You cannot strengthen one by weakening another; and you cannot add to the stature of a dwarf by cutting the leg off a giant.
--Benjamin Franklin

Hydrolysis of Salts

The products of an acid/base neutralization reaction are generally water and a salt [in reactions with the weak base NH_3 and similar nitrogen bases, no water is formed]. Often the salt is soluble in the mixture and there is no obvious visible change which tells us that a reaction has occurred or is complete. That is why indicators are used, along with various instrumental methods, to follow the progress of reactions between acids and bases.

It would be a mistake to assume that a "neutralization" reaction results in a *neutral* solution, however. Perhaps we need a better name for the process which does not imply that the final pH will be 7. As you will see in this exploration, such is not always the case.

An interesting--if mundane--application of hydrolysis reactions is found in baking (better living through chemistry...). Most dry chemical leavening agents sold today contain sodium hydrogen carbonate (baking soda). But $NaHCO_3$ by itself forms very little CO_2 which is the principal agent in the rising of non-yeast baked goods. Baking soda begins to lose its CO_2 at 270ºC (518ºF---if you've never baked anything, *don't* try it at this temperature!!). Older recipes which relied on baking soda alone as a leavening agent always included some source of acid such as lemon juice or vinegar.

Some modern baking powder is a mixture of $NaHCO_3$ and some kind of "alum" or double salt containing aluminum*. And as any good baker will tell you, baking **soda** is NOT interchangeable with baking **powder.** No acid is required when baking powder is used in order for the mixture to produce CO_2 when water is added. Why? Hydrolysis is the answer, as you will see.

*there are generally other compounds present to enhance and prolong the production of CO_2, but they are not of interest here

Preparing to experiment

You will be provided with the following materials:

1. 1 M solutions of these salts:
   $NaCH_3COO$, NaCl, NH_4Cl, NH_4CH_3COO, Na_2CO_3
2. Universal indicator and pH buffers from 1-12
3. solid $NaHCO_3$ (baking soda)
4. solid $KAl(SO_4)_2 \cdot 12\ H_2O$ (alum)
5. 0.1 M HCl
6. 24/96-combo micro plate

Design an experiment to estimate the pH of each salt solution. [include here a solution of alum which you can make yourself with a few crystals of the solid and a little distilled water. [see **Technique** section]

Design an experiment to examine separately the behavior [not pH] of solid $NaHCO_3$ in water, solid $NaHCO_3$ with HCl, and a mixture of $NaHCO_3$ + $KAl(SO_4)_2 \cdot 12\ H_2O$ with water.

Technique

1. Using Universal indicator to estimate pH

Most acid/base indicators pass through 2 or three colors at most as the pH changes. For a broader visual indication of pH a mixture of indicators is often used. The universal indicator in this experiment has relatively distinct color changes for whole pH units from 1 to 12. To develop a set of standard colors to compare your unknowns to all you have to do is place a drop or two (be consistent) of indicator in 12 small wells and add a drop or two (again, be consistent) of the various buffer solutions.

The chemicals

Sodium acetate is a white crystalline solid, hygroscopic and very soluble in water (1 g in 0.8 mL!!). It is used in photography, in analytical chemistry as a buffer and in dyeing as a mordant. It has a heat of fusion four times as great as an equal volume of water which it gives up only slowly. Hence it is used in re-usable hot packs which are commercially available.

Ammonium acetate exists as deliquescent crystals which have a slight odor of acetic acid. It is used for preserving meats, dyeing and stripping.

Potassium aluminum sulfate can be obtained as large clear crystals or as a fine white powder with a sweetish astringent taste. Also known as "alum" or *potassium alum* it is used in dyeing (as a mordant), tanning, making various types of cement, baking powders, purifying water, copper plating, etc.

Analysis

1. Make a table listing the salt solutions you tested in the experiment, their pH, the acids and bases from which they were formed, and whether those acids and bases were strong or weak. [exclude the alum solution]

2. Consider the information in the table and attempt to generalize some simple rule for the hydrolysis of a salt (i.e., will it yield an acidic or basic solution?)

3. In the alum compound used in this experiment two cations are present. One is the potassium ion (from the strong base KOH). The anion is the sulfate ion (from the strong acid H_2SO_4). Consider the remaining cation (Al^{3+}). How does alum-containing baking <u>powder</u> work? [your explanation should have something to do with *hydrolysis*!]

4. Hydrolysis is defined as the equilibrium reaction of an ion in solution with water. For example, for the anion A^-, the hydrolysis reaction could be written:

$$A^- + H_2O \leftrightarrows HA + OH^-$$

Would you expect such a mixture to be acidic or basic?

5. It is possible to write a hydrolysis reaction for a cation also:

$$HB^+ + H_2O \leftrightarrows H_3O^+ + B$$

Would you expect such a mixture to be acidic or basic?

6. There are only three *different* hydrolysis reactions involved in the salt solutions you worked with in this experiment (since many of the salts share common ions). Write them.