# Brönsted-Lowry Acid and Base Equilibria

EXPERIMENT 20B

In Experiment 20A you were introduced to the topic of acids and bases, and you learned that an acid gives off $H^+$ ions in solution and a base gives off $OH^-$ ions in solution. These statements are called the Arrhenius definitions for acid and base. They apply to aqueous solutions.

Another pair of definitions for acid and base has been proposed to take into account the fact that not all acid-base reactions occur in aqueous solution; they can occur in other solvents as well. These definitions are known as the Brönsted-Lowry definitions, after the scientists who first proposed them. According to the Brönsted-Lowry theory, an acid is defined as a proton donor, and a base is defined as a proton acceptor. Another part of this theory states that when an acid and a base react together, they produce another acid and another base. You can see that the Brönsted-Lowry definitions include the Arrhenius definitions, since $H^+$ is the same as a proton, and $OH^-$ reacts with (accepts) a proton ($H^+$) when they neutralize one another.

Using HA to indicate an acid, and $B^-$ to indicate a base, the equation for an acid-base reaction can be shown as follows:

$$\underset{\text{acid}}{HA} + \underset{\text{base}}{B^-} \rightleftharpoons \underset{\text{base}}{A^-} + \underset{\text{acid}}{HB}$$

A pair of substances such as HA and $A^-$ or HB and $B^-$ is called a *conjugate acid-base pair.* ($A^-$ is the conjugate base of HA; HA is the conjugate acid of $A^-$.) If the reaction equilibrium shown above favors the products over the reactants, then HA must be a stronger acid than HB. (That is, HA has the greater tendency to give off protons.) Likewise, $B^-$ is a stronger base than $A^-$ ($B^-$ has a greater tendency to accept protons).

An *acid-base indicator* is a weak acid or base that has a conjugate base or acid which is a different color. The $[H^+]$ at which the color changes varies from one indicator to another; thus, indicators can be used to determine the $[H^+]$ in a solution.

In this experiment you will use five different indicators which will be identified only by number. They will each be added to each of six unknown solutions containing a conjugate acid-base pair. Therefore, you will have eleven solutions to start with, including the indicators that are conjugate acid-base pairs. From the resulting thirty mixtures you will be able to deduce the relative strengths of all eleven as weak acids, and arrange them in order of decreasing strengths of acids (or increasing strengths of conjugate bases). The amounts of solution and indicator involved will vary depending on whether the experiment is performed with a glass plate (or spot plate) instead of test tubes. Using test tubes will require somewhat more of each to see results clearly, but in either case best results are obtained if the amount of indicator is about one quarter of the amount of solution. Your instructor will give you more precise directions.

## OBJECTIVES

1. to obtain an understanding of the equilibria which involve acids and bases
2. to observe the color changes that occur with a number of different acid-base indicators in several different solutions

3. to arrange all the Brönsted-Lowry acids involved in this experiment in order of decreasing strength

## MATERIALS

| **Apparatus** | **Reagents** |
|---|---|
| glass plate | 1*M* HCL |
| *or* spot plate | 1*M* NaOH |
| *or* 13 mm × 100 mm test tubes with rack | 6 solutions of different pH (labelled $HA_1/A_1^-$, $HA_2/A_2^-$, etc., to $HA_6/A_6^-$) |
| lab apron | 5 different indicator solutions (labelled $HIn_1/In_1^-$, $HIn_2/In_2^-$, etc., to $HIn_5/In_5^-$) |
| safety goggles | |

HAZARD

*CAUTION: The hydrochloric acid and sodium hydroxide solutions are corrosive to skin, eyes, and clothing. Wash any spills and splashes with plenty of water. Call your teacher.*

*CAUTION: Some of the unknowns in this experiment are strongly acidic or strongly basic. Treat them all as though they were hydrochloric acid or sodium hydroxide solutions, as described in the CAUTION statement above.*

*CAUTION: Some of the indicators used in this experiment consist of flammable solutions. Make sure there are no burners in the vicinity.*

*CAUTION: Some of the indicators used in this experiment are toxic. Do not get any in your mouth; do not swallow any. Wash any spills or splashes with plenty of water.*

## PROCEDURE

1. Put on your lab apron and safety goggles.
2. On a sheet of white paper the size of your glass plate, mark off five regions, and label them $HIn_1$, $HIn_2$, etc., to $HIn_5$.
3. Place 4 drops of 1*M* HCl on each of these areas on the glass plate.
4. Add 1 drop of each indicator solution to the designated area, and record the color in your copy of Table 1 in your notebook. (These results give you the colors of the acid form of each indicator.) Rinse and dry the glass plate.
5. Repeat Steps 3 and 4, using 1*M* NaOH instead of HCl. (The results give the colors of the base forms of each indicator.)
6. Repeat Steps 3 and 4 with unknown solution $HA_1/A_1^-$ and the five different indicators, and continue the process with all the other unknown solutions until you have recorded the color in all 30 possible combinations of unknown solution with unknown indicator.
7. Wash your hands thoroughly with soap and water before leaving the laboratory; use a fingernail brush to clean under your fingernails.

## REAGENT DISPOSAL

Rinse all chemicals down the sink with plenty of water.

## POST LAB DISCUSSION

The results with HCl and each indicator tell you what the color of the acid form of the indicator is, since HCl is a strong acid and will cause the indicator to accept a proton. The results with NaOH and each indicator tell you what the color of the base form of the indicator is, since NaOH is a strong base and will cause the indicator to donate a proton.

In order to interpret the results and deduce a list of acid strengths, consider the following example:

$$HA_1 + In_3^- \rightleftharpoons A_1^- + HIn_3$$

If in this combination the indicator $HIn_3$ is showing the color of its acid form, then $HA_1$ is a stronger acid than $HIn_3$, because $HA_1$ was able to donate a proton. In addition, $In_3^-$ is a stronger base than $A_1^-$. On the other hand, if in the same example the mixture shows the color of the basic form of $HIn_3$, namely $In_3^-$, then $HIn_3$ is stronger than $HA_1$, and $A_1^-$ is stronger than $In_3^-$. Note that the stronger acid and base always react to give the weaker acid and base.

You will often be using indicators in subsequent experiments. Some of them may be ones you used in this experiment. The important fact to realize about indicators is that they are weak acids just like any other weak acid, and are therefore subject to the shifting of the weak acid equilibrium. The only reason for which these weak acids were chosen as indicators is that the weak acid and conjugate base which constitute the indicator happen to have different colors.

## DATA AND OBSERVATIONS

It would be a good idea to copy this table into your notebook before coming to the laboratory.

**Table 1**

| | $HIn_1/In_1^-$ | $HIn_2/In_2^-$ | $HIn_3/In_3^-$ | $HIn_4/In_4^-$ | $HIn_5/In_5^-$ |
|---|---|---|---|---|---|
| HCl | | | | | |
| NaOH | | | | | |
| $HA_1/A_1^-$ | | | | | |
| $HA_2/A_2^-$ | | | | | |
| $HA_3/A_3^-$ | | | | | |
| $HA_4/A_4^-$ | | | | | |
| $HA_5/A_5^-$ | | | | | |
| $HA_6/A_6^-$ | | | | | |

COMPLETE IN YOUR NOTEBOOK

## QUESTIONS

1. Make up another table like the one showing your observations, but leave out HCl and NaOH. From your results, fill in each box with a statement about the relative strengths of the two acids involved; for instance, $HA_1 > HIn_3$, or $HIn_3 > HA_1$.
2. Arrange the eleven acids in a list, with the strongest at the top and weakest at the bottom. Then write an ionization equation for each by putting $H^+$ and the conjugate base on the right. Label each side of the list with a vertical arrow, one for increasing strength of acid and one for increasing strength of base.

## FOLLOW-UP QUESTIONS

1. The five indicators used in this experiment were bromcresol green, bromthymol blue, indigo carmine, orange IV, and thymolphthalein. Use Appendix 4 to discover the pH range over which each indicator changes color.
2. Use the information from item 1 to identify each indicator used in the experiment.
3. The six unknown solutions were all at a whole number of pH units in the range 0–14. Try to work out the pH of each unknown solution. (For some of them you may not be able to determine the pH exactly, but you should be able to narrow it down to a choice of 2 integral pH values.)
4. One way of determining the pH of a particular solution is to use what is called a *universal indicator*, which consists of a mixture of different indicators that give a number of different color changes as the pH changes. From a reference book, find out the composition of a universal indicator.

## CONCLUSION

State the results of Objective 3.