

Activity C33: Determine pK_a by Half Titration (pH Sensor)

Concept	<i>DataStudio</i>	<i>ScienceWorkshop</i> (Mac)	<i>ScienceWorkshop</i> (Win)
Acids, bases & salts	C33 Half Titration.DS	C33 Half Titration	C33_HALF.SWS

Equipment Needed	Qty	Equipment Needed	Qty
pH Sensor (CI-6507A)	1	Wash bottle	1
Base and support rod (ME-9355)	1	Protective gear	PS
Beaker, 250 mL	5		
Buret, 50 mL	1	Chemicals and Consumables	Qty
Clamp, buret (SE-9446)	2	Acetic acid, 0.1 molar	100 mL
Funnel	1	Buffer solution: high pH	100 mL
Graduated cylinder	1	Buffer solution: low pH	100 mL
Magnetic stirrer and stir bar	1	Sodium hydroxide, 0.10 molar	50 mL
Pipette, 10 mL	1	Water, distilled	500 mL

What Do You Think?

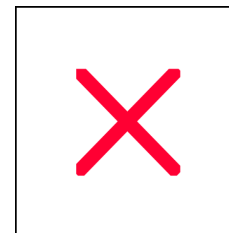
How does the strength of an acid as measured by its pK_a affect the shape of the acid's titration curve?



Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

Background

All acids ionize in water to form hydrogen (H^+) or hydronium ions (H_3O^+). The degree of ionization is an indication of the strength of an acid. An acid that ionizes completely is said to be 'strong'. The ionization is complete and no molecular acid remains in solution. The rate constant (k_f) is a number which indicates the degree of dissociation of the acid. For strong acids like this example, k_f (forward reaction rate) is large and there is no reverse reaction ($k_r = 0$).



Strong Acid

A 'weak' acid ionizes but the ions can reform the original molecular form of the acid. Acids that ionize and then recombine again to form molecules eventually reach equilibrium. Equilibrium is the condition when the rate of the ionization equals the rate of formation of the molecular species.

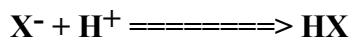
Weak Acid

For a weak acid the ratio of k_f to k_r is a number less than one. The ratio k_f/k_r is also known as K_a or the equilibrium constant. The K_a for the above reaction can be written:

The **negative log of K_a** is known as the **p K_a** of the acid. The smaller the equilibrium constant, the less ionized and weaker the acid. The smaller the K_a , the larger the p K_a because the p K_a is the negative log of K_a . If a base is added to an acid, the acid is neutralized to form a salt and water.



The salt of a weak acid in solution with the weak acid is said to form a buffer. A buffer is a solution which resists large changes in pH because it provides an acid source, in this case, the remaining HX and a base source, in this case, NaX. The sodium salt of the weak acid can react with hydrogen ions to reform an acid that does not ionize very well.



The behavior of a buffer system is given by this buffer equation:

$$\text{pH} = \text{p}K_a + \log \frac{[\text{salt}]}{[\text{acid}]}$$

A buffer solution can be used to determine the p K_a of an acid under special conditions.

For example, if 50 milliliters (mL) of a 0.1 Molar solution of a weak acid, HA, with a p K_a of 4.0 is reacted with 50 mL of 0.1 Molar base (sodium hydroxide, or NaOH), the solution will reach the equivalence point and all of the acid will be neutralized. However, if only 25 mL of base are added, the acid will be 50 percent neutralized. The molar concentrations of the salt and the acid will be equal. This causes the log term in the buffer equation to cancel. The pH of the solution will equal the p K_a of the weak acid:

$$\begin{aligned}\text{pH} &= \text{p}K_a + \log \frac{[\text{salt}]}{[\text{acid}]} \\ &= 4.0 + \log \frac{[0.05]}{[0.05]} \\ &= 4.0 + \log 1 \\ &= 4.0 + 0 \\ \text{pH} &= 4.0 \text{ (the p}K_a \text{ of the acid)}\end{aligned}$$

This relationship can be used to ascertain the pH at the midpoint in the titration of a weak acid.

SAFETY REMINDERS

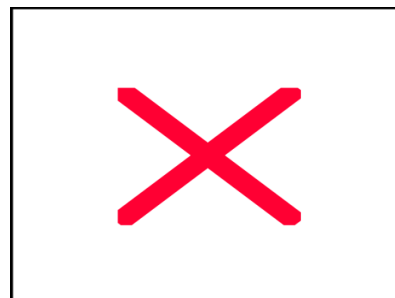
- Wear protective gear.
- Follow directions for using the equipment.
- Handle and dispose of all chemicals and solutions properly.

For You To Do

Titrate a weak acid solution (acetic acid) with a basic sodium hydroxide solution, NaOH, of known molarity. Add the sodium hydroxide solution at a constant rate. Use the pH Sensor to measure the change in pH of the acid solution. Use *DataStudio* or *ScienceWorkshop* to record and display the data. Use the data to determine the p K_a of the weak acid solution.

PART I: Computer Setup

1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the DIN plug of the pH Sensor to Analog Channel A on the interface.
3. Open the file titled as shown;

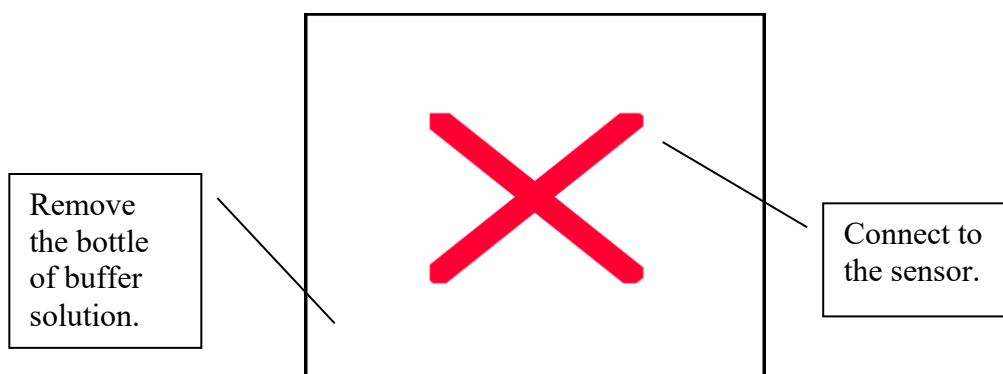


<i>DataStudio</i>	<i>ScienceWorkshop (Mac)</i>	<i>ScienceWorkshop (Win)</i>
C33 Half Titration.DS	C33 Half Titration	C33_HALF.SWS

- The *DataStudio* file has a Digits display of pH and a Graph display of pH versus time. Read the Workbook display for more information.
- The *ScienceWorkshop* document has a Graph display of the pH versus time.
- Data recording is set at five measurements per second (5 Hz).

PART II: Sensor Calibration and Equipment Setup**Calibrate the Sensor**

- To calibrate the pH Sensor you will need the following: wash bottle, distilled water, three beakers, buffer solutions of high pH (e.g. pH 10) and low pH (e.g. pH 4), pH Sensor.
 - Put distilled water into the wash bottle and into one of the beakers. Put about 100 mL of the high pH buffer solution in one of the other two beakers and about 100 mL of the low pH buffer solution into the third beaker.
1. Remove the pH electrode from its bottle of buffer solution. Connect the electrode to the pH Sensor amplifier. To connect the electrode, push the BNC plug onto the receptacle on the



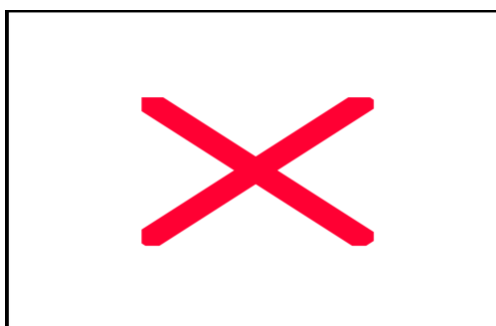
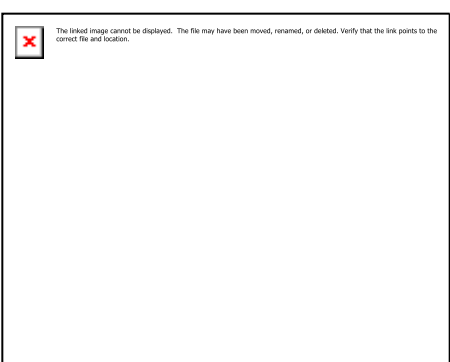
Sensor amplifier and turn the BNC plug clockwise until it 'clicks' into place.

2. Use the wash bottle to rinse the end of the electrode. Soak the pH electrode in the beaker of distilled water for 10 minutes.

3. In the Experiment Setup window, double-click the pH Sensor icon.



- In *DataStudio*, the Sensor Properties window will open. Click the ‘Calibration’ tab. In *ScienceWorkshop*, the Sensor Setup window will open.



4. Calibrate with the high pH buffer solution.

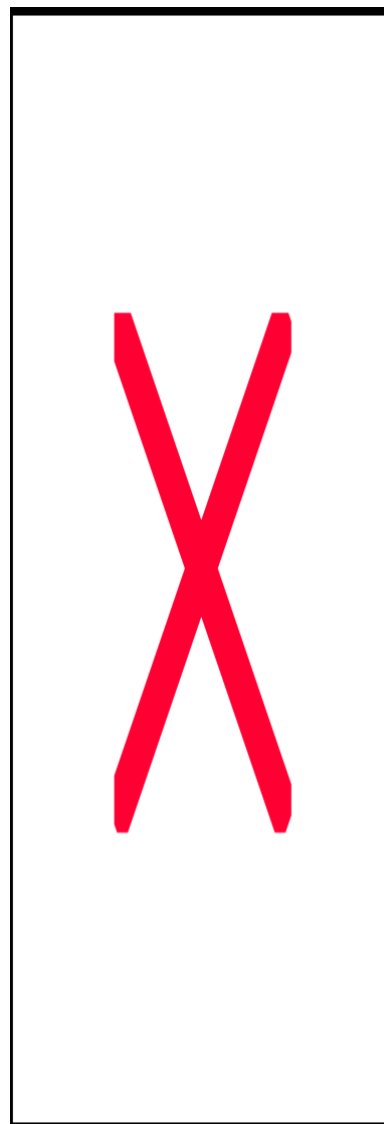
- Put the end of the pH electrode into the high pH buffer solution.
 - Check the voltage under ‘Current Reading’ in *DataStudio* or next to ‘Cur Value:’ in *ScienceWorkshop*.
 - When the voltage stabilizes, click the ‘Take Reading’ button under ‘High Point’ in *DataStudio* or the ‘Read’ button in the row for ‘High Value:’ in *ScienceWorkshop*.
 - Enter the pH value of the buffer solution.
5. Thoroughly rinse the pH electrode with distilled water and dry it with a tissue.
6. Calibrate with the low pH buffer solution.
- Put the end of the pH electrode in the low pH buffer solution.
 - Check the voltage under ‘Current Reading’ in *DataStudio* or next to ‘Cur Value:’ in *ScienceWorkshop*.
 - When the voltage stabilizes, click the ‘Take Reading’ button under ‘Low Point’ in *DataStudio* or the ‘Read’ button in the row for ‘Low Value:’ in *ScienceWorkshop*.
 - Enter the pH value of the buffer solution. Click **OK** to return to the Experiment Setup window.
7. Thoroughly rinse the pH electrode with distilled water and dry gently.

Equipment Setup




1. Place 100 mL of acetic acid in a 250-mL beaker. Put a spin bar in the beaker.
2. Place the beaker with acid and spin bar on the magnetic stirrer.
3. Use the buret clamp and base and support rod to position the pH electrode so the end of the electrode is in the acid, but will not interfere with the spin bar.
4. Use another clamp to support the 50-mL buret so the end of the buret is above the acetic acid. (Be sure the buret valve is closed!)
5. Put 50 mL of the sodium hydroxide solution into the buret.
6. Turn on the magnetic stirrer.

PART III: Data Recording

1. When you are ready, start recording data.
2. Open the buret valve so the base solution pours into the acetic acid at a slow, constant rate.
 - Adjust the buret valve so the solution flows at a rate of about 1 mL per second.
3. When all of the sodium hydroxide is added to the acid, stop data recording.
4. Turn off the magnetic stirrer.
5. Carefully remove the pH electrode, rinse it thoroughly in distilled water, and put it in its bottle of buffer solution.
6. Dispose of the mixture as instructed.



Analyzing the Data

1. Use the built-in analysis tools in the Graph display to find the minimum pH and the maximum pH. (Hint: In *DataStudio*, click the ‘Statistics menu’ button (). In *ScienceWorkshop*, click the ‘Statistics’ button () to open the statistics area in the Graph display. Click the ‘Statistics menu’ button () and select Minimum and Maximum.)
3. Record the pH of the acid solution at the beginning (Minimum “y”) before the reaction. Record the pH of the acid solution at the end of the reaction (Maximum “y”).

Record your results in the Lab Report section.

Lab Report - Activity C33: Determine pKa by Half-Titration**What Do You Think?**

How does the strength of an acid as measured by its pKa affect the shape of the acid's titration curve?

Data Table

Item	Value
Beginning pH	
Ending pH	

Questions

1. What was the pH of the starting acetic acid solution?
2. What happened to the pH of the solution as the sodium hydroxide was added? Is this what you expected to happen?
3. The pH at the end of the plot gives the pK_a of the acid. What is the pK_a of the acetic acid?
4. The negative antilog of the pK_a is the K_a of the acid. What is the K_a of the acid?
5. Sketch the titration graph for a similar titration with a different acid that has a pK_a equal to 2.5. Is this acid a weak or strong acid?

6. The acid used in this experiment is a monoprotic acid which means only one hydrogen ion is ionized. What would happen to the titration graph if a diprotic (two hydrogen ions are ionized) acid would replace the acetic acid used in this experiment.