

Visualizing pH

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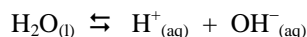
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Introduction

Acids and bases have been known for hundreds of years, but the true nature of acids and bases only started to be understood in the late 1800's. Although there are several definitions that can be used to describe acids and bases, we will use the Arrhenius theory that requires water as a solvent.

Water ionizes to produce hydrogen or hydronium ions, H^+ or H_3O^+ , and hydroxide ions, OH^- , as shown in the equation below:



The concentration of water is 55.6 M (moles/liter) and the concentration of hydronium or hydroxide ions is 1×10^{-7} M. This means that approximately one out of every billion molecules of water is ionized.

An acid is defined as a substance that produces hydronium ions in water solution and a base is defined as a substance that produces hydroxide ions in water solution.

To express the concentration of hydronium ions in acid solutions, we use a term called pH, sometimes referred to as the *power of hydrogen*, (as defined Søren Sørensen in 1909). pH is defined as the negative logarithm of the hydrogen ion concentration:

$$pH = -\log [H^+]$$

The pH scale has a range from 1 to 14. A pH value between 1 and 7 represents an acid and a pH value between 7 and 14 represents a base. A pH value of 7 means the substance is neutral.

pH is a logarithmic scale. That means each pH unit represents a change in H^+ by a factor of 10. For example, an acid solution with a pH of 5 has 10 times more H^+ than an acid solution with a pH of 6. As pH values get lower, from 7 to 1, that means the acid, in comparison to other acids, is stronger, or it is producing more H^+ . As pH values increase from 7 to 14, that means the base, in comparison to other bases, is stronger, or it is producing more OH^- . In water solution, pH values less than 1 or greater than 14 are not defined since we are beyond the capacity of the water to produce additional H^+ or OH^- . A representation of this was developed by the late Hubert Alyea, of Princeton University.

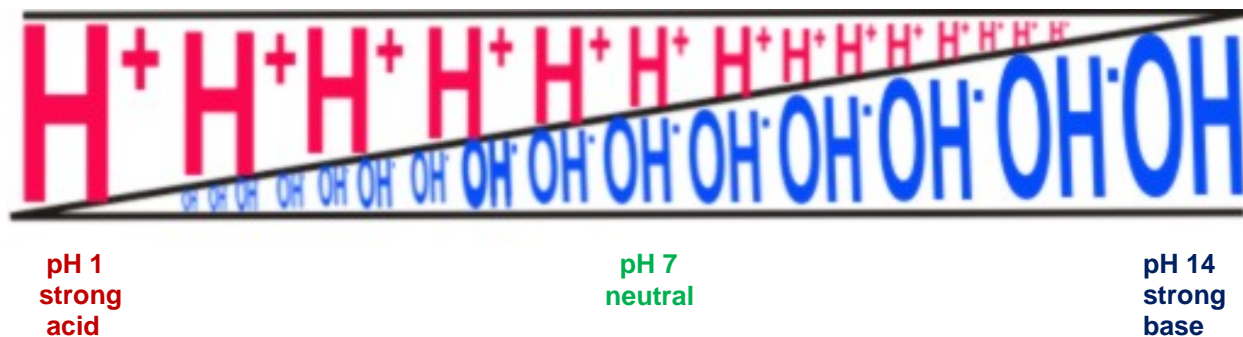


Figure 1. Alyea's representation of the H^+ and OH^- ion ratios in acid and base solutions

This activity uses red cabbage paper to indicate pH of different acid or base solutions. An *indicator* is a substance that changes color as the pH of a solution changes. Most indicators have a single color change at a specific pH value or within a pH range of values. Multiple color changes are usually produced by using a mixture of indicators.

Part 1. Determining pH with Red Cabbage Paper

Materials needed

Red cabbage paper (see procedure for preparing red cabbage paper)

Red cabbage

Knife to cut red cabbage

Filter paper circles (use laboratory filter paper, coffee filters, etc.)

Large funnel

2 beakers, 600-mL or larger

Blender

Cheesecloth

Ethanol, 95%. Denatured ethanol works well for this procedure

0.1 M hydrochloric acid, HCl

0.1 M sodium hydroxide, NaOH

Buffer solutions. Note: pH values of 1, 2, 4, 6, 7, 8, 10, 12, and 14 are recommended. (These can be purchased as solutions or prepared from buffer capsules. Buffer capsules have long shelf lives. Each buffer capsule makes 100 mL of solution. These are available from laboratory supply companies such as Flinn Scientific.)

Use 0.1 M hydrochloric acid, HCl, for the pH 1 solution.

Use 0.1 M sodium hydroxide, NaOH, for the pH 14 solution



Figure 2. Buffer capsules

Plastic bag (Zip-lock type bags are recommended)

Stirring rods (plastic coffee stirrers work well for this)

90-mL to 150-mL (3 oz to 5 oz) plastic cups (plastic is preferred for this procedure as solutions will not soak through the cup over the course of a day)

Permanent black marker

Household materials such as soap, laundry detergent, shampoo, baking soda, vinegar, lemon juice, vitamin C tablets, toothpaste, soda, etc.



Figure 3. Household materials

Procedure

1. Make red cabbage paper

Place pieces of red cabbage in a blender. Cover with a 50% solution of ethanol in water. (Caution: Ethanol is flammable. Ethanol splashing from the blender jar can catch fire due to sparks from the blender motor. Do not fill blender jar more than 50% full to prevent splashing of ethanol from the jar.) Blend to produce a thick slurry.

Strain the mixture through cheesecloth, in a large funnel, into a large beaker. Discard the solids.

Soak filter paper circles in the red cabbage liquid. Place the filter paper circles in a single layer on a clean table top and allow them to dry completely. This may take several hours.

Place the dried red cabbage paper in a plastic bag. Store in a cool place, away from bright light. The paper keeps for at least 6 months.

2. Set up the acid and base solutions

Use the black marker to label each plastic cup with the solution it will contain. For pH solutions, write “pH 1”, “pH 2”, etc. For household materials write the name of the product.

Place about 5 to 10 mL of each solution in the proper labeled cup. Add a stirring rod to each cup.

To make solutions of solids or thick gels or pastes, place some of the material in a labeled plastic cup, add about 10 mL of water and stir to mix.

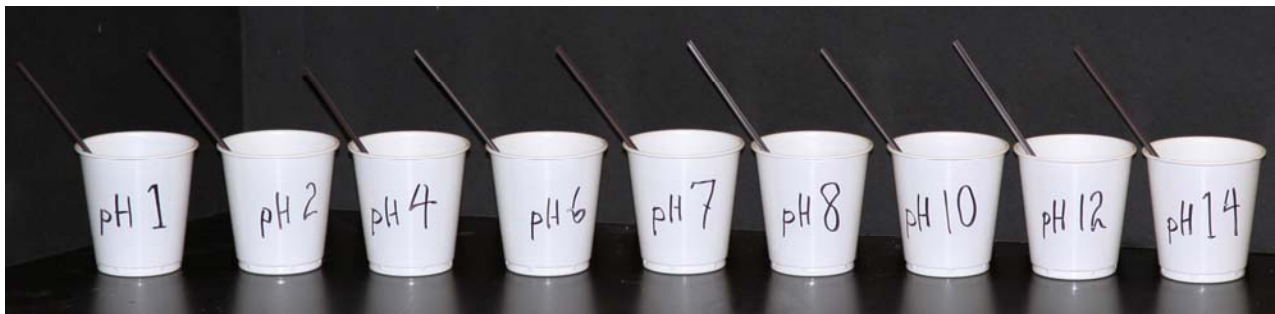


Figure 4. Buffer solutions in labeled plastic cups



Figure 5. Solutions of household products in labeled plastic cups

From this point, this procedure can be done in a classroom, lecture hall, or laboratory. Cups, containing buffer solutions and household materials can be placed on tables, desks, or lab benches around a room.

3. Prepare a color chart of pH colors

Obtain a piece of red cabbage paper.

Note the pH solutions and buffers that are available for the experiment. Using a pencil or pen, label the red cabbage paper with the pH values of the available buffer solutions as shown in Figure 6.

Using stirring rods, placed in the individual pH and buffer solutions, put a small drop of each solution on the red cabbage paper next to the pH value. (For example, put a drop of pH 1 buffer next to the pH 1 label on the paper.)

What results are observed after placing the spots of the buffer solutions on the red cabbage paper?

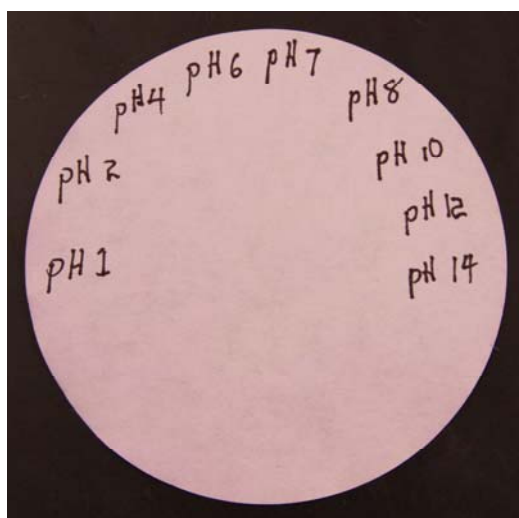


Figure 6. A labeled piece of red cabbage paper

4. Test household materials

Use the solutions of common household materials, available in the laboratory.

Use the stirring rods from each solution to place a drop on an open space in the center area of the red cabbage paper. Label each spot with the identity of the household material used.

Determine the pH of each of the solutions by comparing them to the buffer colors.

Are there any patterns of pH values with certain types of household products?



Figure 7. Spotting the red cabbage paper with solutions

5. Discussion

Discuss the results with the class. Ask which substances are acids, which are bases, and which could not be determined.

Note patterns such as most acids are related to foods, and most bases are related to cleaning products.

If you choose the bases carefully, laundry detergent should have a pH of 12 to 14, a mild soap will have a pH of about 10, a plain toothpaste should have a pH of about 8, and a baby shampoo should have a pH of about 6 to 7. Ask how pH is related to the use of these products.

Do a similar discussion for the products that test as acids.

A student worksheet is attached to the end of this experiment

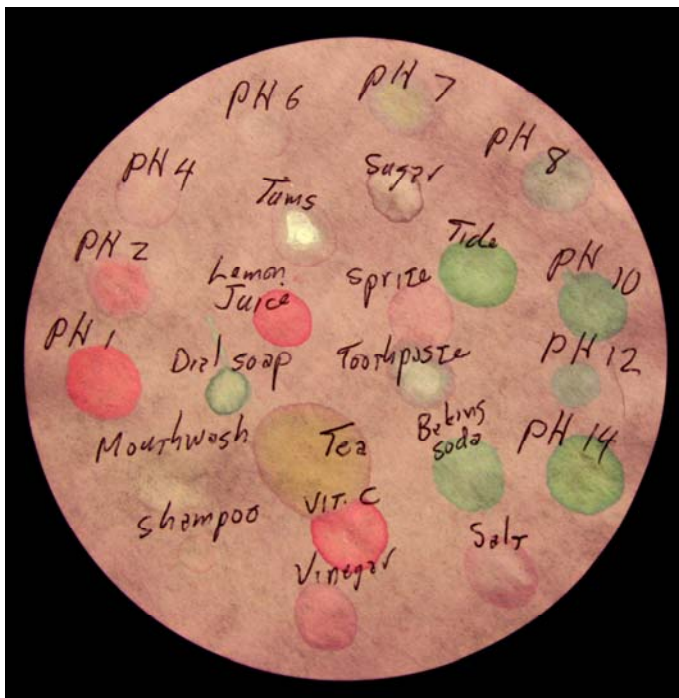


Figure 8. Red cabbage paper at the conclusion of the experiment

Part 2. Taste an acid / Taste a base

Safety Precautions: This activity must be performed in a clean, contamination free area, away from laboratory chemicals. All materials used must be food grade or better and should be newly purchased. If stored, they must be stored away from any possible source or contamination, preferably at home.

Materials needed

- 2 pitchers (plastic preferred). One pitcher should be labeled "ACID" and one pitcher labeled "BASE"
- sour salt (citric acid) Available in supermarkets or organic food stores
- baking soda (sodium bicarbonate)
- water
- 3 ounce drinking cups
- stirring rods – large wood or plastic kitchen spoons

Procedure

Prepare an acid solution. Fill the ACID pitcher with drinking water. Add sour salt (citric acid), small amounts at a time, stirring and tasting until a suitable sour tasting solution is obtained. Cover the pitcher until ready to use.

Prepare a base solution. Fill the BASE pitcher with drinking water. Add baking soda (sodium bicarbonate), small amounts at a time, stirring and tasting until a suitable bitter tasting solution is obtained. Cover the pitcher until ready to use.

Pour about 5 mL of acid and base solutions into separate paper cups. Each student should receive one of each solution.

Instruct the students to SIP a SMALL AMOUNT of the ACID solution. Ask them to describe the taste. If necessary, students may take a second taste of the solution. They should NOT drink all the solution.

Instruct the students to SIP a SMALL AMOUNT of the BASE solution. Ask them to describe the taste. If necessary, students may take a second taste of the solution. They should NOT drink all the solution.

Discard any remaining solutions and the paper cups.

DETERMINING pH WITH RED CABBAGE PAPER

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Obtain a piece of red cabbage paper.

Note the pH solutions and buffers that are available for the experiment. (Note: pH is a measure used to compare the strengths of acids and bases. Buffers are solutions that are made to maintain a constant pH for reference purposes.)

Using a pencil, or pen, label the red cabbage paper with the pH's of the available pH solutions and buffers similar to the diagram in figure 1.

Using the stirring rods, or droppers, in the individual pH and buffer solutions, place one drop of each solution on the red cabbage paper next to the proper label. (For example, put a drop of pH 1 buffer next to the pH 1 label on the paper.)

What results do you observe after placing the spots of the solutions on the red cabbage paper?

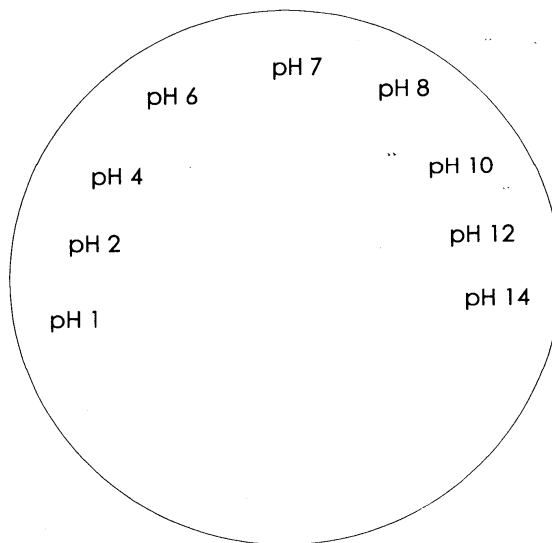


Figure 1. A labeled piece of red cabbage paper.

There are solutions of common household materials in the laboratory. Use the stirring rods from each solution to place a drop on an open space on the red cabbage paper. Label each spot with the identity of the household material used.

Can you determine the pH of each of the solutions?

Can you determine any patterns of pH values with certain types of household products?