Teacher Background

What is ocean acidification?

Recently, scientists have discovered that the chemistry of the ocean is changing. Because of higher levels of carbon dioxide (CO_2) being released into the atmosphere, more carbon dioxide is being absorbed by the oceans than ever before. This diffused CO_2 undergoes a chemical reaction that forms carbonic acid, which lowers the pH of seawater in the process called ocean acidification. (Remember that acidity and pH are inversely related; the lower the pH, the more acidic the solution.) This acidification leads to a reduction of available carbonate ions that form calcium carbonate, the material many marine organisms use to create their shells and skeletons. Not only does acidification make it more difficult for these animals to make their shells, but it also can lead to the weakening or destruction of already formed shells (Australian Academy of Science, 2008; Guinotte & Fabry, 2008; Orr, et al, 2005; The Royal Society, 2005; Usha 2006).

There are natural fluctuations in the flow of carbon dioxide throughout the atmosphere and the oceans. However, since the industrial revolution humans have been increasing the rate at which carbon dioxide is released. The largest source of this increase is due to the burning of fossil fuels, which releases CO_2; however, other actions such as deforestation also contribute to CO_2 release. As carbon dioxide is released in the atmosphere, the ocean acts to restore equilibrium between the concentration of CO_2 dissolved in the water and that which is present in the air, acting as a carbon dioxide sink that absorbs this greenhouse gas. In fact, around one quarter of the CO_2 released into the atmosphere each year is absorbed by the ocean[1].

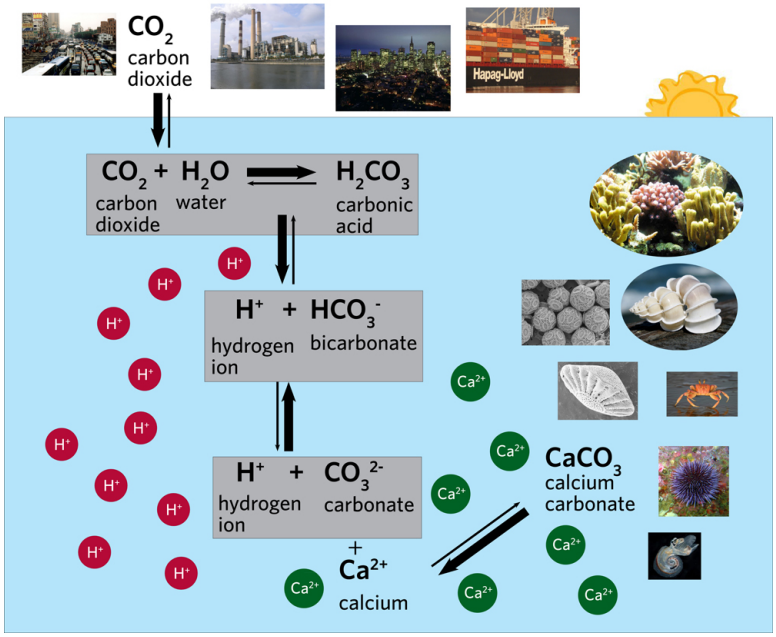


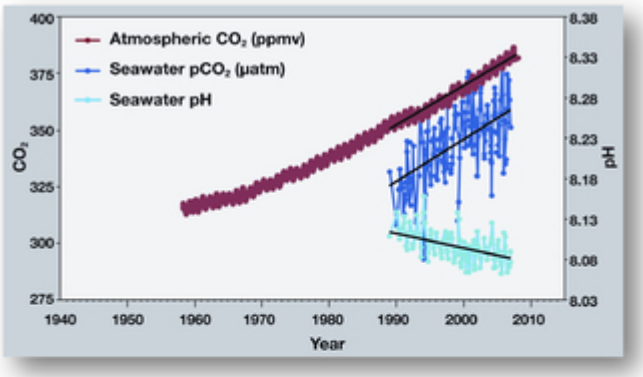
Diagram (left): Under normal conditions in ocean water between a pH of 7.9-8.2, the ionic forms of carbonic acid are present mostly in the forms of bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}). The water is "saturated" with as much carbonate as it can hold, so organisms can easily combine carbonate ions and dissolved calcium ions – which are also in regular supply – to create calcium carbonate shells and skeletons. However, under the more acidic situation represented in the diagram the equilibrium reactions shift in the directions indicated by the thicker arrows. Notice how carbonate is being taken up by all the excess hydrogen ions, making carbonate less available to organisms.

[1] The Ocean in a High CO_2 World Symposium, Summary for Policymakers 2009
http://www.ocean-acidification.net/OAdocs/SPM-lorezv2.pdf

Some of the carbon that is dissolved into seawater from the atmosphere is taken up by photosynthetic organisms such as phytoplankton and algae during photosynthesis (just as it would be on land by plants). The remainder of the carbon dioxide diffuses into the ocean and becomes part of a complex series of acid-base equilibrium reactions. In a healthy system of ocean water at a pH around 8, this absorption of carbon dioxide by seawater leads to the creation of a relatively large amount of bicarbonate (HCO_3^-) ions and a relatively small amount of carbonate ions (CO_3^{2-}). Organisms then use this carbonate, along with the calcium (Ca^{2+}) also dissolved in seawater to create their calcium carbonate ($CaCO_3$) skeletons and shells. Unfortunately, the excess of carbon dioxide being absorbed by the oceans is leading to a drop in pH, or increased acidity of seawater, which tips the acid-base equilibrium to favor the formation of bicarbonate (HCO_3^-) ions. As pH lowers, the scale continues to tip, this time in favor of more carbonic acid (H_2CO_3). This limits organisms' access to carbonate ions (CO_3^{2-}), which are needed to form their calcium carbonate ($CaCO_3$) shells and skeletons. A good description of what is occurring chemically can be found here: http://theotherco2problem.wordpress.com/what-happens-chemically/.

How has the ocean changed over time?

Ocean acidity has increased by 30% since the beginning of the Industrial Revolution. This increase is 100 times faster than any change in acidity experienced by marine organisms for at least the last 200 million years. Half of this increase has occurred in the last 30 years.[2] This increasing rate of acidification has implications for marine life.



This graph shows the correlation between rising levels of carbon dioxide (CO_2) in the atmosphere at Mauna Loa with rising CO_2 levels in the nearby ocean at Station Aloha. As more CO_2 accumulates in the ocean, the pH of the ocean decreases. (Modified after R.A. Feely, Bulletin of the American Meteorological Society, July 2008)

How does ocean acidification affect marine life?

Many shells and skeletons are made up of calcium carbonate and grow continuously throughout most animals' lives. These protective coverings allow animals to survive attacks by predators and withstand harsh conditions. Shells are a necessity of life for these animals. Furthermore, many animals with shells, such as certain types of plankton and many mollusks, are found near the bottom of the ocean food chain. Three kinds of plankton, cocolithophores, pteropods, and foraminiferans, have calcium carbonate shells. Without essential carbonate, these organisms wouldn't be able to grow, reproduce, and be food for other organisms. As a result, declines in their population have the potential to impact the animals that depend on them for food and serve as an indicator of the health of ocean environments.

[2] *Ocean Acidification: A summary for policymakers from the second symposium on the ocean in a high-CO_2 world* (2009)

How does ocean acidification affect us?
The increasing acidity of the ocean affects us in a few major ways. Around 5% of the world's protein comes from the oceans through fishing. Because many of the organisms in the bottom of the food chain have calcium carbonate skeletons, a decrease in these populations has the potential to decrease the populations of animals higher up in the food chain as well.

Corals are animals that also have calcium carbonate skeletons. If corals did not have the carbonate needed for them to create their skeletons, they would not be able to continue to build the coral reefs that many game fish use as their home or hunting grounds. Many of the marine animals that we eat (fish, shellfish) are therefore either directly affected, or indirectly affected by increased acidification.

In addition to affecting our food supply, increased acidification can affect how we use the ocean for recreation. Many tropical countries rely on tourism to their coral reefs. Without carbonate, these coral reefs would begin to decline, potentially causing a drop in tourism. Not only would the economy suffer, but people wouldn't have this recreational outlet. Many people and cultures have a deep connection with the ocean and this connection will be threatened as the health of the ocean continues to decline.

What is causing ocean acidification?
Ocean acidification is occurring due to the increased amount of CO_2 in the atmosphere. Carbon dioxide exists naturally in the atmosphere (for example, we breathe our CO_2). However, human activity has been increasing the amount of carbon dioxide in the atmosphere since the industrial revolution through the burning of fossil fuels such as coal and oil. Fossil fuels currently provide more than 85% of all the energy consumed in the US. Almost half of our electricity is from coal burning power plants, and virtually all of our transportation relies on the burning of fossil fuels[3].

What are misperceptions people may have regarding ocean acidification?
Note that the term ocean acidification refers to the process of the lowering of the ocean's pH level, not the end state of the ocean turning into an acid. Depending on location and conditions, ocean pH currently stands in the high 7s and low 8s, and should not fall below 7. Why? Because each year, the oceans experience runoff of alkaline substances from the land, adding base that neutralizes some of the acidity. The problem arises around the ion equilibrium for carbonic acid at a pH of 7, which disfavors the carbonate ion form. One could even refer to ocean acidification as the process that makes ocean water "less basic or less alkaline."

What is being done currently?
Ocean acidification and its impacts have only recently come into the public eye and is a relatively new area of study. An informal review of literature available online resulted in the following list of actions being done to either learn more about ocean acidification and its effects or directly affect the amount of CO_2 being released in the atmosphere. The following items were found to be true as of January 2011, but keep in mind that the field is progressing and changing

[3] US Energy Information Administration Annual Energy Review August 19, 2010

rapidly. A search using your favorite search engine for 'ocean acidification' will give you a wealth of information on the topic. As with any search, use reputable resources.

Research and Development

- Increase efforts to study the effects of increased acidification of the oceans on marine life
- Increase the amount of money spent on developing renewable energy sources

Government Involvement and Regulation

- Regulate carbon dioxide emissions
- Require businesses to determine the amount of carbon dioxide they produce
- Sign an international treaty to reduce greenhouse gas emissions
- Create policies that would require a reduction in the amount of carbon dioxide emissions from businesses
- Require automakers to increase fuel efficiency to 45 miles/gallon
- Allow companies to buy and sell the right to emit greenhouse gasses. The federal government would set a national cap on emissions and each company would then purchase the right to emit a portion of this total amount. If a company emitted more than its portion, it would have to buy more emission rights from other companies or pay large fees.

Individual Level

- Make personal choices to reduce personal contributions to carbon dioxide emissions and encourage others to do the same
- Contact elected officials to urge action on global warming
- Institute a gasoline tax
- Provide tax rebates to individuals who purchase solar panels or fuel-efficient vehicles