Pool Science: Maintaining proper pH requires an understanding of acid-base concepts

By: Marci K. Harvey and Catherine E. Matthews

Harvey, M., & Matthews, C. (1997). Swimming Pool Science. *The Science Teacher, 64* (5), 35 -37.

After conducting an indicator lab and a titration lab, our laboratory ideas for acid-base chemistry were depleted. Students were getting bored doing nothing but calculations, so we came up with a weeklong project that not only covers the concepts of acid-base chemistry but also helps students answer that age-old question, "When am I ever going to use this information?" The idea for the activity came from a textbook that suggests inviting a pool maintenance person speak to the class about their job (Wilbraham, Staley, and Matta, 1995). Instead, we decided to let the students become the pool crew!

The activity consists of students building a model swimming pool. The only constraint on the pool design is that it can hold only 1.0 liter of water, so a plastic container from any kitchen will suffice. After filling their models with water, students place them outside and expose them to the elements for one week to simulate realistic conditions for outdoor swimming pools.

The ultimate goal of the project is for students to maintain the chemistry of their pools at levels safe for swimmers. This task requires students to use their previous knowledge of acid-base chemistry as well as Le Châtelier's principle. They must also consider the effects that precipitation and temperature have on the pH of the pool. Students keep a daily journal of their work for one week and submit their results for comparison in a classwide discussion at the end of the week.

Because some previous knowledge of acid-base chemistry is required, I use this activity after my class has performed the traditional titration and indicator labs. By titrating a strong acid, such as HC1, with a strong base, such as NaOH, students learn that the two chemicals neutralize each other and that the resulting pH is 7.0.

Before the activity, we also discuss how the buildup of one chemical in a reaction shifts the equilibrium point of that reaction in the opposite direction, as stated by Le Châtelier's principle. Using various indicators—such as litmus paper, probes, and bromothymol blue—helps students practice how to physically determine pH. They then learn how to calculate pH from molar concentrations of H^+ ions for acids or OH^- ions for bases.

When students begin this project, they already have all of the background information they need to be successful. The only additional data that they receive are the formulas and reactions for the compounds that they have at their disposal. We also provide them with a list of safety notes (see box page 36).

DIVING IN

We begin the activity by randomly forming crews of two students. The first day is used for pre-lab activities. Students read the lab and safety sheets and arrange to bring their containers the next day. We discuss the lab

SAFETY NOTES

1. Wear safety goggles.

2. Hydrochloric acid is corrosive to skin and eyes. If you spill acid on yourself, immediately flush the affected area with cold water for 15 minutes and notify the teacher. If acid should get into your eyes, begin flushing your eyes with water immediately and continue doing so for at least 20 minutes.

3. Sodium hydroxide sulfate is a body tissue irritant. If you spill it on yourself, immediately flush the affected area with cold water for 15 minutes and notify the teacher.

4. Sodium carbonate may be a skin irritant. Avoid skin contact with this chemical. Wash your hands thoroughly after use.

procedure as well as how the journals will be kept. The school then provides all the chemicals (HCl, $NaHSO_4$, Na_2CO_3, and $NaHCO_3$) used to adjust the pH and all of the indicators needed to test the pH. The next day students fill their pools with water and record initial observations (appearance, smell, feel, and so on) of the pool and take pH and temperature readings. These data constitute the first journal entry.

Swimming pool chemistry essentially consists of controlling a key reversible reaction. The hypochlorite ion (C10-) from either a liquid sodium hypochlorite solution (household bleach, 5-percent NaC1O) or dry calcium hypochlorite, $Ca(C1O)_2$, reacts with the water in the pool to form hypochlorous acid (HC1O) and OH- ions:

$$ClO^- (aq) + H_2O \leftrightarrow HClO (aq) + OH^- (aq)$$

The HCIO prevents the growth of bacteria and algae in the pool. If the pH of the pool is too high, Le Châtelier's principle predicts that the equilibrium point of the reaction will shift toward the reactants. When this happens the concentration of HC1O becomes too low to keep bacteria and algae from growing. The opposite effect is seen if the pH is too low: Le Châtelier's principle predicts that the reaction equilibrium will shift toward the products. In this case the concentration of HC1O is high enough to keep the pool clean but would render the pool unusable because the high concentration of acid would burn swimmers' eyes.

The question for students becomes how to maintain a safe pH range of 7.2 to 7.8 in the pool. To reduce a high pH, some of the excess OH- ions must be neutralized. Using previous knowledge that acids and bases neutralize one another, students will realize this is the step they need to take. The acids they have a choice of using are either 1.0 M or 0.1 *M* HCl or 1.0 M or 0.1 M $NaHSO_4$. These acids react with the hydroxide ions to reduce the pH of the swimming pool:

$$HCl (aq) + OH^- (aq) \rightarrow H_2O (l) + Cl^- (aq)$$

$$NaHSO_4 (aq) + OH^- (aq) \rightarrow Na^+ (aq) + SO_4^{-2} (aq) + H_2O (l)$$

To raise the pH of the pool, some of the excess acid must be neutralized with either 1.0M or 0.1 M Na_2CO_3 or 1.0 M or 0.1 M $NaHCO_3$ (baking soda). Antacid tablets work on this same principle. The carbonate ion reacts with the acid to produce water and carbon dioxide gas. The equations for these neutralization reactions are as follows:

$$Na_2CO_3\ (aq) + 2H^+ \rightarrow 2Na^+\ (aq) + H_2O\ (l) + CO_2\ (aq)$$

$$NaHCO_3\ (aq) + H^+ \rightarrow Na^+\ (aq) + H_2O\ (l) + CO_2\ (aq)$$

By predicting the products of each of these reactions on paper, students can devise solutions to their problems. They test their predictions by adding chemicals to a 5 milliliter sample of water from their pool and determining how it affects the pH. Molar concentrations must then be calculated so that the students know how much of a chemical they need to add to their entire pool volume (Figure 1). This calculation also gives students some idea about what concentrations of chemicals are most appropriate for their pool. This process is performed each day for one week, and all efforts are recorded in a journal. By the end of the week, students should be able to adjust the pH of their pool to a safe level fairly quickly by analyzing their previous data and molarity calculations.

POOLING RESULTS

At the end of the week, students hold a summit meeting to discuss their findings. Each group prepares a presentation to explain their successes as well as some of their incorrect attempts at maintaining their pool. Overhead transparencies and computers provide ideal ways for students to present their data.

Keeping the research journal is the most important aspect of this project for three reasons. First, students need to learn how to take good notes during experimentation. Second, they need to learn how to report all of their findings, even if the results are unexpected. Third, the journal allows students to review previous thoughts and build new ideas from their past mistakes and experiences. Generally, this type of project opens up students' minds, and allows students to become creative problem solvers.

FIGURE 1.

Sample student journal entry.

pH test used on pool? yes ❑ no ❑

Test used: litmus paper and probe

pH reading: 6.1

Recommended procedure:
We need to raise the pH of the pool. We will try some 0.1 *M* $NaCO_3$ on our 5 mL sample. Then we will try the 0.1 *M* $NaHCO_3$ if necessary.

Calculations of concentrations of chemicals added to the 5 mL sample of pool water:

5.0 mL of water taken from the pool

0.5 mL of 0.1 *M* Na_2CO_3 adjusted the pH of the pool to 7.4

$$\left(\frac{0.1 \text{ mole } Na_2CO_3}{1 \text{ L}}\right) \text{X } 0.0005 \text{ L} = 5.0 \text{ X } 10^{-5} \text{ mol } Na_2CO_3$$

added to 5 mL sample

Calculations of concentrations of chemicals needed for the pool:

$$\frac{5.0 \text{ X } 10^{-5} \text{ mol } Na_2CO_3}{0.0005 \text{ L}} = \frac{X}{1.0 \text{ L}}$$

$X = 0.1$ mol Na_2CO_3 needed in pool

$$\frac{1.0 \text{ mol } (X)}{\text{L}} = 0.1 \text{ mol}$$

$X = 0.1$ L = 100 mL of the 1.0 *M* Na_2CO_3 solution needed in the pool

Summarize day's experiments and results:
We found that the pH of our pool had fallen to 6.1 since yesterday. There was no precipitation, but the temperature was very warm last night. We adjusted the pH back to 7.4 and tested it with litmus and the pH probe to verify the results. Our 5 mL sample needed 0.5 mL of 0.1 *M* Na_2CO_3 to adjust the pH. Using proportions, we calculated the number of moles needed in the 1 L pool to get the correct pH. After we figured out how many moles were needed, we calculated the volume of the 1.0 *M* solution needed to adjust the pH of the pool. It worked out to be 100 mL of the 1.0 *M* Na_2CO_3 solution. We decided to use the 1.0 *M* solution for the big pool because it would have taken a very large volume of 0.1 *M* solution to properly adjust the pH of the entire pool.

At the end of the week, students write their final journal entry. I ask them to make this entry a summary of their experiences and findings. I also allow them to evaluate this experiment by including any comments or suggestions they may have about the experiment itself, their group experiences (did they work well together), the lab procedure, and soon. This evaluation does not affect the grade of the journal but gives students an opportunity to express their opinions and provides the teacher with helpful tips to improve the lesson. Each student then submits a journal for a grade. Journals are graded based upon how well students follow the journal format (Figure 1), the inclusion of calculations, their summaries of daily experiments, and neatness. Requiring each student to submit a journal allows the teacher to determine the level of understanding students are gaining from this experiment.

Swimming pool chemistry is an excellent way for high school chemistry students to study acid-base chemistry. This project illustrates that pH is not just a number to be calculated; it is a complex concept that is affected by other factors such as temperature and weather. Generally, open-ended research is a rare opportunity for students at this level. Thus, many students get their first experience with a real- world application of science when they work on this project. Although the titration and indicator labs fascinate students every year, students prefer to avoid the calculations involved. Swimming pool chemistry provides science students a pleasant alternative to learning calculations and rules governing acid-base reactions.

REFERENCE

Wilbraham, A. C., D. D. Staley, and M. S. Matta. 1995. *Chemistry*. Menlo Park, Cal.: Addison-Wesley.