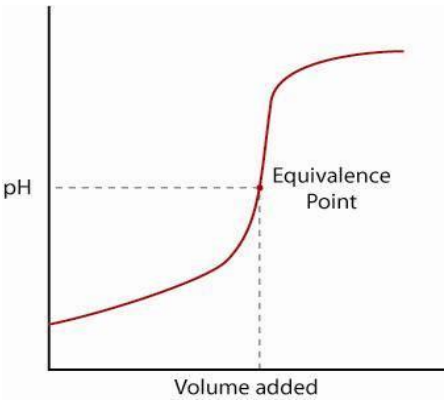
Pre-AP Chemistry I/Chemistry I
Unit #12—Acids and Bases



Titration is a technique used in analytical chemistry to determine the concentration of an unknown acid or base. Titration involves the slow addition of one solution where the concentration is known to a known volume of another solution where the concentration is unknown until the reaction reaches a desired level. For acid/base titrations, a color change from a pH indicator is reached or a direct reading using a pH meter. This information can be used to calculate the concentration of the unknown solution.

If the pH of an acid solution is plotted against the amount of base added during a titration, the shape of the graph is called a titration curve. All acid titration curves follow the same basic shapes.

At the beginning, the solution has a low pH and climbs as the strong base is added. As the solution nears the point where all of the H^+ is neutralized, the pH rises sharply and then levels out again as the solution becomes more basic as more OH^- ions are added.

The curve above shows a strong acid being titrated by a strong base. There is the initial slow rise in pH until the reaction nears the point where there is just enough base added to neutralize all the initial acid. This point is called the equivalence point. For a strong acid/base reaction, this occurs at pH = 7. As the solution passes the equivalence point, the pH slows its increase where the solution approaches the pH of the titration solution.

Interpreting a Titration Curve

A quick look at a titration curve can tell you a lot about the titration that produced it.

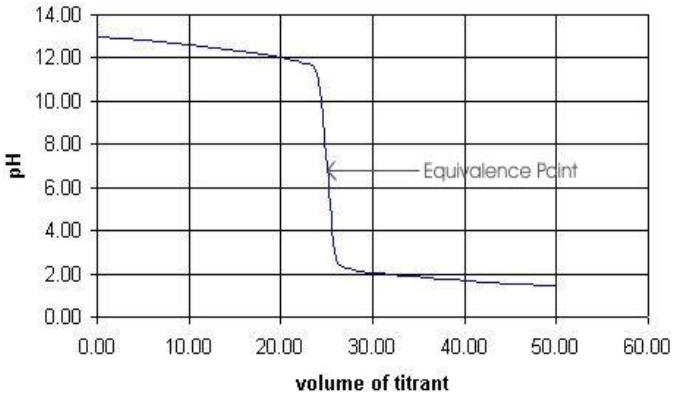
- The initial pH tells you whether the sample is an acid or a base.
- A rise in the curve indicates that the titrant is a base while a decline shows that the titrant is an acid.
- If a titration has been conducted properly, there should be an abrupt change in pH. Just one drop of titrant may be enough to cause an change of up to 6 pH units!
    - If the titrant is an acid, the graph shows a steep decline in pH.
    - If the titrant is a base, the graph shows a steep climb in pH.
- The midpoint of a steep change in pH marks the equivalence point. By interpolation you can obtain the information needed to calculate the concentration of the unknown in an acid-base reaction.

Let's assume that this graph is the result of titrating 25.00 mL of NaOH with standardized 0.100 M HCl.

By interpolation, the volume of titrant needed to neutralize the sample is 25.00 mL. Using stoichiometry, you can calculate the molar concentration of the sample:

$$C_{NaOH} = 25.00\ mL\ HCl \times 0.100\ M \times \frac{1\ mol\ NaOH}{1\ mol\ HCl} \times \frac{1}{25.00\ mL}$$

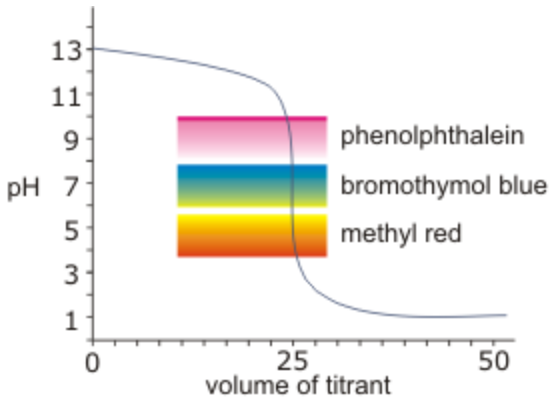
$$= 0.100\ M\ NaOH$$



Important point: The midpoint of an abrupt pH change on a titration curve marks the equivalence point.

Strong Acid-Strong Base Titration Curves

The two graphs you have seen to this point are good examples of titration curves for strong acid-strong base reactions. The typical features of a titration involving a strong base sample and a strong acid titrant are:



- a high initial pH.
- a gradual decline in pH to a point just before the equivalence point.
- a sharp decrease in pH by as many as 6 pH units as the result of the addition of one or two drops of strong acid titrant.
- another gradual decline in pH as excess acid is added.

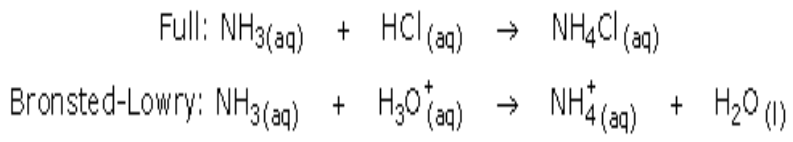
When a strong acid is titrated with a strong base, the pattern is reversed.

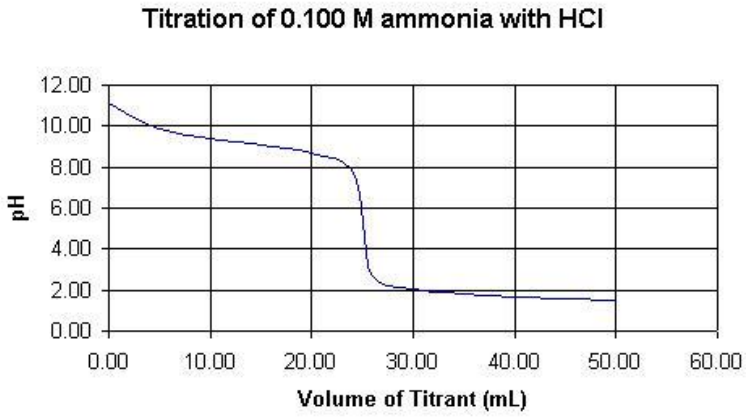
Any indicator that changes color in the pH range between 4 and 10 is generally suitable for a strong acid-strong base titration.

That is, the indicator will change color somewhere along the steep part of the curve. Indicators that change colour before or after the abrupt change in pH are not suitable for detecting the equivalence point.

Strong Acid-Weak Base Titrations

Consider the full chemical equation and the Brønsted-Lowry equation for the reaction between ammonia and hydrochloric acid. Notice that the mole ratio of acid to base is 1:1. If 0.100 *M* solutions of hydrochloric acid and ammonia are used in a titration, then the titration curve should look like this:





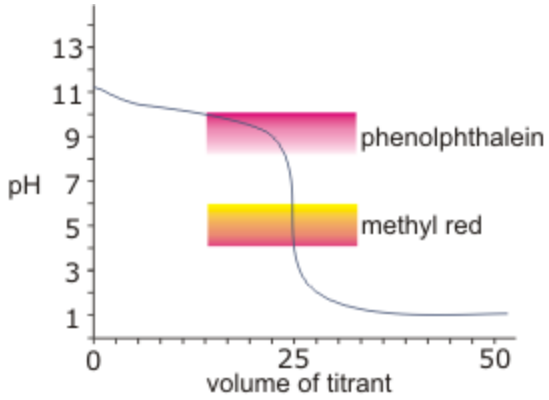
You should notice some important differences in this curve compared to one for the titration of a strong base with a strong acid.

- The initial pH is about 11 which is lower than it would be if the sample was completely ionized in water (13), so the sample is a weak base.
- There is a sudden drop in pH early on in the titration (ammonium ion is a weak acid, could it be reacting with ammonia to accelerate the drop in pH?).
- There is a gradual decline in pH as the ammonia neutralizes the added acid.
- The equivalence point is below pH 7 (actually about pH 5.3) because the weak acid formed as ammonia is neutralized has the ability to donate a proton to water thereby reducing the pH of the mixture.

After the equivalence point is reached, further addition of HCl produces the same decline seen in the titration of a strong base.

There are fewer suitable indicators for a strong acid-weak base titration than there are for the strong acid-strong base titration.

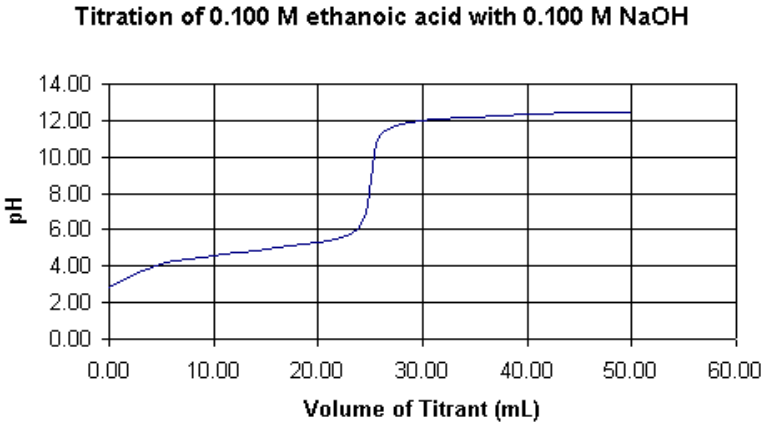
For example, phenolphthalein is not suitable because it changes colour well before the equivalence point. Any indicator that changes colour in the pH range between 7 and 3 is suitable, this includes methyl red.



Strong Base-Weak Acid Titrations

The titration of a weak acid with strong base produces a curve similar to the one for a weak base-strong acid titration. The obvious difference is that pH increases with the addition of titrant.

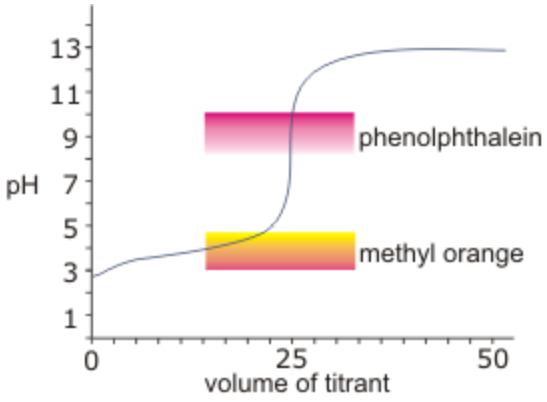
Consider this curve for the titration of 25.00 mL of 0.100 *M* ethanoic acid with 0.100 *M* sodium hydroxide:



Here are some important interpretations of this titration curve.

- The initial pH (about 3) suggests that the acid is weak because if a 0.100 *M* solution were to produce a stoichiometric equivalent of hydronium its pH would be 1.000.
- The initial increase in pH after 5 mL of titrant is added can be attributed to the action of ethanoate ion on water. This is followed by a gradual increase in pH until just before the equivalence point.
- The pH at the equivalence point is greater than pH 7, (it's actually about 8.7). Ethanoate is a weak base. It hydrolyses water to form hydroxide ions. The result is a greater hydroxide ion concentration at the equivalence point and therefore a higher pH.

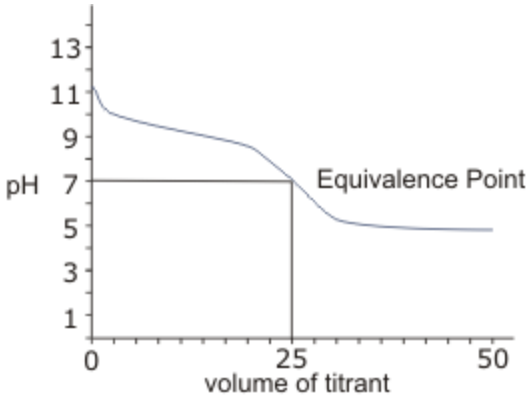
After the equivalence point, the pH increases gradually as it would for a strong base-strong acid titration. As was the case for a weak base-strong acid titration, the number of suitable indicators is lower than for strong base-strong acid titrations due to the narrower pH range associated with the equivalence point.



Phenolphthalein is a suitable indicator whereas methyl orange isn't.

Weak Acid-Weak Base Titrations

The only combination you haven't explored yet is the weak acid-weak base titration. You won't be carrying out any weak acid-weak base titrations in this course, but it is worthwhile considering the Brønsted-Lowry equation and titration curve for the reaction between ammonia and ethanoic acid. Notice that the reaction is not stoichiometric - it doesn't go to completion, yet there is an equivalence point as you can see from this titration curve.

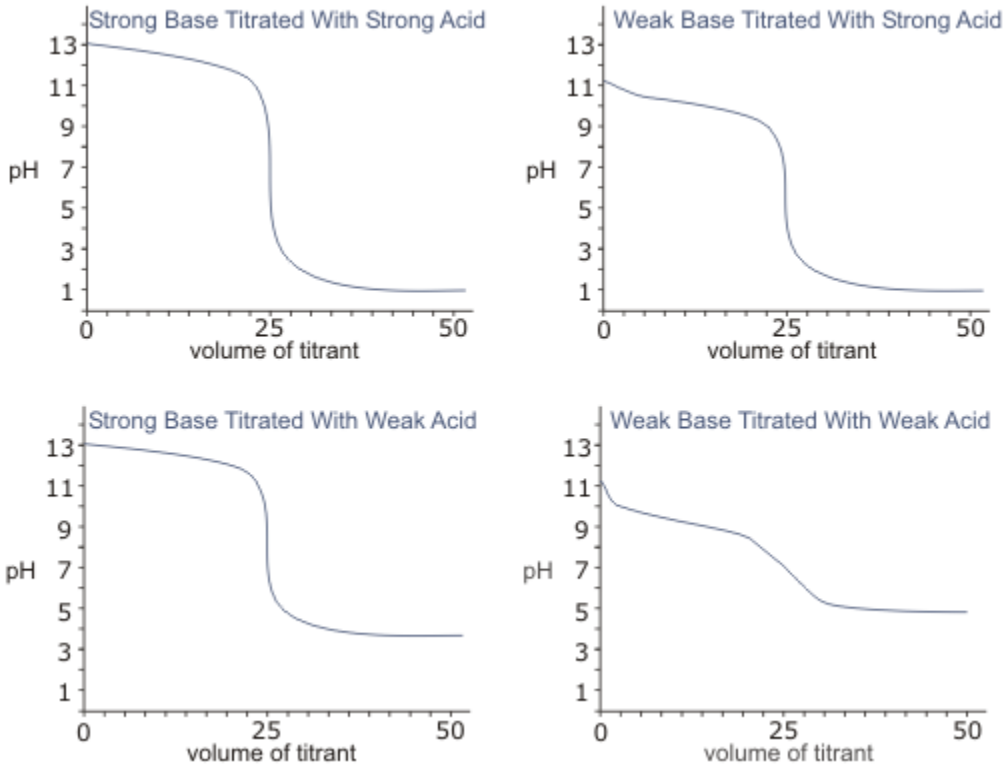


$$NH_{3\,(aq)} + CH_3COOH_{(aq)} \rightleftharpoons NH_{4\,(aq)}^{+} + CH_3COO^{-}_{(aq)}$$

Since there isn't an abrupt change in pH, the equivalence point cannot be detected using an indicator. The pH change occurs over too broad a volume of titrant to give a proper endpoint.

Summary

A pH meter can be used to quantify the pH changes that occur in a sample during an acid-base titration. A graph of sample pH versus volume of titrant is called a titration curve. Titrations involving different combinations of acid and base species produce a variety of characteristic titration curves. The following generalizations apply to monoprotic and monobasic species that have molar concentrations of 0.100 *M*.



- There are fewer useful indicators for titrations involving weak species than there are for strong acid-strong base titrations.
- The equivalence point for strong acid-strong base titrations occurs at pH 7.
- The equivalence point for a weak base-strong acid titration is less than pH 7.
- The equivalence point for a strong base-weak acid titration is greater than pH 7.

Pre-AP Chemistry
Unit #12—Acids and Bases

Titration Curves

DUE DATE: FRIDAY, MARCH 4, 2011
MAJOR GRADE ASSIGNMENT

For this activity, you will be creating a titration curves to determine the end point/equivalence point of the reaction.

Titration Curve #1

1. Plot a titration curve using this data.

Volume of Titrant	0.00	10.11	20.00	22.00	24.00	25.00	26.00	28.00	30.00	40.00	50.00
pH	1.00	1.37	1.95	2.19	2.70	7.00	11.30	11.75	11.96	12.36	12.52

Please answer these questions on the back of your titration curve.

1. Is the titrant an acid or a base? Explain your reasoning.
2. Is the sample acidic or basic? Explain your reasoning.
3. Is the sample a strong or weak species? Explain your reasoning.
4. What is the pH at the equivalence point/end point?

Titration Curve #2

1. Plot a titration curve using this data. (Assume a 0.100 *M* sample.)

Titrant (mL)	0.00	5.00	10.00	12.50	15.00	20.00	24.00	25.00	26.00	30.00	40.00	50.00
pH	2.88	4.13	4.58	4.75	4.93	5.35	6.12	8.74	11.30	11.98	12.35	12.49

Please answer these questions on the back of your titration curve.

1. Is the titrant an acid or a base? Explain your reasoning.
2. Is the sample acidic or basic? Explain your reasoning.
3. Is the sample a strong or weak species? Explain your reasoning.
4. What is the pH at the equivalence point/end point?

Please answer the questions on notebook paper

1. What is a titration?
2. What is a titration curve?
3. What is the equivalence point/end point?
4. How do you know you have hit the equivalence point/end point in a titration?
5. What is an indicator?
6. What is the pH range for an acid?
7. What is the pH range for a base?
8. What are some characteristics of an acid?
9. What are some characteristics of a base?
10. What is the name for an acid-base reaction?