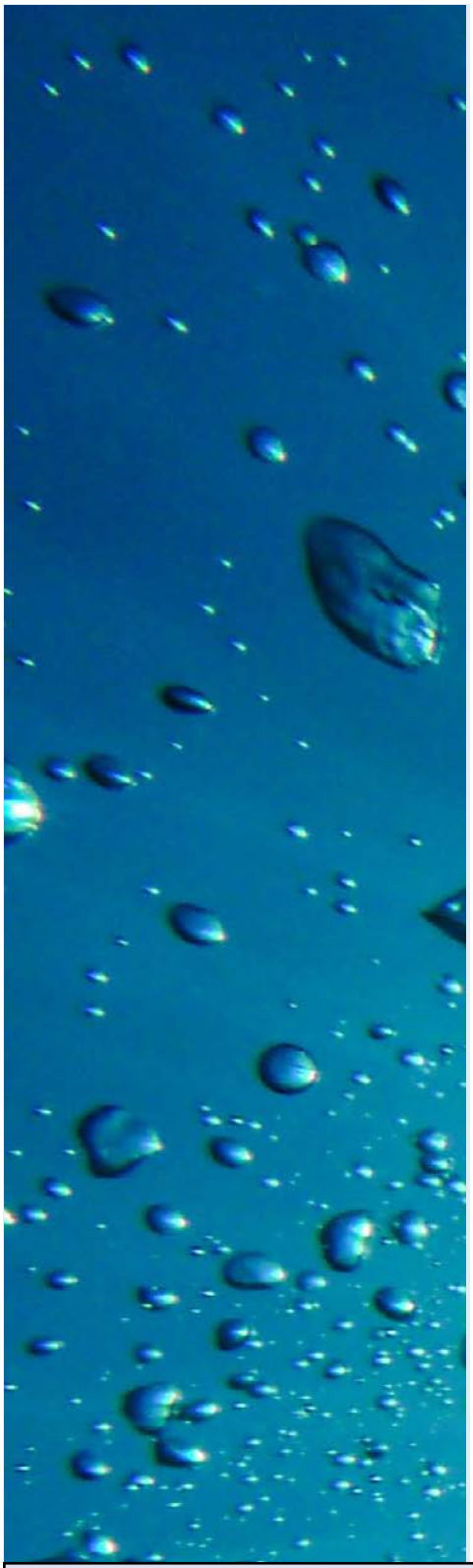


Appendix I
More About pH

What Do pH Numbers Mean?

An "acid" is commonly defined as a chemical that releases hydrogen ions (abbreviated H^+). The pH (which stands for "power of hydrogen") of a solution is defined as the negative logarithm of the hydrogen ion concentration in moles per liter. So,

$$pH = - \log [H^+]$$

where brackets are understood to mean "concentration."

The logarithm of a number x is the power to which another number called the "base" must be raised to produce x. So, the logarithm of 1000 to the base 10 is 3 because 10 raised to the power of 3 is equal to 1000. Where pH is concerned, the base is always 10. If a solution has a hydrogen ion concentration of 1 x 10^{-7} moles/liter, the logarithm of this concentration is -7, and the pH is 7. The pH scale ranges from 0 to 14, which corresponds to a hydrogen ion concentration range of 1.0 mole/liter to 1 x 10^{-14} mole/liter. A pH of 7 is considered neutral. A pH below 7 (higher hydrogen ion concentration) is acidic; a pH above 7 (lower hydrogen ion concentration) is basic.

A decrease of 0.1 pH unit may not seem like much, until we remember that this is a logarithm. So a pH of 8.2 corresponds to a hydrogen ion concentration of:

$1 \times 10^{-8.2}$ moles/liter = 0.00000000631 moles/liter
(10 raised to the -8.2 power)

and a pH of 8.1 corresponds to a hydrogen ion concentration of:

$1 \times 10^{-8.1}$ moles/liter = 0.00000000794 moles/liter

so a drop of 0.1 pH unit represents a 25.8% increase in the concentration of hydrogen ions.

Note that while the term "ocean acidification" is commonly used, the ocean is not expected to actually become acidic (which would mean that the pH was below 7.0). "Acidification" in this case only means that the pH is declining.

The Carbonate Buffer System

pH is a measure of acidity, which is the concentration of hydrogen ions; increasing hydrogen ions causes increased acidity. A pH of 7 is considered neutral; a pH below 7 is acidic; a pH above 7 is basic. Dissolved chemicals cause seawater to act as a pH buffer; that is, seawater tends to resist changes in pH. This Carbonate Buffer System is described by the following equation:

The Carbonate Buffer System Equation

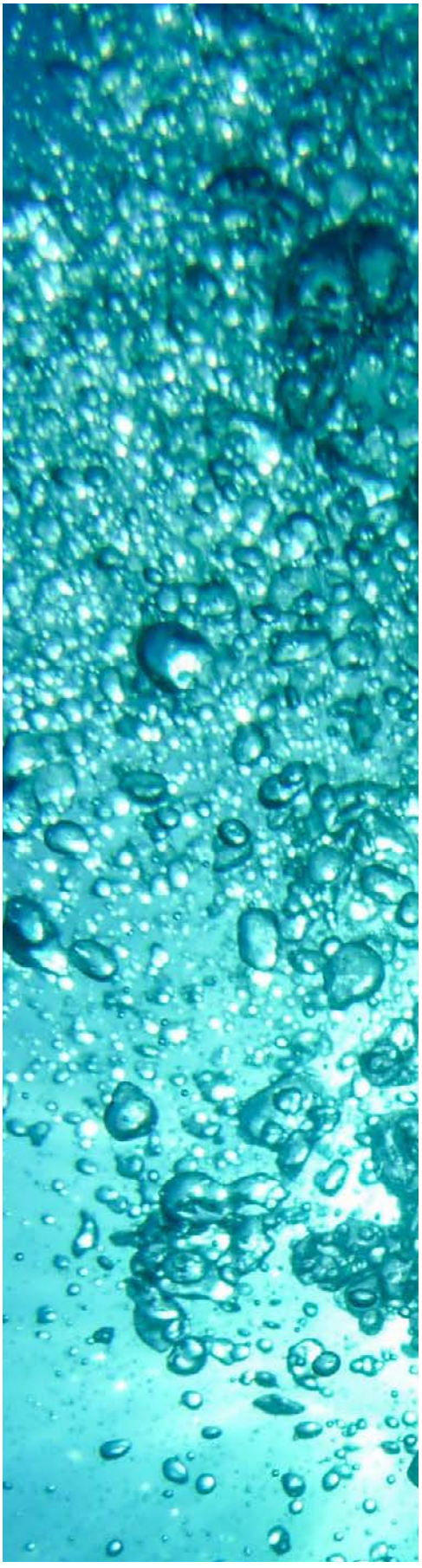
CO_2	+	H_2O	↔	H_2CO_3	↔	H^+	+	HCO_3^-	↔	$2H^+$	+	CO_3^{2-}
carbon dioxide		water		carbonic acid		hydrogen ion		bicarbonate ion		2 hydrogen ions		carbonate ion

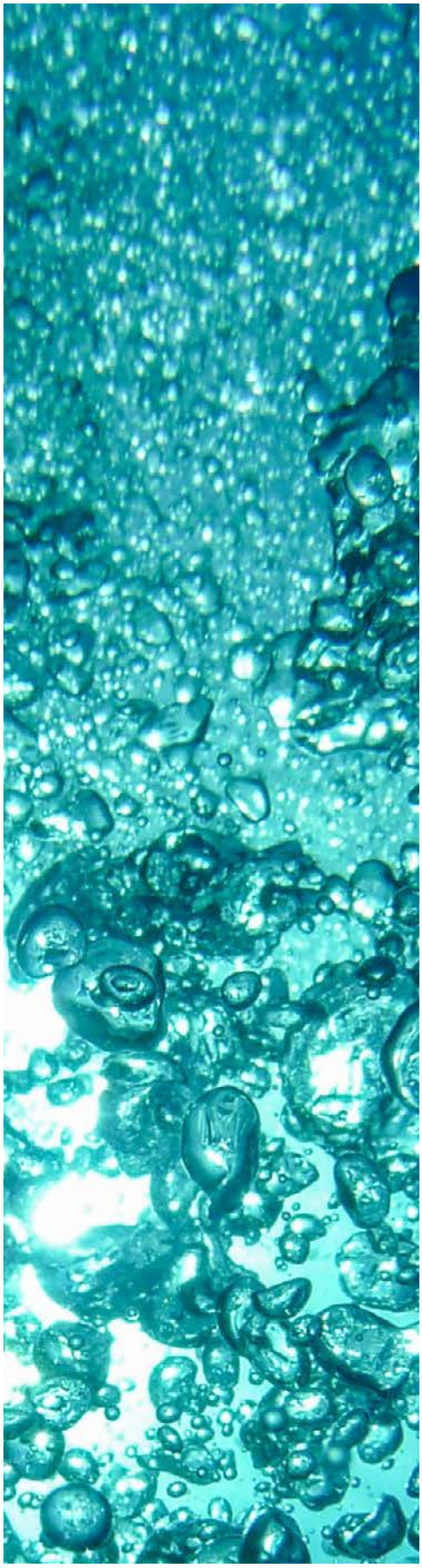
This equation shows that carbon dioxide dissolves in seawater to form carbonic acid, a weak acid. Most of the carbonic acid normally dissociates to form hydrogen ions, bicarbonate ions, and carbonate ions. Carbon dioxide, carbonic acid, bicarbonate ions, and carbonate ions are all present in normal seawater, although not in the same concentrations (about 87% of inorganic carbon is bicarbonate, about 12% is carbonate, and carbonic acid and carbon dioxide combined are about 1%). When these chemicals are in equilibrium, the pH of seawater is about 8.1 – 8.3 (slightly basic). More dissolved carbon dioxide causes an increase in hydrogen ions and a lower ocean pH. But the pH change in seawater is less than if the same amount of carbon dioxide were dissolved in fresh water because the carbonate buffer system in seawater removes some of the added hydrogen ions from solution.

In addition to the reactions described in the carbonate buffer system equation, other reactions also take place between carbon dioxide, carbonic acid, bicarbonate ions, and carbonate ions. One of these other reactions takes place between carbon dioxide, water, and carbonate ions:

CO_2	+	H_2O	+	CO_3^{2-}	↔	$2\ HCO_3^-$
carbon dioxide		water		carbonate ion		2 bicarbonate ions

So, adding carbon dioxide to the ocean system can also cause a decrease in carbonate ions; and carbonate ions are essential to the process of calcification through which many organisms produce shells and other skeletal structures.





Demonstrating the Effect of Dissolved Carbon Dioxide on pH

Increased atmospheric carbon dioxide has a demonstrable effect on ocean pH. A simple demonstration of the impact of dissolved carbon dioxide on pH can be found below. While there is some disagreement about the connection between climatic temperature increase and carbon dioxide from human activity, the increase in atmospheric CO_2 and decline in ocean pH are not theoretical; these changes have been confirmed by actual measurements. The following demonstration illustrates this concept.

Educators are urged to try the following procedures in advance of demonstrating before an audience. It is possible that enough atmospheric carbon dioxide may dissolve in distilled water to lower the pH so that the solution will turn yellow as soon as the indicator solution is introduced. If this happens, adjust the starting pH to slightly above neutral by adding a small pinch of baking soda to the distilled water before introducing the indicator solution.

Materials

- Drinking straw
- 100 ml of distilled water
- 100 ml of seawater (natural or artificial)
- Glass jar or beaker, about 200 ml capacity
- Bromothymol Blue Indicator Solution, 0.04% aqueous

Procedure

Step 1. Pour approximately 100 ml of distilled or tap water into a clean, transparent container. Add 15 drops of bromothymol blue indicator solution.

Step 2. Pour approximately 100 ml of seawater (artificial or natural) into a second clean, transparent container. Add 15 drops of bromothymol blue indicator solution.

Step 3. Blow steadily through a drinking straw into the water in the first container, and record the time required for the color to change from blue to yellow-green.

Step 4. Repeat Step 3 with the water in the second container. Note that it is possible to blow through two straws simultaneously, and if this is done there is no need to record elapsed time.

Step 5. Discuss the following:

- Blowing through the straw bubbles carbon dioxide through the liquid in the containers.
- Carbon dioxide dissolves in water to form a weak acid (carbonic acid).
- Bromothymol blue is blue in basic solutions, and yellow in acidic solutions. The color change happens in the approximate range of pH 6.0-7.6.
- A buffer is a solution that tends to resist changes in pH. Ask students to apply one or more of these facts to explain the results of the demonstration. Do these results suggest that seawater may act as a buffer?