ScholAR Chemistry

Rainbow in a Tube Demonstration

Kit # 94005-08

Materials

Provided in this kit:

- → Hydrochloric acid, HCl, 0.1 M, 30 mL
- → Sodium hydroxide, NaOH, 0.1 M, 30 mL
- → Universal indicator, 100 mL
- → Instructions (this document) including answer key (p.5) and worksheet (p.6)

Required, but not provided:

- → Scholar Chemistry Demonstration Tube and 2 rubber stoppers (Catalog #94002-10)
- → Water, 300 mL
- → Beaker, 500-mL
- → Pipets

Number of uses:

This demonstration can be performed ten times with the materials provided in this kit.

Class time required:

This activity will require 5 minutes for pre-demonstration preparation and 10 minutes to perform.

Overview

In this demonstration, a tube with a rainbow of colors at different pH will be made. Universal indicator is a mixture of different pH indicators that produce characteristic colors at different pH regions. Properly performed, this demonstration should result in reds, oranges, and yellows on the acid end; purples and blues on the basic end; and green in the middle where acid and base ions meet in equal concentrations to neutralize each other.

Concepts

- → Acid/base chemistry
- → Neutralization reactions
- → pH
- → Indicators

National Science Education Standards

Grades 5–8

Content Standard B: Physical Science

- → Properties and Changes of Properties in Matter

Grades 9–12

Content Standard B: Physical Science

- → Chemical Reactions

Acknowledgment

Tim Graham from Roosevelt High School in Wyandotte, Michigan provided the idea and instructions for this demonstration. This Teacher-Developed, Classroom-Tested activity has worked well in Tim's classroom and we are grateful that he shared this activity with ScholAR Chemistry.

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Safety

- → Read all instructions thoroughly before starting the demonstration.
- → Wear gloves, lab apron or lab coat, and safety goggles throughout this demonstration.
- → Review the material safety data sheets (MSDS) for the substances used in the demonstration before starting the demonstration.
- → Hydrochloric acid is strongly corrosive to body tissue and moderately toxic by ingestion.
- → Sodium hydroxide is a severe body tissue irritant.
- → Universal indicator is a flammable liquid and slightly toxic by ingestion.

Background

An acid–base indicator is a substance that changes color as the pH of a solution changes. There are several laboratory acid–base indicators, many of which can be extracted from common plants. Each indicator exhibits a different range of colors at different pH values. For example, the common laboratory indicator litmus turns red if the pH is lower than 7 (acidic) and blue if the pH is higher than 7 (basic). The indicator phenolphthalein is colorless in solutions with a pH less than 8 and magenta (pink) in solutions with a pH greater than 8. Bromothymol blue, another indicator, is yellow in acidic solutions and blue in basic solutions.

Indicators work because they are weak acids which, when in solution, exist in equilibrium with their conjugate base. The acid and its conjugate base each have different colors and as the equilibrium shifts from one direction to the other, the color of the indicator changes. As an example, the equilibrium of a weak acid can be represented by the equation below. HA, the weak acid, would be one color, but its conjugate base, A^-, is a different color.

$$HA \rightleftharpoons H^+ + A^-$$

Consistent with Le Châtelier's principle, if a solution containing the indicator becomes more acidic, the equilibrium will shift to the left and the solution will take the color of the weak acid. On the other hand, if the solution becomes more basic, the equilibrium will shift to the right and the solution will become the color of the conjugate base. Some indicators exhibit only two colors and some exhibit a wide range. Universal indicator (a wide range indicator) is a combination of several other indicators, and therefore provides an array of colors at different pH values. This property of universal indicator is used to produce the "rainbow in a tube". The table below represents the color of universal indicator at each pH.

Color	Red	Orange	Yellow	Green	Green-Blue	Blue	Violet
pH	4	5	6	7	8	9	10

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Teacher Tips

- → Remember the 5 P's of demonstrations. "Prior Practice Prevents Poor Presentations" Always perform the demonstration ahead of time, without a student audience. This allows you to gain confidence in your presentation but also serves to work out the "glitches" that often occur.
- → It will be helpful to leave about a two centimeter "air" bubble in the tube to aid in the mixing process.
- → Make sure both stoppers are secure during the demonstration. It is necessary to hold both stoppers in place while the demonstration is taking place. Pressure will be built up in the tube and the stoppers and solution will come out if not held properly in place.
- → Having a white background available, to act as a background screen, is helpful to emphasize the rainbow of colors at the end of the demonstration.

Pre-Demonstration Preparation

Prior to the demonstrations, add 5 mL of universal indicator to a 500-mL beaker. Dilute the indicator with about 300 mL of water. If this solution is not green in color, add a drop or two of 0.1 M HCl or 0.1 M NaOH to adjust the color to green. (If solution is too yellow, add base; if it is too blue, add acid). This will be the indicator solution that will be used in the demonstration.

Procedure

1. Stopper one end of the tube and fill with the green universal indicator solution. Leave enough space to accommodate the remaining stopper.
2. Add 15 drops of 0.1 M HCl using a pipet to the open end of the demonstration tube and stopper the tube.

   Note: Hold both stoppers in place while the demonstration is taking place. Pressure will be built up in the tube and the stoppers and solution will come out if not held properly in place.
3. Being careful not to agitate the solution, invert the demonstration tube, remove the stopper, and add 15 drops of 0.1 M NaOH. Re-stopper the tube.

   Note: More than 15 drops may have to be added to get the desired colors. The trick is to add an equal number of drops at each end of the tube. If 20 drops of acid are added at one end, then 20 drops of base need to be added to the opposite end.
4. Slowly invert the tube, back-and-forth, several times. As the acid and base ions migrate from the areas of high concentration (the ends), a "rainbow" of colors will be established in the tube.
5. Hold the tube in a horizontal position to display the "rainbow" of colors.

Disposal

Review local regulations or consult with local authorities before disposing of any chemicals in the trash or down the drain. The following are suggested disposal procedures:

- → Wash the solutions down the drain with running water.
- → Keep all leftover reagents in a locked chemical storeroom.

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Addressing Misconceptions and Misunderstandings

→ Some students may think that strength and concentration can be used interchangeably to describe an acid or base. Acid strength describes the degree to which the acid "ionizes" in solution while concentration describes the amount of solute dissolved in solution. Strong acids ionize to a high degree while weak acids tend to ionize to a much lesser degree. For example, sulfuric acid (a strong acid) ionizes to a high degree and acetic acid (a weak acid) ionizes to a lesser degree. Concentration refers to the amount of solute in a particular solution (measured by normality, molarity, molality, etc.)

→ A second student misconception is that "strong" acids and bases are dangerous, while "weak" ones are not. All chemical substances should be treated as though they have the potential to harm if used inappropriately. Hydrofluoric acid (used to etch glass) is a great example. Students tend to think that HF is a strong acid because it reacts with glass (a highly inert material). In reality, hydrofluoric acid is a weak acid, but it is extremely hazardous.

→ The Brönsted-Lowry definition defines an acid as a "proton donor" and a base as a "proton acceptor". Students know that protons are found in the nuclei of atoms, and therefore, wrongly assume that this means that the nuclei of acids and bases are somehow exchanging protons from the nuclei. It is very important that students recognize that the proton (H^+) is not exchanged *between* nuclei in an acid/base reaction.

Extension Ideas

→ A simple demonstration that might help illustrate the first misconception is to test electrical conductivity of both a 1.0 M sulfuric acid (strong acid) solution and 1.0 M acetic acid (weak acid) solution. Students should note that while the concentrations are identical, the sulfuric acid will conduct much better due to the fact that it contains a larger amount of ions (electrolytes) due to sulfuric acid's ability to ionize more completely, hence a stronger acid.

→ To illustrate the color of universal indicator at different pH, students can obtain a well plate and make solutions of different pH and add a drop of universal indicator solution. For example, students can label 14 spots on the well plate 0-14. In spot 0, 14 drops of hydrochloric acid can be added. In spot 1, 13 drops of hydrochloric acid can be added and one drop of sodium hydroxide can be added. As the spot number increases, the hydrochloric acid drop count decreases by one and the sodium hydroxide drop count increases by one. Make sure that the concentrations of hydrochloric acid and sodium hydroxide are equimolar. Students will observe the range of colors produced by universal indicator.

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Rainbow in a Tube Student Worksheet–ANSWER KEY

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1. What observations were made during the demonstration?

   Students should make note and describe what they saw during the demonstration. For example, once the hydrochloric acid and sodium hydroxide have been added to the tube, the tube was then mixed, and the resulting tube had colors ranging from reds, oranges, and yellows on the acid end and purples and blues on the basic end. The center of the demonstration tube was green in color.

2. What is the pH scale? What range is considered acidic? What range is considered basic?

   The pH scale measures the "acidity" of substances. It runs from 0-14 with acids being substances with a pH<7 and bases are substances with pH>7, and neutral substances measuring a pH = 7.

3. What is the name given to a chemical substance that reveals whether a substance is an acid or a base? Give two examples.

   The name given to these types of substances is "indicator". Common to the laboratory are "two-color indicators" (litmus red, phenolphthalein, phenol red, bromothymol blue, etc.) and "wide-range indicators" like the universal indicator used in this demonstration.

4. Why does the demonstration tube appear like a rainbow as opposed to a uniform color?

   The contents of the tube have not mixed very well. The strong acid (HCl) was added to one end and the strong base (NaOH) to the other. Since these are "strong" acids and bases, the universal indicator shows a different color at low and high pH. As the ions migrate away from the ends, the concentration of the ions decrease and the universal indicator registers this with colors that suggest less acid or base ions are present. When the acid and base ions meet in the middle in equal concentrations, the universal indicator should reveal the pH color which approximates neutral (green).

5. What would happen to the color of the solution in the demonstration tube if it was shaken vigorously?

   Shaking the tube should thoroughly mix the solution and reveal the closet approximate pH of the neutralized reaction solution.

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Name _____

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