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# Hydrolysis of Salts

## Weak Acids and Bases

## Introduction

Show the effects of hydrolysis of salts on the acid–base properties of a solution with this colorful demonstration that can be done on an overhead projector.

## Concepts

- Acids and bases
- pH
- Salt hydrolysis

## Background

Acidic and basic properties of aqueous solutions depend on the concentrations of hydrogen ions [$H^+$] and hydroxide ions [$OH^-$]. Water (the solvent in an aqueous solution) dissociates to a small extent into hydrogen ions ($H^+$) and hydroxide ions ($OH^-$) according to Equation 1.

$$H_2O \leftrightarrows H^+(aq) + OH^-(aq) \qquad \textit{Equation 1}$$

When the concentration of $H^+$ is equal to the concentration of $OH^-$, the solution is neutral (pH = 7). When $H^+$ ions exceed $OH^-$ ions, the solution is acidic (pH < 7). When $OH^-$ ions exceed $H^+$ ions, the solution is basic (pH > 7). For example, an aqueous solution of HCl or $H_2SO_4$ has a greater concentration of $H^+$ ions and is therefore acidic. An aqueous solution of NaOH or $NH_4OH$ has a greater concentration of $OH^-$ ions and is therefore basic.

Salts, on the other hand, may undergo hydrolysis in water to form acidic, basic, or neutral solutions. *Hydrolysis* of a salt is the reaction of the salt with water or its ions. A *salt* is an ionic compound containing a cation other than $H^+$ and an anion other than $OH^-$ (or $O^{2-}$). The broad range of cations and anions that combine to form salts (such as $NaNO_2$, $NH_4I$, $CuSO_4$, or NaBr) makes it more difficult to predict whether the resulting salt solution will be acidic, basic, or neutral.

In a dilute salt solution, a soluble salt dissociates completely into its ions. Thus, a water solution labeled "NaBr" actually contains $Na^+$ ions and $Br^-$ ions (Equation 2).

$$NaBr(s) \rightarrow Na^+(aq) + Br^-(aq) \qquad \textit{Equation 2}$$

The acid–base properties of a salt such as NaBr are determined by the behavior of its ions. To decide whether a water solution of NaBr is acidic, basic, or neutral, the effect of the $Na^+$ and $Br^-$ ions on the pH of water must be considered. Some ions have no effect on the pH of water, some ions are acidic because they produce $H^+$ ions in water, and others are basic because they produce $OH^-$ ions in water. In this demonstration, five salts will be tested. The salts will be dissolved in water, the pH of the resulting solutions will be measured, and chemical equations will be written.

## Materials

Aluminum chloride, $AlCl_3 \cdot 6H_2O$, 1 g
Ammonium chloride, $NH_4Cl$, 1 g
Potassium carbonate, $K_2CO_3 \cdot 1.5H_2O$, 1 g
Sodium bicarbonate, $NaHCO_3$, 1 g
Sodium chloride, NaCl, 1 g
Sodium phosphate, tribasic, $Na_3PO_4 \cdot 12H_2O$, 1 g
Sodium phosphate, dibasic, $Na_2HPO_4 \cdot 7H_2O$, 1 g
Sodium phosphate, monobasic, $NaH_2PO_4 \cdot H_2O$, 1 g
Universal indicator solution, 3–5 mL
Water, boiled, distilled or deionized
Beaker, 250-mL
Graduated cylinder, 25-mL
Hot plate or Bunsen burner
Marking pen
Overhead projector
Overhead transparency sheet
Petri dishes (tops or bottoms), 5
Spatulas, 5
Stirrers, 5
Universal indicator color chart

### *Safety Precautions*

*Aluminum chloride, ammonium chloride, potassium carbonate and sodium phosphate are slightly toxic by ingestion and are body tissue irritants. Do not substitute anhydrous aluminum chloride due to its violent reaction with water. Universal indicator solution is an alcohol-based flammable liquid. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.*

## Preparation

1. Place approximately 150 mL of distilled or deionized water in a beaker.
2. Using a hot plate or Bunsen burner, boil the water for about 10–15 minutes to remove any dissolved carbon dioxide. (*Note:* The pH of the water should be near 7.) Cover the beaker and allow the water to cool.
3. Rinse five Petri dishes with distilled water to ensure that they are not contaminated.

## Procedure

1. Place five Petri dishes on an overhead transparency sheet on the overhead projector (or on the demonstration table). Label the transparency with the formulas of the five salts to be used.
2. Add 15–20 mL of boiled distilled or deionized water to each Petri dish (enough to fill the dishes half way).
3. Add 15 drops of universal indicator solution to each Petri dish to achieve a neutral green color. (*Note:* If the solution in any of the dishes is not green after adding the indicator, rinse out the dish with DI water and start again as there must have been some contamination.)
4. Using a different spatula for each solid, add about 1 gram of salt to each Petri dish in the following order:

| Petri Dish | Salt | Solution Color | pH |
|---|---|---|---|
| 1 | Aluminum chloride | Red | 3 |
| 2 | Ammonium chloride | Orange-yellow | 5 |
| 3 | Sodium chloride | Green | 7 |
| 4 | Sodium bicarbonate | Blue | 9 |
| 5 | Sodium phosphate | Purple | 12 |

5. Stir to dissolve each solid using a separate wood stirrer for each.
6. Note the pH of each solution by comparing the solution color to the universal indicator color card.

## Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. Each of the salts may be disposed of down the drain or in the solid waste disposal according to Flinn Suggested Disposal Methods #26a or #26b.

## Tips

- The *Hydrolysis of Salts—Acidic, Basic or Neutral? Demonstration Kit* (Flinn Catalog No. AP6187) contains enough chemicals to perform the demonstration at least seven times with five salts. The quantities provided in the kit are as follows—10 grams (7 g needed) of each of the five salts (aluminum chloride, ammonium chloride, sodium bicarbonate, sodium chloride, and sodium phosphate, tribasic), 35 mL of universal indicator solution, 5 reusable Petri dishes, 35 wood stirrers, and a universal indicator pH card.
- In the video, Kathleen Dombrink uses seven salts. In addition to four of the previously listed chemical salts, she also uses potassium carbonate $K_2CO_3$, sodium phosphate monobasic $NaH_2PO_4$, and sodium phosphate, dibasic $Na_2HPO_4$. The video procedure also varies by using beakers and putting them on a light box instead of in Petri dishes on an overhead projector.
- After reading the discussion, decide if you wish to first perform the demonstration and then discuss the observations. Or you may wish to first have students look at and evaluate the cations and anions of the salts and make predictions as to the acidic or basic nature of the salt solutions. Then perform the demonstration to test their predictions.
- An overhead transparency of the universal indicator color card, the *Universal Indicator Overhead Color Chart* (Flinn Catalog No. AP5367), is available for use on the overhead projector.

## Discussion

Results from this demonstration show that aluminum chloride and ammonium chloride form acidic solutions in water (pH < 7); sodium chloride forms a neutral solution (pH = 7); sodium bicarbonate and sodium phosphate form basic solutions (pH > 7). *Hydrolysis* refers to the reaction of a substance with water or its ions. The chemical equations for the reactions are shown below. The equation for the dissociation of the salts are shown first followed by the net equations that produce either $H^+$ (if acidic), $OH^-$ (if basic), or neither (if neutral). *Note:* Spectator ions are omitted from the net equations.

*Aluminum chloride*

$AlCl_3{\cdot}6H_2O(s) \rightarrow Al(H_2O)_6^{3+}(aq) + 3Cl^-(aq)$

$Al(H_2O)_6^{3+}(aq) \rightarrow \mathbf{H^+}(aq) + Al(H_2O)_5(OH)^{2+}(aq)$ *Acidic*

*Ammonium chloride*

$NH_4Cl(s) \rightarrow NH_4^+(aq) + Cl^-(aq)$

$NH_4^+(aq) \rightarrow \mathbf{H^+}(aq) + NH_3(g)$ *Acidic*

*Sodium chloride*

$NaCl(s) \rightarrow Na^+(aq) + Cl^-(aq)$

$Na^+(aq) + Cl^-(aq) \rightarrow$ No further reaction *Neutral*

*Sodium bicarbonate*

$NaHCO_3(s) \rightarrow Na^+(aq) + HCO_3^-(aq)$

$HCO_3^-(aq) + H_2O(l) \rightarrow H_2CO_3(aq) + \mathbf{OH^-}(aq)$ *Basic*

*Sodium phosphate*

$Na_3PO_4(s) \rightarrow 3Na^+(aq) + PO_4^{3-}(aq)$

$PO_4^{3-}(aq) + H_2O(l) \rightarrow HPO_4^{2-}(aq) + \mathbf{OH^-}(aq)$ *Basic*

While acidic or basic properties of salt solutions can be measured in the laboratory, the acidic or basic nature of a salt can also be predicted by considering the properties of its ions. In general, as shown in Table 1, neutral anions are those derived from strong acids and neutral cations are those derived from strong bases. Acidic cations include all cations except those of the alkali metals and the heavier alkaline earths. Acidic anions include the $HSO_4^-$ and $H_2PO_4^-$ anions. Basic anions include any anion derived from a weak acid; there are no common basic cations.

### Table 1. Acid–Base Properties of Common Ions in Aqueous Solution

| | Neutral | Basic | Acidic |
|---|---|---|---|
| Anion | $Cl^-$ $NO_3^-$<br>$Br^-$ $ClO_4^-$<br>$I^-$ $SO_4^{2-}$ | $C_2H_3O_2^-$ $CN^-$<br>$F^-$ $NO_2^-$<br>$CO_3^{2-}$ $HCO_3^-$<br>$S^{2-}$ $HS^-$<br>$PO_4^{3-}$ $HPO_4^{2-}$ | $HSO_4^-$<br>$H_2PO_4^-$ |
| Cation | $Li^+$ $Ca^{2+}$<br>$Na^+$ $Ba^{2+}$<br>$K^+$ | none | $Mg^{2+}$ $Al^{3+}$<br>$NH_4^+$<br>transition metal ions |

The information provided in Table 1 can be used to predict the acidic or basic nature of the salt; this can then be confirmed by experiment. The five salts tested in this demonstration are listed below. The acidic or basic nature of the cation and of the anion are given, together with a prediction of whether the salt solution will be acidic, basic, or neutral.

| Salt | Cation | Anion | Solution of Salt |
|---|---|---|---|
| $AlCl_3{\cdot}6H_2O$ | $Al^{3+}$ (acidic) | $Cl^-$ (neutral) | Acidic |
| $NH_4Cl$ | $NH_4^+$ (acidic) | $Cl^-$ (neutral) | Acidic |
| NaCl | $Na^+$ (neutral) | $Cl^-$ (neutral) | Neutral |
| $NaHCO_3$ | $Na^+$ (neutral) | $HCO_3^-$ (basic) | Basic |
| $Na_3PO_4{\cdot}12H_2O$ | $Na^+$ (neutral) | $PO_4^{3-}$ (basic) | Basic |

## Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

***Unifying Concepts and Processes: Grades K–12***
Constancy, change, and measurement
***Content Standards: Grades 5–8***
Content Standard B: Physical Science, properties and changes of properties in matter.
***Content Standards: Grades 9–12***
Content Standard B: Physical Science, structure and properties of matter, chemical reactions.

## Answers to Worksheet Results Table

| Petri Dish | Salt | Solution Color | pH | Acid, Base, or Neutral |
|---|---|---|---|---|
| 1 | Aluminum chloride | *Red* | *3* | *Acid* |
| 2 | Ammonium chloride | *Orange-yellow* | *5* | *Acid* |
| 3 | Sodium chloride | *Green* | *7* | *Neutral* |
| 4 | Sodium bicarbonate | *Blue* | *9* | *Base* |
| 5 | Sodium phosphate | *Purple* | *12* | *Base* |

## Answers to Discussion Questions

1. Explain what happened to the salts in the water and what caused the acid-base properties of the solutions.

   *The salts underwent hydrolysis, which is the reaction of a salt with water or its ions. The ions determine the acid–base properties of the resulting solutions. Some ions have no effect on the pH of the water, while some produce* $H^+$ *ions, and others produce* $OH^-$ *ions.*

2. Salt hydrolysis can be described in two chemical equations, the first showing the dissociation of the salt, and the second net equation showing the production of $H^+$ or $OH^-$ ions. Write the two equations for each salt in this demonstration. If neither $H^+$ nor $OH^-$ ions are produced, write "no reaction" for the second equation.

   *a.* $AlCl_3{\cdot}6H_2O(s) \rightarrow Al(H_2O)_6^{3+}(aq) + 3Cl^-(aq)$
   $Al(H_2O)_6^{3+} \rightarrow H^+(aq) + Al(H_2O)_5(OH)^{2+}(aq)$
   ***Note to teachers:*** *You may have to tell students that the aluminum forms a complex ion with water.*

   *b.* $NH_4Cl(s) \rightarrow NH_4^+(aq) + Cl^-(aq)$
   $NH_4^+(aq) + H_2O(l) \rightarrow H^+(aq) + NH_3(g)$

   *c.* $NaCl(s) \rightarrow Na^+(aq) + Cl^-(aq)$
   *No reaction*

   *d.* $NaHCO_3(s) \rightarrow Na^+(aq) + HCO_3^-(aq)$
   $HCO_3^-(aq) + H_2O(l) \rightarrow H_2CO_3(aq) + OH^-(aq)$

   *e.* $Na_3PO_4(s) \rightarrow 3Na^+(aq) + PO_4^{3-}(aq)$
   $PO_4^{3-}(aq) + H_2O(l) \rightarrow HPO_4^{2-}(aq) + OH^-(aq)$

## Acknowledgment

Flinn Scientific would like to thank John Wass, Western Branch H.S., Chesapeake, VA for bringing this demonstration to our attention to share with other teachers.



 

## Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Hydrolysis of Salts* activity, presented by Kathleen Dombrink, is available in *Weak Acid and Bases,* part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

## Materials for *Hydrolysis of Salts* are available from Flinn Scientific, Inc.

Materials required to perform part of this activity are available in the *Hydrolysis of Salts—Acidic, Basic or Neutral? A Colorful Overhead Demonstration Kit* available from Flinn Scientific. Materials may also be purchased separately.

| Catalog No. | Description |
|---|---|
| AP6187 | Hydrolysis of Salts —Acidic, Basic, or Neutral? A Colorful Overhead Demonstration |
| AP5367 | Universal Indicator Overhead Color Chart |
| S0097 | Sodium Phosphate, Monobasic, 100 g |
| S0222 | Sodium Phosphate, Dibasic, 100 g |
| A0225 | Aluminum Chloride, $AlCl_3{\cdot}6H_2O$, 100 g |
| A0266 | Ammonium Chloride, $NH_4Cl$, 100 g |
| S0042 | Sodium Bicarbonate, 500 g |
| S0061 | Sodium Chloride, 500 g |
| S0101 | Sodium Phosphate, Tribasic, 500 g |
| U0009 | Univeral Indicator Solution, 35 mL |
| P0157 | Potassium Carbonate, 100 g |

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.



 

# Hydrolysis of Salts Worksheet

## Results Table

| Petri Dish | Salt | Solution Color | pH | Acid, Base, or Neutral |
|---|---|---|---|---|
| 1 | Aluminum chloride | | | |
| 2 | Ammonium chloride | | | |
| 3 | Sodium chloride | | | |
| 4 | Sodium bicarbonate | | | |
| 5 | Sodium phosphate | | | |

## Discussion Questions

1. Explain what happened to the salts in the water and what caused the acid–base properties of the solutions.

2. Salt hydrolysis can be described in two chemical equations, the first showing the dissociation of the salt, and the second net equation showing the production of $H^+$ or $OH^-$ ions. Write the two equations for each salt in this demonstration. If neither $H^+$ nor $OH^-$ ions are produced, write "no reaction" for the second equation.

   *a.* $AlCl_3{\cdot}6H_2O(s) \rightarrow$

   *b.* $NH_4Cl(s) \rightarrow$

   *c.* $NaCl(s) \rightarrow$

   *d.* $NaHCO_3(s) \rightarrow$

   *e.* $Na_3PO_4(s) \rightarrow$