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Ocean Acidification, Imminent Mass Extinction?

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I teach Phy-Chem and AP Biology in an urban magnet high school. Being a magnet school we draw 65% of our students from the city, New Haven and the remaining 35% from surrounding districts. Phy-Chem is the mandatory freshmen science class and despite the name is heavily focused on environmental sciences. AP Biology is a high school biology class that uses a college curriculum provided by the College Board. Although much of the content and concepts of this unit may be applicable and adaptable to the AP Biology curriculum, the target audience of this unit are Phy-Chem students. This curriculum unit was developed with the Next Generation Science Standards (NGSS) in mind. The state of Connecticut has adopted the NGSS and this unit allows an instructor to effortlessly weave many of them into their classroom activities. The unit will allow one to meet NGSS from chemistry, life science, physical science, and environmental science as well as engineering.

My high school utilizes a block schedule wherein we have four classes per day, each running for about 90 minutes. Students have eight classes total and any given class meets either 2 or 3 times per week. This presents challenges for teachers concerning homework and turn-around time for feedback because of long gaps between class meetings. What the block schedule does offer is a longer class period wherein lab experiments are more easily carried out.

Central components of high school science curriculum are the carbon cycle and climate change. These two topics are robust as stand-alone units, and a cohesive curricular practice is to weave the topics together. The common thread in this case can easily be ocean acidification. A unit on ocean acidification can breathe life, literally, into a carbon cycle unit. As our oceans absorb excess atmospheric carbon dioxide, carbon released by human activity that is also affecting our climate, the millennia-old processes that sequester that carbon are being compromised by the chemical reactions occurring. The acidification of the ocean is disrupting the carbon cycle in ways that we had not previously thought of.

In accordance with the new NGSS standards and the need for a phenomenon to facilitate multi-dimensional learning, ocean acidification presents itself as an effective phenomenon. Through climate change and specifically elevated concentrations of CO_2 in the atmosphere and oceans, humans have significantly increased the concentration of oceanic free hydrogen ions in less than 250 years. These free hydrogen ions (hydronium ions; free protons) are what is reflected by a pH reading. This has resulted in an ocean pH drop from preindustrial times of 8.16 to the present 8.07(1). This rate of oceanic pH change has not been seen for

55 million years. Humans have altered something so massive, the ocean, in a relative “blink” of time when considered on a geologic or evolutionary time scale. Organisms cannot adapt in such a short time frame and we may be on the cusp of the next major extinction event.

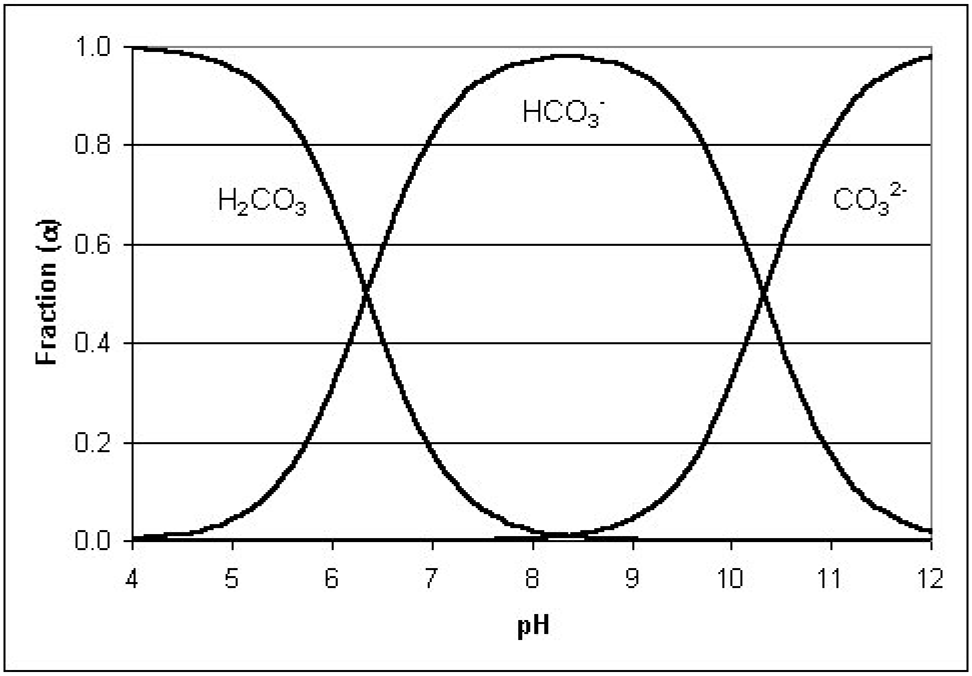
This unit will present an explanation of how carbon dioxide released into the atmosphere is resulting in a drop of pH in our oceans. The chemistry will be addressed as well as an explanation of the impacts on shell forming organisms as they are affected directly by a change in seawater alkalinity. The unit will also examine the interconnectedness of marine and terrestrial organisms as we understand that micro and macroscopic organisms in the ocean are the base for enormous food webs that reach beyond the ocean. Furthermore, phytoplankton, which are vulnerable to ocean acidification (2), are responsible for a significant portion of the oxygen production on this planet (3). This unit will also tie in the carbon cycle as it is inextricably linked and impacted by this event. The unit will also discuss some of the more recent findings concerning the immediate impact on organisms, some findings promising and others alarming. Lastly, the possibility of the being on the verge of a major extinction event will be examined. The purpose of the unit is not to prove an extinction event, but merely to force one to consider how significant an impact anthropogenic carbon dioxide may be having on this planet.

Oceanic pH Change

The phenomenon of ocean acidification refers to the rapid increase in acidity of the world’s oceans. When ocean pH is discussed it is in reference to a global average ocean pH. It should be noted that the pH of seawater is not consistent spatially across the globe. There are areas with significantly higher and areas with significantly lower pH values. Since the year 1760, the start of the industrial revolution, the average ocean pH has dropped from 8.16 to 8.07. This can be attributed to the carbon dioxide that is continually emitted through the combustion of fossil fuels. Carbon dioxide readily dissolves into water as it attempts to equilibrate concentrations between the ocean and the atmosphere. Based on atmospheric CO_2 measurement and Henry’s constant for CO_2, it is estimated that the ocean absorbs approximately 26% of anthropogenic carbon dioxide which equates to 2.5 billion tons of the gas annually. Estimates are drawn from data collected between 2001 and 2011 (4). Henry’s law describes the amount of a given gas that will dissolved in solution determined the by the partial pressure of the gas in the system.

Dissolved carbon dioxide (CO_2) chemically reacts with water (H_2O) to form the weak acid carbonic acid (H_2CO_3). Being that H_2CO_3 is an acid it dissociates in water forming hydronium ions (H^+) and carbonate ions (CO_3^{2-}), pK_a’s for this divalent acid are 6.3 for bicarbonate (HCO_3^-) and 10.3 for carbonate (CO_3^{2-}). This initially seems like a benefit for shell building organisms because they utilize CO_3^{2-}, combining it with calcium ions (Ca^{2+}), to form calcium carbonate ($CaCO_3$) the main constituent of the shell. Unfortunately, excess of H^+ in the water compete with Ca^{+2} forming bicarbonate (HCO_3^-), effectively locking up the CO_3^{2-}. Furthermore, carbonate availability decreases as pH decreases. Below, the ionization fraction plot of carbon dioxide (see Figure 1). Note how the equilibrium between ionic states is pH dependent and as we drive the pH of the ocean down, available carbonate decreases. The pK_a is an equilibrium constant indicating the pH were 50% of a compound exists in the H^+ associated form (e.g. HCO_3^-) and 50% exists in the H^+ dissociated form (e.g. CO_3^{2-}). Not all organisms rely on free carbonate, but those that do will have increasingly difficult time acquiring free carbonate in the seawater as the ocean becomes more acidic. Below are the chemical equations for the formation of CO_3^{-2} (see Figure 2). These free H^+ are the "acid" in acidity, the more H^+ there are in solution the more acidic the water is. The more CO_2 there is in the atmosphere the more CO_2 there will be dissolved in the ocean, resulting in free H^+.

Figure 1: Graphical representation of the pH dependent ion concentrations of carbon dioxide in water. Note that with a pH below 8 concentrations of carbonate are negligible. (5)



Ionization fraction plot of carbon dioxide.

Figure 2: Series of chemical reactions involving carbon dioxide and water.

$C0_2 (g) + H_2O \rightleftarrows H_2C0_3 (aq)$

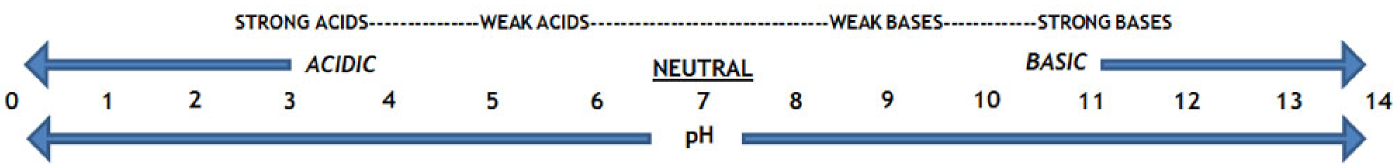
$H_2C0_3 (aq) \rightleftarrows H^+ (aq) + HCO3^- (aq)$

$HCO3^- (aq) \rightleftarrows H^+ (aq) + CO_3^{2-} (aq)$

Chemical reactions of carbon dioxide in water.

The pH scale runs from 0, strong acids, to 14, strong bases (see Figure 3). A pH reading is an indication of the concentration of hydronium ions (H^+) in solution. The p denotes negative logarithm base 10. The higher the pH value the less free hydroniums and conversely the lower the pH the more free hydroniums there are. The scale is also logarithmic and each movement from one number to another in sequence represents a 10 fold difference in hydronium concentration. For example, the concentration of hydronium ions in a solution of pH 9 is ten times higher than that of a solution with pH 10. A pH value of 7 is neutral. Readings above 7 are in the basic or alkaline range of pH, see Figure 3 below. The ocean, because of all the dissolved minerals that buffer the water, has historically had a basic pH. Throughout this unit I may interchangeably refer to the pH of the ocean becoming “more acidic,” “less basic,” “less alkaline,” or that it is “losing alkalinity.” There is some confusion around the term “ocean acidification” when the ocean is not in fact acid to begin with and has not become acidic, it has become less basic. Ocean acidification is so named to describe the addition of carbonic acid (H_2CO_3) via the dissolution of CO_2 gas.

Figure 3



The pH scale.

Connecting the Carbon Cycle

The advent of the industrial revolution has included the widespread and massive use of fossil fuels. Fossil fuels are coal, oil (including derived products), and natural gas. Coal was the primary source of energy originally, followed by advent and inclusion of oil, and then natural gas. These energy dense, due to their hydrogen-carbon bonds, materials were vital to the modernization of the world. The combustion of these carbon based fuels, as well as land use changes, releases CO_2 in the atmosphere. In 2016 36,183 metric tons of CO_2 were emitted (6). This is equivalent to 79,769,765 pounds of CO_2. Considering that the ocean absorbs 26% of the anthropogenic CO_2, over 10,121 metric tons CO_2 were dissolved into seawater in excess of natural sources.

Carbon cycles through this planet, from reservoir to reservoir, through a set of biogeochemical processes. Reservoirs can be differentiated as long-term or short-term based on the relative amount of time that any given carbon atom will spend within them. Long-term reservoirs refer to processes or sinks that sequester carbon for tens of thousands to millions of years. Examples of long-term reservoirs include rock, such as limestone, fossil fuels, and the deep ocean. Conversely short-term carbon reservoirs allow carbon to move in and out of them in time spans as short as minutes to thousands of years. Examples of short term reservoirs include all living things, the atmosphere, and the shallow ocean. The vast majority of carbon on earth is locked up in long-term storage, primarily limestone formations. There are some 100,000,000 GT (gigatons) of carbon sequestered in limestone (7). Consider that the estimated total carbon on this planet is roughly 100,050,000 GT. The carbon in the fossil fuel derived carbon dioxide that is decreasing the pH of the ocean was in long-term storage, until it was removed by humans. It can be argued that carbon is simply being cycled through it’s natural set of reservoirs and will simply keep cycling. However, humans have accelerated the cycling, and changed balances by moving gigatons of carbon out of long term storage in fossil fuels, releasing them into short-term reservoirs, the atmosphere and shallow ocean. Through concrete making humans have also moved carbon from long-term to short-term reservoirs. Our activity has increased the amount of carbon in the atmosphere and ocean significantly in a very short amount of time. The excess carbon in the atmosphere is trapping heat, resulting in climate change and the excess carbon in the ocean is driving down the ocean’s pH.

The movement of carbon from the short-term reservoirs and back into the long-term storage is an important solution in correcting the aforementioned problem we have caused. This process naturally begins simply with our shell forming organisms, the bulk of which are living in the oceans. These organisms take carbon, as carbonate (CO_3^{2-}) out of the seawater and incorporate it into their structures. Shell, and carbon skeleton forming, organisms include but are not limited to phyto- and zooplankton, crustaceans, bivalves, corals, echinoderms, and mollusks. When these organisms die, their shells deposit on the ocean floor. These calcium carbonate structures accumulate over time and with pressure from the overlying water and layers of sediment are formed into limestone. This process is important because it is cycling carbon out of short-term storage where it affects the chemistry of the ocean or the global temperature and puts it into long-term storage. Thus, beyond a decrease in pH, ocean acidification may inhibit a central, natural mechanism for moving carbon into long-term storage.

Major Extinctions

Over the past 444 million years there have been 5 major extinction events (8). These major extinction events are characterized by the disappearance of 75% or more of all species. Note that this means the species are gone, it is not so much about the death of individual organisms but more so about the removal of a species from the planet. Historically life has rebounded, even following the Permian extinction event wherein 96% of species went extinct (8). What we, humans, have difficulty comprehending is the timescale for the rebound. Yes, we may currently be living in the sixth major extinction, and the biosphere will likely rebound, but that will take millions of years. Humans have only been extant for a couple hundred thousand years. The entire history of the human race pales in comparison to the amount of time it will take for the planet to reestablish a network of flora and fauna as complex and diverse as we have today. Our actions in just a couple of centuries are impacting the evolutionary product of 65 million years, and longer as some of our current species are well over 200 million years old.

The normal rate of extinctions per year is known as the background rate. This is estimated to be one to five per year. It is believed that currently the extinction rate is 1,000 to 10,000 times the normal background rate (9). We have not identified all of the organisms on the planet and many are going extinct even before they are described. We cannot immediately prove causation between ocean acidification and the extinction of a species, but it is immediately evident that the pH of the ocean has an impact on shell and skeleton formation. Hard corals build calcium carbonate skeletons that become the structures we know as coral reefs. Generally corals are classified as soft or hard. The hard corals are the ones that produce the calcium carbonate deposits. As the ocean becomes more acidic there is an increased likelihood that the aforementioned calcium carbonate structures will dissolve.

Effects of Ocean Acidification: Coral Reefs and Their Importance

The primary concern about ocean acidification is the disturbance to calcification activities. Countless organisms rely on calcium carbonate to build shells and skeletons, these organisms will be referred to as calcifying organisms. The calcium and carbonate ions had historically been readily available to organisms in the water column for them to assimilate into calcium carbonate structures. This had been the case as species evolved over the past several million years or longer. The current rapid change to the ocean's chemistry is jeopardizing the supply of carbonate ions, thus jeopardizing calcifying organisms. The acidity of the water also dissolves the shells, thus energy must be invested by the organism to remake lost structures or worse yet, it impedes their ability to create the shell that they need for survival.

This disturbance to calcification processes threatens our coral reefs and the plankton that are the base of the oceanic food chain and significant source of atmospheric oxygen. The IPCC (Intergovernmental Panel on Climate Change) is predicting a pH of 7.8 by centuries end, this will reduce the concentration of carbonate by 50% (10).

Coral reefs are important for many reasons. They are the most diverse ecosystems in the ocean, also rivaling the tropical rainforests on land. This diversity not only provides fantastic economic value in scuba, fishing, and tourism but is essential to the health of the ocean. Diversity ensures the survival of some, following major environmental disturbances. The high number of occupied niches almost guarantees that there will be those that thrive following a catastrophic event. This is paramount to the long term recovery of the ocean but is unfortunate in the short term as the rate of acidification is so high that major diversity loss will be experienced. In fact, the growth rate of reefs will be on the decline in the foreseeable future as these organisms cope with the stress of changing pH. It helps to consider that organisms in the ocean have evolved in an environment that provided a constant pH for millennia, thus adaptability to fluctuations in pH was not a selective pressure. As it will be discussed later in this unit, some organisms adapt favorably, but the context of historical selective pressures is important to consider.

The coral reef landscape is changing for some reefs. Corals that are less branchy are faring better in this new more acidic environment. Considering two structures, one thin and branchy and the other thick and bulbous, and both being aragonite (calcium carbonate product), the thicker structure is favored as the aragonite is dissolved and weakened in the acidic ocean. Thus the dominant species on reefs is changing, consequently changing the landscape of the reef. Furthermore, some species of coral can utilize bicarbonate (HCO_3^-), an ion that is increasingly available in our new more acidic ocean waters. These organisms have a distinct advantage over corals that rely solely on carbonate ions.

Coral reefs provide opportunities for us to discover medicines to address human diseases. Drugs are developed from plants and animals of the reef. Through researching organisms scientists encounter new chemicals and observe biological solutions, to biological problems. The coral reefs potentially hold promise of remedies for cancers, immune system diseases, and antibiotics. The medical problems that humans face are not unique to humans and have often been overcome by another organism, but if we do not have the time to research natural solutions, they may forever be lost.

Coral reefs are nurseries for oceanic fish. Many fish spend their larval and even juvenile stages within coral reefs. The reefs offer food and shelter within their endless microhabitats. Some of the fish that rely on coral reefs as nurseries are the fish that humans rely on for commercial fishing. Humans cannot easily replicate what the reef naturally provides for these species. The reefs also directly supply food, many rely on fish and invertebrate reef inhabitants for sustenance.

Coral reefs also protect coastline from erosion, acting as wave breaks, lessening the severity of waves hitting the shore. As storm waves approach the coastline a coral reef can interrupt the wave, causing it to lose energy, decreasing the damage it may cause when it hits land. With ocean acidification not only is the ability of coral to secrete exoskeleton, which becomes the foundation of the reef, compromised, but the existing calcium carbonate structures are being dissolved. Both actions weaken the reef, increasing the likelihood that storm surge will cause more severe damage in the future as our reefs are less capable of absorbing the impacts.

Effects of Ocean Acidification: Disturbance to Primary Productivity

The primary producers (converters of solar energy to chemical energy) in terrestrial ecosystems are grasses and trees, in the ocean they are phytoplankton. Phytoplankton are in jeopardy because many of them produce a calcium carbonate shell. These microscopic photosynthetic organisms are crucial components to food webs and oxygen production. On a positive side, many algae and plant species show increased productivity in situations of higher acidity because of the increase in available carbon dioxide. The deciding factor between which species does well and which does not ties back to the presence of a shell, something more difficult to construct in a more acidic ocean.

Central to any food web are the primary converters, they are taking solar energy and essentially converting it into chemical energy. They use solar energy to drive reactions that build sugars, thus storing energy in chemical bonds. This energy is passed through the ecosystem when the primary converter is then consumed. It is of massive consequence to loose primary productivity of the largest ecosystem on the planet. Some of these organisms will adapt. Many have features that facilitate quick adaptation, such as high reproductive rates and sexual reproduction. Overall though, the landscape is going to change, the diversity will decrease, leaving the ocean's ecosystem even less stable as ecosystem stability is dependent upon diversity. An organism called a coccolithophore has been one of interest in research as it is widely dispersed in our oceans and is a shell forming photosynthesizing algae.

Some algal species that are paramount to our reefs are not responding well to increased acidity. These algal species are called coralline algae's and they build shells. Coralline algae have two important roles in the reef ecosystem. They help to bind corals together, acting as sort of bridge or cement between adjacent corals. These algae are easy to identify when you are viewing a reef aquarium, they are the purple film or layer that is on the glass and rock work. Coralline algae also supply a location for a larval coral to seed. Although some coral may not be adversely affected by a more acidic condition, if their larvae cannot ever seed (attach) to the reef, the future of the reef is in jeopardy. Coralline algae are particularly susceptible because the shell they excrete is that of high-magnesium calcite, an even more soluble compound than the aragonite produced by corals (11).

Effects of Ocean Acidification: Shell Former Animals

An oyster, clam, snail, mussel, urchin, sea star, crab, or lobster is a more likely familiar sea creature to our students than coral or phytoplankton. They have likely seen a lobster and held seashells. They may not be aware of the internal shell forming of the urchin or sea star, but acquiring the dried versions for you classroom is relatively easy. Many of these organisms, especially the bivalves and mollusks will struggle as sea water becomes more acidic as they will expend more energy to generate shell material as they compete with the increased rate at which it is dissolving. Oyster larvae are particularly susceptible as they need to generate their shells shortly after hatching, if they are not able to make and maintain a shell they perish. The acidic water is dissolving the shell faster than they can produce it. It is not only the shells that are in peril, the attachment fibers, byssal threads, that a mussel utilizes have a more difficult time adhering to surfaces in waters with a decreased pH (11).

The echinoderms, although likely stressed by the reduction of carbonate ions, are faring well. The shell of an urchin is covered in organic layer that which helps to shelter it from the surrounding water wherein it will more readily, than in the recent past, dissolve. The organic covering allows for the maintenance of a microenvironment more suitable for the production and maintenance of the shell. This is likely the case for other echinoderms (12). Although that may be promising more recent studies, focusing on juvenile sea urchins, find that ocean acidification has deleterious effects on the growth of these organisms. In the juvenile stage sea urchins more rapidly mineralize their skeletons and spines, the acidic conditions of the ocean are working against this chemical process (13).

Interestingly, crustaceans that which also use an organic layer over their carapace, called an epicuticle, show increased ability to form shells in a more acidic than normal environment (13). Lobsters, shrimp, and crabs are being found to produce stronger shells as the pH drops within the projected IPCC range (12).

Near the bottom of the oceanic food chain we find the zooplankton. The shell formers fall under two major categories, pteropods and foraminifera. Their aragonite shells are dissolving more easily as pH decreases and their need to adapt is more pressing (12). The high reproductive rates of these miniature creatures bolster their potential to evolve fast enough in response to the anthropogenic changes the ocean is experiencing. Quite simply, the more offspring, whether it be do to rate or yield, the more likely advantageous mutations will arise. The current selective pressures on these organisms include increasing ocean temperatures and decreasing carbonate availability, both due to anthropogenic atmospheric carbon.

Effects of Ocean Acidification: Fishes

Less studied are the direct effects of a dropping oceanic pH on the ocean’s fishes. Note that biological studies around ocean acidification did not begin until 2003 (11). Applied logic and some recent studies indicate that many fish likely have an uphill battle with ocean acidification. The extra- and intracellular chemistry of fish will inevitably be more difficult to maintain in homeostasis as the fish contends with an environment with more free hydronium ions than that of the environment they evolved in. Maintaining a consistent pH within and around the cells is paramount to proper cellular function. Fish are either more stressed as their bodies expend energy to maintain homeostasis or stressed by increased acidity in the face of a lack of any homeostatic mechanisms. The pH of a fluid has an impact on the chemical reactions occurring within the fluid, sensory functions may be jeopardized for fish because of ocean acidification. A failure of sensory functions may be the reason that scientists have observed that clownfish have a reduced ability in locating their homes in order to avoid predation (11).

Some of the Research

Although it seems bleak for oceanic creatures, particularly because of the possible catastrophic impact ocean acidification may have on phytoplankton, the base of the food web, there has been research that shows the resilience of many species and the potential for adaptation. Unfortunately though, this must be tempered with the fact that the ocean is an unimaginably complex ecosystem and whole ecosystem studies have not been conducted and likely cannot be done so easily (14). Below is a discussion of just one of the many research projects that have been conducted concerning ocean acidification and deals with the response of different marine calcifiers.

This research presents some interesting findings about the organisms involved. The methods of the experiment involved four conditions, current levels of CO_2 (409ppm), ~2, 3, and 10 times that of the preindustrial world where in the concentration of atmospheric CO_2 was approximately 280ppm. Recall that the IPCC continually increasing carbon dioxide scenario, their least conservative model, for 2100 is an atmosphere with a CO_2 concentration of 788ppm (10). Organisms were exposed to a concentration of 2856ppm and thrived, a level only used to elicit results in a reasonable time and mimic worst case scenario. Of the 18 organisms, ten experienced reduced calcification as CO_2 increased, and six of these ten had a net loss of calcified product at the highest level. Four of the 18 had an increased calcification rate through the 3 times preindustrial level scenario (~903ppm CO_2) which exceeds the IPCC estimate. These same four organisms exhibited decreased calcification when in the highest CO_2 condition. Three of the 18 demonstrated increased calcification rates right through the highest scenario, these were the crabs, shrimp, and lobsters (crustaceans). Lastly, one organism, the blue mussel, did not exhibit any change in calcification rates throughout the 3 experimental scenarios (12).

The positive response of some of the organisms is believed to be attributed to the organism's maintenance of an increased pH at the site of calcification. This supports the existence of carbonate ions to be used in aragonite construction. Recall that carbonate ions favor a higher pH. Secondly, the existence of an organic layer, albeit varying among organisms, seems critical to the success of the organism in an acidic ocean environment. The organic layer protects the shell from dissolution in the surrounding seawater. As the percentage of shell covered by an organic layer increased, the instance of increased calcification increased. Organisms, such as lobsters, that cover their entire shell with a protective organic layer did not experience the deleterious effects to calcification that other less-covered organisms did.

Classroom Activities

Hands-on activities are our most effective ways to help our students develop their understandings of complex topics as this allows them to apply abstract concepts to real-world activities. Grasping the concept of pH can be difficult for students because it is so abstract. Thankfully universal pH indicator allows students to see that pH change is occurring. Students can then make connections between the indicator color change and the amount of free hydrogen ions in solution.

Shells in Acid

Many iterations of this activity can be found through an online search, I am providing the general format for the activity. Students will be exposing seashells to vinegar for 24-48 hours in order to observe the corrosive effects of the acid on the shells.

You want to begin with a discussion of what shells are made of and how these organisms have pulled carbonate and calcium out of the water to form them. Discuss how this biological process can be reversed by exposing the shells to an acid that will react with the calcium carbonate, breaking down the shell, essentially reversing the reaction. You will want to acquire an assortment of seashells, either commercially or by collection, wash them and allow students to observe and handle them. Allow students to select a shell for experimentation and instruct them to take a digital photo for reference purposes. Students will then place their shells in a beaker of vinegar for 24 to 48 hours. They will note the initial reaction of the shell with the vinegar as bubbles of carbon dioxide form. Note that the ocean will not likely ever become as acidic as vinegar (pH 2) but nonetheless the effect of acid on the calcium carbonate shell is the same. The strength of the vinegar only accelerates the reaction, albeit significantly. In sufficient time (1-2 days) remove the shells, wash off, and compare the condition of the shell to that of the digital image.

Rainbow Tornado

This is a demonstration of the color change capability of universal indicator. This requires a 1000ml glass graduated cylinder, large magnetic stir bar, stirring plate, deionized water, universal pH indicator, 0.1M NaOH, and 0.1M HCl. Fill the cylinder with water and add 5ml of universal indicator. With the cylinder on the stirring plate and the magnet in place adjust the stirring until you achieve a “tornado” effect. There will be a cavitation and the typical cyclone appearance. Add either the acid or the base drop by drop. What will happen is you can momentarily observe different areas of the water column at different pH, as indicated by the indicator. Wear to gloves and goggles when handling chemicals. During the demonstration discuss with students how the color of the column is indicating the amount of free hydrogen ions. The color scale for universal pH indicator is readily available online.

This demonstration should be preceded by or in conjunction with a discussion about pH and the pH scale. The demonstration is used expose students to universal indicator in fun way and can be followed by an activity wherein students test the pH of various chemicals and determine pH via indicator color.

Bubbling Carbon Dioxide in Water

This activity will allow students to visualize and observe the effect of carbon dioxide on pH. They must first understand that dry ice is a solid form of pH and as it changes from a solid to a gas some of the gas will dissolve into the water. This activity should follow any activity that allows students to become familiar with universal pH indicator and the pH scale.

This is an activity that students can perform themselves. The supplies needed are dry ice, 250ml beakers, deionized water, and universal indicator. Students will fill the beaker with water and add 1ml of universal indicator. They then place a small piece of dry ice in the beaker and note how the pH of the solution drops as indicated by the color change. This can be done in a more controlled manner by bubbling carbon dioxide into the beaker if you have compressed gas available.

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Appendix: Implementing District Standards (Implementing NGSS)

HS-ESS 2-7

Construct an argument based on evidence about the simultaneous coevolution of Earth's systems and life on Earth.

HS-ESS 2-6

Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.

HS-ETS 1-2

Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems than can be solved through engineering.

HS-ESS 3-6

Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.

HS-ESS 3-4

Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.