Acid–Base Titrimetry

This brief tutorial describes the basic procedure for conducting a titration in the Chem 260 lab. Although the tutorial uses acid-base chemistry as an example, the discussion also applies to other types of reactions.

What is an Acid-Base Titration?

An acid–base titration is an technique in which a solution that contains an acid (or a base) is added dropwise to a solution that contains a base (or an acid). The solution added dropwise is called the titrant and the solution to which the titrant is added is called the sample. The sample normally is placed in a flask whose size is sufficient to contain both the sample and the added titrant, and that has sufficient room to swirl the solution without having it slosh out of the flask. The titrant is placed in a buret allowing for its controlled addition to the sample.

How is a Titration Used to Determine the Concentration of an Acid or Base?

Suppose, for example, that we have a monoprotic acid, HA, of unknown concentration and a monoprotic base, B, whose concentration is known. When we mix them together, the acid and base react according to the following stoichiometry

$$\mathrm{HA}(aq) + \mathrm{B}(aq) \longrightarrow \mathrm{HB}^{+}(aq) + \mathrm{A}^{-}(aq)$$

Let's assume, as well, that the reaction essentially proceeds to completion. If we titrate a solution of HA with B until they mix in an exact stoichiometric ratio, then we know that

$$\text{moles B} = \text{moles HA} \tag{1}$$

because the reaction's stoichiometry is 1:1. The moles of HA and the moles of B are equal to the product of their respective molarities, M, and volumes, V; thus

$$M_{\mathrm{HA}} \times V_{\mathrm{HA}} = M_{\mathrm{B}} \times V_{\mathrm{B}} \tag{2}$$

As an example, if 36.42 mL of a 0.116 M solution of B completely reacts with 25.00 mL of HA, then the concentration of HA is

$$M_{\mathrm{HA}} = \frac{M_{\mathrm{B}} \times V_{\mathrm{B}}}{V_{\mathrm{HA}}} = \frac{(0.116\ \mathrm{M})(36.42\ \mathrm{mL})}{25.00\ \mathrm{mL}} = 0.169\ \mathrm{M\ HA}$$

If the acid is diprotic, H_2A, and we react it with sufficient B such that both protons are completely consumed, then

$$\mathrm{H_2A}(aq) + 2\mathrm{B}(aq) \longrightarrow 2\mathrm{HB}^{+}(aq) + \mathrm{A}^{2-}(aq)$$

and

$$2 \times M_{\mathrm{H_2A}} \times V_{\mathrm{H_2A}} = M_{\mathrm{B}} \times V_{\mathrm{B}} \tag{3}$$

Obviously, there are many other possibilities (diprotic bases, triprotic acids, etc.), but the details for such cases follow easily from this description.

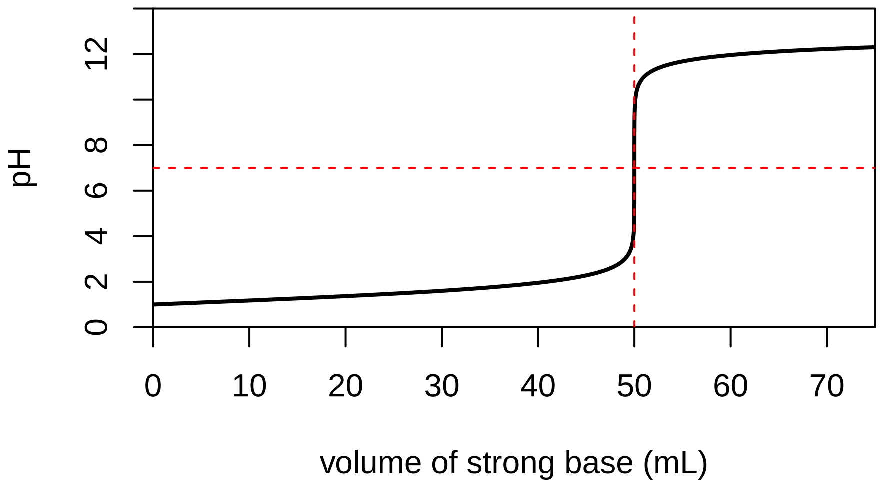

Figure 1: Titration curve for a strong acid using a strong base as a titrant.

Sometimes the acid or base is obtained as a solid. Suppose, for example, you need to determine the concentration of a monobasic strong base, B, by titrating it against a known mass of a solid monoprotic weak acid, HA. In this case we obtain the concentration of the base using the following equation

$$\mathrm{B} = M_{\mathrm{B}} \times V_{\mathrm{B}} = \frac{\mathrm{g\ HA}}{MM_{\mathrm{HA}}} = \mathrm{HA} \qquad (4)$$

where MM_{HA} is the molar mass of HA.

How Do We Know When an Acid and Base Have Been Mixed Stoichiometrically?

When the titrant and the sample are mixed in an exact stoichiometric ratio, then the titration has reached its *equivalence point*. Finding this equivalence point is the key to any titration and there are two general approaches for accomplishing this: use a visual indicator that changes color at the equivalence point, or measure the sample's pH as the titrant is added. Using an indicator to find the equivalence point is straightforward and needs no detailed discussion (you just add the titrant dropwise until the indicator changes color, recording the total amount of titrant needed to reach the equivalence point).[1]

Suppose the sample is a strong acid and the titrant is a strong base. Before we add the titrant the sample's pH depends on the strong acid's concentration. Adding titrant causes a slow increase in pH as the strong base neutralizes the strong acid. The rate at which the pH changes becomes greater as we approach the equivalence point, reaching its maximum rate of change at the equivalence point, which in this case occurs when the pH is 7.00. After the equivalence point, the rate of change in pH becomes smaller, resulting in a slow, gradual rise in pH. The resulting titration curve looks something like Figure 1 where the pH at the equivalence point is indicated by the horizontal dashed line and the volume at the equivalence point is indicated by the vertical dashed line.

Titration curves for other samples are similar in shape. If the sample is a strong base and the titrant is a strong acid, for example, then the titration curve begins at a more basic pH and ends at a more acidic pH; the general shape, as shown in Figure 2, is the same. Note that the equivalence point in this case also occurs at a pH of 7.00.

[1] To be exact, a visual indicator signals an endpoint, not an equivalence point. If we choose an appropriate indicator, then the difference between the endpoint and the equivalence point is of no consequence. Selecting an appropriate indicator is a topic that we will not explore in this course.

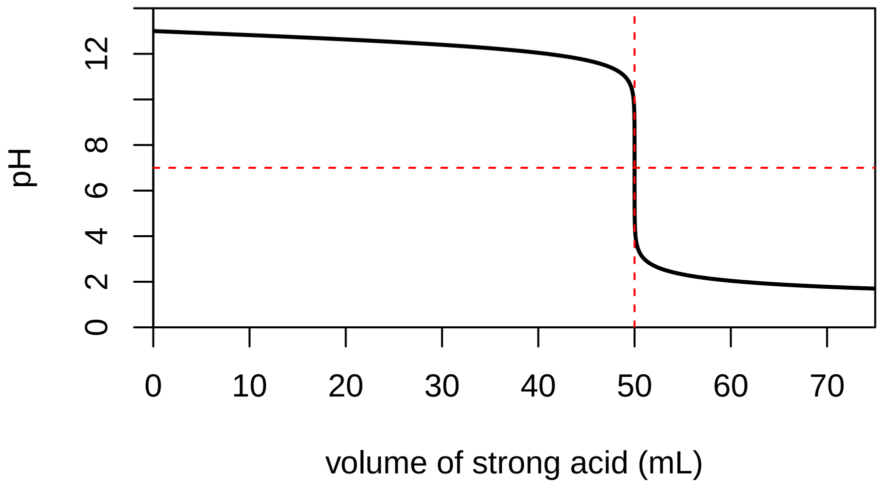

Figure 2: Titration curve for a strong base using a strong acid as a titrant

Although the equivalence points in Figure and Figure 2 are both 7.00, this is not always the case. If we titrate a weak acid, HA, with a strong base, for example, the pH at the equivalence point is basic because the reaction

$$\mathrm{HA}(aq) + \mathrm{OH^-}(aq) \longrightarrow \mathrm{H_2O}(aq) + \mathrm{A^-}(aq)$$

produces a solution of the weak acid's conjugate weak base, A^-, at the equivalence point; the pH, therefore, is greater than 7.00. Titrating a weak base with a strong acid, of course, gives an equivalence point that is less than 7.00.

Automated Titrations

The most common equipment for a titration is a manual buret in which the analyst (that's you!) opens and closes the stopcock, recording the pH after each addition of titrant. This is time-consuming and tedious. A more convenient method for recording a titration curve is to use an automated titrator that records both the volume of titrant added and the pH as a function of time. In this case the titrant is allowed to stream into the sample, usually at a slow rate, and the pH is monitored continuously. In the Chem 260 lab this is accomplished using the Vernier Drop Counter. Further details on its use is available on the course's website.

Titrations Based on Other Types of Reactions

Although this tutorial uses acid-base reactions to explain titrimetry, any chemical reaction can serve as the basis of a titration provided that the reaction is favorable, that it occurs rapidly, and that there is a suitable means to identify the equivalence point. The shape of such titration curves are similar to an acid-base titration curve.