

S W I M M I N G

Mr. Smith handed his daughter a stack of books and a plastic box. "Christie, you have been begging for a swimming pool so here's the deal. The pool will be installed next week and I am appointing you our pool chemist for the summer. It's up to you to keep the water clean and safe."

Christie soon learned that pool chemistry is complicated. First, she needed to know the volume of the family's new swimming pool. The usual formula for volume is, of course, length x width x depth. However, because the bottom of the Smiths' pool slopes gradually from three feet to six feet, Christie needed to use the average depth of 4.5 feet in the formula.

The pool is 50 feet long by 20 feet wide. Christie looked up the conversion factor—one cubic foot of water equals 7.48 gallons, and calculated that the pool contains 33,660 gallons of water (4500 ft³ x 7.48 gal/ft³).

In chemistry class, Christie had used liters and molarity for volume and concentration. However, the pool literature that she read used gallons and ppm for these values. Parts per million (ppm) is often used instead of molarity when the concentration is very low. One pound of a chemical in one million pounds of water is one ppm. That's the same proportion as one penny in \$10,000.

Swimming pools have filtration systems that remove debris and particles from the water. But sanitation of the pool water requires chemicals and frequent testing. The Smiths use "hard water" from their own well to fill the swimming pool. It is called "hard" because it contains ions that combine with soap and form a scum that makes it hard to wash with. The hard water is a factor that Christie had to consider when deciding which pool chemicals to use. Water with more than 100 ppm of calcium and magnesium ions is classified as hard water.

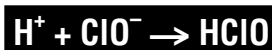
Many pools use chlorine compounds to kill bacteria and viruses. The active chemical is HClO, hypochlorous acid, which passes through the cell wall and oxidizes or "burns up" the interior of the bacterium. Christie read that the concentration of HClO should be kept above 1.0 ppm. (Chemists usually write the formula for hypochlorous acid as HClO, but people in the swimming pool industry prefer to express it as HOCl.) Many factors affect this concentra-

tion and one of the most important of these is pH. In water HClO dissociates to a slight extent to form the hydrogen ion and the hypochlorite ion.



hypochlorous acid hydrogen ion + hypochlorite ion

The opposite reaction



is also taking place. That is, there is an equilibrium in water involving HClO, H⁺, and ClO⁻, which we can depict by the equation



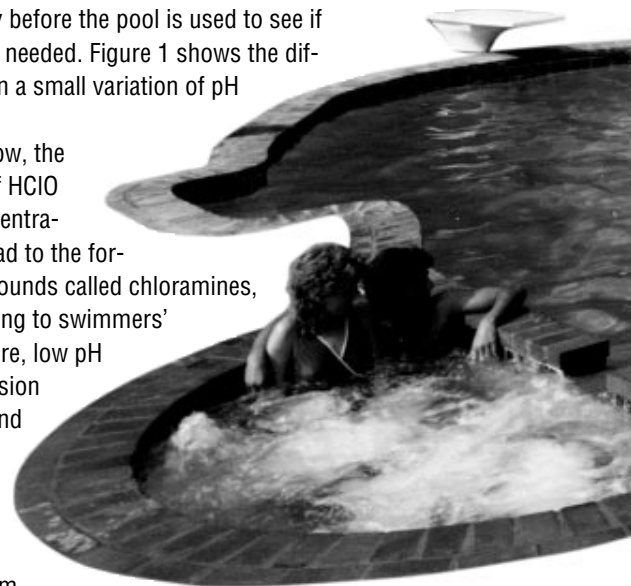
An acceptable pH range is 7.2 to 7.8, at which HClO and ClO⁻ are present in approximately equal concentrations. Christie will test for pH every day before the pool is used to see if adjustments are needed. Figure 1 shows the difference that even a small variation of pH can make.

If the pH is low, the concentration of HClO rises. High concentrations of HClO lead to the formation of compounds called chloramines, which are irritating to swimmers' eyes. Furthermore, low pH can cause corrosion of metal pipes and concrete surfaces. Christie can raise the pH of the pool by adding sodium carbonate. Her testing kit has a chart that gives the exact amount to add. This treatment raises the pH by removing some of the hydrogen ions from solution.



hydrogen ion + sodium carbonate bicarbonate ion + sodium ions

A high pH is not good either because, under alkaline conditions, the ClO⁻ concentration is increased while the concentration of HClO is decreased, and the HClO is better at killing microbes. Also, mineral deposits will begin to form on the pipes and pumps. Christie will need to add an acid to lower the pH. One good choice is muriatic acid (diluted hydrochloric acid).



POOLS

by Roberta Baxter



hydrochloric acid hydrogen ion + chloride ion

The additional hydrogen ion will combine with ClO^- to form the better oxidizer, HClO .

There are six basic chlorine chemicals used to sanitize home pools. Each has advantages and disadvantages, so Christie must study them all to make the decision of which to use. All six produce HClO when dissolved in water.

One of the compounds that is widely used is sodium hypochlorite—the active ingredient in household bleach. When sold for use in pools, it is twice as concentrated as laundry bleach. When it dissolves in water it forms hypochlorous acid.



PHOTO OF CHRISTIE: AARON LEVIN. PHOTO OF POOL COURTESY OF SYLVAN POOLS.

Christie has filled two chambers in this test kit with pool water. She is adding a solution of phenol red to the first chamber, and the resulting color change will indicate the pH. A reagent in the second chamber will indicate the chlorine concentration. In bright sunlight it is advisable to test the water several times a day because the disinfectant, hypochlorous acid, is rapidly decomposed by ultraviolet light.



sodium hypochlorite + water hypochlorous acid + sodium ion + hydroxide ion

Pool bleach is fairly inexpensive and easy to use. But Christie learns that there are some disadvantages. One big problem with using bleach in a pool is that HClO is unstable in sunlight. The ultraviolet radiation in sunlight breaks the HClO molecule down into water and chloride ions. On a hot, bright day, 90% to 100% of the HClO can

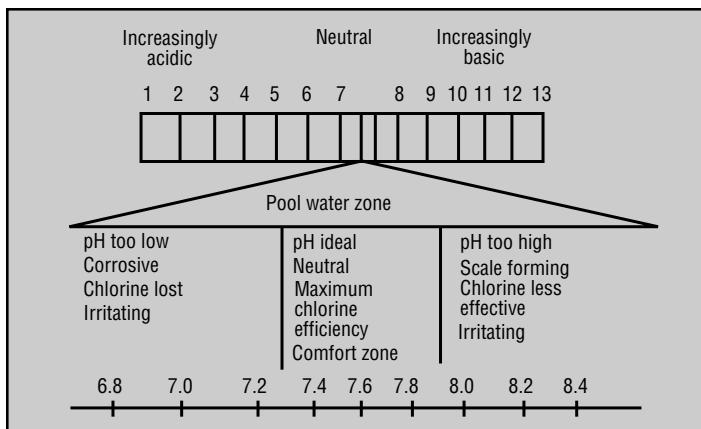


Figure 1. The chemical reactions that take place in swimming pools are highly affected by pH. For proper disinfecting, as well as swimmer comfort, pH must be maintained in the narrow range of 7.2 to 7.8.

be gone in minutes, leaving the pool without disinfecting power. This is one reason commercial pools are required to test the water every hour.

Another product, called powdered bleach, is calcium hypochlorite.



calcium hypochlorite + water hypochlorous acid + calcium ion + hydroxide ion

Calcium hypochlorite is easier for Christie to handle. She can simply add the proper number of tablets to a basket in the filter system. Water that is flowing from the filter back to the pool flows through this basket where it dissolves the tablets. However, adding a calcium compound increases the water hardness, which can lead to mineral deposits.

One of the most common chemicals for home pools is the one that Christie chooses for the Smiths' pool, trichloroisocyanuric acid or "trichlor." In contrast to sodium hypochlorite and calcium hypochlorite, trichlor is an organic compound. Whereas the inorganic compounds ionize very quickly in water to produce HClO, trichlor releases chlorine into the water gradually. Also, because trichlor is not decomposed by ultraviolet radiation, it acts as a reserve supply of HClO on sunny days. (see Figure 2).

A disadvantage of trichlor is that the other reaction product, cyanuric acid, eventually builds up in the water and Christie must test for cyanuric acid. When the concentration is too high, Christie can lower it by draining some of the pool water and replacing it with fresh water. It will probably be several months before she must do this.

Before using the pool each day, Christie tests the water to measure pH and free chlorine (HClO concentration). Less frequently she will run additional tests to measure cyanuric acid, total chlorine, cal-

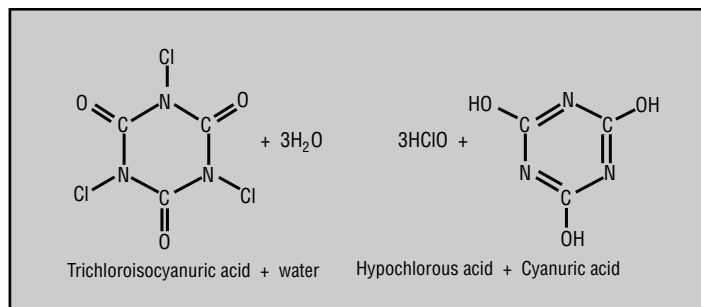


Figure 2. Trichloroisocyanuric acid is a good choice for outdoor pools because it is not decomposed by ultraviolet light. The first reaction product, HClO, disinfects the water; the second, cyanuric acid, absorbs UV and protects the UV-sensitive HClO.

cium hardness, total mineral concentration (called total alkalinity), and total dissolved solids. She will not need the test for calcium if she is not using calcium hypochlorite.

After a lot of reading and a little practice with the test kit, Christie has adjusted all of the concentrations properly. But she also knows that each time her friends swim in the pool and each time the sun shines, the concentrations will change and she will have to add the necessary chemicals. Throughout the summer the water is clean and sparkling, and she hears her father remark to the neighbors that Christie has become a real pool chemist.

Hot line

If you are having difficulties bringing your pool water into chemical balance, you can call the pool hot line operated by Dr. Alison Osinski, who is an independent pool consultant and a member of the National Swimming Pool Foundation's Educational Advisory Committee. Osinski says that, unfortunately, the majority of backyard pools are not properly maintained.

To use the hot line you must be at least 18 years old; your phone bill will be charged \$2.95 a minute. The number is 900/446-6075, extension 820.

It's a gas

For years, chlorine gas, Cl₂, was the disinfectant of choice at college swimming pools and other large pools that have a full-time operator. Due to its toxicity, Cl₂ is seldom used in commercial pools today. This gas was used in gas warfare in World War I. Sophisticated equipment is required to meter just the right amount of Cl₂ into the water.



chlorine gas + water hypochlorite + hydrochloric acid

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REFERENCES

- "Dirty Pool," *Discover*. Vol. 9, No. 6, p. 10. June 1988.
 Patel, T. "Water without the whiff of chlorine," *New Scientist*. Vol. 136, No. 1846, p. 19. November 7, 1992.
 Raloff, J. "Chlorination: residue clouds water safety." *Science News*. Vol. 135, No. 22, p. 342. June 3, 1989.

CHEM MATTERS

Classroom Guide

A supplement to Chem Matters Magazine

April 1994

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ADDITIONAL INFORMATION ABOUT THE ARTICLES

Buried in Ice

The first of John Franklin's voyages to the Arctic, in 1821, was also tragic. Eleven of twenty men died as they tried to escape starvation and the onset of winter by going up an uncharted river. Robert Hood was one of the men who died, and Franklin named the river in his memory. On his second expedition, begun in 1825, Franklin surveyed 1,237 miles of coastline that is now part of Alaska and Canada. He was knighted shortly afterwards. The surveys conducted by these two trips—and the many expeditions sent to rescue Franklin—nearly completed the mapping of the Canadian Arctic. The first successful navigation of the entire passage was made by the Norwegian explorer Roald Amundsen in 1903 (Amundsen was later the first to reach the South Pole, in 1911). The Arctic region is still a land of adventure and an interesting topic for library research. You might direct your students to *National Geographic*, August 1990, p. 2; May 1989, p. 584; and January 1986, p. 128 as a starting point.

Owen Beattie's expedition to Beechey Island to collect samples from the bodies of John Hartnell and William Braine was the subject of a spring 1990 *NOVA* program, *Buried in Ice*. The program provides a detailed view of how modern archeology is a multidisciplinary process that combines the efforts of researchers from many fields, including history, medicine, cultural anthropology, and the sciences. The video is no longer sold by PBS but it is still available in some rental locations including Pennsylvania State University (call 1-800/826-0132 and ask for title 60774, \$19.00) and the University of Minnesota (call 1-800/847-8251 and ask for title 1N1808, \$16.00 plus postage).

The isotopic ratio analysis was done with a thermal ionization mass spectrometer. Besides the samples of solder and tissue from the remains of the seamen, Kowal

included bone samples from native Inuit people and caribou from the same time period and geographical area, solder from food tins manufactured in the 1880s, and modern human bone. The ratios studied were $^{206}\text{Pb}/^{204}\text{Pb}$, $^{207}\text{Pb}/^{204}\text{Pb}$, and $^{208}\text{Pb}/^{204}\text{Pb}$, respectively. The agreement of the ratios in the solder and tissue from the remains is almost the same as the analytical uncertainty of the method and instrument, and significantly different from the other samples, establishing convincingly that the solder was the source. Kowal's easily understood report is in the journal *Nature*, Vol. 343, January 25, 1990, pp. 319–320.

As recently as the late 1970s, 90 % of the food cans made in the United States were still being soldered with lead. The last lead-soldered can rolled off a U.S. can-making line on November 28, 1991, and all food containers are now lead-free.

Swimming Pools

Chlorine is not the only way to sterilize pools. According to Dr. Eric W. Mood, who is associate clinical professor at Yale University School of Medicine and head of a joint effort of the American Public Health Association and the National Environmental Health Association to improve health and safety in bathing places, the addition of ozone combined with a small amount of residual chlorine is the best possible way to disinfect a pool. A year's supply of chlorine chemicals for the average pool costs about \$150 to \$200; an ozonator costs about \$850 to \$2,000. Another alternative is a device that electrolytically generates silver and copper(II) ions. An ionizer costs \$500 to \$1000. A free "Residential Pool Chemical Guide" can be obtained from the National Spa and Pool Institute, 2111 Eisenhower Avenue, Alexandria, VA 22314, 800/323-3996.

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Buried in Ice

1. How many years of provisions did Franklin take on his expedition?
2. In 1850 the first evidence was found that the expedition had spent winter on Beechey Island. What was the evidence?
3. In 1859 Captain Francis Leopold M'Clintock made a major discovery on King William Island, just south of Beechey Island, that answered many of the questions about the Franklin expedition. What was M'Clintock's discovery?
4. In 1981 physical anthropologist Owen Beattie went to King William Island to find evidence to support his idea that a combination of the disease, scurvy, and starvation doomed the expedition. He was surprised by a result that suggested another cause. What did Beattie learn?
5. The hair and other body tissue that Beattie collected on his second and third trips was well preserved by permafrost. What is permafrost?
6. How did Walter Kowal show that the lead found in the crewmen's hair was from the solder in the tin cans that had been used to preserve the food taken on the expedition?
7. The pathologist who performed the autopsies on the frozen bodies determined that the immediate cause of death was not lead poisoning but something else. What was the cause of the crewmen's death? How did the lead poisoning contribute to the death of the crewmen?
8. Lead poisoning has several symptoms. List some of them.
9. Lead has no normal function in the body, and the exact way it effects us is unclear, but studies have suggested how it might work. What is the probable way that it acts as a poison?
10. *For further exploration.* Talk to your health teacher or biology teacher and find out the major sources of exposure to lead today. Determine how many of them are present in your community, and if they are present find out if your community has a plan to reduce them. What ways can you suggest to reduce your own exposure to lead?

Swimming Pools

1. Name the metals whose ions make water "hard."
2. What is the purpose of the hypochlorous acid, HClO, in most swimming pools?

3. Write the equilibrium equation for the ionization of HClO. In which direction will a decrease in the pH shift the equilibrium?
4. What chemical compound is usually used to raise the pH when it is too low? Write the equation that shows the reaction of the compound with the H⁺ ion.
5. What chemical compound is usually used to lower the pH when it is too high? Write the equation that shows the reaction of this compound that releases the H⁺ ion.
6. One of the three common chlorine compounds used in home swimming pools is sodium hypochlorite. Write an equation to show how it reacts with water to form hypochlorous acid and sodium ions.
7. A second common chlorine compound used in home swimming pools is calcium hypochlorite. Write an equation to show how it reacts with water. Why is there a disadvantage in adding calcium ions to the pool water?
8. What is the major problem caused by sunlight when sodium or calcium hypochlorite are used to sanitize swimming pool water?
9. The third common chlorine compound used to treat swimming pool water is trichloroisocyanuric acid. What is its shorthand name? What is the major difference between it and the other two commonly used chlorine compounds?
10. What problem develops with the long-term use of trichloroisocyanuric acid? How is the problem treated?
11. *For further exploration.* Get a pool test kit and try the tests on the water from a local swimming pool. Try the tests on ordinary tap water and distilled water. Find out what reactions are occurring during the tests and prepare a chart listing them and giving their purpose. Can you suggest any other tests that might be done instead of the ones in the test kit?

Designer Catalysts

1. What is the chemical definition of a catalyst?
2. How does a catalyst make the process of a chemical reaction faster?
3. Why can't a catalyst change the amount of energy released or absorbed by a chemical reaction in going from reactants to products?
4. The most impressive catalysts are nature's enzymes. What is an enzyme?
5. What is a "biomimetic catalyst?"

6. Why must the metal porphyrin complex stay rigid in a biomimetic catalyst?
7. What shape did John Shelnut and his co-workers find to be just right for holding methane so that it can be converted into its alcohol, methanol?
8. What would be the principle advantage of converting methane, ethane, and propane into their alcohols, methanol, ethanol, and propanol?
9. Why is removing excess carbon dioxide from the atmosphere desirable?

Magic Sand

1. What mineral is the main component of beach sand?
2. What feature of the surface of a grain of sand makes water attracted to it so that the water wets the sand?
3. In what way is magic sand different from ordinary beach sand? How does the difference affect the attraction of water for the surface of the grains of sand?
4. The Estes Company had two uses in mind when they developed magic sand. Name one of them.
5. How can magic sand improve the soil in which plants are raised?
6. How is magic sand useful in the Arctic?
7. *For further exploration.* Test the possible use of magic sand in cleaning up after oil spills. Add water to a large test tube until it is about two-thirds full. Add oil (motor oil or vegetable oil) to the test tube to form a layer about 5 mm deep, measuring the volume of oil used. Weigh some magic sand and then sprinkle just enough sand on the oil to cause it to sink. Weigh the sand left over.

On January 7, 1994, a barge carrying 1.5 million gallons of No. 6 heating oil struck a reef just 300 meters from San Juan's main tourist beach. About 750,000 gallons (about 2,840,000 L) spilled. According to your experiment calculate how much magic sand would be required to sink the oil that was spilled. If magic sand costs about 90¢ per pound, what would be the cost of this much sand? See if you can find out the cost of the actual cleanup and compare the figures. (Fortunately for San Juan Congress passed legislation after the *Exxon Valdez* spill in Alaska in 1989 requiring cleanup equipment to be stockpiled at 19 sites, and San Juan was one of them. Containment of the San Juan spill began just hours after the accident.)