PART I: Investigating Buffers

Students will be able to…	● Identify the independent (manipulated) and dependent (responding) variables in a scientific investigation. ● Draw conclusions about the proportional relationships between two variables using quantitative data. ● Describe the chemical function of a buffer solution. ● Identify properties that affect the effectiveness of a buffer.

KEY VOCABULARY (Definitions written in terms appropriate for this activity)

- **Independent (Manipulated) Variable** – The variable in a lab experiment that is being tested. The scientist chooses several values of this variable to test.
- **Dependent (Responding) Variable** – The variable in a lab experiment that is being measured. The dependent variable responds to the independent variable in an experiment.
- **Conjugate acid-base pair** – A pair of chemicals that turn into each other when a proton is gained or lost during an acid-base reaction.
- **Concentration** – The amount of substance (solute) in a given volume of solution or solvent.
- **pH** – A measure that indicates how acidic or basic a substance is.
- **Buffer** – A solution that can resist changes in pH because it contains a conjugate acid-base pair.

ADDITIONAL BACKGROUND INFORMATION

This part of the lab is intended to be inquiry-based. Students do not need to know much at all about buffers, or even acids and bases, to get something out of the lab. Focus on understanding scientific questions, identifying variables, and analyzing quantitative data with proportional relationships. Variables are *directly proportional* when both the independent (manipulated) and dependent (responding) variables increase, or when they both decrease. Variables are *inversely proportional* when the independent variable increases and the dependent variable decreases, or vice versa.

INSTRUCTIONAL TIPS AND TRICKS

Every scientific question can be phrased using the format *How does INDEPENDENT VARIABLE (IV) affect DEPENDENT VARIABLE (DV)?* This format will ensure the resulting experiment has only one independent (manipulated) and one dependent (responding) variable. The format also makes it very easy to recognize what the variables are.

Although *independent variable* and *dependent variable* are the widely accepted terms used in the scientific community, students may easily mix them up because the words are so similar. The words “manipulated” and “responding” can be used to teach the same concept with less confusion, especially for students in lower level classes or who are not planning to pursue a future in science.

It is a good idea to complete the first question together as a class to practice the procedure and demonstrate how to answer the questions.

If your students do not each have a device with an internet connection, you could watch all the data collection videos together as a class and then discuss the analysis questions all together or in small groups. It is also an option to watch the data collection videos yourself and prefill the data tables for your students. This would reduce the time requirement significantly and you can still discuss the variables and their proportionality as a way to introduce buffers.

PART II: Practicing Titrations

Students will be able to…	● Safely and effectively set up and use a buret system to dispense liquids. ● Measure and record pH data using a digital probe and linked software.

KEY VOCABULARY (Definitions written in terms appropriate for this activity)

- **Burette (Buret)** – A graduated glass tube which is tapered at one end and is used to administer precise increments of a liquid.
- **Titration** – A process of chemical analysis in which incremental amounts of a reacting substance are added to a sample and quantitative changes in a particular characteristic of the sample are observed.
- **Neutralization Reaction** - When an acid and a base react to form water and a salt.

WET LAB MATERIALS LIST

*Quantities listed are for one student lab group.

Consumables	Equipment
• 0.2 *M* Hydrochloric acid (100 mL) • 0.2 *M* Sodium hydroxide (100 mL) • Distilled water (>100 mL) • pH 7 Buffer solution (100 mL) • Masking tape	• 1 Ring stand • 2 Burettes and 1 clamp • Masking tape and Marker • pH sensor and related hardware/software (optional ring stand and clamp for probe) • Kimwipes or lint free tissues • 1 600-mL beaker • 2 100-mL beakers • Stir bar(s) and stir plate • Cup and pipette OR wash bottle

INSTRUCTIONAL TIPS AND TRICKS

If you don't have the Vernier pH probe and Logger Pro software, this lab can be completed using any other pH measuring device. A digital pH probe will get the most precise results, but the concept can still be communicated effectively using only litmus paper.

PART III: Determining Buffer Components for a Desired pH

Students will be able to…	• Describe how an acid and base each react in aqueous solutions. • Explain how the strength and concentration of an acid or base affects the pH of a solution. • Explain how buffer solutions work to maintain pH in a solution. • Determine the appropriate buffer components for a desired pH by calculating pK_a.

KEY VOCABULARY (Definitions written in terms appropriate for this activity)

- **Acid** – Any substance that can donate one or more protons to another substance.
- **Base** – Any substance that will accept one or more protons from another substance.
- **pH** – A measure that indicates how acidic or basic a substance is.
- **Strength** – How likely it is that an acid or base will donate or accept a proton in an acid-base reaction.
- **Weak acids and bases** - Substances that partially dissociate into their ions in an aqueous solution or water.
- **Strong acids and bases** - Substances that fully dissociate into their ions in an aqueous solution or water.
- **Concentration** – How many particles of a particular substance are present in a certain volume of a solution.
- **Conjugate acid-base pair** – A pair of chemicals that turn into each other when a proton is gained or lost during an acid-base reaction.
- **Buffer** – A solution that can resist changes in pH because it contains a conjugate acid-base pair.

ADDITIONAL BACKGROUND INFORMATION

The Henderson-Hasselbalch equation is:

$$pH = pK_a + log\frac{[A^-]}{[HA]}$$

In the text for Part III, the following variation of this equation is derived.

$$pK_a = pH - log\frac{[A^-]}{[HA]}$$

Typically the Henderson-Hasselbalch equation is solved for the ratio $\frac{[A^-]}{[HA]}$. This ratio can be used to adjust the pH of a buffer solution if the pK_a of the acid component used is not exactly equal to the target pH. The conjugate acid and base chosen for the buffer are chosen based on their strength, which of course has a significant effect on the pH of the solution. Concentration has a lesser effect on the pH, which is why it is used to fine-tune the pH after the components are chosen.

In this activity, the target pH for each scenario is exactly equal to the pK_a of the acids, so the concentration adjustment is not necessary. This is why the term can be eliminated by assuming the $\frac{[A^-]}{[HA]}$ ratio will always be 1:1.

INSTRUCTIONAL TIPS AND TRICKS

You can check for student understanding by asking the students to draw diagram equations, like those pictured in the text, to illustrate the reactions described for the strong and weak acids and bases.

Some students may not understand how the hydroxide ion affects pH because pH is determined by hydronium concentration. It is useful to discuss the self-ionization of water and explain that even “pure” water has hydroxide and hydronium ions present. The hydroxide ions produced by the dissociation of a strong base will take protons from the hydronium ions already present, thereby decreasing the hydronium concentration.

It is usually helpful to demonstrate the process of completing the required tasks. In this activity, you could complete scenario 1 together as a class and then assign the following 3 scenarios to complete individually or in groups.

PART IV: Evaluating Buffer Effectiveness

Students will be able to…	• Prepare a buffer solution by accurately calculating and measuring the required amounts of both the acid and the base components. • Use a burette set-up to administer precise quantities of acid and base to the buffer solution and accurately record the resulting pH. • Analyze data by graphing and by identifying key data points. • Evaluate buffer effectiveness using key data points recorded from the lab. • Use evidence from lab data to verify or falsify a claim.

KEY VOCABULARY (Definitions written in terms appropriate for this activity)

- **Buffer** – A solution that can resist changes in pH because it contains a conjugate acid-base pair.
- **Buffer capacity** – A measure of the amount of acid or base that can be added to a buffer solution without significantly changing the pH of that solution.
- **Titration** – A process of chemical analysis in which incremental amounts of a reacting substance are added to a sample, and quantitative changes in a particular characteristic of the sample are observed.
- **Titrant** - The solution being added during a titration.
- **Analyte** - The solution being analyzed during a titration.
- **pH** – A measure that indicates how acidic or basic a substance is.
- **Conjugate acid-base pair** – A pair of chemicals that turn into each other when a proton is gained or lost during an acid-base reaction.
- **Neutralized** - When a strong acid or base is added to a buffer solution, the buffer reacts with it to keep the pH from changing much.
- **Equivalence point** - During a titration, this is the steepest part of the resulting titration curve. It indicates the point where the titrant has completely neutralized the analyte.
- **Half equivalence point** - At this point, the weak acid (or base) has been exactly half-neutralized by the titrant. This results in equal concentrations of both the weak acid and its conjugate base (or both the weak base and its conjugate acid).

ADDITIONAL BACKGROUND INFORMATION

The liquid form of ammonia is actually ammonium hydroxide (NH_4OH).

WET LAB MATERIALS LIST

*Quantities listed are for one student lab group.

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<td>
<u>Consumables</u>

0.2 M Hydrochloric acid (160 mL)
0.2 M Sodium hydroxide (160 mL)
Distilled water (200 mL)
pH 7 Buffer solution (100 mL)
Masking tape and Sharpies
2 Dixie Cups
3 Plastic pipettes
Kimwipes
Paper towel
Salts/solutions for Buffers

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<td>
<u>Equipment</u>

Safety glasses
1 Ring stand
2 50-mL Burettes and 1 clamp
pH sensor and related hardware/software (optional ring stand and clamp for probe)
(1) 600-mL beaker
(1) 250-mL beaker
(4) 100-mL beakers
(1) 50-mL graduated cylinder
Stir bar and stir plate
Cup and pipette OR wash bottle

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INSTRUCTIONAL TIPS AND TRICKS

Depending on the duration of your class periods, this lab could be split into 3 different days. On day 1, have students prepare their buffer solutions. If this doesn't take the entire period, you can review the titration procedure and gather lab materials. Having the buffers sit overnight will ensure that all the salts are fully dissolved. On day 2, complete just the acid titration. This will leave plenty of time for proper clean-up procedures. If you have extra time after the titration, you can have your students graph their acid data. Then on day 3, complete the base titration.

At the start of both the acid and base titration, be sure that the starting pH of the buffer is within +/- 0.5 of the specified pH for each scenario. If needed, adjust the initial buffer pH with 1*M* HCl or 1*M* NaOH, then proceed with the wet lab procedure.