Virtual Chemlab Workbook
Student Edition
BYU Independent Study
Chemistry 47
Pressure-Volume Relationship for Gases

Purpose
Investigate the relationship between the pressure and volume of a gas.

Background
Robert Boyle, a philosopher and theologian, studied the properties of gases in the 17th century. He noticed that gases behave similarly to springs; when compressed or expanded, they tend to ‘spring’ back to their original volume. He published his findings in 1662 in a monograph entitled *The Spring of the Air and Its Effects*. You will make observations similar to those of Robert Boyle.

The purpose of this experiment is to learn about the relationship between pressure and volume of an ideal gas. In order to do this, you will be changing the pressure or volume while the other is kept constant and observing what happens.

Procedure
1. Start *Virtual ChemLab* and select *Pressure-Volume Relationship for Gases* from the list of assignments.
2. The lab will open in the Gases laboratory.
3. Note that the balloon contains an ideal gas with a molecular weight of 4 g/mol. There is 0.3 mol of gas at a temperature of 298 K, a pressure of 1 atm, and a volume of 7.336 L. To the left of the pressure meter is a lever that will decrease and increase the pressure as it is moved up or down; the digit is changed depending on how far the lever is moved. Digits may also be clicked directly to type in the desired number. You may want to practice adjusting the lever so that you can decrease and increase the pressure accurately. Make sure the moles, temperature, and pressure are returned to their original values before proceeding.
4. Click on the *Lab Book* to open it. If data from a previous student appears, delete it. Once back in the lab, click the *Save* button to start recording your data. Increase the pressure from 1 atm to 10 atm one atmosphere at a time. Click *Stop*. A blue data link will appear in the lab book. To help keep track of your data links, enter ‘Ideal Gas 1’ next to the link.
5. *Zoom Out* by clicking the green arrow next to the *Save* button. Click *Return Tank* on the gas cylinder. Choose *Ideal 8* (Ideal 8 MW = 222 g/mol). Click on the balloon chamber to *Zoom In*. Repeat the experiment with this gas labeling the data link as ‘Ideal Gas 8.’
6. *Zoom Out* by clicking on the green arrow next to the *Save* button. Click on the *Stockroom* and then on the *Clipboard* and select *Balloon Experiment N2*. Set the parameters to 0.3 mol of gas at a temperature of 298 K, and a pressure of 1 atm (the volume should be 7.336 L). You may have to click on the *Units* button for some of the variables to change it to the correct unit. Repeat the experiment with this gas labeling the data link ‘Real Gas N2.’
Analysis
1. Click the data link for Ideal Gas 1. Click the Select All button in the Data Viewer window that will pop up. If you are using Windows use CTRL-C, or on a Macintosh CMD-C to copy the data. Paste the data into a spreadsheet and create a graph with volume on the x-axis and pressure on the y-axis. Also create a graph for your data from Ideal Gas 8 and Real Gas N₂.

2. Based on your data, what relationship exists between the pressure and volume of a gas (assuming a constant temperature)? (Student response)

3. Look up a statement of Boyle’s Law in your textbook. Do your results further prove this? (Student response)

4. Complete the tables from the data saved in your lab book. Use only a sampling of the data for pressure at 1, 3, 6, and 9 atm.

<table>
<thead>
<tr>
<th>Volume (L)</th>
<th>Pressure (atm)</th>
<th>Product (P × V)</th>
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5. What conclusions can you make about the PV product with Ideal Gas 1, MW = 4 g/mol? (Student response)

How is the PV product affected using an ideal gas with a different molecular weight (Ideal Gas 8)? (Student response)
6. How are your results affected using a Real Gas (N₂)?
   *(Student response)*

**Going Further**

Based on the results of this lab, develop a hypothesis to explain why weather balloons are only partially filled before they are released into the atmosphere. (These balloons can reach altitudes of 40,000 ft.)

*(Student response)*
Temperature-Volume Relationship for Gases

Purpose
Investigate the relationship between the temperature and volume of a gas.

Background
Charles’ Law was discovered by Joseph Louis Gay-Lussac in 1802, based on unpublished work done by Jacques Charles in about 1787. Charles had found that a number of gases expand to the same extent over the same 80 degree temperature interval. You will be observing properties similar to those that Charles studied.

The purpose of this experiment is to learn about the relationship between temperature and volume of an ideal gas. You will do this by keeping all variables constant except temperature and volume to observe what happens.

According to the kinetic theory of gases, the average kinetic energy of the gas increases with the temperature. When gas is in a rigid container, the pressure (exerted by the gas on the walls of the container) increases as the temperature increases.

Procedure
1. Start Virtual ChemLab and select Temperature-Volume Relationship for Gases from the list of assignments.

2. The lab will open in the Gases laboratory.

3. Note that you are using an Ideal gas with a molecular weight of 4 g/mol. There is 0.05 mol of gas at a temperature of 100°C, a pressure of 1 atm, and a volume of 1.531 L. To the left of the temperature meter is a lever that will decrease and increase the temperature as it is moved up or down; the digit is changed depending on how far the lever is moved. Digits may also be clicked directly to type in the desired number, or they can be rounded by clicking on the $R$ button. You may want to practice adjusting the lever so that you can decrease and increase the temperature accurately. Make sure the moles, temperature, and pressure are returned to their original values before proceeding.

4. Click on the Lab Book to open it. If data from a previous student appears, delete it. Once back in the lab, click the Save button to start recording your data. Increase the temperature from 100°C to 1000°C 100 degrees at a time. Click Stop. A blue data link will appear in the lab book. To help keep track of your data links, enter ‘Ideal Gas 1’ next to the link.

Analysis
1. Click the data link for Ideal Gas 1. Click the Select All button in the Data Viewer window. If you are using Windows, use CTRL-C or on a Macintosh CMD-C to copy the data. Paste your data into a spreadsheet and create a graph with volume on the $x$-axis and temperature on the $y$-axis.
2. Based on your data, what relationship exists between the pressure and volume of a gas
(assuming constant temperature)?
(Student response)

3. Look up a statement of Charles’ Law in your textbook. Do your results further prove this?
(Student response)

4. Using the spreadsheet, fit the data to a curve (linear fit). The lowest possible temperature is
reached when an Ideal Gas has zero volume. This temperature is the $y$-intercept for the
plotted line. What is this temperature?
(Student response)

5. Zoom Out by clicking on the green arrow next to the Save button. Click on the Stockroom
and then on the Clipboard and select Balloon Experiment N2. Set the parameters to 0.05 mol
of gas at a temperature of 100°C, and a pressure of 1 atm (the volume should be 1.531 L).
You may have to change the units for some of the variables. Repeat the experiment that was
performed on the ideal gas by increasing the temperature from 100°C to 900°C by
increments of 100°C saving the data to the lab book and label the link as ‘Real Gas N2.’ Plot
the data and fit it to a linear curve.

6. What lowest temperature did you find for the Real Gas (N2)?
(Student response)

Going Further
Develop a Hypothesis
Interpret the results of this lab in terms of the kinetic theory of matter as it applies to gases.
(Student response)
Investigation of Gas Pressure and Mass

Purpose
Investigate the relationship between the internal pressure of a gas and the applied external pressure by placing weights on a frictionless massless piston.

Background
An understanding of pressure is an integral part of our understanding of the behavior of gases. Pressure is defined as the force per unit area exerted by a gas or other medium. The pressure of a gas is affected by many variables, such as temperature, external pressure, volume, number of moles of a gas, and other factors. This experiment will help you to become more familiar with pressure.

Procedure
1. Start Virtual ChemLab and select Investigation of Gas Pressure and Mass from the list of assignments.

2. The lab will open in the Gases laboratory.

3. To investigate the relationship between mass added to the piston to apply an external pressure, note that in this experiment $P_{int} = P_{mass} + P_{ext}$ where $P_{int}$ is the internal pressure or the pressure of the gas in the cylinder, $P_{mass}$ is the pressure being exerted on the gas by adding weights to the piston, and $P_{ext}$ is the pressure being exerted on the piston by the gas in the chamber. If there is no mass on the piston, then $P_{int} = P_{ext}$.

4. Click the green Piston button to move the piston into position. Record the mass (Force, in tons) and the internal pressure (in psi) in the Data Table.

5. Click on the tenths place for mass and add 0.5 tons of mass to the piston. Record the mass and internal pressure in the Data Table. Repeat this for 2.5 tons (the weight of a small car).

<table>
<thead>
<tr>
<th>mass (tons)</th>
<th>external pressure (psi)</th>
<th>calculated internal pressure (psi)</th>
<th>internal pressure from meter (psi)</th>
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Analyze
1. You must now calculate the pressure being exerted by the 0.5 tons or, $P_{mass}$. First, convert tons to psi (pounds per square inch).

How many pounds is 0.5 tons?
(Student response)
The diameter of the piston is 15 cm. What is the radius (in cm)?
(Student response)

1 inch = 2.54 cm. What is the radius of the piston in inches?
(Student response)

The area of the circular piston is found by \( A = \pi r^2 \). What is the area of the piston in square inches (in²)?
(Student response)

The pressure exerted on the piston by the added mass in pounds per square inch (psi) can be determined by dividing the mass in pounds by the area in square inches. What is the pressure exerted by the added mass in psi?
(Student response)

The internal pressure is the sum of the external pressure and the added mass. What is the calculated internal pressure? Compare your calculated answer to the internal pressure meter answer. How do they compare?
(Student response)

2. Predict the internal pressure (in psi) when 2.5 tons are added.
(Student response)

How does your calculated answer compare to the internal pressure meter when you add 2.5 tons of mass? Record your data in the Data Table.
(Student response)
Derivation of Ideal Gas Law

Purpose
Derive the Ideal Gas Law from experimental procedures and determine the value of the Universal Gas Constant ($R$).

Background
An ideal gas is a hypothetical gas whose pressure, volume, and temperature follow the relationship $PV = nRT$. No ideal gases actually exist, although all real gases behave similarly to ideal gases near room temperature and pressure. All gases can be described to some extent using the Ideal Gas Law, and it is important in our understanding of how all gases behave. You will be deriving the Ideal Gas Law.

The state of any gas can be described using the four variables: pressure ($P$), volume ($V$), temperature ($T$), and the number of moles of gas ($n$). Each experiment in the Gases Simulation allows three of these variables (the independent variables) to be manipulated or changed and then shows the effect on the remaining variable (the dependent variable).

Procedure
1. Start Virtual ChemLab and select Ideal Gas Law from the list of assignments.

2. The lab will open in the Gases laboratory.

3. Use the balloon experiment to describe the relationship between pressure ($P$) and volume ($V$). Increase and decrease the pressure using the lever to the left of the pressure to determine the effect on volume. What can you conclude about the effect of pressure on volume? Write a mathematical relationship using the proportionality symbol ($\propto$).
   
   (Student response)

4. Use this same experiment to describe the relationship between temperature ($T$) and volume, by increasing and decreasing the temperature. What can you conclude about the effect of temperature on volume? Write a mathematical relationship using the proportionality symbol ($\propto$).
   
   (Student response)

5. Use this same experiment to describe the relationship between moles of gas and volume, by increasing and decreasing the number of moles ($n$). What can you conclude about the effect of moles on volume? Write a mathematical relationship using the proportionality symbol ($\propto$).
   
   (Student response)
6. Since volume is proportional to inverse pressure, temperature and moles we can combine these three proportions into one proportion showing $V$ proportional to $1/P$, $T$, and $n$. Write one combined proportion to show the relationship of volume to pressure, temperature and moles.

(Student response)

7. This proportional relationship can be converted into a mathematical equation by inserting a proportionality constant ($R$) into the numerator on the right side. Write this mathematical equation and rearrange with $P$ on the left side with $V$.

(Student response)

8. This equation is known as the Ideal Gas Law. Using data for volume, temperature, pressure and moles from one gas apparatus experiment, calculate the value for $R$ with the units L-atm/K-mol. (Show all work and round to three significant digits).

(Student response)

9. Using the relationship between atmospheres and mm Hg of 1 atm = 760 mm Hg, calculate the value for $R$ with the units L-mm Hg/K-mol. (Show all work and round to three significant digits).

(Student response)

10. Using the relationship between atmospheres and kPa of 1 atm = 101.3 kPa, calculate the value for $R$ with the units L-kPa/K-mol. (Show all work and round to three significant digits).

(Student response)
**Ideal vs Real Gases**

**Purpose**
To investigate how temperature and pressure changes affect ideal and real gases.

**Background**
In the Ideal Gas Law lab previously completed, you learned how to derive the Ideal Gas Law \( PV = nRT \) from observations about the relationships between volume, temperature, pressure and moles. You calculated the value for the Universal Gas Constant \( R \) for an ideal gas. In this experiment you will also calculate the Universal Gas Constant \( R \) but with both ideal and real gases and at high and low temperatures and pressures.

**Procedure**
1. Start *Virtual ChemLab* and select *Ideal vs Real Gases* from the list of assignments.

2. The lab will open in the Gases laboratory with Ideal Gas 1.

3. Click on the *Units* buttons to change the units to L or mL for volume, atm for pressure, and K for temperature.

To change the value of pressure, temperature or moles, the lever to the left of each number can be used. The value will decrease and increase as the lever is moved up or down; the digit is changed depending on how far the lever is moved. Digits may also be clicked directly to type in the desired number. Clicking to the left of the farthest left digit will add the next place; for example, if you have 1.7 atm you can click left of the 1 and enter 2 to make it 21.7 atm or click left of the 2 and enter 5 to make it 521.7 atm.

The small \( R \) button in the upper left corner rounds the number. Clicking several times will round from ones to tens to hundreds. The green arrow to the left of the *Save* button will *Zoom Out*. Clicking *Return Tank* on the gas cylinder will return the tank to the rack and allow you to select a different gas. Clicking the gas chamber will *Zoom In* to allow you to change parameters.

Be careful not to make the balloon so large that it bursts. If it does, click the red *Reset* button in the top right and then reset your units and values for each parameter.

Remember that volume must be in L. If mL appears, you must convert to L in your calculations.

4. Complete the Data Table for the following gases and conditions (all with 0.1 mol):
   a. Ideal gas at low \( T = 10 \) K, high \( T = 1000 \) K, low \( P = 1 \) atm, high \( P = 15 \) atm
   b. Methane gas (CH\(_4\)) at low \( T = 160 \) K, high \( T = 400 \) K, low \( P = 1 \) atm, high \( P = 15 \) atm
   c. Carbon dioxide gas (CO\(_2\)) at low \( T = 250 \) K, high \( T = 1000 \) K, low \( P = 1 \) atm, high \( P = 15 \) atm
### Data Table

<table>
<thead>
<tr>
<th>Gas</th>
<th>V (L)</th>
<th>P (atm)</th>
<th>T (K)</th>
<th>n (mol)</th>
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</thead>
<tbody>
<tr>
<td>Ideal, low T, low P</td>
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<tr>
<td>Ideal, low T, high P</td>
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### Analysis

1. If $PV = nRT$ then $R = \frac{PV}{nT}$. Complete the Results Table for each experiment above. Use four significant digits.

### Results Table

<table>
<thead>
<tr>
<th>Gas</th>
<th>Calculated R (l-atm/K-mol)</th>
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<tbody>
<tr>
<td>Ideal, low T, low P</td>
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<td>Ideal, low T, high P</td>
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<td>Ideal, high T, high P</td>
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<td>CO₂, high T, low P</td>
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<td>CO₂, high T, high P</td>
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</tbody>
</table>

2. Which gases and conditions show significant deviation from the ideal value of $R$? Explain (see text page 429).

(Student response)
Acid-Base Titrations

**Purpose**
To standardize a NaOH solution and to measure the molarity of an unknown acetic acid solution by titration with standardized NaOH.

**Background**
Titrations provide a method of quantitatively measuring the concentration of an unknown solution. In an acid-base titration, this is done by delivering a titrant of known concentration to an analyte of known volume. (The concentration of an unknown titrant can also be determined by titration with an analyte of known concentration and volume.) Titration curves (graphs of volume vs. pH) have characteristic shapes. By comparison, the graph can be used to determine the strength or weakness of an acid or base. The equivalence point of the titration, or where the analyte has been completely consumed by the titrant, is identified as the point where the pH changes rapidly over a small volume of titrant delivery. There is a steep incline or decline at this point of the titration curve. In this assignment, you will determine the molarity of an unknown solution of NaOH by using a primary standard, potassium hydrogen phthalate (KHP). You will then use a standardized solution of NaOH to determine the molarity of an unknown solution of acetic acid.

**Procedure**

**Part 1**
1. Start *Virtual ChemLab* and select *Acid-Base Titrations* from the list of assignments.

2. The lab will open in the Titrations laboratory.

3. Click the **Lab Book** to open it. Click the **Buret Zoom View** window to bring it to the front. Click the **Beakers** drawer and place a beaker in the spotlight next to the balance. Click on the **Balance** area to zoom in, open the bottle of KHP by clicking on the lid (*Remove Lid*). Drag the beaker to the balance to place it on the balance pan; tare the balance. Pick up the **Scoop** and scoop out some KHP; as you drag your cursor and the scoop down the face of the bottle it picks up more. Select the largest sample possible and drag the scoop to the beaker until it snaps in place which will place the KHP in the beaker (about 1 g). Unload the full scoop twice into the beaker so you have around 2.0 g and record the mass of the sample in the Data Table. Place the beaker in the spotlight outside the balance and **Zoom Out**.

4. Drag the beaker to the sink and hold it under the tap to add a small amount of water. Place it on the stir plate and add the calibrated pH meter probe to the beaker. Add *Phenolphthalein* for the indicator.

5. The buret will be filled with NaOH. Click the **Save** button in the **Buret Zoom View** window so the titration data be saved. The horizontal position of the orange handle is off for the stopcock. Open the stopcock by pulling down on the orange handle. The vertical position delivers solution the fastest with three intermediate rates in between. Turn the stopcock to one of the fastest positions. Observe the titration curve. When the blue line begins to turn up,
double-click the stopcock to turn it off. Move the stopcock down one position to add volume drop by drop.

There are two methods for determining the volume at the equivalence point: (1) Stop the titration when a color change occurs. Click the Stop button in the Buret Zoom View. A blue data link will appear in the lab book. Click the blue data link to open the Data View window. Scroll down to the last data entry and record the volume at the equivalence point in Data Table 1. OR (2) Add drops slowly through the equivalence point until the pH reaches approximately 12. Click the Stop button in the Buret Zoom View. A blue data link will appear in the lab book. Click the blue data link to open the Data View window. Click Select All button to copy and paste the data to a spreadsheet. Plot the first derivative of pH vs volume. The peak will indicate the volume of the equivalence point since this is where the pH is changing the most as volume changes.

Repeat at least two additional times recording data in Data Table 1. Do not forget to refill the buret with NaOH and place the pH meter and indicator in the beaker each time.

The molecular weight of KHP is 204.22 g/mol.

Unknown # _____

Data Table 1

<table>
<thead>
<tr>
<th>Trial</th>
<th>mass KHP (g)</th>
<th>volume NaOH (mL)</th>
<th>molarity NaOH (mol/L)</th>
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<tbody>
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<td>1</td>
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<td>5</td>
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</table>

Analyze
1. Write a balanced chemical equation for the reaction of KHP and NaOH.
   (Student response)

2. What is the average molarity of the unknown NaOH for your closest three titrations?
   (Student response)

Part 2
1. Click in the Stockroom. Click on the clipboard and select Weak Acid Strong Base Unknown. The base is 0.3060 M NaOH and the buret has been filled with it. The weak acid is an unknown concentration of acetic acid. 25 mL of acetic acid has been added to the beaker. The indicator is phenolphthalein and has already been added. The pH meter has been turned on and calibrated.

2. Open your lab book and click the Save button on the Buret Zoom View window before starting the titration. Begin the titration by opening the stopcock on the buret. Observe what happens to the pH as the titration proceeds. It is important that the volume increments and pH measurements
near the equivalence point are small enough that the equivalence point can be determined as closely as possible. As the titration nears the end point, decrease the rate of delivery to the slowest rate. You may want to run a preliminary titration to have a general idea where the equivalence point will be. Immediately after the color of the indicator changes, stop the titration and read the amount of titrant that has been delivered from the buret by clicking **Stop** in the Buret Zoom View window. Open the blue data link in the lab book and determine the volume at the equivalence point using one of the methods described in Part 1. Record the volume in Data Table 2.

3. Move the used beaker to the disposal bucket and repeat the experiment at least two more times. Fill the buret with NaOH. Place a beaker in the spotlight left of the stir plate and fill the beaker half full with acetic acid (HAc). Open the Pipets drawer and double-click on a 25 mL pipet. Click the pipet bulb (**Fill Pipet**) to fill the pipet. Move the beaker to the spotlight right of the stir plate and drag a new beaker to the spotlight under the pipet and click the pipet bulb to **Empty Pipet**. Drag the beaker to the stir plate. Place the pH meter probe in the beaker and add phenolphthalein indicator. Make certain the lab book is open and click **Save** in the Buret Zoom View. Now you may proceed with the titration in the same fashion you did before.

Unknown # _____

**Data Table 2**

<table>
<thead>
<tr>
<th>Trial</th>
<th>volume NaOH (mL)</th>
<th>molarity NaOH (mol/L)</th>
<th>volume HAc (mL)</th>
<th>molarity HAc (mol/L)</th>
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**Analyze**

1. Write a balanced equation for the reaction between HAc and NaOH.  
   *(Student response)*

2. What is the average molarity of the unknown acetic acid solution?  
   *(Student response)*
Ionization Constants of Weak Acids

Purpose
Measure ionization constants of weak acids such as bromocresol green (BCG).

Procedure
1. Start Virtual ChemLab and select Ionization Constants of Weak Acids from the list of assignments.

2. The lab will open in the Titration laboratory.

3. Using the bottle of 0.1104 M NaOH, fill the buret. The bottle will snap into position to pour and remain until buret is full. Click the buret to open the buret window.

4. Click the Beakers drawer and place a beaker from the drawer in the spotlight to the left of the stir plate. Fill the beaker half full with 0.1031 M HAc. Open the Pipets drawer and double-click on a 10 mL pipet. Click the pipet bulb (Fill Pipet) to fill. Move the beaker to the spotlight right of the stir plate and place a new beaker under the pipet and click the pipet bulb to Empty Pipet. Move the beaker with 10 mL HAc and place it on the stir plate. Click the Stir Plate Switch to turn it on. Place the calibrated pH meter probe in the beaker. Add Bromocresol Green to the beaker (double-click on the bottle labeled Bro G).

5. What is the color and pH of the solution? (Student response)

6. The horizontal position of the orange handle is off for the stopcock. Open the stopcock by pulling down on the orange handle. The vertical position delivers solution the fastest with three intermediate rates in between off. Turn the stopcock two stops down from the off position. When there is a color change, double-click the stopcock to turn it off. If it is necessary to repeat the experiment, do not forget to refill the buret with NaOH and place the pH meter in the beaker on the stir plate.

7. What is the color and pH of the solution? (Student response)

Continue to add NaOH as before. What is the final color of the solution? (Student response)

Analyze
1. An acid-base indicator is usually a weak acid with a characteristic color. Because bromocresol green is an acid, it is convenient to represent its rather complex formula as HBCG. HBCG ionizes in water according to the following equation:
\[
\text{HBCG} + \text{H}_2\text{O} \rightarrow \text{BCG}^- + \text{H}_3\text{O}^+
\]
(yellow) (blue)

The \(K_a\) (the equilibrium constant for the acid) expression is

\[
K_a = \frac{[\text{BCG}^-][\text{H}_3\text{O}^+]}{[\text{HBCG}]}
\]

When \([\text{BCG}^-] = [\text{HBCG}]\), then \(K_a = [\text{H}_3\text{O}^+]\). From the pH of the solution the \([\text{H}_3\text{O}^+]\) and \(K_a\) can be determined.

2. What color is an equal mixture of HBCG and BCG\(^-\)? What is the pH at the first appearance of this color?
   (Student response)

3. What is the \(K_a\) for bromocresol green?
   (Student response)

\textbf{You are the Chemist}

Design and carry out an experiment to measure the \(K_a\) of bromocresol purple and methyl orange.
Study of Acid-Base Titrations

Purpose
To observe the changes that occur during the titration of a strong acid and strong base.

Background
Titrations provide a method of quantitatively measuring the concentration of an unknown solution. In an acid-base titration, this is done by delivering a titrant of known concentration to an analyte of known volume. (The concentration of an unknown titrant can also be determined by titration with an analyte of known concentration and volume.) Titration curves (graphs of volume vs. pH) have characteristic shapes. By comparison, the graph can be used to determine the strength or weakness of an acid or base. The equivalence point of the titration, or the point where the analyte has been completely consumed by the titrant, is identified by the point where the pH changes rapidly over a small volume of titrant delivery. There is a steep incline or decline at this point of the titration curve. In this assignment, you will observe this titration curve by titrating the strong acid HCl with the strong base NaOH.

Procedure
1. Start Virtual ChemLab and select Study of Acid-Base Titrations from the list of assignments.
2. The lab will open in the Titration laboratory.
3. Click the Lab Book to open it; if other students have left data links highlight and delete them.
4. The buret will be filled with NaOH. The horizontal position of the orange handle is off for the stopcock. Click the Save button in the Buret Zoom View window. Open the stopcock by pulling down on the orange handle. The vertical position delivers solution the fastest with three intermediate rates in between. Turn the stopcock to one of the fastest positions. Observe the titration curve. When the volume reaches 35 mL, double-click the stopcock to stop the titration. Click Stop in the Buret Zoom View. A blue data link will be created in the lab book, click on it to view the data.

Analyze
1. The beaker contains 0.3000 M HCl and the buret contains 0.3000 M NaOH. Write a complete balanced equation for the neutralization reaction between HCl and NaOH.

   (Student response)

The following questions can be answered by examining the Plot and Data Viewer windows.

2. What was the pH and color of the solution at the beginning of the titration?

   (Student response)
3. What was the pH and color of the solution at the end of the titration?
   *(Student response)*

4. Examine the graph of the pH vs volume. Sketch the shape of the titration graph of pH vs volume (blue line).
   *(Student response)*

5. What happens to the pH around 25 mL?
   *(Student response)*

6. What would cause the change observed in question #4?
   *(Student response)*

7. Examine the graph of the conductivity vs volume. Sketch the shape of the titration graph of conductivity vs volume (red line).
   *(Student response)*
8. What happens to the conductivity during the titration?
   (Student response)

9. What would cause the change observed in question #8?
   (Student response)

**Further Investigations**
Complete a similar laboratory activity except using a polyprotic acid. Click in the Stockroom. Click on the clipboard and select *Polyprotic Acid Strong Base*.

1. What observations can you make about the graph of a titration with a polyprotic acid?
   (Student response)
Molecular Weight Determination by Acid-Base Titration

Purpose
Determine the molecular weight of a solid acid by titration methods.

Background
Titrations provide a method of quantitatively measuring the concentration of an unknown solution. In an acid-base titration, this is done by delivering a titrant of known concentration to an analyte of known volume. (The concentration of an unknown titrant can also be determined by titration with an analyte of known concentration and volume.) Titration curves (graphs of volume vs. pH) have characteristic shapes. By comparison, the graph can be used to determine the strength or weakness of an acid or base. The equivalence point of the titration, where the analyte has been completely consumed by the titrant, is identified as the point where the pH changes rapidly over a small volume of titrant delivery. There is a steep incline or decline in the titration curve at this point of the titration curve. In this assignment, you will determine the molecular weight of an unknown acid powder by weighing the solid to determine the mass and titrating to determine the moles of acid.

Procedure
1. Start Virtual ChemLab and select Molecular Weight Determination by Acid-Base Titration from the list of assignments.

2. The lab will open in the Titration laboratory.

3. Click the Lab Book to open it. Click the Buret Zoom View window to bring it to the front. Click the Beakers drawer and move a beaker to the spotlight next to the balance. Click on the Balance area to zoom in, open the bottle by clicking on the lid (Remove Lid). Drag the beaker to the balance to place it on the balance pan; Tare the balance. Pick up the Scoop and scoop out some sample; as you drag your cursor and the scoop down the face of the bottle it picks up more. Select the largest sample possible and drag the scoop to the beaker until it snaps in place which will place the sample in the beaker (about 1 g). Record the mass of the sample in the Data Table. Place the beaker in the spotlight outside the balance and Zoom Out.

4. Drag the beaker to the sink and hold it under the tap to add a small amount of water. Place it on the stir plate and add the calibrated pH meter probe to the beaker. Add Phenolphthalein for the indicator.

5. The buret will be filled with NaOH. The horizontal position of the orange handle is off for the stopcock. Click the Save button in the Buret Zoom View window. Open the stopcock by pulling down on the orange handle. The vertical position delivers solution the fastest with three intermediate rates in between. Turn the stopcock to one of the fastest positions. Observe the titration curve. When the blue line begins to turn up, double-click the stopcock to turn it off. Move the stopcock down one position to add solution drop by drop.

There are two methods for determining the volume at the equivalence point: (1) Stop the titration when a color change occurs. Click the Stop button in the Buret Zoom View. A blue
There are two methods for determining the volume at the equivalence point: (1) Stop the titration when a color change occurs. Click the Stop button in the Buret Zoom View. A blue data link will appear in the lab book. Click the blue data link to open the Data View window. Scroll down to the last data entry and record the volume at the equivalence point in Data Table 1. OR (2) Add drops slowly through the equivalence point until the pH reaches approximately 12. Click the Stop button in the Buret Zoom View. A blue data link will appear in the lab book. Click the blue data link to open the Data View window. Click Select All button to copy and paste the data to a spreadsheet. Plot the first derivative of pH vs volume. The peak will indicate the volume of the equivalence point since this is where the pH is changing the most as volume changes.

Repeat at least two additional times recording data in Data Table 1. Do not forget to refill the buret with NaOH and place the pH meter in the beaker and add indicator each time.

The concentration of the NaOH is 0.1961 M. The moles of acid are calculated by multiplying the volume of the NaOH (in L) by the molarity of the NaOH. Dividing the mass of the acid sample by the moles will provide the molecular weight in g/mol.

**Data Table 1**

<table>
<thead>
<tr>
<th>Trial</th>
<th>mass of acid sample (mL)</th>
<th>volume NaOH (mL)</th>
<th>molarity NaOH (mol/L)</th>
<th>molecular weight (g/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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6. What is the average molecular weight of your three closest answers?  
(Student response)

7. Calculate your percent error by the following formula using only the values used in the average if you complete more than three trials:

\[
\% \text{Error} = \frac{(\text{highest answer} - \text{lowest answer})}{\text{average}} \times 100\%
\]

(Student response)
Precipitation Reactions: Formation of Solids

**Purpose**
To observe, identify, and write balanced equations for precipitation reactions.

**Procedure**
1. Start *Virtual ChemLab* and select *Precipitation Reactions: Formation of Solids* from the list of assignments.

2. Lab will open in the Inorganic laboratory.

3. React each of the cations (across the top) with each of the anions (down the left) according to the table below using the following procedures:

<table>
<thead>
<tr>
<th></th>
<th>AgNO₃ (Ag⁺)</th>
<th>Pb(NO₃)₃ (Pb²⁺)</th>
<th>Ca(NO₃)₂ (Ca²⁺)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na₂CO₃ (CO₃²⁻)</td>
<td>a</td>
<td>f</td>
<td>k</td>
</tr>
<tr>
<td>Na₂S (S²⁻)</td>
<td>b</td>
<td>g</td>
<td>l</td>
</tr>
<tr>
<td>NaOH (OH⁻)</td>
<td>c</td>
<td>h</td>
<td>m</td>
</tr>
<tr>
<td>Na₂SO₄ (SO₄²⁻)</td>
<td>d</td>
<td>i</td>
<td>n</td>
</tr>
<tr>
<td>NaCl (Cl⁻)</td>
<td>e</td>
<td>j</td>
<td>o</td>
</tr>
</tbody>
</table>

   a. Click in the *Stockroom*. Once inside the stockroom, drag a test tube from the box and place it on the metal test tube stand. Then click on the bottle of Ag⁺ metal ion solution on the shelf to add it to the test tube. Click **Done** to send the test tube back to the lab. Click on the **Return to lab** arrow.

   b. Drag the test tube containing the Ag⁺ from the blue rack to the metal test tube stand. Click on the **Divide** button (the large red arrow) four times to make four additional test tubes containing Ag⁺. With one test tube in the metal stand and four others in the blue rack, click on the Na₂CO₃ bottle on the reagent shelf, observe what happens in the window at the bottom left. Record your observation in the table above. If the solution remains clear, record NR, for no reaction. Drag this test tube to the red disposal bucket on the right.

   c. Drag a second tube from the blue rack to the metal stand. Add Na₂S, record your observations and discard the tube. Continue with the third, fourth and fifth tube, but add NaOH, Na₂SO₄, and NaCl respectively. Record your observations and discard the tubes. When you are completely finished, click on the red disposal bucket to clear the lab.

   d. Return to the stockroom and repeat steps a-c for five test tubes of Pb²⁺ and Ca²⁺.

(Student response)

**Analyze**
1. Translate the following word equations into balanced chemical equations and explain how the equations represent what happens in grid spaces $a$ and $g$.
   a. In grid space $a$, sodium carbonate reacts with silver nitrate to produce sodium nitrate and solid silver carbonate. 
      (Student response)
   
   b. In grid space $g$, sodium sulfide reacts with lead (II) nitrate to produce sodium nitrate and solid lead (II) sulfide. 
      (Student response)

2. Write a word equation to represent what happens in grid space $m$. 
   (Student response)

3. What happens in grid space $d$? What other reactions gave similar results? Is it necessary to write an equation when no reaction occurs? Explain. 
   (Student response)

4. Write balanced equations for all precipitation reactions you observed. 
   (Student response)

5. Write balanced net ionic equations for all precipitation reactions you observed. 
   (Student response)
Identification of Cations in Solution

Purpose
Identify the ions in an unknown solution through the application of chemical tests.

Background
Detectives in mystery novels often rush evidence from the crime scene to the lab for analysis. In this experiment, you will become a chemical detective. You will conduct laboratory analyses to determine the ionic composition of an unknown solution. The process of determining the composition of a sample of matter by conducting chemical test is called qualitative analysis. Solutions of unknown ions can be subjected to chemical tests and the results can be compared to the results given by known ions. By conducting the appropriate tests and applying logic, the identities of the ions present in an unknown solution can be determined.

The analyses you perform are based on the idea that no two ions produce the same set of chemical reactions. Each ion reacts in its own characteristic way. In this experiment, you will observe several types of chemical reactions commonly used as tests in qualitative analysis. These reactions include the color of a flame as the chemical is placed in the flame and the formation of a precipitate (solid). As you complete this analysis, remember that careful observation and logical reasoning are the keys to being a good detective. Who knows what ions lurk in your unknown solution?

Procedure
1. Start Virtual ChemLab and select Identification of Cations in Solution from the list of assignments.

2. The lab will open in the Inorganic laboratory.

3. Enter the stockroom by clicking inside the Stockroom window. Once inside the stockroom, drag a test tube from the box and place it on the metal test tube stand. You can then click on a bottle of metal ion solution on the shelf to add it to the test tube. When you have added one metal ion, click Done to send the test tube back to the lab. Repeat this process with a new metal ion. Continue doing this until you have sent one test tube for each of the following metal ions to the lab: Na⁺, K⁺, and a Na⁺/K⁺ mixture. Fill one test tube with just water by clicking on the bottle of distilled water. Now click on the Return to Lab arrow.

4. When you return to the lab you should note that you have four test tubes. Just above the periodic table there is a handle. Click on the handle to pull down the TV monitor. With the monitor down you can drag your cursor over each test tube to identify what metal ion the test tube contains, and you will see a picture of what it looks like in the lower left corner.
Part 1, Flame Tests
1. You will use two of the buttons across the bottom, Flame and Flame w/ Cobalt (blue glass held in front of the flame.) A test tube must be moved from the blue test tube rack to the metal test tube stand in order to perform the flame test. You can drag a test tube from the blue rack to the metal test tube stand to switch places with a test tube in the metal test tube stand.

2. Flame test sodium ion only. Flame w/ Cobalt test sodium ion only. Record your observations.
   (Student response)

3. Flame test potassium ion only. Flame w/ Cobalt test potassium ion only. Record your observations.
   (Student response)

4. Flame and Flame w/ Cobalt test a mixture of sodium and potassium. Record your observations.
   (Student response)

5. Flame test a blank (distilled water) with and without cobalt glass to get a feel for what it looks like with no chemicals other than water. Record your observations.
   (Student response)

6. Return to the Stockroom. On the right end of the supply shelf is a button labeled Unknowns. Click on the Unknowns label to create a test tube with an unknown. Now click on Na⁺ and K⁺. On the left side make the minimum = 0 and maximum = 2. Click the Save button. An unknown test tube titled Practice will show in the blue rack. Drag the practice unknown test tube from the blue rack to place it in the metal stand and click Done to send it to the lab. Return to Lab.

7. Flame test the Practice Unknown and determine if it contains sodium or potassium or both or neither. Click on the Lab Book. On the left page, click the Report button, Submit, then Ok. If the ion button is green, you correctly determined whether the ion was present or not. If the ion button is red you did not make the correct analysis. Click the red disposal bucket to clear the lab. If you want to repeat with a new practice unknown, return to the stockroom and retrieve it from the blue rack. When you are confident that you can make a correct determination with sodium and potassium, proceed to Part 2.

Part 2, Insoluble chlorides
1. Return to the Stockroom. In a new test tube, place three ions: Ag⁺, Hg₂²⁺, and Pb²⁺. (There is Hg₂²⁺ and Hg₂²⁺ on the shelf. Make sure you obtain Hg₂²⁺.) Return to Lab. As you proceed with the chemical analysis watch the TV screen to see the chemistry involved in the chemical
2. Move the test tube to the metal stand. Click the reagent bottle NaCl to add chloride to the test tube. What observations can you make? (Student response)

Click the Centrifuge button. What observations can you make? (Student response)

Each of the three ions form insoluble precipitates (solids) with chloride. If the solution turns cloudy white it indicates that at least one of the three ions is present. Now, we must determine which one.

3. Turn the heat on with the Heat button. Observe the TV screen. What happened? If you cannot tell, turn the heat on and off while observing the TV screen. (Student response)

With the heat turned on, click Decant. Drag your cursor over the new test tube in the rack. What appears on the TV screen? What appears in the picture window? (Student response)

This is the test for Pb$^{2+}$. If heated, it is soluble. When cooled it becomes insoluble.

4. Turn off the Heat. With the test tube containing the two remaining ions in the metal stand, click the NH$_3$ bottle on the reagent shelf. What do you observe? (Student response)

Addition of ammonia produces a diammine silver complex ion which is soluble. The mercury produces a black solid. This is the test for mercury.

5. Centrifuge and then Decant to pour the silver ion into another test tube. Move the tube with the black mercury solid to the red disposal bucket. Move the tube containing silver back to the metal stand. Click the pH 4 reagent bottle. What do you observe? (Student response)

The silver ion is soluble as the diammine silver complex ion in pH 10 and is insoluble as AgCl in pH 4. You can click alternately on each of the pH bottles to confirm this test for silver ion.
6. Return to the Stockroom and create an unknown with Ag\textsuperscript{+}, Hg_2\textsuperscript{2+}, and Pb\textsuperscript{2+}. Use minimum = 0 and maximum = 3. Return to the lab and complete the analysis. Report your results in the Lab Book and check to determine if you can correctly identify these three ions. When you are confident that you can correctly identify Ag\textsuperscript{+}, Hg_2\textsuperscript{2+}, and Pb\textsuperscript{2+} proceed to Part 3.

**Part 3, Selected transition metal ions**

1. Return to the Stockroom. In a new test tube, place three ions: Co\textsuperscript{2+}, Cr\textsuperscript{3+}, and Cu\textsuperscript{2+}. Return to Lab. As you proceed with the chemical analysis watch the TV screen to see the chemistry involved in the chemical reactions.

2. Move the test tube to the metal stand. Click the NaOH bottle on the reagent shelf. What observations can you make? 
   *(Student response)*

3. Click **Centrifuge** and **Decant**. What observations can you make as you drag your cursor over each test tube? 
   *(Student response)*

   This is the test for chromium. If the new test tube in the blue rack is green when decanted then chromium is present. You can confirm it by placing the clear green test tube in the metal stand and clicking pH 10. Then adding HNO_3. What observations can you make? 
   *(Student response)*

4. With the test tube containing the precipitate in the metal stand, add NH_3. What observations can you make? 
   *(Student response)*

5. **Centrifuge** and **Decant**. Add HNO_3 to the tube in the metal stand containing the precipitate. What observations can you make? 
   *(Student response)*

   This is the confirmatory test for cobalt ion (Co\textsuperscript{2+}).

6. Place the test tube from the blue rack which is the decant from step # 5 in the metal stand. Add HNO_3. What observations can you make? 
   *(Student response)*

   This is the confirmatory test for copper.

7. Return to the Stockroom and create an unknown with Co\textsuperscript{2+}, Cr\textsuperscript{3+}, and Cu\textsuperscript{2+}. Use minimum = 0 and maximum = 3. Return to the lab and complete the analysis. Report your results in the Lab Book and check to determine if you can correctly identify these three ions.
Qualitative Analysis

Purpose
Develop a systematic panel of chemical tests to identify an unknown solution of eight metal cations.

Background
In the Identification of Cations in Solution experiment, you learned how to identify eight metal cations in three groups. In this experiment you will complete a qualitative analysis scheme using the information learned in the previous experiment with an unknown solution containing one to eight of the ions.

Procedure
1. Start Virtual ChemLab and select Qualitative Analysis from the list of assignments.

2. The lab will open in the Inorganic laboratory.

3. Click to enter the Stockroom. Create an unknown with Na\(^+\), K\(^+\), Ag\(^+\), Hg\(_2\)\(^{2+}\), Pb\(^{2+}\), Co\(^{2+}\), Cr\(^{3+}\), and Cu\(^{2+}\). Set minimum = 0 and maximum = 8. This means that you could have only water or any number of the ions up to all eight. Click Save. Move the Practice Unknown to the metal stand and Return to Lab.

4. Move the test tube to the metal stand and click the Divide button three times. Move the three new test tubes to the right end of the blue rack. These three tubes are duplicates of your unknown. If you make a mistake and need to begin again, you can use one of these. Before you use the last one make additional duplicates.

5. From your experience in the previous lab, you know how to analyze the three different groups: flame tests, insoluble chlorides, and selected transition metals. Now that all three groups are combined you will still analyze the unknown as three separate groups. First, flame test for Na\(^+\) and/or K\(^+\). Remember, neither may be present and one of the other six ions will have a unique flame test that you have not seen before. Second, test for the insoluble chlorides. If you obtain a precipitate when adding NaCl then Centrifuge and Decant. The decant will contain the third group. Third, complete the analysis on the transition metals.

6. Report your results in the Lab Book and check to see if you correctly identified the presence or absence of each of the eight cations.
Analysis of Baking Soda

**Purpose**
Determine the mass of sodium hydrogen carbonate in a sample of baking soda using stoichiometry.

**Procedure**
1. Start [Virtual ChemLab](#) and select *Analysis of Baking Soda* from the list of assignments.

2. The lab will open in the Titration laboratory.

3. The beaker has 1.5000 g of the impure solid NaHCO₃ and is filled with water to make a volume of 25.00 mL. The indicator methyl orange is in the beaker. The calibrated pH meter is in the beaker, the graph window is open. Click on the Lab Book to open it and delete any previous data saved by another students. Click on the Buret Zoom View window and the pH meter window to bring them to the front. Click the Save button on the graph window before starting the titration. Begin the titration by opening the stopcock on the buret. Observe what happens to the pH as the titration proceeds. It is important that the volume increments and pH measurements near the equivalence point are small enough so the equivalence point can be determined as closely as possible. When the graph starts to curve downward decrease the rate of delivery to the slowest rate. Immediately after the color of the indicator changes, stop the titration by double-clicking the stopcock. Click the Stop button in the Buret Zoom View window. Click the blue data link in the lab book. Scroll down the Data Viewer window to the last volume entry in the left column and record the volume in the Data Table.

There are two methods for determining the volume at the equivalence point: (1) Stop the titration when a color change occurs. Click the Stop button in the Buret Zoom View. A blue data link will appear in the lab book. Click the blue data link to open the Data View window. Scroll down to the last data entry and record the volume at the equivalence point in Data Table 1. OR (2) Add drops slowly through the equivalence point until the pH reaches approximately 12. Click the Stop button in the Buret Zoom View. A blue data link will appear in the lab book. Click the blue data link to open the Data View window. Click Select All button to copy and paste the data to a spreadsheet. Plot the first derivative of pH vs volume. The peak will indicate the volume of the equivalence point since this is where the pH is changing the most as volume changes.

Unknown sample # _______

**Data Table**

<table>
<thead>
<tr>
<th>mass unknown sample (g)</th>
<th>volume HCl (mL)</th>
<th>molarity HCl (mol/L)</th>
</tr>
</thead>
</table>

**Analyze**

1. Write a balanced chemical equation for the reaction between NaHCO₃ and HCl.

   *(Student response)*
2. Calculate the moles of HCl by multiplying the volume of HCl in liters and the molarity of HCl in mol/L. (Keep four significant digits in all of the calculations.) (Student response)

3. The moles of HCl can be converted to moles of NaHCO₃ using the coefficients from the balanced equation. What is the mole to mole ratio of HCl to NaHCO₃? How many moles of NaHCO₃ are present in the sample? (Student response)

4. Calculate the grams of NaHCO₃ by multiplying the moles of NaHCO₃ by the molecular weight of NaHCO₃ (84 g/mol). (Student response)

5. The % NaHCO₃ present in the sample can be calculated by dividing the mass of NaHCO₃ from question #4 by the mass of the sample from the Data Table and multiplying by 100. What is the % NaHCO₃? (Student response)
Oxidation-Reduction Titrations, Determination of Iron

Purpose
Determine the percent composition of iron in a sample using an oxidation-reduction titration with potassium permanganate.

Background
Titrations provide a method of quantitatively measuring the concentration of an unknown solution. In an acid-base titration, this is done by delivering a titrant of known concentration to an analyte of known volume. (The concentration of an unknown titrant can also be determined by titration with an analyte of known concentration and volume.) Reduction-oxidation (redox) titrations can also be used to measure concentrations. In redox titrations, voltages of the mixture of an oxidant and reductant can also be measured as the titration proceeds. All titration curves have characteristic shapes. The equivalence point of the titration, or the point where the analyte has been completely consumed by the titrant, is identified by the point where the voltage changes rapidly over a small volume of titrant delivered. There is a steep incline or decline at this point of the titration curve. In this assignment, you will observe this titration curve by titrating KMnO₄ with FeCl₂.

Procedure
1. Start Virtual ChemLab and select Oxidation-Reduction Titrations, Determination of Iron from the list of assignments.

2. The lab will open in the Titrations laboratory.

3. Record the FeCl₂ Unknown # in the Data Table. Click the Lab Book to open it. Click the Buret Zoom View window to bring it to the front. Click the Beakers drawer and place a beaker in the spotlight next to the balance. Move the FeCl₂ bottle to the spotlight next to the balance. Click on the Balance area to zoom in and open the bottle of FeCl₂ by clicking on the lid (Remove Lid). Drag the beaker to the balance to place it on the balance pan. Tare the balance. Pick up the Scoop and scoop up some sample by dragging the scoop to the bottle and then down the face of the bottle. Pick up the largest sample possible and place it in the beaker (about 1 g). Continue dragging the scoop to the beaker until it snaps in place which will place the sample in the beaker. Unload the full scoop twice into the beaker so you have around 2.0 g and record the mass of the sample in the Data Table. Place the beaker in the spotlight outside the balance and Zoom Out.

4. Place the beaker on the stir plate. Drag the 50 mL graduated cylinder under the tap in the sink and fill it with distilled water. Pour the water into the beaker on the stir plate. Place the electrode in the beaker and turn on the volt meter.

5. The buret will be filled with KMnO₄. The horizontal position of the orange handle is off for the stopcock. Click Save on the Buret window to save the titration to the lab book. Open the stopcock by pulling down on the orange handle. The vertical position delivers volume the fastest with three intermediate rates in between. Turn the stopcock to one of the fastest
positions. Observe the titration curve. When the blue line begins to turn up, double-click the stopcock to turn it off. Move the stopcock down one position to add volume drop by drop.

There are two methods for determining the volume at the equivalence point: (1) Stop the titration when a color change occurs. Click the Stop button in the Buret Zoom View. A blue data link will appear in the lab book. Click the blue data link to open the Data View window. Scroll down to the last data entry and record the volume at the equivalence point in the Data Table. OR (2) Add drops slowly through the equivalence point until the voltage reaches approximately 1.50 V. Click the Stop button in the Buret Zoom View. A blue data link will appear in the lab book. Click the blue data link to open the Data View window. Click the Select All button to copy and paste the data to a spreadsheet. Plot the first derivative of voltage vs volume. The peak will indicate the volume of the equivalence point since it is where the voltage is changing the most as volume changes.

6. Sketch the graph of the titration below. Label the axes.

The reduction potential of Fe$^{2+}$ is 0.732 volts. The reduction potential of MnO$_4^-$ in acidic solution is 1.507 volts. If you titrate FeCl$_2$ into KMnO$_4$, what happens to the voltage of the solution as the titration starts and proceeds to the end?

__________________________________________________________________________
__________________________________________________________________________

Repeat the titration at least two additional times recording data in the Data Table. Do not forget to refill the buret with KMnO$_4$, place the voltage meter in the beaker and add water each time.

The molecular weight of FeCl$_2$ is 151.91 g/mol.
Unknown # ______

Data Table

<table>
<thead>
<tr>
<th>Trial</th>
<th>mass FeCl₂ (g)</th>
<th>volume KMnO₄ (mL)</th>
<th>molarity KMnO₄ (mol/L)</th>
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Analyze
1. Write a balanced net ionic equation for the reaction in acidic solution of FeCl₂ and KMnO₄ (Fe²⁺ becomes Fe³⁺ and MnO₄⁻ becomes Mn²⁺).

2. The moles of MnO₄⁻ can be determined by multiplying the volume of MnO₄⁻ required to reach the endpoint multiplied by the molarity of the MnO₄⁻. What are the moles of MnO₄⁻?

3. The moles of FeCl₂ can be calculated by using the mole ratio from the balanced equation. What are the moles of FeCl₂?

4. The mass of FeCl₂ in the sample can be calculated by multiplying the moles of FeCl₂ by the molecular weight of FeCl₂. What is the mass of FeCl₂ in the sample?

5. The % iron in the unknown sample can be determined by dividing the mass of FeCl₂ in the sample by the total mass of the unknown sample. What is the % iron in your unknown sample?

6. What is the average % iron in the unknown sample using your best three answers?