Acids and Bases: Cabbage Juice pH Indicator

Teacher Version

**** If printing the labs in black & white, be sure to print out a color version of the cabbage juice pH scale separately ****

Acids and bases are found in a variety of everyday items, including food and drink, medicine, and cleaning products. In this lab, we will learn about what makes an acid or base "strong," and use the juice from red cabbage to test the pH of common household liquids and perform neutralization experiments.

California Science Content Standards:

- **5. Acids and Bases: Acids, bases, and salts are three classes of compounds that form ions in water solutions.**
- 5a. Students know the observable properties of acids, bases, and salt solutions.
- 5b. Students know acids are hydrogen-ion-donating and bases are hydrogen-ion-accepting substances.
- 5d. Students know how to use the pH scale to characterize acid and base solutions.
- **5g. Students know buffers stabilize pH in acid-base reactions.

Key Concepts:

- The pH of a solution is determined by the concentration of specific **ions**.
- Ions are negatively or positively charged **atoms**. If a solution contains extra hydrogen ions (H^+), it is **acidic**. If a solution contains extra hydroxyl ions (OH^-), the solution is **basic**, or **alkaline**.
- **Strong** acids have a high percentage of their atoms found as ions (ie unbound), whereas **weak** acids have only a low percentage of ions in solution.
- The **pH scale** ranges from 0 to 14 in water. The closer to 0, the stronger the acid, whereas the closer to 14, the stronger the base. A pH of 7 is neutral, or neither basic nor acidic.
- When an acid and a base are mixed, the hydrogen ions from the acid bind the hydroxyl ions of the base, forming water. This is referred to as **neutralization** of the acid and base.

Prerequisites:

The advanced lab addresses the concept of a logarithmic scale, and does some basic calculations. Probably appropriate for late-middle school or high school students.

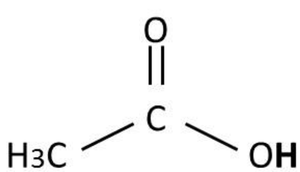
Complete List of Materials:

- Colored & silver paper clips
- Pre-cut cabbage
- Blender
- Strainer
- Large container
- Measuring spoons
- 7+ clear plastic cups (depends on how many things you're testing)
- Lemon juice
- Baking soda
- Shampoo (preferably clear)
- Glass cleaner (with ammonia)
- Milk of Magnesia
- Warhead Sour Spray or sour candy, such as Sour Patch Kids
- Other options include: vinegar (pH 2-3), apple juice (pH 4)
- Eye droppers

Introductory Mini-Lecture:

Our lab today investigates ***acids*** and ***bases***. Has anyone heard of an acid before? [Kids will probably say acids "dissolve" things – comic book references, etc.] Strong acids are known to be dangerous because they can break down things like rocks or metals (or comic book villains!). What *is* an acid, though?

These are two examples of acids. [Draw structures below on the board, leaving off the "weak" and "strong" at this point] The letters in this structure represent different chemical atoms. What letter (or atom) do these two acids have in common? [Answer: H] This "H" stands for ***hydrogen***. While it's stuck to the rest of the acid, it's just an "H" atom. However, the special thing about acids is that they come apart when you put them in water – the "H" separates from the rest of the molecule. When that "H" comes off, it becomes an ***ion***, meaning that it has a ***charge***. In this case, it has a ***positive*** charge, so we write it as "H+".



Acetic Acid (Weak)

HCl

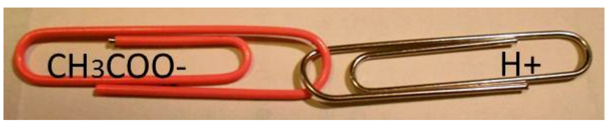
Hydrochloric Acid (Strong)

Acids are referred to as "strong" or "weak" depending on how many of the individual acid molecules break up in water. For example, this molecule on the left (acetic acid – the acid found in vinegar) is a weak acid [add the "weak" and "strong" labels to the diagrams] – if I put 100 of them in water, only 1 or 2 would actually let go of a hydrogen ion! Hydrochloric acid, though, is a strong acid. If I put 100 of them in water, all 100 would break apart. The same is true for bases, except that a base releases a ***hydroxyl*** ion instead of a hydrogen ion. These are "OH-" molecules, or an oxygen and a hydrogen stuck together that have a ***negative*** charge.*

The number of hydrogen or hydroxyl ions matter, because they are very ***reactive*** – they can bind to other atoms. This includes the atoms in the water! Since water is made up of a hydrogen ion and a hydroxyl ion stuck together (making H_2O), an acid will try and steal the OH- ion from water (leaving an extra H+ behind). Conversely, a base will try and steal the H+ ion from water (leaving an OH- behind). This will be important in part 2 of this lab.
* Teacher Note: The students may ask why this oxygen and hydrogen don't break up to form H+ ions. This is because oxygen by itself (just "O") has a charge of -2. Since hydrogen has a charge of +1, you get an overall charge of -1. Since chemical molecules are always trying to reach a neutral state, this oxygen is very unlikely to give up its hydrogen. Instead, it's looking to steal another hydrogen ion from something else (also a characteristic of a base!).

Part 1 – Modeling Acids and Bases

In this section, we will model what the differences are between **strong** acids or bases and **weak** acids or bases.



Model of an acetic acid

Model of a hydrochloric acid

1. Make 5 paper clip models of acetic acid (a weak acid) and hydrochloric acid (a strong acid), using silver for the hydrogen atoms and two different colors for the rest of the molecule.
2. Now imagine that you add each of your 5 acid molecules to water by putting them in the correct column below (feel free to rip this page out to be able to answer the questions while keeping the molecules in the "water").

STRONG	**WEAK**

Q1. What happens to these acids in water? Model this with your paperclip molecules. How do a weak acid and a strong acid differ?

The molecules dissociate, or break apart. In the weak acid, only a small fraction separate (1 of the 5). In a strong acid, however, all of them separate (5 of 5).

Q2. If the acidity of a solution is based on the number of H+ ions (more ions = more acidic), which of your two solutions would be more acidic?

The strong acid solution would be more acidic, since it has more free hydrogen (H+) ions (5 vs 1).

Q3. Now lets compare solutions. Imagine that I put ***10*** *"weak" acid molecules into a new glass of water. How many H+ ions will you have in each of these solutions?*

5 strong acid molecules: ___~5___H+ions 10 weak acid molecules:___~2___ H+ions

Q4. Which will be more acidic, the solution with 5 strong acids, or the one with 10 weak acids? Circle one. Why did you choose that solution?

5 strong acid molecules OR 10 weak acid molecules

The one with 5 strong acids has ~5 H+ ions, while the one with 10 weak acids has only ~2. Therefore the strong acid solution will still be more acidic.

Q5. What if I add ***50*** *weak acid molecules to water? How many H+ ions will each solution have?*

5 strong acid molecules: ____~5______ 50 weak acid molecules: _____~10_____

Q6. Which solution will be more acidic? Why?

5 strong acid molecules OR 50 weak acid molecules

A solution with 50 weak acid molecules will have ~10 H+ ions, and will be more acidic than the strong acid solution with 5 ions.

Part 2 – Determining the pH of Household Substances

Strong acids and bases are dangerous, and can really only be found in laboratories or chemical plants. Weak acids and bases, however, are incredibly useful, and can be found all around us! But how do you test whether something is acidic or basic?
You can rank how acidic or basic something is using a scale called the "***pH scale***." As we learned in the last section, the number of hydrogen (H+) or hydroxyl (OH-) ions in a solution affects how acidic or basic it is. pH is measured using chemicals that change color when they bind to the extra hydrogen or hydroxyl ions in water. So, for example, the more acidic a solution, the more hydrogen ions there are, and the more the color will change! A solution of water, where the H+ and OH- ions are in balance, is called ***neutral***, and it has a pH of 7. As you add more acid (and therefore more hydrogen ions), the pH goes down. A pH of 0 is the strongest an acid can be in water.

Alternatively, the more of a base you put in water, the more hydroxyl ions there are (either from the base itself, or from the broken water molecules). This means that there are less H+ ions than there would be in a neutral (water) solution, and so you will have a pH *higher* than 7. As you get farther from neutral, the solution gets more basic (and the number of OH- molecules increases). A pH of 14 is the strongest a base can be in water.

Let's measure the pH of some things that you can find in your house.

Q7. Would you guess that the following substances are acidic, neutral, or basic? Circle your answer.

Water	Acidic	**Neutral**	Basic
Lemon Juice	**Acidic**	Neutral	Basic
Baking Soda	Acidic	Neutral	**Basic**
Shampoo	**Acidic**	Neutral	Basic
Windex (Ammonia)	Acidic	Neutral	**Basic**
Milk of Magnesia	Acidic	Neutral	**Basic**
Warhead Sour Spray/Sour Candy	**Acidic**	Neutral	Basic
Vinegar	**Acidic**	Neutral	Basic

Making the pH Indicator (this can be done in advance):

1. Put the red cabbage leaves into the blender with 800mL of water.
2. Close the top and let it blend at high power for 30 seconds.
3. Pour the mixture through a strainer into a large container. (This should provide you with 600-800 ml of cabbage juice.)

Testing pH:

4. Pour 1 Tbsp of each individual liquid into its respective cup (except for baking soda).
5. For baking soda, add 1 tsp of baking soda into 2 tsps water.
6. For the sour candy, add a few drops of water to the candy to dissolve the sour coating. Swirl until dissolved and remove the candy. Use the dissolved coating to test pH.
7. Pour 1Tbsp of cabbage juice into each of the cups, swirling gently.

Q8. Write down what color each solution turns the cabbage juice, based on the following pH scale.

pH	pH less than 7 = Acid			pH more than 7 = Base		
	2	4	6	8	10	12
Colour	Red	Purple	Violet	Blue	Blu-Grn	Grn-Yel

Liquid:	Color	Predicted pH	Actual pH
Water	***Violet***	***Variable***	***7***
Lemon Juice	***Red***	***Variable***	***2***
Baking Soda	***Blue***	***Variable***	***8***
Shampoo	***Purple / Violet***	***Variable***	***5.5***
Glass Cleaner (Ammonia)	***Blue-Green***	***Variable***	***10***
Milk of Magnesia	***Blue-Green***	***Variable***	***10***
Warhead Spray/Sour Candy	***Red***	***Variable***	***2***
Vinegar	***Red / Purple***	***Variable***	***3***

Now find out from your teacher what the actual pH of each of the substances is, and see how accurate the cabbage juice indicator was!

Q9. Categorize your results below:

Very Acidic	Mildly Acidic	Neutral	Mildly Basic	Very Basic
Lemon Juice ***Warhead Spray /Sour Candy*** ***Vinegar***	***Shampoo***	***Water***	***Baking Soda***	***Glass cleaner*** ***Milk of Magnesia***

ADVANCED VERSION ONLY

QSA10. All of the acids and bases in these solutions are "weak," yet we get some pretty extreme pH values. How is that possible? (Think about the questions in part 1)

The more strongly acidic or basic solutions likely have a much higher ***concentration*** *of the acid or base. As we mentioned before, 50 weak acid molecules in a solution will have a lower pH than 10 weak acid molecules in solution (assuming you're keeping the solution volume constant).*

Part 3 - Neutralization

Since acidic hydrogen ions (H+) have a positive charge, and basic hydroxyl ions (OH-) have a negative charge, they like to stick to each other when mixed together. When they do, they form H_2O – do you remember what that is? [It's water!] This is referred to as *neutralization,* since you are turning the acid and the base into water, which has a neutral pH.

In order for neutralization to work, you need an equal number of H+ ions and OH- ions. If you have extra H+ left over, the solution will still be acidic. If you have extra OH- ions left over, it will still be basic. Only when the number of ions is equal can you be at a neutral pH.

BASIC VERSION ONLY

To figure out how much of an acid or a base you will need to neutralize a solution, you can count how many steps away from neutral a certain pH is. For example, pretend I had a solution at pH 4 and a solution at pH 10. pH 4 is three steps away from neutral (7-4=3). pH 10 is also three steps away from neutral (10-7=3). Therefore I will need approximately an equal amount of the two solutions in order to get to a neutral pH.

pH	pH less than 7 = Acid			pH more than 7 = Base		
	2	4	6	8	10	12
Colour	Red	Purple	Violet	Blue	Blu-Grn	Grn-Yel

QS10. Look back at the pH of lemon juice and of glass cleaner. What are the two pH's? How many steps away from neutral (pH 7) are each of them?

Lemon juice (pH 2) is five steps away, and glass cleaner (pH 10) is three steps away

ADVANCED VERSION ONLY

To determine how much of an acid or a base you will need to neutralize a solution, you will need to figure out how many ions there are at a given pH. The pH scale is logarithmic, meaning that one "step" in the scale (from 5 to 4, for example) reflects a difference of 10-times the number of extra hydrogen ions. Similarly, a step from 8 to 9 has 10-times the number of extra hydroxyl ions. A pH of 7 has an equal number of hydrogen and hydroxyl ions.

QSA11. Lemon juice has a pH of about 2, and glass cleaner a pH of about 10. How many hydrogen ions would you predict in a solution at pH 2, assuming that a pH of 7 has 1 ion? How many hydroxyl ions would you predict in a solution at pH 10, assuming that a pH of 7 has 1 ion?

A pH of 2 is 5 steps away from pH 7, so it has 10^5 ions, or 100,000 H+. A pH of 10 is only 3 steps away from pH 7, so it has 10^3 ions, or 1,000 OH-.

QS11, QSA12. To get to a neutral pH, do you think you'll need more lemon juice, more glass cleaner, or equal amounts of each? Why?

You should need more glass cleaner, since you need an equal number of hydroxyl and hydrogen ions in order to reach a neutral pH.

1. Add 10 drops of water to 1 Tbsp of red cabbage juice in a clear cup.
2. Add 10 drops of lemon juice to 1 Tbsp of red cabbage juice in a second cup.

QS12, QSA13. How many drops of glass cleaner do you think it will take to get to a neutral pH?
Answers will vary

***Teacher note: For the advanced students, who just learned that a difference of 2 steps in the pH scale = 100x more, they may predict that 100 x 10 drops = 1,000 drops. In theory, this is correct, however because the lemon juice and glass cleaner aren't "pure" acid and base, they don't behave exactly as predicted. The point to emphasize is that you require substantially more glass cleaner, because it is closer to neutral.*

3. Now add 1 drop at a time of glass cleaner to the lemon juice, swirling carefully after each drop. Count how many drops it takes to turn the solution the same color as the water.
4. Consult with others in your group to see how many drops they used, and enter the numbers into the chart below.

	Trial 1	Trial 2	Trial 3
Number of Drops:	***~100***	***~100***	***~100***

QS13, QSA14. Why does the solution turn from reddish to dark purple as you add the glass cleaner?
Because the base in the glass cleaner (ammonia) is reacting with the hydrogen ions of the acid, removing them from solution (technically you are not actually making water in this case, since ammonia is producing a slightly different type of ion, but it still binds to hydrogen and prevents it from floating around as a free ion)

BASIC VERSION ONLY

QS14. Did the number of drops match your prediction? If not, why do you think it was so different?
You almost certainly needed more. This is because as you get farther and farther from neutral, the space between the steps gets bigger and bigger. If it takes 10 drops to get from 6 to 7, then it takes 100 drops to get from 5 to 7, and so on. Since lemon juice is two pH units farther from neutral, you need a LOT more glass cleaner to make up that difference.

ADVANCED VERSION ONLY

Although the math isn't very straight-forward for weak acids and bases (like we have here), you can actually calculate the volume of strong acid needed to neutralize a strong base, and vice versa, using the formula below.

Acid volume x Concentration of ions in acid = Base volume x Concentration of ions in base

QSA15. If I have 1 volume of a strong acid at pH 5, how much of a strong base at pH 10 would I need to get to a neutral pH?

A pH of 5 is 2 pH units away from 7, so it has 100 (10x10) hydrogen ions. A pH of 10 is 3 pH units away from 7, so it has 1,000 (10x10x10) hydroxyl ions. You need an equal number of H+ and OH- to reach a neutral pH. That is why the two sides of the equation are set equal to each other.

$$1 \times 100 = ? \times 1{,}000$$
$$100 = ? \times 1{,}000$$
$$100 / 1{,}000 = ?$$
$$1/10 = ?$$

Therefore, you need 1/10 volume of a strong base at pH 10 to neutralize 1 volume of a strong acid at pH 5

Concept Questions:

QS15, QSA16. Look at the list of things which have very acidic pH's. What do these substances have in common? Can you think of other foods that probably also have acidic pH's?

They are all very SOUR to eat! Orange juice, grapefruit juice, and apple juice all have acidic pH's.

** Teacher note: The reason that acids taste sour is the same as the reason they are acids – an excess of H+ ions! "Sour tastes are evoked by all acids in dilute solutions. Apparently, it is the hydrogen ion that activates taste receptors and leads to a sensation of sourness." http://www.unmc.edu/physiology/Mann/mann10.html

QS16, QSA17. Fats and oils (like butter, vegetable oil, or even the oil on your skin!) can react with the OH- ions in bases and feel "slippery" or "soapy." Can you think of instances where that property would be useful? What kinds of things do you think basic products would be useful for (besides neutralizing acids)?

Cleaning supplies (including glass cleaner!) are often basic for this reason – they are good at lifting oil and grease off of surfaces.

** Teacher note: Have the students touch the glass cleaner and rub it between their fingers – it feels slippery! Compare to the lemon juice, or just water.

QS17, QSA18. Stomach acid has a pH of about 2. Normally the stomach protects itself by producing a slippery substance that's resistant to the acid, but sometimes it breaks down. What do you think happens? Do you know what this is called? How could you reduce the amount of acid (think of things that we tested!)?

The acid can break down the stomach wall, which leads to ulcers. Excess acid can be neutralized by basic compounds, like Milk of Magnesia (which is commonly used for stomachaches).

** Teacher note: Ulcers are actually the result of a combination of stomach acid and a bacterial infection. The bacterial component was dismissed by doctors initially, but the researcher who discovered it proved them wrong by *drinking a beaker of the bacteria himself*, giving himself ulcers. Now that's dedication to science!
http://discovermagazine.com/2010/mar/07-dr-drank-broth-gave-ulcer-solved-medical-mystery

QS18, QSA19. What is acid rain? Why do you think it's bad for oceans, rivers, lakes, and other natural environments?

Air pollution from cars and factories gets mixed into rain clouds, making water with small amounts of sulfuric and nitric acid in it. When it falls back to the ground as rain, fog, or snow, the acid can change the pH of the water on the ground, which can kill fish and plants which are sensitive to this change in pH.