NATIONAL CENTER FOR CASE STUDY TEACHING IN SCIENCE

In-Class Reading for *Sponges and Bubbles: A Refreshed Investigation of pH and Buffers*

The story below is adapted from "Acids, pH, and Buffers: Some Basic Chemistry for Biological Science" by Terry Platt, Department of Biology, University of Rochester. Originally published May 27, 2010 by the National Center for Case Study Teaching in Science, all rights reserved.

Part I – Symptoms and Examination

Sarah Mathews arrived at the Emergency Room with her daughter Molly, where the little girl immediately underwent a physical exam and lab samples were obtained for analysis. By this time, she was almost unarousable, and was breathing rapidly and deeply. The physician on duty, Dr. Pedro Martinez, intubated Molly's trachea for airway protection and carried out hyperventilation, which he said was "to avoid hypoventilation and a worsening of her metabolic acidosis."

"What does that have to do with aspirin?" asked Sarah, anxiously.

Dr. Martinez replied, "Well, aspirin was originally a trademark for acetosalicylic acid, which can inhibit a pathway, leading to inflammation, but it is also a weak organic acid. That means at high levels it can lower the pH of your blood from its normal value of about 7.4—and any level below about 7 begins to be dangerous. As you can see, the nurse is also starting to administer activated charcoal through a nasogastric tube to absorb any residual aspirin in Molly's stomach and prevent its entry into the bloodstream."

"Oh," said Sarah, "our son Paul was trying to explain pH to my husband and me last night—but what do you mean by dangerous, and what can you do to get it back up again?"

They were interrupted by another nurse who came in with lab results. Dr. Martinez frowned as he looked over the data. They revealed a pH of 6.8 and a plasma salicylate level of 100 mg/dL, together with a number of other electrolyte abnormalities. He hadn't seen a pH that low for some time. It certainly explained Molly's rapid and deep respiration.

Questions

6. What do you think is happening in Molly's case?

7. When Molly and Molly's mother are breathing deeply and heavily what are they doing with respect to the equilibria?

Part II – Treatment

The doctor immediately ordered emergency treatment with intravenous bicarbonate (to correct the systemic acidosis), hydration (fluid replacement to compensate for Molly's vomiting), and hemodialysis (to correct electrolyte imbalance and remove dissolved salicylate—aspirin—from her body).

He continued with his explanation to Sarah. "We use bicarbonate—the same compound as in baking soda—as a 'buffer,' that is, a substance that can combine with the 'acid' ions (which, you may know, are protons in solution), thus soaking them up to reduce the acidity and raise the pH. One of the good things about bicarbonate is that it is a 'natural' substance. Your body in fact normally has moderate amounts of bicarbonate all the time, and that's how the CO_2 produced in your tissues by metabolism is transported to your lungs to be exhaled. In fact, bicarbonate is produced whenever you dissolve carbon dioxide in water, but hydrogen ions are also produced, which makes the solution more acidic. I can show you the simple formula indicating the chemical equilibrium, or perhaps you'd like to ask your son Paul to do it?"

They saw that Molly's breathing was returning to a more normal rate, and breathed a collective sigh of relief. "She's out of danger now, but we'll keep a close eye on her for a while yet," said Dr. Martinez.

Questions

8. When Molly is administered bicarbonate by the doctor, what effect does this have on the equilibria?

9. Explain Molly's treatment using what you learned from the sponge experiment.

10. What does blowing into the straw do to the solution? In other words, what is the difference between your breath and the air?

11. How do your conclusions compare to the theoretical relationship between pH and buffers and the sponge metaphor?

12. At what pH would you expect the color of the solution to turn from fuchsia to clear?

13. Why is Molly breathing so rapidly and deeply when she arrives at the emergency room, despite being nearly comatose?

Part III – Explanations

Sarah, however, still curious, asked, "So does that mean when you *remove* CO_2 from a solution, it becomes less acidic and the pH goes back up?"

"Gee, Mrs. Mathews," replied Dr. Martinez, "you'd make a terrific chemist!"

"And that's why Molly's breathing was that way? Her body was trying to raise its pH by getting rid of as much CO_2 as it could, even though it didn't really help much, because the problem was all that aspirin, which she couldn't get rid of!"

The doctor answered, "Yes, and in medical terminology we call that the difference between *metabolic* acidosis, which is Molly's problem—lots of acidic compounds in her bloodstream—and *respiratory* acidosis, which can occur if too much dissolved CO_2 builds up there."

"But that must mean that in your tissues, where metabolism is going on and resulting in all that CO_2 and water, the pH is lower than in your lungs, where your body is getting rid of CO_2! Is that why my leg muscles got so sore after my 10-minute sprint home this afternoon—though I've always heard it is from lactic acid buildup?"

Dr. Martinez answered, "Well, you're correct on the first count, and the low pH from the lactic acid, not from CO_2, is the problem in the second instance—but my pager is going off, and I have to rush over to check on another patient. Molly will be fine, but don't hesitate to give me a call if you have any further questions—and fix that latch on your medicine cabinet!"

Questions

14. Based on what you know about buffers, why was breathing heavily not enough?

15. How did the bicarbonate treatment help Molly?

16. How else might you raise the pH of Molly's blood to get it back into the normal range? How does this work?