Activity 7

Acids, Bases, and Indicators—Colorful Chemistry

What Do You Think?

If you add red cabbage to boiling water a special bluish colored solution is made. Vinegar, a common acid, will turn the solution red. Ammonia, a common base, will turn the solution green.

1. What are some other properties of acids and bases you know about?
2. How can you tell the difference between an acid and a base?

Record your ideas about these questions in your Active Chemistry log. Be prepared to discuss your responses with your group and the class.

Investigate

1. Your teacher will provide you with samples of some of the materials listed below. Place a small amount of each solution in a separate well of a well plate. Add a small piece of polished zinc (or magnesium) to each of the solutions.

- hydrochloric acid (HCl(aq))
- lemon or orange juice (citric acid)
- vinegar (acetic acid, CH₃COOH(aq))
- sulfuric acid (H₂SO₄(aq))

GOALS

In this activity you will:
- Identify common household acids and bases.
- Identify characteristic properties of acids and bases and learn to tell the difference between acids and bases.
- See how strong acids and bases behave differently from weak acids and bases.
- Determine the pH of various solutions using indicators.
- Categorize solutions based on the pH scale.
- Use the mathematical definition of pH.
Active Chemistry

Cool Chemistry Show

- mineral water or carbonated beverage (contains H$_2$CO$_3$(aq))
- milk
- dishwashing solution
- sodium hydroxide (NaOH(aq))
- magnesium hydroxide (contains Mg(OH)$_2$(aq))
- apple juice (malic acid)
- potassium hydroxide (KOH(aq))
- calcium hydroxide (Ca(OH)$_2$(aq))
- household ammonia (NH$_3$(aq))

a) Make a data table to record your observations.

b) Which substances reacted with the metal? How could you tell? What do these substances have in common? (Consider the chemical formulas listed for some of the substances.)

c) Which substances did not react with the metal? What do these substances have in common? (Consider the chemical formulas listed for some of the substances.)

2. Place small amounts of each solution you used in Step 1 in a separate well of a well plate. Test the solutions with one or more common laboratory indicators. (Your teacher will provide acid-base indicators like blue litmus paper, red litmus paper, phenolphthalein, bromothymol blue, and methyl red.) Indicator papers are activated simply by dipping a small piece of the paper into the solution and noting any color change. If the indicator is a solution, add a drop or two to the substance being tested and note any color change. You will need to use fresh test solutions if you want to test with more than one indicator solution.

a) Make a chart and record your observations.

3. Use your observations as well as previous experiences to answer the following:

a) Make a list of some of the observable properties for acids and bases. For example:
- How do substances containing acids or bases taste? You should never taste substances in a lab, but you have probably had the opportunity to taste vinegar or lemon juice at home, or you may have accidentally gotten soap in your mouth.
How do acids and bases feel? You must be very cautious when handling chemicals both at home and in the lab. However, you’ve probably had the experience of touching cleaning materials, such as soaps or floor cleaners. Think about vinegar or citrus fruits. How do they feel on a cut on your skin or a canker sore in your mouth?

4. The pH scale can also be used to describe acids and bases. This number scale ranges from 0 to 14. Acid solutions have a pH less than 7. The more acidic a solution is, the lower the pH. Base solutions have a pH greater than 7. The more basic a solution is, the higher the pH. Neutral solutions have a pH of 7. There are a number of ways to measure pH. You will use pH paper and/or a universal indicator solution. Determine the pH of some of the substances you used in Step 1.

   a) Make a data table that includes the name of the substance, the pH test, and whether the substance is an acid, a base, or a neutral substance.

   b) You may have used both pH paper and universal indicator solution to measure pH. Both are made from a combination of indicators to produce a range of colors throughout the pH scale.

   Universal indicator solution contains four separate indicators, including the following: Thymol blue is a chemical that changes color twice. Between a pH of 1.2 and 2.8, it changes from red to yellow. Between a pH of 9.0 and 9.6, it changes from yellow to blue. Methyl red is another indicator but it changes from red to yellow in the pH range of 4.8 to 6.0. Bromothymol blue is a third component which changes color from yellow to blue in the pH range 6.0 to 7.6.

   How could these three chemicals be used to create an indicator scale? What are the limitations of the pH scale if only these three chemicals are used?

5. Use the pH paper to test additional common household substances in order to determine which are acids and which are bases. (Hint: Try carbonated beverages, tea, coffee, baking powder, mayonnaise, power drinks, pickle juice, window cleaner, and stain removers.) Your teacher may give you some pH paper to take home with you.

   a) Make a list of common acids and bases found in your school or home. When possible, include both the name and formula for each substance you test.

6. Dispose of all chemicals as directed by your teacher. Clean and put away any equipment as instructed. Clean up your workstation.
7. Here are two activities that display the characteristics of acids and bases in a colorful way. Your teacher may show you these as demonstrations.

- Paint a message on a large sheet of paper or poster board using phenolphthalein indicator solution. (How about painting a message announcing your Cool Chemistry Show?) Allow the message to dry completely and hang the paper/poster board where everyone can see it. Use a window glass cleaner that contains ammonia water and when you are ready to reveal the message, lightly spray the design with the basic solution. (The secret message can also be revealed with a dilute ammonia solution. As the ammonia evaporates, the secret message that has been revealed will disappear again.)

- Rinse a small beaker with a strong acid and label it “A.” Rinse another small beaker with a strong base and label it “B.” Let both beakers air dry. In another beaker (label it “I”) add 20 drops of phenolphthalein indicator solution to about 50 mL of distilled water. When you are ready, pour some of the solution from beaker “I” into beaker “A.” Then pour the solution from beaker “A” into beaker “B.”

  a) Record your observations.

  b) Account for the observations in each case.

---

**ChemTalk**

**ACIDS AND BASES**

**Arrhenius’s Definition of Acids and Bases**

**Acids** and **bases** were first classified according to their characteristic properties. As you’ve experienced, acids and bases have different, distinct interactions with indicators (substances that change color with changes in the acidic or basic nature of another material). Some acids react with metals, while bases do not. Bases have a characteristic bitter taste and slippery feel, while acids have a characteristic sour taste. In fact, the term acid comes from the Latin word *acidus*, which means sour. Acids and bases are also good conductors of electricity.

In the 19th century, a chemist named Svante Arrhenius attributed the characteristic properties of acids to their ability to produce hydrogen ions when dissolved in water. If you look at the formulas for many common acids (HCl, H₂CO₃, H₂SO₄), you’ll notice that they all have H as a common element. When these acids
are added to water, a hydrogen atom can be drawn off into the water solution. The hydrogen atom leaves an electron behind, forming a positive hydrogen ion (H\(^+\)) and a negative ion. Consider the action of hydrogen chloride in aqueous solution:

\[
\text{HCl(g)} \rightleftharpoons \text{H}^+(aq) + \text{Cl}^-(aq)
\]

The chemical equation shown above is valuable because of its simplicity. However, in reality, the hydrogen ion (H\(^+\)) is simply a proton and readily attaches itself to a water molecule. The result is called a hydronium ion (H\(_3\)O\(^+\)).

\[
\text{H}^+(aq) + \text{H}_2\text{O}(l) \rightarrow \text{H}_3\text{O}^+(aq)
\]

To be more complete, the chemical equation above could be written as shown below. (Your teacher may allow you to use the simpler form of the equation—using the hydrogen ion as opposed to the hydronium ion.)

\[
\text{HCl(g)} + \text{H}_2\text{O}(l) \rightarrow \text{H}_3\text{O}^+(aq) + \text{Cl}^-(aq)
\]

Arrhenius also addressed bases and their characteristic properties. He defined a base as a substance that produces hydroxide ions (OH\(^-\)) when dissolved in water. Let’s look at a base using Arrhenius’s definition. When solid sodium hydroxide is dissolved in water, both sodium ions and hydroxide ions are produced, as shown in the chemical equation below:

\[
\text{NaOH(s)} \rightleftharpoons \text{Na}^+(aq) + \text{OH}^-(aq)
\]

Over time, scientists have extended their definition of acids and bases beyond Arrhenius’s definition to be more inclusive. These include the contributions of scientists like Johannes Brønsted of Denmark, Thomas Lowry of England, and Gilbert Lewis of the United States described in the *Artist as Chemist* chapter.

**Neutralizing Acids and Bases**

When acids and bases react together in solution, the hydrogen ions and hydroxide ions react in a one-to-one ratio to produce water. The remaining ions can join to form a salt. The process of an acid and base reacting to form water and a salt is called **neutralization**. Because the hydrogen ions and hydroxide ions have formed water, the solution is said to be neutral. The process of neutralization is shown in the chemical equations on the next page. The chemical formula for water is actually H\(_2\)O. In the equations on the next page the formula is written as HOH, so that you can see where the hydrogen and hydroxide ions end up.
Chem Words

titration: a procedure for determining the concentration of an unknown chemical by having it react with measured amounts of a second chemical of known concentration.

endpoint: the point at which the indicator changes color.

buffer: a solution containing a weak acid (or weak base) and the salt of the weak acid (or base). A buffer solution will resist large changes in pH when small amounts of acid or base are added to the solution.

If a suitable indicator is added to the reaction system, it will change colors when neutralization occurs. The point at which the indicator changes color is called the endpoint.

Consider the reaction of a strong acid (HCl) and a strong base (NaOH), as shown in the equation above. These substances are described as “strong” because they ionize completely in solution. For every HCl molecule, one hydrogen ion is released. For every NaOH molecule, one hydroxide ion is released. These two ions then combine in a one-to-one ratio to form a neutral water molecule.

Titration

Chemists take advantage of the neutralization process to help determine the concentration of solutions of acids or bases. Suppose you wanted to determine the concentration of an acid solution. You would add measured amounts of a base to the acid until the solution became neutral (pH = 7). The name of this experimental procedure is titration. The actual titration technique requires you to know the concentration of the base. It also requires an indicator, such as phenolphthalein, or a pH meter to determine when the solution reaches pH 7. The neutralization point or endpoint of a strong acid titrated with a strong base is at a pH of 7 as shown in graph for hydrochloric acid vs. sodium hydroxide.

Buffers

A buffer is a solution that resists changes in pH when a small amount of acid or base is added. Because of this buffering effect, titration of a solution of a weak acid with a strong base is slightly different than the titration of a strong acid. When a weak acid such as acetic acid is titrated with a strong base like NaOH, the endpoint or equivalence point is not pH = 7. Also, the endpoint does not occur as suddenly as with a strong acid. As you neutralize some of the weak acid, some of the acid’s conjugate base is formed. In the case of acetic acid, the conjugate base
is the acetate ion. The acetate ion is a weak base itself and a buffer solution is created which contains both the weak acid and its conjugate base. The solution now resists a change in pH as more of the strong base is added. The increase in pH is more gradual and the end point will be shifted to the basic side. The equivalence point or endpoint of acetic acid titrated with a strong base is 8.72, not 7.00.

\[
\text{CH}_3\text{COOH} + \text{OH}^- \rightleftharpoons \text{CH}_3\text{COO}^- + \text{H}_2\text{O}
\]

acetic acid  base  acetic ion  water

The titration of a weak base such as ammonia (NH₃) with a strong acid will also show these characteristics. The pH will decrease more slowly and the endpoint will be shifted to a pH less than 7.00.

Buffers are frequently used intentionally in situations where the chemist wants to avoid large changes in pH. Your blood is a natural buffer based upon the carbon dioxide-carbonic acid-bicarbonate system which maintains the pH at 7.4.

In all cases, a good buffer will absorb small quantities of acid or base with little change in pH. Any acid added to the system reacts with the conjugate base to maintain a constant pH.

\[
\text{CH}_3\text{COOH} + \text{CH}_3\text{COO}^- + \text{H}_3\text{O}^+ \rightleftharpoons \text{CH}_3\text{COOH} + \text{CH}_3\text{COOH} + \text{H}_2\text{O}
\]

If a strong base is added to the buffer system, it reacts with the weak acid to maintain a constant pH.

\[
\text{CH}_3\text{COOH} + \text{CH}_3\text{COO}^- + \text{OH}^- \rightleftharpoons \text{CH}_3\text{COO}^- + \text{CH}_3\text{COO}^- + \text{H}_2\text{O}
\]

**The pH Scale**

In this activity you observed that one way of describing acids and bases is by examining their effects on indicators. Scientists also use the pH scale to express how acidic or basic a solution is. This number scale ranges from 0 to 14. Acid solutions have a pH less than seven. The more acidic a solution is, the lower the pH. Base solutions have a pH greater than seven. The more basic a solution is, the higher the pH. Neutral solutions have a pH of seven. The pH of a
substance can be measured using methods like a pH meter or probe, pH paper, or universal indicator solution.

Acid and base indicators are compounds that are sensitive to pH. The color of the indicator changes as the pH of the solution changes. Most indicators are weak acids or weak bases that typically exhibit two different colors under varying pH conditions. The table above shows some common laboratory indicators and the colors they display under different pH conditions.

The pH scale ranges from 0 to 14 and is used to express the concentration of the hydrogen (H\(^+\)) or hydronium ion (H\(_3\)O\(^+\)) of a solution at 25ºC. Mathematically, it is defined as the negative logarithm of the hydrogen ion concentration in moles per liter (M).

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

where the brackets [ ] stand for “concentration of” (hydrogen ions in solution). Because pH is a logarithmic scale, the concentration of the hydrogen ion [H\(^+\)] actually increases or decreases tenfold for each unit on the scale. An acid with a pH of 2 has a [H\(^+\)] that is 10 times greater than an acid with a pH of 3 and 100 times the concentration of an acid with pH 4. A base with a pH of 10 has a [H\(^+\)] that is 10 times less than a base with a pH of 9.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Color change</th>
<th>pH Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>methyl violet</td>
<td>yellow to blue</td>
<td>0.0 to 1.6</td>
</tr>
<tr>
<td>thymol blue</td>
<td>red to yellow</td>
<td>1.2 to 2.8</td>
</tr>
<tr>
<td>methyl orange</td>
<td>red to yellow</td>
<td>3.2 to 4.4</td>
</tr>
<tr>
<td>bromocresol green</td>
<td>yellow to blue</td>
<td>3.8 to 5.4</td>
</tr>
<tr>
<td>methyl red</td>
<td>red to yellow</td>
<td>4.8 to 6.0</td>
</tr>
<tr>
<td>litmus paper</td>
<td>red to blue</td>
<td>5.5 to 8.0</td>
</tr>
<tr>
<td>bromothymol blue</td>
<td>yellow to blue</td>
<td>6.0 to 7.6</td>
</tr>
<tr>
<td>thymol blue</td>
<td>yellow to blue</td>
<td>8.0 to 9.6</td>
</tr>
<tr>
<td>phenolphthalein</td>
<td>colorless to pink</td>
<td>8.2 to 10.0</td>
</tr>
<tr>
<td>thymolphthalein</td>
<td>colorless to blue</td>
<td>9.4 to 10.6</td>
</tr>
</tbody>
</table>

Chem Words
pH: a quantity used to represent the acidity of a solution based on the concentration of hydrogen ions (pH = – log[H\(^+\)]).

Checking Up
1. Use a chart to compare the properties of acids and bases. Be sure to include headings like taste, feel, pH, and reaction with metals.
2. What characteristic property did Arrhenius attribute to acids and bases?
3. Describe the process that occurs when an acid reacts with a base.
4. Why are litmus paper and phenolphthalein particularly useful indicators for distinguishing between acids and bases?
5. What does pH stand for?
6. How much more acidic is a solution of pH 3 than one of pH 5?
What Do You Think Now?
At the beginning of the activity you were asked:

- What are some other properties of acids and bases you know about?
- How can you tell the difference between an acid and a base?

Have your answers changed now that you have completed this activity?

Think about the following questions:

- Is it accurate to describe a mixture of an acid and a base as in “conflict”?
- What happens when equal amounts of acid are added to equal amounts of a base?
- How would you know how strong an acid is or how strong a base is?

Chem Essential Questions

What does it mean?
Chemistry explains a macroscopic phenomenon (what you observe) with a description of what happens at the nanoscopic level (atoms and molecules) using symbolic structures as a way to communicate.

Complete the chart below in your Active Chemistry log.

<table>
<thead>
<tr>
<th>MACRO</th>
<th>NANO</th>
<th>SYMBOLIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explain what you saw when you used an indicator to identify if a solution was an acid or a base.</td>
<td>What characteristic of a solution makes it an acid? A base?</td>
<td>How does the pH scale help to describe whether a substance is an acid, a base, or neutral?</td>
</tr>
</tbody>
</table>

How do you know?
Make specific reference to your data and give experimental evidence that some substances are acids, some are bases, and some are neutral.

Why do you believe?
List some experiences you have had with acids, bases, and neutralization in your everyday life (foods, personal care products, cleaning products, etc.). Are indicators or tests involving a color change ever used in everyday life? Give examples.

Why should you care?
As your group prepares for the Cool Chemistry Show, consider how you might include some acid/base chemistry in your part of the show. How could you present acids and bases in an interesting way? Be prepared to share your thoughts with the rest of the class.
Reflecting on the Activity and the Challenge

In this activity you expanded your knowledge about acids and bases by becoming familiar with many of their characteristics. You learned about Arrhenius’s definition of acids and bases. You also learned a bit about pH, another way of expressing the acid or base nature of substances. This information will all come in handy as you plan your presentation for the Cool Chemistry Show. Remember that the fifth-grade teacher has specifically asked that your class includes presentations and information about acids and bases.

Chem to Go

1. Identify which of the following characteristics relate to acids and which relate to bases:
   a) taste sour       b) release hydroxide ions (OH\(^-\)) when dissolved in water
   c) feel slippery    d) release hydrogen ions (H\(^+\)) when dissolved in water
   e) turn pink in the presence of phenolphthalein
   f) react with metals to produce hydrogen gas
   g) taste bitter     h) turn red litmus paper blue
2. Use Arrhenius’s definition of an acid to help you write a chemical equation that shows the acidic nature of the following:
   a) sulfuric acid (H\(_2\)SO\(_4\))       b) carbonic acid (H\(_2\)CO\(_3\))
3. Use Arrhenius’s definition of a base to help you write a chemical equation that shows the basic nature of the following:
   a) potassium hydroxide (KOH)       b) calcium hydroxide (Ca(OH)\(_2\))
4. If you prepared the same concentration of two strong acids, sulfuric and hydrochloric, why would the pH of the sulfuric acid be lower than the pH of the hydrochloric acid?
5. Distilled water should have a neutral pH of 7, but water often has a pH less than 7. Suggest a reason for this lowering of the pH.
6. If you bubbled carbon dioxide through water, what would the new pH of the solution be?
7. Lemon juice, curdled milk, and vinegar all taste sour. What other properties would you expect them to have in common?
8. Which statement correctly describes a solution with a pH of 9?
    a) It has a higher concentration of H\(_3\)O\(^+\) than OH\(^-\) and causes litmus to turn blue.
    b) It has a higher concentration of OH\(^-\) than H\(_3\)O\(^+\) and causes litmus to turn blue.
    c) It has a higher concentration of H\(_3\)O\(^+\) than OH\(^-\) and causes litmus to turn red.
    d) It has a higher concentration of OH\(^-\) than H\(_3\)O\(^+\) and causes litmus to turn red.
9. Which pH change represents a hundredfold increase in the concentration of H$_3$O$^+$?
   a) pH 5 to pH 7    c) pH 3 to pH 1
   b) pH 13 to pH 14   d) pH 4 to pH 3

10. Preparing for the Chapter Challenge

You have seen a number of interesting color changes using acids, bases, and indicators. Choose one or two different cool activities to demonstrate in your show. Describe the procedure you will use and explain the chemistry involved. You may also wish to include an interesting scenario to accompany your “presto-change-o” demonstrations.

Inquiring Further

1. Titration

Titration is a procedure for determining the concentration of one chemical by having it react with measured amounts of a second chemical. An acid is titrated with a base; a base is titrated with an acid. Research how chemists perform a titration and the importance of indicators. With your teacher’s permission, demonstrate titration to your class.

2. The changing definition of an acid and base

The definition of acids and bases has changed through time. You are familiar with the earliest definitions that defined acids and bases in terms of their characteristic properties. The traditional definition has been expanded a number of times to include other substances that behave like acids and bases, but don’t fit the traditional definition. Review (from Artist as Chemist) and further research the expansion through time of the definition of acids and bases. Identify the scientists involved and the changes that were made. Consider researching chemists such as Johannes Bronsted of Denmark, Thomas Lowry of England, or the American chemist Gilbert Lewis.

3. Is it pH balanced?

You may have heard the term “pH balanced” used to describe a shampoo or a deodorant. What does this term mean? What is the pH of most shampoos? Deodorants? Is it important for a shampoo or deodorant to be “pH balanced”? Conduct some research, both in and out of lab, to get answers to these questions. Focus just on shampoos or just on deodorants.