Acids and bases have real-life significance. The human body functions properly only when delicate acid-base balances are maintained and crops grow best in soil with the proper pH. In addition, many substances used in the home are acids or bases.

Properties of Acids
The word acid comes from the Latin word acere, which means "sour." Well known from ancient times were vinegar, sour milk and lemon juice. Aspirin, or acetylsalicylic acid, tastes sour if you don’t swallow it fast enough. Chemically, all acids are compounds that generate hydrogen ions [H⁺] when mixed with water. Examples of acids are hydrochloric acid (HCl) which is secreted by our stomachs to aid in the digestion of food; sulfuric acid (H₂SO₄) which is found in car batteries; acetic acid (H₃C₂O₂) which is found in vinegar; phophoric acid (H₃PO₄) which is found in Coca-Cola; and ascorbic acid (C₆H₈O₆) which is also known as vitamin C and found in fruits and vegetables.

Properties of Bases
Bases taste bitter (like soap or baker's chocolate) and feel slippery to the touch. Chemically, bases generate hydroxide ions [OH⁻] when mixed with water. Examples of bases are sodium hydroxide (NaOH) used in drain cleaning agents or magnesium hydroxide (Mg(OH)₂) found in some antacids; other bases contain carbonate such as calcium carbonate (CaCO₃) found in some antacids or sodium bicarbonate (NaHCO₃) also known as baking soda.

Pure Water: It's Neutral
When water exists in its pure state, H₂O, it undergoes a natural dissociation to a very small degree to form [H⁺] and [OH⁻] ions. Notice that when one molecule of water dissociates, one of each chemical species is produced. Thus in pure water, the concentrations of hydrogen and hydroxide are equal. They are in equilibrium with each other and that is why pure water is neutral. If an acid or a base is added to water this equilibrium is disturbed, which causes one of them to increase in concentration while the other decreases in concentration. The more concentrated the acid or base, the greater the disruption in the equilibrium.

pH Scale
The pH scale is used to measure how acidic or basic a solution is. The pH scale ranges from 0 - 14. As the pH becomes lower, the concentration of hydrogen ions becomes greater, and the solution becomes more acidic. As the pH becomes higher, the concentration of hydroxide ions becomes greater, and the solution becomes more basic. A pH from 0 - 6 is acidic, and a pH from 8 - 14 is basic. A pH of 7 is a neutral solution.

Concentration
Chemists use the concentration units of moles per liter (abbreviated M), to represent a known mass of a substance dissolved in a liter of solution. The concentrations of acid solutions that are commonly used vary between 10⁻¹ and 10⁻¹⁴ moles per liter. Because this concentration range is so large and cumbersome to communicate, chemists have developed a more convenient method of describing acid concentrations. This method is the pH scale. The pH scale is a logarithmic scale, which means that if an acid is diluted to one tenth of its original concentration, the pH of the solution will increase by only one exponential unit.
The concentrations of \([H^+]\) and \([OH^-]\) in solution have an inverse relationship with each other. However, there are limits to the extent these concentrations can exist in water. As it turns out, the product of their concentrations in water is always equal to \(10^{-14}\). This inverse relationship of \([H^+]\) and \([OH^-]\) is illustrated in the diagram to the right. Mathematically this relationship can be written as:

\[
10^{-14} = [H^+] \times [OH^-]
\]

**Calculating pH of an Acidic Solution**

The pH scale is a reverse logarithmic representation of hydrogen ion \([H^+]\) concentration, so a change in value on the pH scale represents a ten-fold difference in \(H^+\) concentration. For example, a change in pH from 2 to 3 represents a 10-fold decrease in \(H^+\) concentration, and a shift from 2 to 4 represents a one-hundred \((10 \times 10)\)-fold decrease in \(H^+\) concentration. The formula for calculating pH is:

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

Taking the log of a number expressed in scientific notation is simply the exponent of the number. Taking the negative log is done by multiplying the exponent by -1. Therefore, if a solution that has an acid concentration of \(10^{-1}\) moles per liter, it has a pH of 1. If we dilute that solution to one tenth of its original concentration, the acid concentration will be \(10^{-2}\) moles per liter and the pH will be 2.

**Calculating pH of a Basic Solution**

If the solution which is being tested is basic, then the hydroxide concentration \([OH^-]\) is greater than the hydrogen concentration \([H^+]\). For example, if the hydroxide concentration is \(10^{-2}\) moles per liter, then the hydrogen concentration can be determined as follows:

\[
10^{-14} = [10^{-2}] \times [H^+]
\]

\[
[H^+] = 10^{-12}
\]

Using the equation above for determining the pH of a solution, the pH is:

\[
pH = - \log [10^{-12}] \quad \text{or} \quad pH = 12
\]

The pH is always determined from the hydrogen concentration. For acids, the hydrogen concentration is high and the pH is below 6. For bases, the hydrogen concentration is low and the pH is 8 or above.

**Acid-base Indicators**

Acid – Base indicators are chemicals that produce different colors when put into solutions of different acidity or basicity. For example, litmus is a chemical obtained from lichens. In an acid solution (pH less than 7) blue litmus turns red. In a basic solution (pH greater than 7) red litmus turns blue. When cabbage is chopped up and soaked in water, the resulting cabbage juice displays different colors when put in solutions of different acidity. When cabbage juice is added to a solution the pH of the solution can be estimated depending upon the color which the solution changes. In this laboratory we will use “Universal Indicator” that will react to indicate a range of pH values.
Complete the table below:

<table>
<thead>
<tr>
<th>Hydroxide Ion Concentration</th>
<th>Hydrogen Ion Concentration</th>
<th>Universal Indicator Color</th>
<th>pH</th>
<th>Part</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{-13}$</td>
<td>$10^{-1}$</td>
<td>Dark</td>
<td>1</td>
<td>Strong Acids</td>
</tr>
<tr>
<td>$10^{-12}$</td>
<td>$10^{-2}$</td>
<td>Red</td>
<td>2</td>
<td>Strong Acids</td>
</tr>
<tr>
<td>$10^{-11}$</td>
<td>$10^{-3}$</td>
<td></td>
<td>3</td>
<td>Strong Acids</td>
</tr>
<tr>
<td>$10^{-10}$</td>
<td>$10^{-4}$</td>
<td></td>
<td>4</td>
<td>Weak Acids</td>
</tr>
<tr>
<td>$10^{-9}$</td>
<td>$10^{-5}$</td>
<td></td>
<td>5</td>
<td>Weak Acids</td>
</tr>
<tr>
<td>$10^{-8}$</td>
<td>$10^{-6}$</td>
<td>Yellow</td>
<td>6</td>
<td>Neutral</td>
</tr>
<tr>
<td>$10^{-7}$</td>
<td>$10^{-7}$</td>
<td>Green</td>
<td>7</td>
<td>Neutral</td>
</tr>
<tr>
<td>$10^{-6}$</td>
<td>$10^{-8}$</td>
<td></td>
<td>8</td>
<td>Weak Acids</td>
</tr>
<tr>
<td>$10^{-5}$</td>
<td>$10^{-9}$</td>
<td></td>
<td>9</td>
<td>Weak Acids</td>
</tr>
<tr>
<td>$10^{-4}$</td>
<td>$10^{-10}$</td>
<td></td>
<td>10</td>
<td>Weak Acids</td>
</tr>
<tr>
<td>$10^{-3}$</td>
<td>$10^{-11}$</td>
<td>Dark</td>
<td>11</td>
<td>Strong Bases</td>
</tr>
<tr>
<td>$10^{-2}$</td>
<td>$10^{-12}$</td>
<td>Blue</td>
<td>12</td>
<td>Strong Bases</td>
</tr>
<tr>
<td>$10^{-1}$</td>
<td>$10^{-13}$</td>
<td></td>
<td>13</td>
<td>Strong Bases</td>
</tr>
<tr>
<td>$10^{0}$</td>
<td>$10^{-14}$</td>
<td></td>
<td>14</td>
<td>Strong Bases</td>
</tr>
</tbody>
</table>

**PART I: DETERMINING ACIDITY AND BASICITY OF HOUSEHOLD SAMPLES**

Solutions of household chemicals or drinks have been prepared. Obtain two clean 6-well plates, pour the sample solutions into separate wells so that the well is approximately half full. Be sure to record the name of the sample in each well.

Add 3 drops of universal indicator to each, and record the color of the solution. Using the Universal Indicator Color Pallet as a standard for comparison, estimate the pH of each of the household items.
Located around the room are several demonstrations which help illustrate the properties of acids, bases, and indicators. Try each one and provide an explanation of how each demonstrates these concepts.

**STATION #1: DISAPPEARING INK**

Moisten an area of the paper towel with the disappearing ink (do not soak it). Hold up the towel, stretching it between your hands, and blow on it. The carbon dioxide in your breath will cause the disappearing ink to change from blue to colorless. Once the ink has vanished, make it reappear by spraying a small amount of sodium hydroxide solution on the disappearing ink.

- **Under what conditions (acidic or basic) is the ink blue? Clear?**
  - Blue – Basic
  - Clear - Acidic

- **How does blowing on the towel change the pH?**
  - Decreasing pH.

- **Answer this question after completing Station 4: pHacts About Rainwater. What chemical is responsible for lowering the pH of the Disappearing Ink when blowing on it?**

  *Carbon dioxide (CO₂) reacts with the water to form carbonic acid (H₂CO₃)*

**STATION #2: NATURAL INDICATORS**

Chemicals that change color due to changes in pH are indicators. They indicate the acidity or basicity of their environment. Add a small portion of cabbage juice indicator to 2 wells of a clean 6-well plate.

- **What is the color of the neutral solution?**
  - Purple

- **Add a small amount of vinegar to one of the wells. What is the color change under acidic conditions?**
  - Pink

- **Now add some baking soda solution to the other well and note the color change under basic conditions.**
  - Green
**Station #3: Acid & Base Ingredients**

Many of the products you eat or use contain natural acids and bases as flavorings or active ingredients. Look at the list of ingredients on the packages and identify the acids or bases.

<table>
<thead>
<tr>
<th>Item</th>
<th>Ingredient</th>
<th>Acid or Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insect Sting Medication</td>
<td>Ammonium hydroxide</td>
<td>Base</td>
</tr>
<tr>
<td>Coca-Cola</td>
<td>Phosphoric Acid</td>
<td>Acid</td>
</tr>
<tr>
<td>Jello</td>
<td>Citric Acid, Fumaric Acid</td>
<td>Acid</td>
</tr>
<tr>
<td>Antacid</td>
<td>Calcium Carbonate</td>
<td>Base</td>
</tr>
<tr>
<td>Drain Cleaner</td>
<td>Sodium Hydroxide</td>
<td>Base</td>
</tr>
<tr>
<td>Sour Candy</td>
<td>Citric Acid, Fumaric Acid</td>
<td>Acid</td>
</tr>
</tbody>
</table>

* Provide an explanation how the medicine reduces the itching caused by insect bites?

  *The insect injects an acid when it bites which causes the itching sensation. The base in the medicine neutralizes the acid to alleviate the itching.*

**Station #4: The pHacts about Rainwater**

As rain precipitates from clouds if falls through a mixture of atmospheric nitrogen (N\(_2\)), oxygen (O\(_2\)), Argon (Ar), carbon dioxide CO\(_2\)), and other chemicals. The first three components of air do not react with water; however, rain in the "natural" state will be slightly acidic because carbon dioxide from the air reacts with water to form carbonic acid (H\(_2\)CO\(_3\)). Even though this is a weak acid, it generates enough hydrogen ion in natural water to drop the pH to about 5.6, well below the neutral value of 7.

Test for the production of carbonic acid by putting 50 mL of distilled water into the flask and add 10 drops of universal indicator. Using a clean drinking straw, exhale into the water and note the color change of the indicator.

* What color is the indicator when neutral? **Yellow/Green** When acidic? **Red**

* Write a chemical equation to show the reaction of water and carbon dioxide to form carbonic acid.

\[
\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3
\]
STATION #5: ACID RAIN

Pollutants in the air also react with water to form acids and produce an even lower pH; primarily the oxides of nitrogen and sulfur. A few natural processes contribute these acid-forming materials; sulfur oxides are formed by volcanoes and nitrogen oxides are formed by lightning. The production of these oxides are tied to the combustion of fossil-fuels. These oxides react with water in the atmosphere, forming sulfurous and nitrous acids, lowering the pH below the “natural” level of 5.6. The term "acid rain" or acid precipitation normally refers to any acidification beyond the "natural" value.

Test for the production of sulfurous acid by putting 10 mL of distilled water in the jar and add 10 drops of Universal Indicator. Light a match (which contains sulfur) and immediately throw the match into the flask and stopper the opening. Shake the flask and note the change in color of the indicator.

★ What color is the indicator when neutral? **Yellow / Green**
★ When acidic? **Red**
★ Write a chemical equation to show the reaction of water and sulfur dioxide gas to form sulfurous acid (H₂SO₃).

\[
\text{SO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{SO}_3
\]

STATION #6: CONSEQUENCES OF ACID RAIN

Economically, acid rain destroys limestone and marble building materials and corrodes exposed metals in bridges and buildings. Every few years the Golden Gate and Brooklyn Bridge must be repainted because acid-rain intensifies the normal corrosion processes.

Ecologically, rain (or snow) are the only sources of new water to lakes and rivers. Acid rain lowers the pH and has the potential to decrease the abundance of life in these bodies of water. Acid rain also has a side-effect of leaching metals from soils, dissolving what would normally be an insoluble material, and releasing toxic metals, like lead and mercury, from landfills and natural mineral deposits.

The harmful effects of acid rain can be illustrated by the vigorous reaction of hydrochloric acid with the basic compound calcium carbonate (CaCO₃) found in limestone.

Add a few drops of hydrochloric acid to the surface of a piece of limestone.

Observations: **The acid reacts with the calcium carbonate to produce a gas.**

What gas is produced when an acid reacts with a carbonate base? **CO₂**

STATION #7: COMPLETE THE FOLLOWING pH POEM

For tea it's **5**, for tomatoes it's **4**;
While household ammonia is **11** or more.
It's **7** for water, if in a pure state,
But rain water is **6**, and sea water is **8**.
It's basic at **10**, quite acidic at **2**,
And well above **12** when the indicator turns blue.
Some find it a puzlement. Doubtless their fog,
Has something to do with that **negative log**.