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The Chemistry of Ocean Acidification and its Impacts on Marine Ecosystems

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Introduction

Climate change is a global phenomenon marked by significant changes long-term increasing temperatures across the world.[1] In the contiguous United States, "annual average temperatures have increased by 1.8°F since the beginning of the 20th century."[1] These large-scale climate changes are considered to be the result of human release of greenhouse gases such as carbon dioxide (CO_2) into the atmosphere in higher levels than would have otherwise occurred naturally without anthropogenic (human-based) influence. The combustion of fossil fuels is the primary contributor of this CO_2 gas production, but there are others as well including deforestation and land-use changes and other industrial processes such as cement production.[2]

One major concern resulting from climate change is ocean acidification. Ocean acidification is defined by the long term reduction of the ocean pH.[3] The term ocean acidification refers to the concept that due to the uptake of human-produced atmospheric CO_2, ocean pH has dropped by approximately 0.1 pH units since the beginning of the Industrial Revolution.[4] As ocean acidification progresses, a large variety of different marine organisms and ecosystems are negatively affected. If this trend continues, the damage to these ecosystems will be catastrophic.

The following unit will discuss the fundamental chemistry of ocean acidification, the effects of ocean acidification and other climate change impacts on marine organisms, and the process of data retrieval and analysis of relevant climate change data. This unit will contain basic concepts related to acid and base chemistry, more advanced chemical and ecological concepts related to marine populations, and data analysis concepts with an emphasis on graphing data sets and trend identifications.

School Description and Rationale

I will be teaching this unit for my 10th grade Chemistry students at Franklin Military Academy. As a specialty school within Richmond Public Schools, we are a relatively small school that has students from many different areas of the City of Richmond. I am the only Chemistry teacher at Franklin, and I expect to teach about 45-50 Chemistry students next school year. From my experience teaching at the school so far, many of the students face challenges with their mathematics skills, which creates opportunities for me to assist the students in making improvements in those areas. In past years, I have noticed that by offering several methods of mathematics skills practice presented through a Chemistry context, the students can achieve significant growth. Additionally, I have found in previous years that students thrive in an environment where they can complete hands-on and laboratory-based activities that encourage critical thinking. I've intentionally planned my unit to contain these types of activities.

The topic of pH, acids, and bases in chemistry can be challenging for students to master. In addition, I have not always found that these topics are the most interesting for my students. Ocean acidification is an interesting way to teach this topic to students. I am hoping that by establishing local, real-world connections to these concepts, the students will become more interested and engage more closely with them. I am also creating this unit with the purpose of bringing together concepts from biology and environmental science and connecting them with these chemistry concepts. This cross-curricular learning process will ideally engage students who are less interested in the chemistry components and more interested in biology or environmental science. It will also show how several different science topics can be connected.

Richmond, Virginia is geographically quite close to the Norfolk and Virginia Beach, Virginia areas. Many of the students have been to these coastal areas to visit family and friends or participate in extracurricular activities. This will make it easier for students to make connections when we are talking about the oceans because many of them will have experienced it before. In addition to this, the James River also passes through Richmond. Since it is part of the Chesapeake Bay Watershed, it is in turn connected to the Atlantic Ocean.

This is an important topic for students to learn about because it shows that the human production of CO_2 can have negative impacts on local marine ecosystems. In addition to biodiversity loss, the reduced health of marine ecosystems will also have negative effects on local fishing economies and aquaculture.[1] It should be noted that the best possibilities for reducing these risks rely heavily on the reduction of carbon dioxide and other greenhouse gas emissions.

Unit Content

The content that will be addressed in this unit is general climate change impacts, hydrocarbons and the combustion of fuels, fundamental chemistry of acids, bases, pH, and indicators, the chemistry of ocean acidification, biodiversity loss, and the graphing and analysis of relevant data. The goals of this unit are to provide basic knowledge about relevant chemistry concepts as they relate to ocean acidification, explain the connections between ocean acidification and biodiversity loss, and present student-friendly data that can be used to further investigate ocean acidification and its connection to climate change impacts. This unit serves to allow students to engage with these topics through a cross-curricular approach that enables teachers from various disciplines (chemistry, biology, ecology, environmental science, mathematics, or others) to use the content as they see fit.

Climate Change Impacts

The impacts of climate change differ for different regions of the world. Within the United States, a range of different regions have begun to experience impacts of climate change, such as droughts, extreme weather events, biodiversity loss, air quality concerns, human health concerns, sea level rise, and ocean acidification.[1] The extent to which these impacts in specific regions will occur is unknown, with various models predicting different levels of impact at different confidence levels.[5] Future projections are contingent upon different scenarios in the Representative Concentration Pathways (RCPs).[5] These pathways represent the extent to which greenhouse gases will be emitted within this century, and they are based upon how we will respond to our greenhouse gas emissions. Cutting as many further carbon emissions as possible projects the best outcomes for our global temperature and climate change future.[5]

Hydrocarbons and the Combustion of Fuels

Carbon is an element on the periodic table with an atomic number of 6. Hydrogen is an element on the periodic table with an atomic number of 1. Carbon is known as one of the building blocks of life due to its chemical structure and ability to combine with hydrogen in order to form large molecules that are vital for everyday biological life. In addition to their role in biological life, carbon and hydrogen compounds, known as hydrocarbons, have been used as fuels. The process of combustion, or burning these hydrocarbon fuels in the presence of oxygen gas, produces a different carbon compound, carbon dioxide (CO_2) as well as water (H_2O) and a substantial amount of energy released as heat.[6] The general chemical equation for the combustion process of a simple hydrocarbon fuel is as follows: $C_nH_{2n+2} + O_2 \rightarrow CO_2 + H_2O + \text{energy}$. The n in the equation could be any whole number, typically between 1 and 22. This chemical reaction jump-started the Industrial Revolution with its ability to take naturally occurring hydrocarbon fuels found in the Earth, such as methane, crude oil, and coal, and turn them into energy used to power factories, automobiles, homes, and many other facets of life.

The downside of producing all of this power was the production of CO_2 and its release into our atmosphere for over 100 years. CO_2 is a greenhouse gas, meaning that it is a gas that traps some of the heat energy radiated from the Earth within our atmosphere, rather than allowing it to be released into space.[1] The amount of CO_2 in the atmosphere has increased by approximately 40% since the Industrial Revolution.[1] As a result of this anthropogenic emission of CO_2, the global temperature of Earth has increased, bringing with it many other changes in our climate. As a result of higher atmospheric CO_2 levels, there are higher carbonic acid (H_2CO_3) levels and thus ocean acidification.[1]

Ocean Acidification: an Impact of Climate Change

Ocean Acidification Chemistry

Many climate change impacts are the direct or indirect result of increasing atmospheric CO_2 levels. Ocean acidification is no exception to this phenomenon. Before the Industrial Revolution, the ocean pH was approximately 8.2, while currently ocean pH is approximately 8.1.[7] This increase in ocean acidity results from higher levels of CO_2 present in the atmosphere. According to Henry's Law, an increase in the partial pressure of a gas will increase the amount of gas dissolved in a liquid.[8] As the amount of atmospheric CO_2 has increased since the Industrial Revolution, the partial pressure of CO_2 (pCO_2) has also increased. With this increase in pCO_2, more CO_2 has dissolved in the oceans.

The ocean acidification process is driven by additional CO_2 dissolved in seawater. This dissolved CO_2 reacts with water to produce carbonic acid (H_2CO_3).[7] Carbonic acid is a weak acid that readily dissociates in the presence of water into bicarbonate ions (HCO_3^-) and hydronium ions (H_3O^+). The general chemical equation for this is: $H_2CO_3 + H_2O \leftrightarrow HCO_3^- + H_3O^+$. This equation is written with a double-sided arrow to indicate that it is a reversible reaction given the conditions of the solution. The forward reaction is favored in an ocean environment because the ocean pH is approximately 8.1, and higher concentrations of bicarbonate are favored with a pH value in this range. An increase in the forward reaction increases the concentration of H_3O^+ ions, which results in a lower and more acidic pH.[9]

Chemistry of Acids, Bases, pH, and Indicators

Acids are substances with a pH less than 7, neutral substances have a pH of exactly 7, and bases are substances with a pH greater than 7.[9] Pure water has a pH of exactly 7 due to the self-ionization of water into equal concentrations of hydronium (H_3O^+) ions and hydroxide (OH^-) ions. Acids have a higher concentration of H_3O^+ ions while bases have a higher concentration of OH^- ions.[9] pH represents the negative log of the concentration of H_3O^+ ions in a substance. Since the pH scale operates using the log base 10 system, a substance with a pH of 5 has a concentration of H_3O^+ ions that is 10 times larger than a substance with a pH of 6.[9] Acid-base indicators are chemical substances that change color based on their pH range.[10] Indicators can also be made from natural products such as red cabbage.[10] Different types of pH paper can also be made from indicators, the most common of which is universal indicator solution, which has a wide color range. The pH paper can be dipped in a chemical and it will change color according to its pH.[10]

The Role of Carbonate Ions in Ocean Acidification

The mechanism of ocean acidification also has a slightly different pathway when it occurs in the presence of carbonate ions (CO_3^{-2}). In this pathway, CO_2 reacts with water (H_2O) and carbonate ions (CO_3^{-2}) present in the water to form bicarbonate ions (HCO_3^-).[11] The general equation for this process is as follows: $CO_2 + H_2O + CO_3^{-2} \leftrightarrow 2HCO_3^-$. This is also a reversible reaction, depending on the conditions of the ocean water solution. An increase in the forward reaction is caused by increased amounts of CO_2 dissolved in the water, which shifts the chemical equilibrium toward decreased concentrations of carbonate ions (CO_3^{-2}) that are naturally present in seawater.[11]

Since carbonate ions play an important role in the mechanism of ocean acidification, one metric scientists have used to measure levels of these ions is the aragonite saturation.[12] Aragonite is a form of carbonate ions that is used by marine organisms to produce their calcium carbonate structures.[12] Climate scientists have been studying the relationship between ocean acidification and its effects on aragonite saturation and pH level. In the Chesapeake Bay from 1986-2015, there have been overall reductions in pH and aragonite saturation.[13] Since aragonite saturation measures the amount of usable calcium carbonate in the water, a lower level of aragonite saturation indicates that there is less calcium carbonate that marine organisms can use to build their shells.

Biodiversity Loss of Marine Ecosystems

Ocean Acidification and Shellfish

Certain marine organisms, including many shellfish, such as oysters and mollusks, rely on carbonate ions in order to produce their calcium carbonate ($CaCO_3$) shells or skeletons.[7] The general chemical equation for the formation of calcium carbonate in these organisms is $CO_3^{-2} + Ca^{+2} \leftrightarrow CaCO_3$. At a lower pH, bicarbonate ion production increases according to the following equation, $CO_2 + H_2O + CO_3^{-2} \leftrightarrow 2HCO_3^{-}$. As a result of this, more carbonate ions must enter the water environment to re-establish the chemical equilibrium. The primary sources of these ions are the calcium carbonate shells and skeletons of marine organisms, so they begin to dissolve in the slightly more acidic water in order to produce carbonate ions.[4] Ocean acidification negatively affects pteropods through this mechanism. As the pH of the water decreases, the shells of developed pteropods have the potential to dissolve, causing them to die.[4] These small sea snails are significant parts of marine food webs. If their numbers are reduced, then the populations of marine creatures that eat them will also diminish over time.

The limitation on the amount of carbonate ions and the more acidic pH in the ocean also negatively affects coral polyps and their ability to produce reef structures.[7] Similar to how shellfish rely on carbonate ions in order to build their shells, coral polyps rely on carbonate ions in order to build their skeletons, which in turn become coral reefs. These coral reefs have the ability to become biodiverse marine ecosystems by providing homes for many other marine organisms.[14] Approximately one fourth of the ocean's fish rely on the health of coral reefs.[15] Without healthy reefs, many species of marine life are at risk such as fishes, invertebrates, plants, sea turtles, birds, and marine mammals.

As ocean acidification impacts shellfish and coral, this will in turn have an impact on fisheries and aquaculture.[3] With declining ocean pH values, fishing and aquaculture systems will produce less healthy organisms. This will negatively affect humans through our inability to rely on these organisms as a stable source of food. It will also have a negative economic impact on the communities that rely on fishing and aquaculture for their livelihoods.[3]

Eutrophication and Hypoxia

Eutrophication and hypoxia are processes that work in conjunction with ocean acidification to negatively affect certain types of marine life.[16] Eutrophication describes the process of a marine environment becoming enriched by additional nutrients that are not ordinarily present in those areas. This enrichment causes increased plant and algae growth.[17] One well-documented location with observed eutrophication is the Gulf of Mexico.[16] When additional sediments force their way into estuaries like the Gulf of Mexico, the amount of algae and plants increases as their habitat becomes more favorable.[16] Algae and plant production have also benefitted from warmer water temperatures in this area. When algae and plants die, they sink to the bottom of the estuary. As the organic material at the bottom of the estuary decays, it removes O_2 from the water and produces CO_2.[17] Hypoxia is the term that describes this resulting reduction in O_2 levels. When there are lower levels of oxygen in the water, this puts significant strain on marine organisms, especially those with limited mobility, such as mollusks.[15]

Hypoxia has several contributing factors related to other climate change impacts.[18] One of these factors is the result of an increase in extreme precipitation events. During these events, nutrient-rich sediment loads have found their way into coastal waters at an increased rate.[3] This process is likely to continue as more extreme weather events are projected to occur within the next century. In addition to these increased extreme precipitation events carrying nutrients, increased fertilizer use has also contributed to more nutrient-rich sediment entering coastal waters.[18]

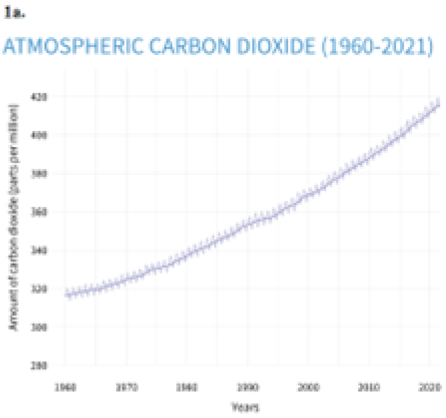
Ocean Temperature Increases

The surface temperature of the oceans has been increasing by about 1.3℉ on average per century globally, which has already had significant impacts on certain marine ecosystems.[3] Certain organisms thrive in cooler waters, so as the temperature of the water in these regions are increasing, they are not able to thrive in these environments. Large ecosystem changes are likely in areas where larger temperature increases are occurring. Additionally, since the saturation concentration of oxygen is lower in warmer water, some areas are experiencing deoxygenation, which limits the survival and reproductive capacity of marine organisms.[3] The reduction of oxygen levels and the higher temperatures have had major impacts on fisheries and aquaculture and fisheries, and this is likely to continue as temperatures continue to increase in the future. It is worth noting that all three of these factors, ocean acidification, ocean temperature, and ocean deoxygenation, work in tandem to negatively impact various marine ecosystems.[3]

Data Retrieval and Analysis

Atmospheric CO_2 data

Given that this unit is about climate change and how it specifically impacts the oceans, it is important to consider the processes of data retrieval and data analysis. One metric that is concerned with both of these topics is the amount of atmospheric CO_2. These numbers have dramatically changed since the beginning of the Industrial Revolution.[1] Graphs of this data show clear trends and are easy to analyze, which makes this topic a good starting point for the data section of the unit. This graph shown in Figure 1a presents a great opportunity for students to practice understanding trends in data.[19] They will be able to observe that the amount of atmospheric CO_2 has increased by about 100 ppm within the past 60 years. Stretching this concept a bit further, students can analyze a graph of atmospheric CO_2 amounts and CO_2 emissions, as shown in Figure 1b. This will encourage students to consider and speculate whether or not these two variables are related.



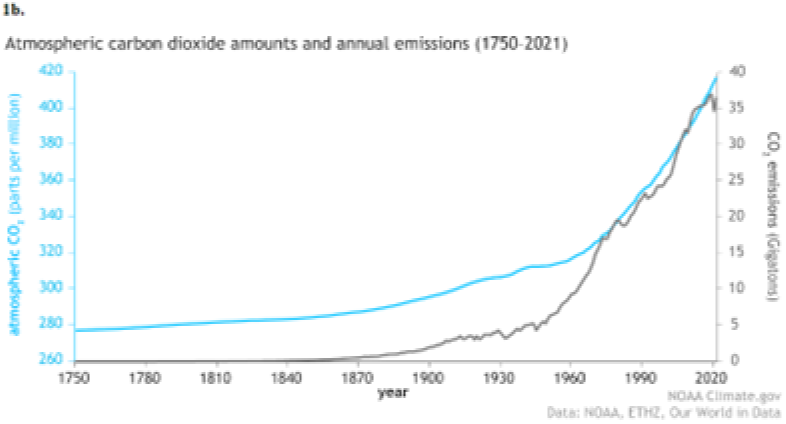
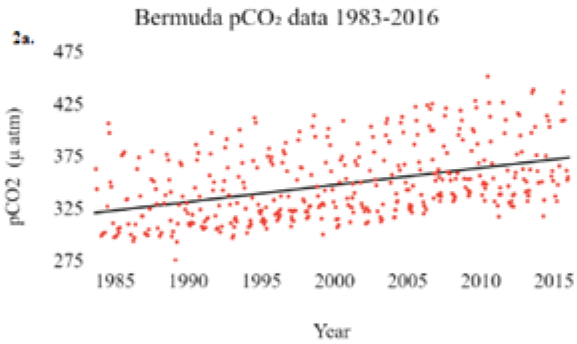


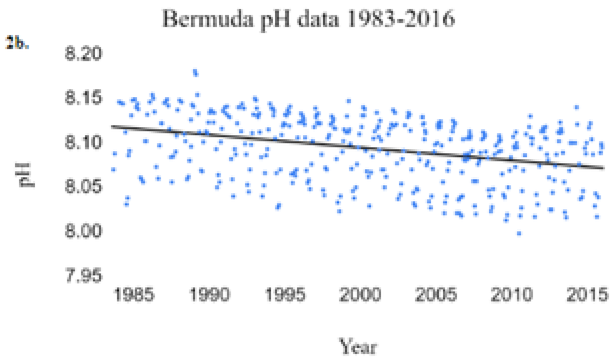
Figure 1a: The amount of atmospheric CO_2 has been increasing significantly since the 1960s. This image is composed of data from NOAA.[19]

Figure 1b: The amount of atmospheric CO_2 has increased as CO_2 emissions have increased.[1]

Dissolved CO_2 and pH data

One important metric for measuring ocean acidification is the amount of dissolved carbon dioxide in water. This is sometimes referred to as the partial pressure of carbon dioxide in water, or pCO_2. There is good data about this topic from various sources, each over a long span of time, that is available from the United States Environmental Protection Agency (EPA).[20] One large data set with information about pCO_2 and pH that is geographically fairly close to Richmond is the data set from Bermuda through 1983-2016.[20] A graph of Year vs. pCO_2, shown in Figure 2a, displays the data in a clear manner showing that pCO_2 has increased over time. Using the same Bermuda data set obtained from EPA, one can also investigate the relationship between ocean pH and time. A graph of Year vs. pH, shown in Figure 2b, displays the data in a clear manner showing that the ocean pH near Bermuda has decreased slightly over time. Using this same data set, a graph of pCO_2 vs pH can be created, as shown in Figure 2c. This graph shows a very clear trend, and the R^2 value of 0.984 indicates a strong relationship between these two variables. In agreement with the chemistry presented above, this graph shows what we would predict, that pCO_2 and pH are inversely related. When pCO_2 is higher, pH is lower and when pCO_2 is lower, pH is higher.





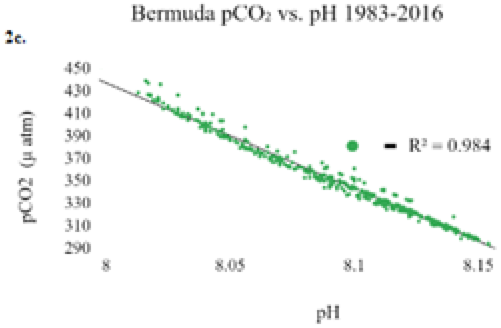


Figure 2a: Graph of Bermuda pCO_2 data acquired from 1983-2016.[20]

Figure 2b: Graph of Bermuda pH data acquired from 1983-2016.[20]

Figure 2c: Graph of Bermuda pCO_2 vs. pH data acquired from 1983-2016.[20]

Teaching Strategies

Hands-on Laboratory-based Learning

I will teach several of the concepts in this unit by utilizing laboratory-based activities. I have found in past years that my chemistry students have heightened interest, engagement, and understanding when they are able to complete hands-on laboratory activities. Additionally, laboratory activities allow students to experience scientific phenomena either before or after they learn about it in a more formal context. I plan to implement several laboratory activities involving pH, indicators, acids, and marine organism shells.

Jigsaw Reading

I plan to implement the jigsaw reading approach while teaching my unit. This strategy uses multiple groups of students and can work in any size classroom. Within the groups, each student is responsible for reading a different section of text and sharing their knowledge with the other students in the group. This approach allows students to practice their reading skills as well as their summarizing and presentation skills. I plan to implement this strategy when introducing some of the impacts of climate change across different regions of the United States.

Demonstration-based Learning

I plan to provide some chemistry demonstrations to encourage students to think critically about some of the chemistry in this unit as well as some of the scientific processes and pathways behind them. Demonstrations are a good method for encouraging students to come up with their own ideas about how or why something they observe has happened. I will implement this strategy when introducing the concept of combustion for CO_2 production.

Data-based Learning

I plan to teach the students to retrieve and analyze real life data because these two related processes will build skills that students will benefit from throughout the remainder of their academic pursuits. In addition to encouraging students to explore the world of free data, I would like to work with the students to enhance their understanding of computer tools such as Google Sheets and Microsoft Excel. This teaching strategy will increase the ability of students to formulate their own conclusions about graphs of data that they have put together.

Direct Instruction and Guided Practice

I plan to use some direct instruction and guided practice to help the students understand some of the more complex chemistry concepts. This strategy will be limited because I want the students to be working, thinking, collaborating, and problem solving as much as possible. However, for some aspects of the unit, particularly the section about pH, students in the past have benefitted from direct instruction and guided practice due to the complexity in mathematical understanding.

Classroom Activities

This unit will be nine class periods in length, where each class period is 90 minutes. Although it is written as a chemistry unit, sections of this unit can be adapted for use in physical science, biology, ecology, environmental science, or elementary school science classrooms.

Climate Change Impacts (1 class period)

As an introduction to this unit, I will show part of a short documentary in order to lead the students into a discussion about climate change impacts on the world and in different regions of the United States. Answering questions throughout the video will allow them to consider the wide scope and importance of this topic. I will also have the students complete a “jigsaw” reading activity where each group member reads a short selection of the 2018 NCA Climate Report, then has a chance to discuss what they’ve read as a group.

Hydrocarbons and the Combustion of Fuels (1 class period)

For this section of the unit, I will begin with a demonstration of the combustion of a candle. I will ask the students to consider which elements or compounds are required for the chemical reaction to take place and which elements or compounds are produced as a result. We will review the general chemical equation for a combustion reaction, and then they will be able to practice balancing this type of reaction. I will also have the students calculate the mass of CO_2 produced by the combustion of a hydrocarbon to show that for every gram of hydrocarbon burned, more than one gram of CO_2 will be produced. In groups, I will then have students look at data for carbon dioxide levels from before the Industrial Revolution until today so that they can try and observe any patterns or trends. I will have the students look at some data displaying global average temperatures for that same time period to see what patterns or trends they are able to find. This will help them make the connection between the two variables, CO_2 production and global temperature. I will have the students complete an additional short reading for homework.

Ocean Acidification: an Impact of Climate Change (3 class periods)

For the section of the unit about the chemistry of ocean acidification, two experiments or demonstrations can be conducted to show the relationship between CO_2 and water pH. The first experiment involves adding phenolphthalein indicator to a slightly basic solution in a beaker with a stir bar and placing it in a vase that can be covered. A small candle is then added into the vase and lit. After lighting the candle, the vase is then covered. As the candle undergoes combustion, it will produce CO_2, and as it produces CO_2, some of the gas will dissolve in the water as it stirs. This will cause the indicator to change the solution color from pink to colorless, indicating that the solution is changing from basic to more acidic.

An additional experiment involves adding some bromothymol blue indicator to a beaker with some water. A student then blows bubbles into the beaker through a straw and can watch as the solution changes from blue to yellow, indicating a change from neutral to acidic. I will provide the students with guided notes about the chemical equations in this part of the unit. I will demonstrate a simplified reaction of carbon dioxide (CO_2) and water (H_2O) to produce bicarbonate ions (HCO_3^-) and hydronium ions (H_3O^+).

For the chemistry of acids, bases, and pH section of the unit, I plan to begin with a virtual demonstration through PhET (University of Colorado Boulder) about the different pH values of household and other common substances and allow the students to synthesize general trends about acidic and basic substances.[21] Additionally, I may also have the students complete a laboratory activity about pH similar to the PhET activity. A broad range of substances can be brought in to illustrate different pH values of household substances. Tap water, sparkling water, coffee, antacid, orange juice, vinegar, cocoa powder, ammonia, and bleach can be used to achieve a wide range of different pH values using pH test strips or pH probes.

I plan to have an additional activity to build student knowledge about indicators. Students can extract pigments from hibiscus and tea leaves and use these pigments to create indicator solutions that show a range of colors when exposed to solutions with different pH values. Indicators are substances that naturally change color within different pH ranges. This can be connected to how pH paper works.

After allowing them to engage with the differences between acids and bases, I am planning to implement guided notes about these topics and draw connections between pH and molarity, which they will recognize from a previous unit. After modeling the use of the pH equation, I will enable the students to practice in groups and on their own in order to become more familiar with basic pH calculations and begin to understand them from the chemical context of the concentration of H_3O^+ . This discussion of basic pH principles will lead into the concept of ocean pH and how it can vary depending on the chemical composition of the water. The students can calculate and compare the pH values of a solution with more H_3O^+ and a solution with less H_3O^+ ions. This will allow them to draw the mathematical connection to why additional dissolved CO_2 in the ocean will reduce the pH.

I will continue this unit with guided notes about carbonate ions and their importance for certain marine organisms. I will present the updated reaction between CO_2, H_2O, and CO_3^{-2} to produce HCO_3^- , and explain how this reaction occurs in the presence of carbonate ions. Students will have the opportunity to look at aragonite saturation data and begin to see relationships between aragonite saturation and dissolved CO_2 in ocean water.

Biodiversity Loss of Marine Organisms (2 class periods)

For this section of the unit, I plan to begin with the laboratory experiment related to marine organism shells. I will have the students create a solution that is chemically similar to seawater and have them split it into 3 different beakers. One beaker will have a pH close to that of the ocean (8), one will have a pH lower (6), and the third will have a pH even lower (4). The students will observe the effects of more acidic water on the shells. I will then have them discuss in groups why ocean acidification could have a negative impact on marine organisms. This will be the basis of this section of the unit. Additionally, we will review notes related to this phenomenon and watch some short videos to illustrate the effects of ocean acidification on marine organisms such as pteropods, shellfish, and coral. This will set the stage for the next section of the unit.

We will begin the biodiversity section of this unit with an ecology-based food web activity so that the students can see the importance of smaller organisms such as pteropods that are closer to the bottom of the food chain. When given a food web, students will complete food pathways that involve pteropods. Then, they can remove the pteropods to see how many other organisms will be affected. As fish and other marine organisms can no longer rely on pteropods for their primary food source, their numbers will diminish. Since many of these organisms are toward the base of the marine food chain, their reduction will cause the reduction of other species that utilize them as food sources.

Additionally, I will draw the students into a conversation about coral reefs and the biodiversity that they can support within their ecosystems. We will watch some pieces of the documentary *Chasing Coral* about coral reefs so that students can experience the rich marine life in those regions and learn more about climate change impacts specifically on coral reef ecosystems.

Other Climate Change Impacts (1 class period)

This section of the unit will focus on the effects of eutrophication and hypoxia on certain marine organisms in estuaries. This will create a good opportunity for students to recall the process of photosynthesis. I will refresh them about this with an online interactive activity. After this activity, the students will work in groups to brainstorm a multi-step mechanism for why more sediments and nutrients being added to water as well as greater CO_2 concentrations would cause algae populations to increase, estuary hypoxia to occur, and marine organisms that are not highly mobile to be negatively affected.

I will also include guided notes for discussion about surface ocean temperatures and their relationship to deoxygenation in oceans. Students will be able to make connections between deoxygenation and hypoxia due to their similar effects on marine organisms. Another activity in this section of the unit will be a brief student-led research investigation about the different marine species that live in the Chesapeake Bay and how they would be impacted by increasing water temperatures.

Data Retrieval and Analysis (1 class period)

For the section of the unit focused on data analysis, I will frame it through the lens of the EPA Bermuda data set. This data set will be downloaded in its entirety from the EPA website. Once downloaded as a .csv file, it can be opened with any data software, such as Microsoft Excel or Google Sheets. Once the data is available in the software, it can be turned into three different graphs as shown in the Unit Content section, pCO_2 data acquired from 1983-2016, pH data acquired from 1983-2016, and pCO_2 vs. pH data acquired from 1983-2016. This is a great opportunity for the students to be able to consider different features within this graphing software such as titling the graph, labeling axes with units, setting the minimum and maximum values for each axis, and creating a trendline. Using a trendline and the equation of a line, students can also practice estimating pH and PCO_2 values given the other. This is a good exploration for students to learn about graphing and observing general trends in data. This also offers a great opportunity for students to practice their skills with graph analysis by making a claim based on the graphed data.

I am hoping to show my students how easy it is to access countless data for free from government sources. I am also hoping to show the value of looking at data closely to see if there are any recognizable patterns or features of interest. More specifically as it relates to ocean acidification, I would like students to become well versed in some of the evidence for long term climate change effects and even more so the evidence of climate change impacting their local environments.

Appendix on Implementing District Standards

The Commonwealth of Virginia has its own set of standards called the Virginia Standards of Learning. The 2018 Virginia Standards of Learning for Chemistry that are covered in this unit are:

CH. 1 a-f (The student will demonstrate an understanding of scientific and engineering practices by: asking questions and defining problems; planning and carrying out investigations; interpreting, analyzing and evaluating data; constructing and critiquing conclusions and explanations; developing and using models; obtaining, evaluating, and communicating information)

CH. 5 b and d (The student will investigate and understand that solutions behave in predictable and quantifiable ways. Key ideas include: changes in temperature can affect solubility; pH and pOH quantify acid and base dissociation).

Throughout the unit, the students will be asking questions and defining problems as well as planning and carrying out investigations as they see demonstrations and complete laboratory activities. They will be analyzing and evaluating real life climate change impact data. They will be developing and using models as well as constructing and critiquing their explanations to the ecological mechanism behind hypoxia affecting certain marine organisms. They will be obtaining, evaluating, and communicating information as they complete their self-guided project about marine life in the Chesapeake Bay. The students will engage with the concepts of solutions, temperature, as well as pH, acids, and bases throughout the unit.

Notes

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1. Jay, et al., “Overview.” in *Impacts, Risks, and Adaptation in the United States*
2. Fahey, et al., “Physical drivers of climate change.” in *Climate Science Special Report*
3. Pershing, et al., “Oceans and Marine Resources.” in *Impacts, Risks, and Adaptation in the United States*
4. PMEL Carbon Program., “What is Ocean Acidification?”
5. Hayhoe et al., “Climate models, scenarios, and projections.” in *Climate Science Special Report: Fourth National Climate Assessment*
6. CK-12., “Lesson 11.6 Combustion Reaction.” in *CK-12 Chemistry for High School*.
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