{ mL H}_2\text{SO}_4 \text{ soln}}{25.00 \text{ mL NaOH soln}} \left(\frac{10^3 \text{ mL}}{1 \text{ L}} \right) \left(\frac{3.0 \text{ mol H}_2\text{SO}_4}{10^3 \text{ mL H}_2\text{SO}_4 \text{ soln}} \right) \left(\frac{2 \text{ mol NaOH}}{1 \text{ mol H}_2\text{SO}_4} \right) \\ &= \frac{2.8 \text{ mol NaOH}}{1 \text{ L NaOH soln}} \text{ or } \mathbf{2.8 \text{ M NaOH}} \end{aligned}$$

Exercise - Calculating Molarity from Titration Data: When 34.2 mL of a 1.02 M NaOH solution is added from a buret to 25.00 mL of a phosphoric acid solution that contains phenolphthalein, the solution changes from colorless to red.

- a. What is the titrant in this procedure? What is the indicator? What is being titrated?

NaOH is the titrant, phenolphthalein is the indicator, and the phosphoric acid solution is being titrated.

- b. What is the molarity of the phosphoric acid?

$$\frac{? \text{ moles H}_2\text{SO}_4}{\text{L H}_3\text{PO}_4 \text{ soln}} = \frac{34.2 \text{ mL NaOH soln}}{25.00 \text{ mL H}_3\text{PO}_4 \text{ soln}} \left(\frac{1.02 \text{ mol NaOH}}{10^3 \text{ mL NaOH soln}} \right) \left(\frac{1 \text{ mol H}_3\text{PO}_4}{3 \text{ mol NaOH}} \right) \left(\frac{10^3 \text{ mL}}{1 \text{ L}} \right)$$

$$= \mathbf{0.465 \text{ M H}_3\text{PO}_4}$$

Glossary

- **Titration:** The addition of one solution (solution #1) to another solution (solution #2) until a chemical reaction between the components in the solutions is complete.
- **Titrant:** The solution added in a titration.
- **Indicator:** The substance added in a titration to show (by a change of color) when the reaction is complete.
- **Buret:** A volume-measuring instrument used to add measured volumes of the titrant in a titration.
- **Endpoint:** The stage in a titration where enough of the titrant has been added to react completely with the substance being titrated.

Objectives

The goal of this paper is to teach you to do the following.

1. Define all of the terms in the Chapter Glossary.
2. Describe the general steps for a titration to determine the molarity of a solution of a substance.
3. Describe how phenolphthalein is able to show when the endpoint is reached in the titration of an acid with a base.
4. Given the volume of a substance before it is titrated, the molarity of the titrant, and the volume of titrant necessary to reach the endpoint, calculate the molarity of the substance titrated.

Problems

1. Write a description of the general steps for the titration procedure to determine the molarity of a solution of a substance. (Obj #2)
2. Write a description of how phenolphthalein is able to show when the endpoint is reached in the titration of an acid with a base. (Obj #3)
3. The molarity of a hydrochloric acid solution can be determined by titrating a known volume of the solution with a sodium hydroxide solution of known concentration. If 14.7 mL of 0.102 M NaOH is required to titrate 25.00 mL of a hydrochloric acid, HCl, solution, what is the molarity of the hydrochloric acid? (Obj #4)
4. If 36.2 mL of 0.152 M NaOH is required to neutralize 25.00 mL of an acetic acid, $\text{HC}_2\text{H}_3\text{O}_2$, solution, what is the molarity of the acetic acid? (Obj #4)
5. The molarity of a sodium hydroxide solution can be determined by titrating a known volume of the solution with a hydrochloric acid solution of known concentration. If 19.1 mL of 0.118 M HCl is required to neutralize 25.00 mL of a sodium hydroxide solution, what is the molarity of the sodium hydroxide? (Obj #4)
6. If 7.3 mL of 1.25 M HNO_3 is required to neutralize 25.00 mL of a potassium hydroxide solution, what is the molarity of the potassium hydroxide? (Obj #4)
7. If 12.0 mL of 1.34 M NaOH is required to neutralize 25.00 mL of a sulfuric acid, H_2SO_4 , solution, what is the molarity of the sulfuric acid? (Obj #4)
8. If 46.2 mL of 2.50 M NaOH is required to neutralize 25.00 mL of a phosphoric acid, H_3PO_4 , solution, what is the molarity of the phosphoric acid? (Obj #4)
9. If 11.3 mL of 0.110 M HCl is required to neutralize 25.00 mL of a barium hydroxide solution, what is the molarity of the barium hydroxide? (Obj #4)
10. If 8.6 mL of 0.0994 M HNO_3 is required to neutralize 25.00 mL of a strontium hydroxide solution, what is the molarity of the strontium hydroxide? (Obj #4)