

# The Origins of Acids and Alkalis

by  
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## Overview

This teaching module is intended for introductory high school chemistry students. It will present a historical background for the origins of acids and bases. It will begin with the earliest concepts and indicators of acids and bases from the Greeks and Egyptians; it will finish in the mid 17<sup>th</sup> century with Boyle's introduction of litmus paper as an indicator. Therefore, students will be presented with an understanding of the development of acid-base chemistry in order to develop a strong foundation in acid-base reactions. Students will be given the opportunity to think in a historical context, and they will be able to perform experiments to help gain an understanding of the development of acid-base theory. Also to help present a historical perspective, students will become familiar with the early language and terminology used throughout the discovery of acids and bases. Throughout the topic, students will be asked to think about things could be used as an indicator of acids and bases. There will be two experiments conducted; one will observe the effervescence of acid-base reactions and the other will use plant juice and litmus paper as an acid indicator.

## Early Observations

In ancient times, the Egyptians and Greeks defined certain substances based upon their taste. Both the Greeks and the Egyptians had discovered that one particular substance was very sour. This became to be known as vinegar, which was produced from the fermentation of fruits to produce wine. Therefore, a new categorization of substances was developed that included all things that were sour.

Question to the class: *What things in everyday life are sour? What ingredients are found in things that are sour?*

The Greeks were also familiar with a different category of substances. They found three slippery substances left behind as residue after burning certain materials. These three substances were: potash, soda, and lime. Potash, which must have been the first to be discovered, was produced from wood ashes. When some waters were produced and allowed to evaporate, the film left behind was soda. Lime was produced from burning seashells. Ultimately, the Greeks discovered a new category to define substances based upon the property of feeling slippery.

Question to the class: *What things in everyday life feel slippery? Soap and oil are slippery, but are they the same? Yogurt is sour and slippery; which category does it fit into?*

In 1386, to build on the Greek's definition of sour or slippery, a new terminology was developed to speak about things that felt slippery. From the Arabic word *al-qaliy*,

which means “the ashes”, the term alkaline was developed. This word was then used to speak about things that felt slippery.

### **Fabrics in France**

During the middle ages, the advancement towards defining sour and slippery substances was slow. European trading with China led to the introduction of the highly valued clothing good, silk. During the 16<sup>th</sup> century in France, fabric dyers found that when particular chemicals were added to the dyeing agent, the colors became more vibrant and even changed colors. Deeper and richer colors could be produced by adding these chemicals to the dyeing vats. The dyers notice that when one chemical was added to the vat, it turned the dye a red color. On the other hand, when a different chemical was added to the vat, it turned the dye a bluish-green color.

*Question to the class: What do you think the differences between the two chemicals were? Why didn't the fabric workers understand what was happening to their dyes?*

The fabric workers understood that certain substances changed the color and intensity of the dyes used in the industry. They did not need to know how it worked; they just needed to know that the dyes changed colors. For this reason, the fabric workers did not know that the dyes introduced another method for distinguishing between substances the Greeks defined as sour and slippery. Also, there was not a good understanding of the definition of alkaline, except that alkali substances were slippery. Therefore, the phenomenon was overlooked by the fabric workers and science all together.

*Question to the class: How did the fabric worker's perspective play a role in overlooking the significance that some chemicals turn dyes red, while others turned the dyes bluish-green?*

### **Separating Gold and Silver**

As trading with China's silk continued, Europeans were also obtaining precious metals such as gold and silver. However, these metals were often mixed together to produce an alloy. In 1626, an attempt to separate gold from silver led to an important advancement towards understanding substances that were only definable by their taste and texture. It was found that the sour substances defined by the Greeks also could dissolve silver. When a sour substance was added to the gold/silver alloy and allowed to boil, the silver dissolved. After the solid gold pieces were removed, the silver was then re-obtained by allowing the sour substance to boil away. This discovery of the dissolving properties of sour tasting substances led to a new terminology. From the Latin word *acidus*, which means “sour”, the term acid was developed. This term was then used to define sour tasting substances that had dissolving properties.

*Question to the class: From what you have learned so far, what are the characteristic properties of acids? From what you are learned so far, what are the characteristic properties of alkalis?*

## Discovering Salts

Johann Rudolph Glauber began as a pharmacist; however, he soon changed his line of work and became alchemists. Living in Amsterdam, Glauber ran many experiments concerning acids and alkalis, which were not yet distinctly defined. In his laboratory, he ran many experiments and observed their reactions. A few significant discoveries Glauber made were that of *spiritus salis* (hydrochloric acid), *spirit of alum* (sulfuric acid), and *spiritus acidus nitri* (nitric acid). *Spirit of alum* and *spiritus acidus nitri* were used for separating gold and silver; however, he was the first to produce concentrated amounts of either chemical. From his experiments of these three compounds with various chemicals, Glauber noticed that some chemicals reacted violently with one another producing an effervescence effect.

Question to the class: *What two types of chemicals do you think Glauber added together to produce an effervescence effect? Have you seen an effervescence reaction before? What are the ingredients for an effervescence reaction to take place?*

Question to the class: *What is the significance of the effervescence in acid-alkali experiments? Could effervescence be used as an indicator for acids and alkalis?*

In 1658, he described these violent reactions as being a “battle”:

“when nitri fixi (potassium carbonate base) is added to spiritom nitri (nitric acid)...the spiritus acidus and liquor fixus have slain each other”

The fact that acids and alkalis “battle” one another is not the only significant discovery made by Glauber. Also in 1658, Glauber noted that when an acid and an alkali react, they produce a new kind of compound called a salt:

“Liquor fixus (potassium hydroxide alkali) and spiritus acidus nitri (nitric acid) are in their nature...totally unlike, foes and adversaries of each other...and when the two are brought together...and the one part has overcome and killed the other, neither liquor nor a spiritus acidus can be found in their dead bodies, but the same has been made, as both were before and from which they were derived, namely ordinary saltpeter (potassium nitrate salt).”

Question to the class: *Glauber describes acid-alkali reactions as a “battle”, what does he mean by this? What is happening in the reaction that is causing the violent “battle”? What may be the technical term for Glauber’s “battle”?*

This observation that an acid and alkali react to yield a salt was a huge advancement in acid-alkali alchemy. In fact, this led Glauber to find another important chemical salt. From one of his experiments, Glauber found that when *spirit of alum* (sulfuric acid) was reacted with ordinary table salt, that a new salt was produced. This salt was *sal mirabilis* (sodium sulfate), which was also called Glauber’s salt. By producing many unattained compounds (hydrochloric acid, nitric acid, sulfuric acid, sodium sulfate, etc.), Glauber contributions to alchemy were very important.

With the discoveries presented by Glauber, the chemical world added another terminology and was now broken into three categories: acid, alkali, and salt. What are the properties of these three categories that make them different from one another?

### **Robert Boyle's Indicators**

Robert Boyle was born in Ireland where he grew up until he was eight years old. He was then sent to school and traveled around Europe with a French tutor. After his stint of traveling and studying, Boyle returned to Ireland where he joined the Invisible College. The Invisible College was not actually a college at all; it was a group of prominent philosophers who inquired about questions relevant to the time period. This group later became the Royal Society of London for the Improvement of Natural Knowledge after it had been granted by the King of England. Boyle was named to the council and held an important role in the Royal Society.

Question to the class: *Why is it important that Boyle was a member of the Royal Society? How does this strengthen his work as a scientist?*

During the 17<sup>th</sup> century, the majority view of compounds suggested that all chemical compounds are composed of the same four elements: fire, earth, water, and air. For example, when a log is burned in a fire, it leads to the four elements. The log begins to combust (fire), sap flows from the wood (water), smoke rises from the log (air), and the ashes (earth) are left behind after the log is finished burning. Boyle disagreed with this hypothesis and suggested that differences in compounds were to “different textures” (configuration and cohesion of different elements). For this reason and many others, Boyle was known as the “skeptical chemist”. In fact, Boyle wrote his first book *The Sceptical Chemist*, which questioned the majority views of alchemy.

Boyle found Glauber's work interesting. The new category of salts intrigued him and helped to support his hypothesis that not everything is composed of the same four elements. Boyle began experimenting with acids and alkalis. From his experiments, he was able to fit a better definition of an acid and alkali. On top of what the Greeks and Egyptians defined as being sour and what metal purifiers noted as excellent solvents, Boyle added that acids could also precipitate certain substances. Acids were very good in precipitating sulfur. On top of what the Greeks defined as being slippery, Boyle noticed that alkalis also contained “detergent properties”. Alkalis were also good at dissolving sulfur and oils; and just like Glauber, he found that alkalis were good at counteracting the properties of acids. He also noticed that some chemicals do not fit into the category of an acid or alkali.

Question to the class: *With the new properties of acids and alkalis proposed by Boyle, is soap an alkali? What properties of soap make it alkaline? Is oil an alkali? What property does oil lack that soap has?*

Question to the class: *Boyle says that alkalis counteract acids. Does this statement still apply when looking at how acids and alkalis react with sulfur? How?*

Question to the class: *If some compounds do not fit into the class of acid or alkali, what is it? Look back into the three categories defined by Glauber for the answer.*

Boyle continued his research of acids and alkalis and began to conduct experiments concerning how to identify an acid or alkali using indicators. He set up a number of different experiments which he published in his 1664 book *Experimental History of Colours*. Boyle knew from the French silk dyers that dyes were made from plant juices, so he began to experiment with the affects of acids on certain plant juices. He discovered what the French dyers had known a century before, only now he understood why the phenomenon they observed occurred. He noted that when an acid is placed in a jar containing a purple plant juice, the solution becomes red. Also, when an alkali is reacted with the same purple plant juice, the solution becomes bluish-green. Boyle had rediscovered an interesting and useful means of testing if a chemical was acidic or alkaline.

Question to the class: *If an acid changes the purple solution to red, and an alkali changes it to bluish-green, what would a salt change the purple solution to? Explain your reasoning.*

The development of acid and alkali indicators did not stop there. Boyle began to create small pieces of paper that had been soaked in lichens juice. After the paper had been removed from the juice and dried, it became a soft purple color. When the paper is touched to something acidic in character, the paper becomes red. Likewise, when the paper is touched to something alkaline in character, it becomes bluish-green. This new technique uses the same concept as the plant juice testing, but it is made much simpler by touching paper to the sample.

### **Further Reading**

Boyle, Robert. Experimental and Considerations Touching Colours. First Occasionally Written, Among Some Other Essays, to a Friend; and Now Suffer'd to Come Abroad as the Beginning of an Experimental History of Colours. London. 1664.

Brock, William H. Porter, Roy. Editor. The Norton History of Chemistry. W. W. Norton and Company. New York. London. 1992.

Bensaude-Vincent, Bernadette. Stengers, Isabelle. A History of Chemistry. Harvard University Press. Cambridge, Massachusetts. London. 1996.

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## Experiment 1

### **Plant Juice and Litmus Paper as an Indicator**

#### **Purpose**

The purpose of this experiment is to characterize some everyday samples as acidic, basic, or salt. To conduct this experiment, red cabbage juice and litmus paper will be used as indicators. Also, discuss the results by comparing to the original hypothesis of each chemical as it pertains to Boyle's description on acid and base properties.

#### **Supplies**

The supplies needed for this experiment include: red cabbage juice (provided by the teacher), a hotplate, a pot, a filter or strainer, litmus paper, baking soda water, vinegar, lemon juice, lime juice, soda pop, hand soap, dish soap, tap water, distilled (bottled) water, salt water, vegetable oil, several small dixie-cups, and plastic pipettes.

#### **Preparation for the Teacher**

To make the red cabbage juice indicator:

1. Blend some red cabbage leaves in a blender along with  $\frac{1}{2}$  cup of distilled water.
2. Boil the cabbage leaves for 10 minutes.
3. Filter the cabbage chunks from the now bluish-purple solution.
4. Allow for the cabbage solution to cool.
5. Place a small beaker containing the cabbage solution at each lab station.

#### **Application**

From the record of French silk dyers, Boyle used various plant juices to measure the character of certain chemicals. This led to his development of litmus paper. From his experiments, he determined that plant juices and litmus paper turn red when in contact with acids. He also determined that plant juices and litmus paper turn bluish-green when in contact with bases. This experiment gives students a first hand look at Boyle's work and allows them to work in a historical setting.

Name: \_\_\_\_\_

## Plant Juice and Litmus Paper as an Indicator

In this experiment, you will be testing various acids and alkalis with red cabbage juice and litmus paper indicators. This experiment was first preformed in 1664 by Robert Boyle, who from his work with plant juices developed litmus paper. Litmus paper is a form of plant juice indicator, and it still has applications today in the laboratory and in industry.

Boyle's work showed that acids change plant juice and litmus paper from purple to red. Alkalis, on the other hand, change plant juice and litmus paper bluish-green. Using this knowledge, determine whether some common everyday items are alkaline or acidic.

### Procedure

1. From the list of samples that will be tested, make a hypothesis as to whether it is acidic, basic, or neutral.
2. Obtain a small amount of each sample listed on **Table 1** and place each in an individual dixie-cup.
3. Use your plastic pipette to gather some cabbage juice and squirt a few drops on each sample.
4. Observe the effects of the cabbage juice on the sample. Record your observations in **Table 1**.
5. Now using the litmus paper, touch the sample with the litmus paper.
6. Observe the effects of the sample on the litmus paper. Record your observations in **Table 1**.
7. Determine if the sample is an acid, a base, or neutral. Record your answer in **Table 1**.
8. Answer the questions on the back of this sheet.

**Table 1**

SAMPLE	Hypothesis (acid, base, neutral)	Plant Juice	Litmus Paper	Acid, Base, Neutral?
baking soda water				
vinegar				
lemon juice				
lime juice				
soda pop				
hand soap				
dish soap				
tap water				
distilled water				
salt water				
vegetable oil				



## **Effervescence as an Indicator**

### **Purpose**

The purpose of this experiment is to use the base sodium bicarbonate (baking soda) as an indicator in the same manner as Johann Rudolph Glauber. Also, discuss and consider the effectiveness of effervescence as an indicator.

### **Supplies**

The supplies needed for this experiment include: baking soda, vinegar, lemon juice, lime juice, uncarbonated soda pop, hand soap, dish soap, tap water, distilled (bottled) water, salt water, vegetable oil, several small dixie-cups, spatula, and paper towels (to clean up the mess, of course)

### **Preparation**

1. Several days before the experiment, open a 1-2 liter bottle of Pepsi/Coke to reduce the carbonation.
2. Prepare the following solutions by adding water to: hand soap, dish soap, salt.

### **Application**

From his work on acids and bases, Glauber noted that when a base is added to an acid, effervescence is observed. From these experiments, Glauber concluded that acids and bases perform in a “battle” until they have “slain” one another to produce neither an acid nor a base, but a salt. This experiment gives students a first hand look at Glauber’s experiments with acids and bases and allows them to work in a historical setting.

Name: \_\_\_\_\_

## Effervescence as an Indicator

In this experiment, you will be testing various acids and alkalis using baking soda (sodium bicarbonate). Since the previous lab used litmus paper as an indicator, you should already know which samples are acids and alkalis. If you do not remember which samples are acids and alkalis, you should review the previous experiment before conducting this experiment. This experiment was first performed in 1658 by Johann Rudolf Glauber, who was able to determine an acid by adding an alkali and observing the bubbles. In everyday life, the action of effervescence can be seen when Alka-seltzer is dropped in water.

Glauber's work showed that alkalis can be used to determine acids. Also, it showed that acid-alkali reactions result in the production of a salt. Using this knowledge, determine whether some common everyday items are acidic.

### Procedure

1. Obtain a small amount of each sample listed on **Table 1** and place each in an individual dixie-cup.
2. Use your spatula, scoop a small amount of baking soda into the dixie-cup.
3. Continue to add small amounts of baking soda until the exact moment the baking soda solution stops bubbling.
4. Observe the effects of the baking soda on the sample. Record your observations in **Table 1**.
5. Determine if the sample is an acid. Record your answer in **Table 1**.
6. Now using the litmus paper, touch the sample with the litmus paper. Record your observations in **Table 1**.
7. Determine if the sample (after adding the baking soda) is an acidic, a basic, or neutral. Record your answer in **Table 1**.
8. Answer the questions on the back of this sheet.

**Table 1**

SAMPLE	Effervescence?	Acid?	Litmus Paper	Acid, Base, Neutral?
vinegar				
lemon juice				
lime juice				
soda pop				
hand soap				
dish soap				
tap water				
distilled water				
salt water				
vegetable oil				

### Questions

1. Why didn't all the samples show signs of effervescence when baking soda was added?
2. Why did some samples bubble more violently than others?
3. Is Glauber's method of using effervescence as an indicator a good one? Is it more or less accurate than Boyle's plant juice and litmus paper indicators? Explain your reasoning.
4. When baking soda is added to an acid, effervescence is observed. However, when baking soda is added repeatedly, the effervescence stops. Why did the effervescence stop even though more baking soda was added?
5. What happened to the acid when the baking soda was added?