Kaleidoscopic Chemistry

VIRGINIA AQUARIUM & MARINE SCIENCE CENTER

Explore pH and its applications in a series of activities using pH indicator made from purple cabbage juice.

What is pH?

pH is a measure of the amount of hydrogen within a substance. The greater the concentration of hydrogen within a solution, the more acidic. pH is measured on a scale of 0 to 14, where a substance with a pH value between 0 and 6 is acidic, 7 is neutral, and substances with pH values between 8 and 14 are considered basic, or alkaline. Examples of acidic substances are urine, gastric acid, and battery acid. Acidic foods tend to taste sour, bitter, or tart. Distilled water is an example of a neutral substance. Basic, or alkaline, substances often feel slippery to the touch. Dish detergent and bleach are common, household substances that are basic.

pH Scale

Increasing Acidity ←							Neutral	→ Increasing Alkalinity						
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14

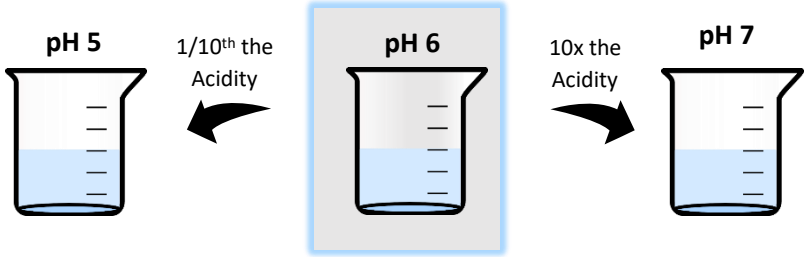
Do you think the following solutions are acidic, neutral, or basic? Sort them into the category boxes below.

Vinegar Soda Distilled Water Ocean Water Baking Soda
Grapefruit Juice Ammonia Oven Cleaner Milk Coffee

Acid	Neutral	Base

What does the pH value mean?

pH is a logarithmic scale, meaning **every unit change in pH equals a ten-times difference in acidity**. Therefore, a substance with a pH value of 6 is ten times more acidic than a substance with a pH value of 7. A substance with a pH value of 6 is one tenth the acidity of a substance with a pH value of 5.



Determine the difference in acidity for the following fill in the blank scenarios.

1. A substance with a pH value of 5 is ..... times more acidic than a substance with a pH value of 6.
2. A substance with a pH value of 5 is ..... times more acidic than a substance with a pH value of 7.

3. A substance with a pH value of 5 is 1,000 times more acidic than a substance with a pH value of _____ .
4. A substance with a pH value of 4 is 1/10th the acidity of a substance with a pH value of _____ .
5. A substance with a pH value of _____ is 100 times more acidic than a substance with a pH value of 11.

Why measure pH?

pH is an important component when determining water quality. The ideal pH value for water varies by its designated usage. The pH value ranges described in the table provided are considered desirable by the Environmental Protection Agency's National Recommended Water Quality Criteria for Aquatic Life.

Designated Use	pH Value
Drinking Water	6.5-8.5
Freshwater Aquatic Life	6.5-9.0
Marine (saltwater) Aquatic Life	6.5-8.5

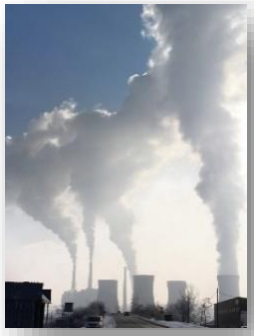
Different organisms thrive at different pH levels, but pH values lower than 5 or higher than 9 is considered harmful to living tissues. Some bacteria, however, are adapted to thrive at pH values at either end of the pH scale.

Normal pH of sea water ranges from 8.0 to 8.2 at the surface and decreases with increasing depth. Some marine communities are more sensitive to pH changes, especially smaller organisms like phytoplankton and zooplankton. Some organisms in biologically active waters are adapted to natural, cyclical changes that occur throughout the day due to photosynthetic activity. Even though aquatic organisms are adapted to living within a range of pH, rapid, human-made pH changes can be harmful.

What factors affect pH?

There are both naturally-occurring and human-made phenomena that influence the pH of natural waters. Below you will find a list of scenarios that lower the pH value of water systems, which makes the water more acidic.

Draw an arrow categorizing the following scenarios into naturally-occurring or human-made sources of acidity.



III

Burning of coal and releasing carbon dioxide gas waste, which can be dissolved into oceans as carbonic acid.

Naturally- Occurring Source of Acidity

IV

Smoker vents on volcanic ridge crests emitting hot acidic fluids, metals, and hydrogen sulfide.

Human-made Source of Acidity

I

Leaf litter releasing tannic acid into a pond water.

II

Smog from vehicle exhaust that accumulates in the atmosphere and dissolved into oceans.

pH Indicator

pH testing in field and laboratory studies are sometimes performed with the assistance of a class of chemicals known as indicators. Chemical indicators change color in the presence of acids, neutrals, and/or bases. Indicators can be synthesized in laboratories, but they also occur naturally. Purple cabbage can be used to create a pH indicator. Purple cabbage contains a pigment called anthocyanin (pronounced “an-thow-sai-uh-nin”). Anthocyanin pigment can provide either red, purple, black or blue coloration to plants. Can you think of any other plants that might contain anthocyanin? Anthocyanin reacts with acids and bases differently to reveal a unique color change. This means that anthocyanin-rich juice extracted from purple cabbage can be used as a pH indicator.

Materials

- Chopped purple cabbage
- Water
- A pot
- Stove
- Container to store juice, like a mason jar or pitcher

Instructions

1. Place chopped cabbage into a pot and submerge cabbage with water. With adult supervision, heat the pot until it boils for five to ten minutes. Let cool.
2. Once cooled, separate the pieces of cabbage from the liquid. The liquid now contains anthocyanin pigment that can be used as a pH indicator.

How to use the cabbage juice pH indicator

Cabbage juice indicator is an example of a universal indicator, meaning it changes color in the presence of an acid and basic substance. Some indicators only change color in the presence of a base and some only change color in the presence of an acid. Cabbage juice indicator will present the following color changes:

- Will change from purple to red, with increasing acidity
- Will remain purple when in contact with a neutral substance
- Will change from purple to blue/green, to yellow with increasing alkalinity

Cabbage Indicator Colors	
	Acid
	Neutral
	Base/Alkaline
	Strong Base

Once you have made your pH indicator, complete the following three activities!

Activity 1 | Test Household Items

Materials

- Cabbage juice pH indicator
- Clear glass cups, bowls, Tupperware, or white ice cube tray.
- Various Household Items to test pH values (Tap water, shampoo, hair conditioner, lemon juice, orange juice, toothpaste, soda, vinegar, dish soap, laundry detergent, seltzer tablets, antacid tablets, rubbing alcohol, etc)
- Measuring cup
- Tablespoons

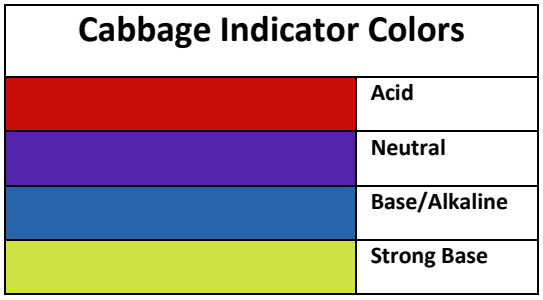
Instructions

1. Gather household items you want to test.
2. To determine if the solution is an acid, neutral or base, add the indicator. If you have a diluted indicator than you'll probably have to add equal parts of indicator to solution to notice color. For acidic solutions, the indicator will turn red, and for basic solutions the indicator will turn blue (strong bases will make the indicator change to yellow). Solutions that remain purple are neutral.

Household Item pH Test*

**Always obtain permission from an adult before experimenting with household products*.

Record your findings in the table below.



Product/Solution	Color of Product/Solution before Indicator is Added	pH Prediction: Acid, Neutral, or Base?	Color of Solution After Indicator Was Added	Acid, Neutral, or Base?
Tap Water				

Products/solutions that are acidic:

Products/solutions that are neutral:

Products/solutions that are basic:

Did you test the pH of any of the examples provided in the sorting activity from page one? If so, did your cabbage juice experiment support your guess about whether the examples were acidic, neutral, or basic?

Activity 2 | "Magic" Breath

Change the color of your pH indicator with your breath! Animals exhale carbon dioxide as a waste product generated from cellular respiration. Cellular respiration is the process in which cells convert food into energy for growth, survival, and reproduction. In this process, oxygen is used to breakdown carbohydrates (sugar) into carbon dioxide, water, and energy in the form of a molecule called ATP.

In this demonstration, you will observe how carbon dioxide gas can influence the pH value of a liquid. When carbon dioxide gas is dissolved into water, it produces carbonic acid. How do you think carbonic acid dissolved into cabbage juice will alter pH? Find out in this fun demonstration!

Materials

- Cabbage Juice Indicator
- Reusable straw
- Measuring cup
- Clear cup

Instructions

1. Measure and pour 1/4 cup of indicator into a clear cup.
2. Exhale through the straw into the indicator solution, creating bubbles. Keep exhaling until you notice a color change. Make sure you catch your breath between exhalations! What color should the indicator change to if you are producing carbonic acid with your breath?

Turn this into a science experiment!

If carbon dioxide is a byproduct of cellular respiration, would exercise influence your carbon dioxide output? Complete the steps below to find out.

1. Measure and pour 1/4 cup of indicator into a clear cup.
2. Exhale through the straw into the indicator solution, creating bubbles. Keeping your exhalations consistent in duration until you notice a color change. Make sure you catch your breath between exhalations!
3. In the chart below, record the number of exhalations it takes to turn the indicator to an acidic pH.
4. Empty and rinse the cup. Add ¼ cup of indicator solution.
5. Complete 10 jumping jacks.
6. Perform steps 2-4, while increasing the number of jumping jacks according to the chart below.

Number of Jumping Jacks	Number of Breaths Needed to Change the Indicator Color
0 (At rest)	
10	
20	
30	
40	
50	

As you exhaled into the indicator, what color change did you notice? Why did the indicator change to this color?

Did the number of exhalations needed to change the color of the indicator change by performing jumping jacks?

What is your independent variable, meaning what did you alter?

What was your dependent variable, meaning what responded to the independent variable?

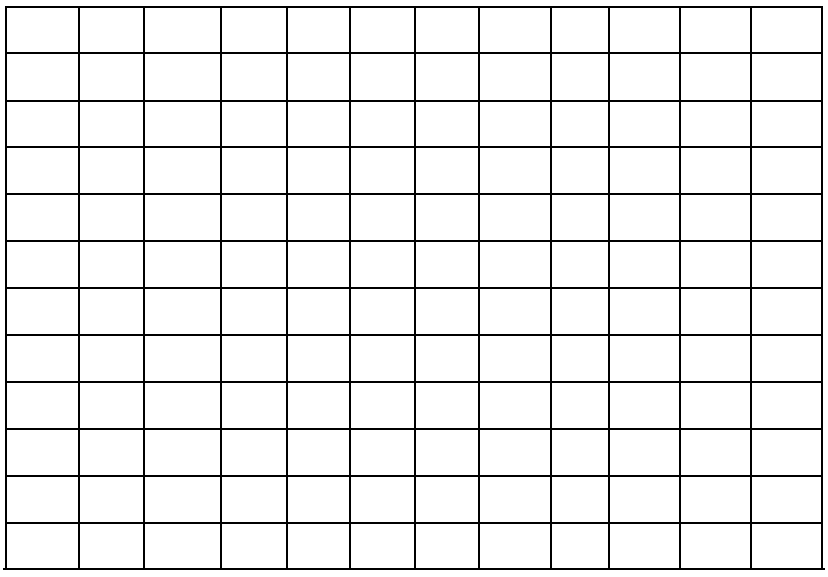
List a few constants in your experimental procedure.

List possible sources of error in your experimental procedure.

Graph your data. Give your graph a title, label the axes appropriately, and plot the data collected from your experiment.

Title:

Dependent Variable:



Independent Variable:

Extension to “Magic Breath”

This demonstration serves as model of ocean acidification. Ocean acidification is the observed change in the average pH ocean water tied to the increased presence of carbon dioxide gas in earth’s atmosphere.

Research Ocean Acidification at NOAA's Ocean Acidification Page and write a description of how the “Magic Breath” demonstration can be used to model the process of ocean acidification.

Activity 3 Secret Messages

Secret Message/pH Paintings

Materials

- Cabbage Juice Indicator
- A clear and colorless substance that will change the color in the presence of cabbage juice pH indicator
- Paper (thicker paper works better)
- Paint brush, cotton swap, and/or spray bottle

Instructions

1. Using a paint brush or cotton swab, write a memo or draw a picture using your clear and colorless substance. Great products to use for this step are vinegar, baking soda solution, and lemon/lime soda. Think about what color your product will change to when pH indicator is added.
2. Allow the picture/message to dry.
3. Apply the pH indicator to the entire surface of the paper to reveal what was drawn by the clear substance. This step can be completed by painting the indicator over the paper or by applying it through a spray bottle.

Bass illustration painted with cabbage juice, lemon juice, and baking soda solution.

Virginia Aquarium & Marine Science Center

Photo Credits

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References

“What is Ocean Acidification”. *National Oceanic and Atmospheric Administration U.S. Department of Commerce*, https://oceanservice.noaa.gov/facts/acidification.html. Accessed 6 May 2020.

“Magic Breath” activity adapted from Teach Engineering’s “Breathing Cells” activity.

Cawley, Kaelin; Schaefer Zarske, Malinda; Yowel , Janet. “Breathing Cells.” *Teach Engineering*, https://www.teachengineering.org/activities/view/cub_cells_lesson02_activity1. Accessed 15 January 2016.

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Answer Key

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pH Scale

Increasing Acidity ←							Neutral	→ Increasing Alkalinity						
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14

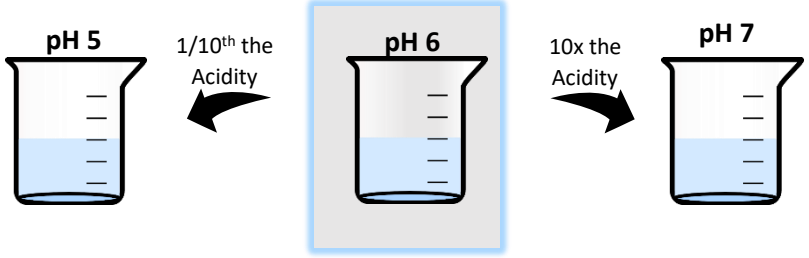
Do you think the following solutions are acidic, neutral, or basic? Sort them into the category boxes below.

Vinegar, Soda, Distilled Water, Ocean Water, Baking Soda, Grapefruit Juice, Ammonia, Oven Cleaner, Milk, Coffee

Acid	Neutral	Base
Vinegar, Soda, Grapefruit Juice, Milk, Coffee	Distilled Water	Ocean Water, Baking Soda, Ammonia, Oven Cleaner

What does the pH value mean?

pH is a logarithmic scale, meaning **every unit change in pH equals a ten-times difference in acidity**. Therefore, a substance with a pH value of 6 is ten times more acidic than a substance with a pH value of 7. A substance with a pH value of 6 is one tenth the acidity of a substance with a pH value of 5.



Determine the difference in acidity for the following fill in the blank scenarios.

1. A substance with a pH value of 5 is **10** times more acidic than a substance with a pH value of 6.
2. A substance with a pH value of 5 is **100** times more acidic than a substance with a pH value of 7.

3. A substance with a pH value of 5 is 1,000 times more acidic than a substance with a pH value of 8 .
4. A substance with a pH value of 4 is 1/10th the acidity of a substance with a pH value of 3 .
5. A substance with a pH value of 9 is 100 times more acidic than a substance with a pH value of 11.

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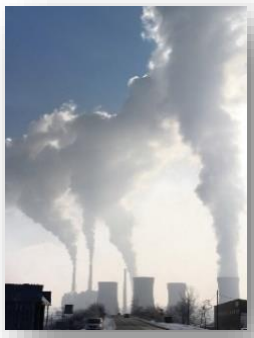

III

Burning of coal and releasing carbon dioxide gas waste, which can be dissolved into oceans as carbonic acid.

I

Leaf litter releasing tannic acid into a pond water.

Naturally- Occurring Source of Acidity

Human-made Source of Acidity

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Smoker vents on volcanic ridge crests emitting hot acidic fluids, metals, and hydrogen sulfide.

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Smog from vehicle exhaust that accumulates in the atmosphere and dissolved into oceans.

pH Indicator

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Materials

- Chopped purple cabbage
- Water
- A pot
- Stove
- Container to store juice, like a mason jar or pitcher

Instructions

1. Place chopped cabbage into a pot and submerge cabbage with water. With adult supervision, heat the pot until it boils for five to ten minutes. Let cool.
2. Once cooled, separate the pieces of cabbage from the liquid. The liquid now contains anthocyanin pigment that can be used as a pH indicator.

How to use the cabbage juice pH indicator

Cabbage juice indicator is an example of a universal indicator, meaning it changes color in the presence of an acid and basic substance. Some indicators only change color in the presence of a base and some only change color in the presence of an acid. Cabbage juice indicator will present the following color changes:

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Cabbage Indicator Colors	
	Acid
	Neutral
	Base/Alkaline
	Strong Base

Once you have made your pH indicator, complete the following three activities!

Activity 1 | Test Household Items

Materials

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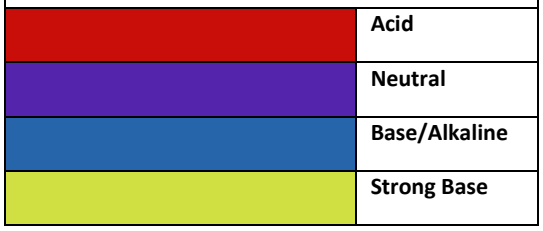
- Various Household Items to test pH values (Tap water, shampoo, hair conditioner, lemon juice, orange juice, toothpaste, soda, vinegar, dish soap, laundry detergent, seltzer tablets, antacid tablets, rubbing alcohol, etc)
- Measuring cup
- Tablespoons

Instructions

1. Gather household items you want to test.
2. To determine if the solution is an acid, neutral or base, add the indicator. If you have a diluted indicator than you'll probably have to add equal parts of indicator to solution to notice color. For acidic solutions, the indicator will turn red, and for basic solutions the indicator will turn blue (strong bases will make the indicator change to yellow). Solutions that remain purple are neutral.

Household Item pH Test*

**Cabbage Indicator Colors*



**Always obtain permission from an adult before experimenting with household products*.

Record your findings in the table below.

Product/Solution	Color of Product/Solution before Indicator is Added	pH Prediction: Acid, Neutral, or Base?	Color of Solution After Indicator Was Added	Acid, Neutral, or Base?
Tap Water	**Clear and colorless**	**Neutral**	**purple**	**neutral**

Products/solutions that are acidic:

Products/solutions that are neutral:

Products/solutions that are basic:

Did you test the pH of any of the examples provided in the sorting activity from page one? If so, did your cabbage juice experiment support your guess about whether the examples were acidic, neutral, or basic?

Activity 2 | "Magic" Breath

Change the color of your pH indicator with your breath! Animals exhale carbon dioxide as a waste product generated from cellular respiration. Cellular respiration is the process in which cells convert food into energy for growth, survival, and reproduction. In this process, oxygen is used to breakdown carbohydrates (sugar) into carbon dioxide, water, and energy in the form of a molecule called ATP.

In this demonstration, you will observe how carbon dioxide gas can influence the pH value of a liquid. When carbon dioxide gas is dissolved into water, it produces carbonic acid. How do you think carbonic acid dissolved into cabbage juice will alter pH? Find out in this fun demonstration!

Materials

- Cabbage Juice Indicator
- Reusable straw
- Measuring cup
- Clear cup

Instructions

1. Measure and pour 1/4 cup of indicator into a clear cup.
2. Exhale through the straw into the indicator solution, creating bubbles. Keep exhaling until you notice a color change. Make sure you catch your breath between exhalations! What color should the indicator change to if you are producing carbonic acid with your breath?

Turn this into a science experiment!

If carbon dioxide is a byproduct of cellular respiration, would exercise influence your carbon dioxide output? Complete the steps below to find out.

1. Measure and pour 1/4 cup of indicator into a clear cup.
2. Exhale through the straw into the indicator solution, creating bubbles. Keeping your exhalations consistent in duration until you notice a color change. Make sure you catch your breath between exhalations!
3. In the chart below, record the number of exhalations it takes to turn the indicator to an acidic pH.
4. Empty and rinse the cup. Add ¼ cup of indicator solution.
5. Complete 10 jumping jacks.
6. Perform steps 2-4, while increasing the number of jumping jacks according to the chart below.

Number of Jumping Jacks	Number of Breaths Needed to Change the Indicator Color
0 (At rest)	
10	
20	
30	
40	
50	

As you exhaled into the indicator, what color change did you notice? Why did the indicator change to this color? Exhalations into the cabbage juice pH indicator made the solution change from purple to red. Exhaling carbon dioxide gas into the indicator created carbonic acid, which changed the pH and made the solution more acidic.

Did the number of exhalations needed to change the color of the indicator change by performing jumping jacks? The exact results will vary by the individual; however, you should expect to see a decrease in the number of exhalations needed to change the pH when more jumping jacks are performed.

What is your independent variable, meaning what did you alter? The independent variable for this experiment is the number of jumping jacks performed during each round. For each round, ten jumping jacks were added.

What was your dependent variable, meaning what responded to the independent variable? The amount of carbon dioxide gas produced in the exhalations needed to change the pH of the indicator was the dependent variable of this experiment. With an increase in the number of jumping jacks, the concentration of carbon dioxide gas per exhalation increased due to an increase in cardiovascular activity. The increase in the concentration of carbon dioxide meant there was an increase in carbonic acid dissolved into the pH indicator and therefore, less breaths were needed to make the indicator solution become more acidic.

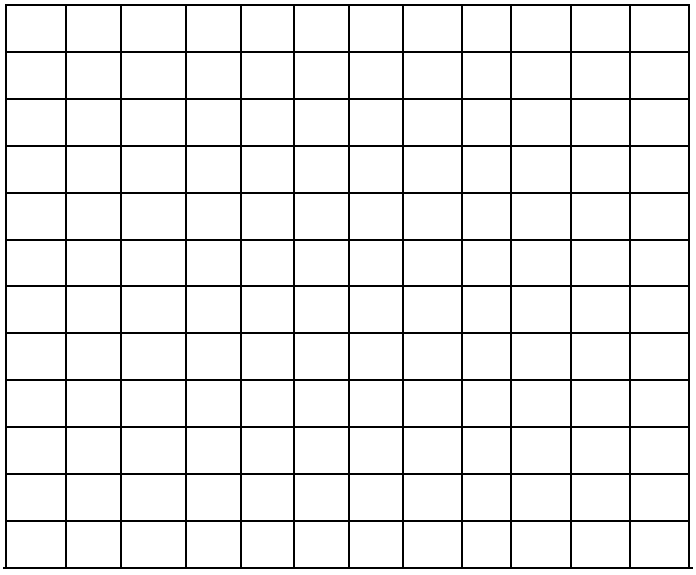
List a few constants in your experimental procedure. Constants performed in the experimental procedure of this experiment included: Making the exhalations consistent in duration (each exhalation lasted for 3 seconds); heart rate was returned to resting rate before each round of jumping jacks; using the same amount of indicator solution for each round; and the same pH indicator solution was used for each round.

List possible sources of error in your experimental procedure. One potential source of error in the experimental procedure for this experiment is the subjectivity of color changing pH indicators and making sure that the indicator changed to the same exact shade of red for each round.

Graph your data. Give your graph a title, label the axes appropriately, and plot the data collected from your experiment.

Title:

Dependent Variable:



Independent Variable:

Extension to “Magic Breath”

This demonstration serves as model of ocean acidification. Ocean acidification is the observed change in the average pH ocean water tied to the increased presence of carbon dioxide gas in earth’s atmosphere.

Research Ocean Acidification at NOAA's Ocean Acidification Page and write a description of how the “Magic Breath” demonstration can be used to model the process of ocean acidification.

Ocean acidification is the shift in the average pH of ocean water to a more acidic value. Ocean acidification is linked to the increase in carbon dioxide within the atmosphere due to the increased burning of fossil fuel. Carbon dioxide gas enters the oceans at the ocean/atmosphere interface (where they meet) where it is dissolved to form carbonic acid. With the “Magic Breath” demonstration, carbon dioxide supplied by exhalation is dissolved into a water based (aqueous) solution to form carbonic acid. The incorporation of carbonic acid changed the pH of the solution, making it become acidic. This reaction was observed through a color change presented by the cabbage juice pH indicator.

Activity 3 Secret Messages

Secret Message/pH Paintings

Materials

- Cabbage Juice Indicator
- A clear and colorless substance that will change the color in the presence of cabbage juice pH indicator
- Paper (thicker paper works better)
- Paint brush, cotton swap, and/or spray bottle

Instructions

1. Using a paint brush or cotton swab, write a memo or draw a picture using your clear and colorless substance. Great products to use for this step are vinegar, baking soda solution, and lemon/lime soda. Think about what color your product will change to when pH indicator is added.
2. Allow the picture/message to dry.
3. Apply the pH indicator to the entire surface of the paper to reveal what was drawn by the clear substance. This step can be completed by painting the indicator over the paper or by applying it through a spray bottle.

Bass illustration painted with cabbage juice, lemon juice, and baking soda solution.

Photo Credits

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