SASTA OLIPHANT SCIENCE AWARDS

SOUTH AUSTRALIAN SCIENCE TEACHERS ASSOCIATION

Prize Winner

Scientific Inquiry

Year 7-8

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Seymour College

Oliphant Science Awards 2021

A Scientific Inquiry

Ocean Acidification: Impacts of Increasing Concentrations of Dissolved Carbon Dioxide on Seashells

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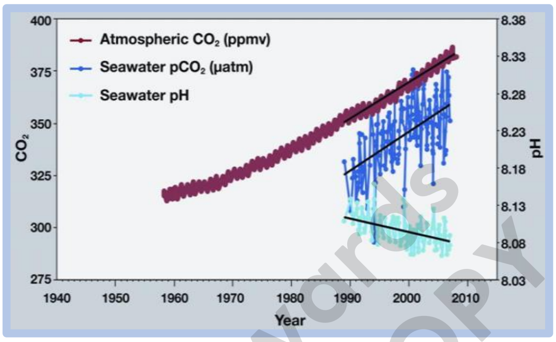
Introduction:



From: https://ocean.si.edu/ocean-life/invertebrates/ocean-

Once a thriving home to millions of sea creatures, the Great Barrier Reef is now threatened with extinction. The Great Barrier Reef Foundation believes that ocean acidification, due to climate change, is a major cause of this threat.

Scientists fear that by the end of the 21st century, the ocean's acidity (pH) may drop by up to 0.32 units, a level at which all coral growth will cease. Its destruction would not only be a loss of heritage and beauty, but it would also greatly impact both the economy and our food supply.

Questioning and Predicting:

- ### Research Aim:

The aim of this experiment was to study the impact of ocean acidification on seashells.

- ### Research Question:

Does increasing the concentration of carbon dioxide in the ocean cause seashells to dissolve at a faster rate?

- ### Hypothesis/Prediction:

If the concentration of dissolved carbon dioxide is increased, then the seashells will dissolve at a faster rate. This is because the more acid in the seawater, the more likely it is for it to collide and react with the insoluble carbonates in the shell and form soluble bicarbonates.

Planning and Conducting:

Choice of Scientific Method:

Conducting a laboratory experiment gives a tighter control of variables, is replicable and makes it easier to examine the cause and effect.

What is a fair test?

To ensure a fair test, only one variable (the independent variable) should be changed, and all the other conditions (controlled variables) must be kept the same. This pinpoints the effect on the dependent variable, so that it can be accurately observed and quantified. A control group (where there the independent variable is unchanged), is useful to determine if the independent variable is the cause of the changes on the dependent variable.

In this experiment the independent variable was the pH of the seawater, while the dependent variable was the mass of shell dissolved. A shell in pure seawater was used as the control to show that the dissolving was due to the change in pH. The controlled variables are shown in Table 1.

To maintain the credibility of the experiment, potential biases (systematic & random) should be avoided.

Table 1: Experimental Variables:

Dependent Variable	The amount (g) of shell dissolved after each week
Independent Variable	The pH of the seawater (Due to dissolved Carbon dioxide)
Controlled Variables	The type, size and brand of the jars
	The type (cockle shell) and weight (6.00g)
	The temperature of seawater
	Amount of drying time and time in jars
	The pH meter (electronic)
	The weighing scale (electronic)
	The type of carbonated water

Equipment and Materials

Method:

1. 5 similar cockle shells were collected on the same day from Henley Beach and sanded to weigh 6.00g.
2. 5 identical jars were washed and dried to remove any contaminants.
3. The pH meter was calibrated.
4. 475ml of seawater (collected from Henley beach) was poured into the first jar. Its pH was 8.0.
5. The first shell was placed into this jar and the lid was tightly sealed.
6. Its pH was written on the jar for easy identification.
7. 100 ml of fresh carbonated water was poured into a measuring cylinder.
8. The pH meter was rinsed with distilled water and dried with a piece of filter paper to prevent cross-contamination.
9. 450 ml of seawater was poured in the next jar. Its pH was measured. Using a pipet, 1 ml of carbonated water was added at a time while constantly stirring with the rod (to ensure even concentration), until the pH meter read 7.5.
10. The 2nd cockle shell was placed inside the jar and the lid was tightly sealed.
11. The pH (7.5) was written on the jar.
12. Steps 8-11 were repeated, adding enough carbonated water to make the pH of the rest of the jars 7.0, 6.5 and 6.0 respectively.
13. The initial shell weights (6.00g) were recorded.
14. The jars were kept in the same room where the ambient temperature was maintained at 18-19^{o}C.
15. After 7 days, the shells were extracted from their jar using tweezers. Excess water was removed with paper towels, and they were left to air dry for 2 hours to eliminate all water.
16. The shells were weighed on the electric weighing scale and their weights were recorded into the logbook.
17. Fresh carbonated water was added to each jar to reduce their pH to their original values.
18. The 5 shells were returned their allocated jars and the lids were tightly shut.
19. Steps 15-18 were repeated 6 more times, over 7 weeks.

Table 2 - Equipment and Materials:

Cockle shell (Approx. 6g) x5
Sandpaper
500ml jar with lid x5
2.5 L of seawater
500ml of carbonated water (Coles)
Pipet
Sheet of paper towel (for drying) x7
Logbook and pen to record data
Electronic weighing scale (0.01g Digital Precision Platform Scale)
pH meter (Goofly Digital pH Meter)
Stirring rod
250ml measuring cylinder
Permanent marker

Annotated Diagrams of the Experiment Setup:

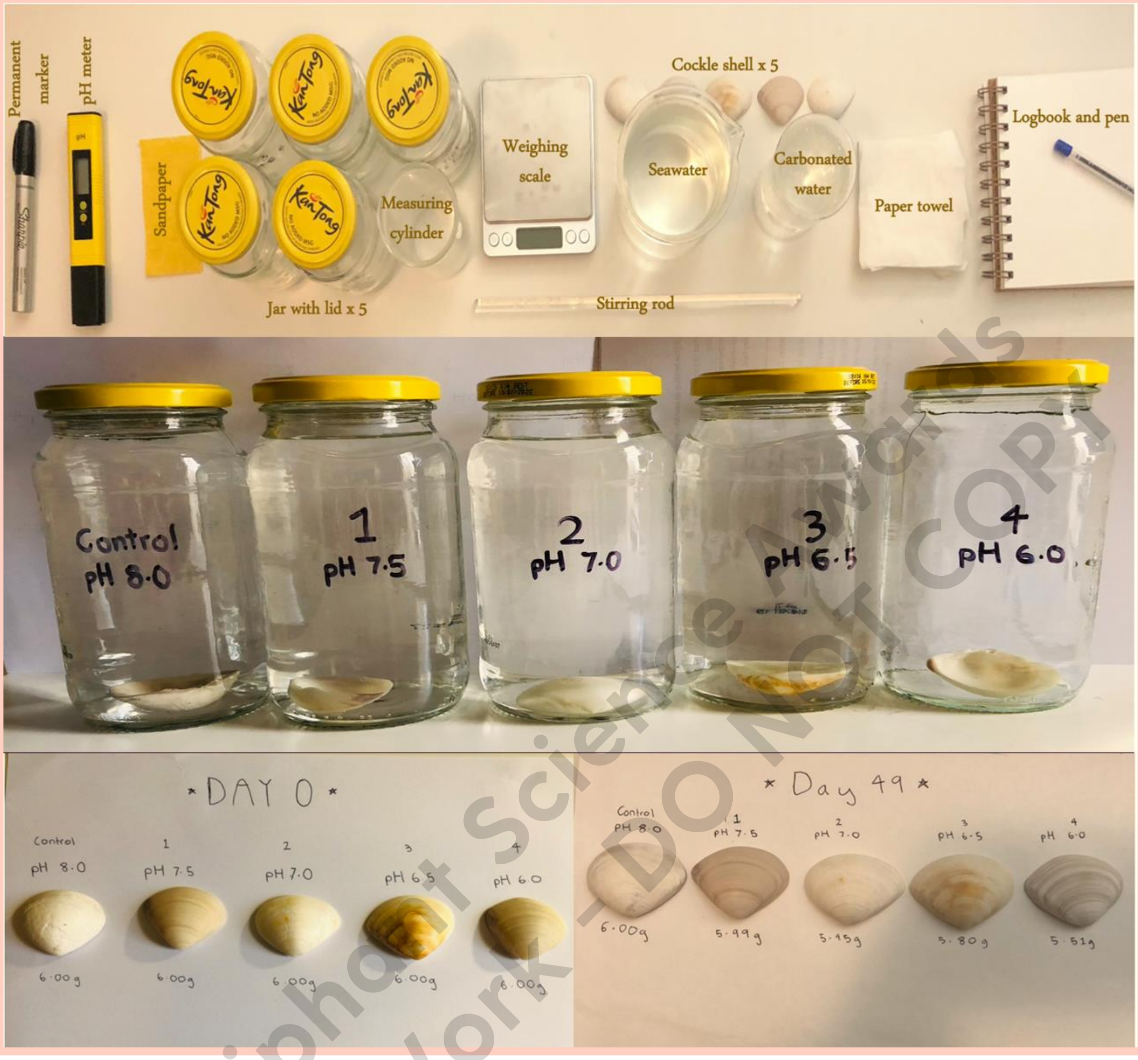


Table 3: Safety and Risks

Risks	Steps taken to reduce risks
Sanding shells creates fine dust that may irritate the throat, eyes and skin.	⇒ Wash hands and face after sanding ⇒ Sand the shells outdoors to prevent dust from accumulating inside ⇒ If irritation does occur, seek help from an adult and rinse with water.
The glass jars and measuring cylinders could shatter and cut skin.	⇒ Careful when handling glassware ⇒ If a cut from glass does occur, seek help from an adult. ⇒ Adult supervision is required
When calibrating the pH meter, buffer solutions were used. These may cause chemical irritation if in contact with the skin or eyes.	⇒ Wear gloves and safety goggles when handling chemicals ⇒ Wash hands after use

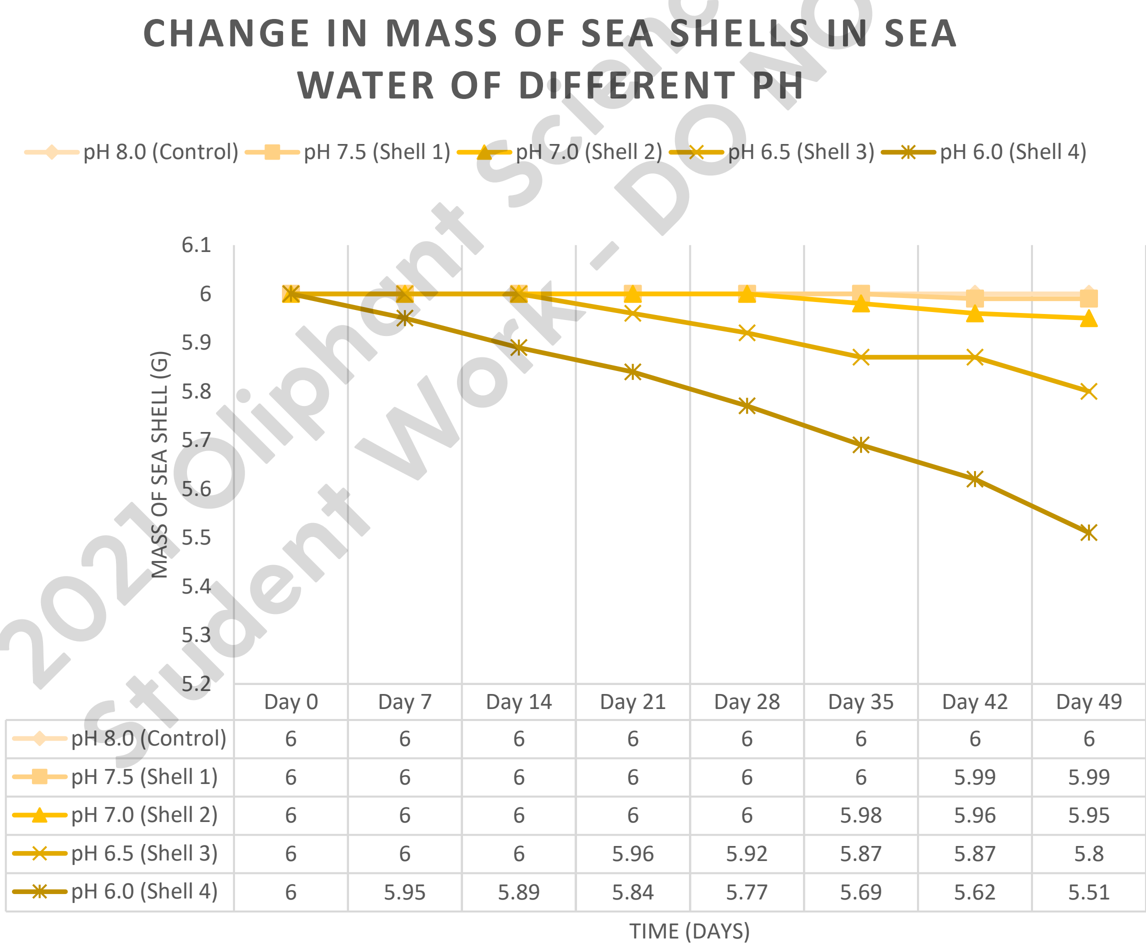
Processing and Analysing data and information:

○ Results

○ Table 4: Mass of shell loss (g) in seawater of different acidity

Acidity	Day 0		Day 7		Day 14		Day 21		Day 28		Day 35		Day 42		Day 49	
pH 8.0	0	0.0%	0	**0.0%**	0	**0.0%**	0	**0.0%**	0	**0.0%**	0	**0.0%**	0	**0.0%**	0	**0.0%**
pH 7.5	0	0.0%	0	**0.0%**	0	**0.0%**	0	**0.0%**	0	**0.0%**	0	**0.0%**	0.01	**0.2%**	0.01	**0.2%**
pH 7.0	0	0.0%	0	**0.0%**	0	**0.0%**	0	**0.0%**	0	**0.0%**	0.02	**0.3%**	0.04	**0.7%**	0.05	**0.8%**
pH 6.5	0	0.0%	0	**0.0%**	0	**0.0%**	0.04	**0.7%**	0.08	**1.3%**	0.13	**2.2%**	0.13	**2.2%**	0.2	**3.3%**
pH 6.0	0	0.0%	0.05	**0.8%**	0.11	**1.8%**	0.16	**2.7%**	0.23	**3.8%**	0.31	**5.2%**	0.38	**6.3%**	0.49	**8.2%**

○ Graph 1:



	Day 0	Day 7	Day 14	Day 21	Day 28	Day 35	Day 42	Day 49
pH 8.0 (Control)	6	6	6	6	6	6	6	6
pH 7.5 (Shell 1)	6	6	6	6	6	6	5.99	5.99
pH 7.0 (Shell 2)	6	6	6	6	6	5.98	5.96	5.95
pH 6.5 (Shell 3)	6	6	6	5.96	5.92	5.87	5.87	5.8
pH 6.0 (Shell 4)	6	5.95	5.89	5.84	5.77	5.69	5.62	5.51

○ Results (continued)

At Day 0, all 5 cockle shells weighed 6.00g.

The control shell (pH 8.0) remained at a constant 6.00g throughout the experiment.

In the rest of the jars, the shells lost more mass if their pH was lower. Over the course of 49 days, shell 4 lost 0.49g (8.2%), shell 3 lost 0.2g (3.3%), shell 2 lost 0.05g (0.8%) and shell 1 lost 0.01g (0.2%).

The lower the pH, the earlier their mass loss was observable. Shell 4 lost 0.05g after 7 days, shell 3 lost mass (0.04g) after 21 days, shell 2 lost 0.02g after 35 days and shell 1 only started losing mass (0.01g) after 42 days.

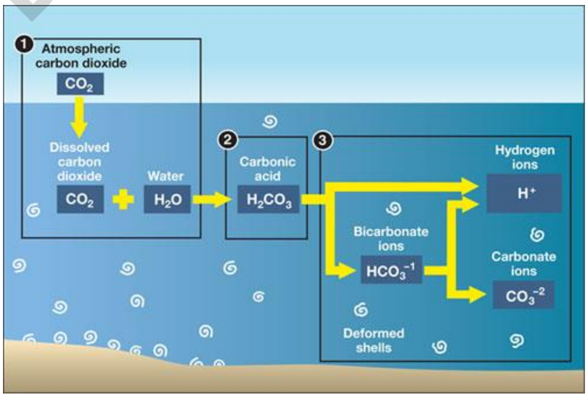
As observed in graph 1, once the shells began to lose mass, the rate of mass loss was relatively linear:

The average mass of shell lost per week were: shell 1 - 0.005g per week, shell 2 - 0.017g per week, shell 3 - 0.04g per week and shell 4 - 0.07g per week.

The final masses of the 5 cockle shells were: 6.00g for the control shell (pH 8.0), 5.99g for shell 1 (pH 7.5), 5.95g for shell 2 (pH 7.0), 5.8g for shell 3 (pH 6.5) and 5.51g for shell 4 (pH 6.0).

○ Discussion

Covering over 70% of the Earth's surface, the ocean is an integral part of our ecosystem. It acts as a buffer – absorbing up to 30% of all carbon dioxide emissions when levels rise and releasing some back into the atmosphere when levels decline. It uses a carbonate/hydrogen carbonate system to regulate the concentration of carbon dioxide and maintain a healthy pH of 8.1-8.3:



From: https://environmentalchangewestern.wordpress.com/2014/11/17/the-rainforests-of-the-ocean-soon-to-disappear/

$$CO_{2(g)} + H_2O_{(l)} \rightleftharpoons H_2CO_{3(aq)} \rightleftharpoons H^+_{(aq)} + HCO^-_{3(aq)}$$

This system can best be understood by breaking it up into its components.

- Firstly, the atmospheric carbon dioxide dissolves into the ocean.

$CO_{2\ (g)} \rightleftharpoons CO_{2\ (aq)}$ - Equation 1

- Next, some of this dissolved carbon dioxide reacts with the water molecules, forming carbonic acid.

$CO_{2(aq)} + H_2O_{(l)} \rightleftharpoons H_2CO_{3(aq)}$ - Equation 2

- Then, the newly formed carbonic acid disassociates into bicarbonate and hydrogen ions, which increases the acidity of the ocean.

$H_2CO_3(aq) \rightleftharpoons H^+_{(aq)} + HCO_3{}^-{}_{(aq)}$ - Equation 3

However, during the last 150 years human activities, such as burning fossil fuels, have caused extreme rises in carbon dioxide emissions. Consequently, the amount of dissolved carbon dioxide in the ocean has also rapidly increased (Equation 1).

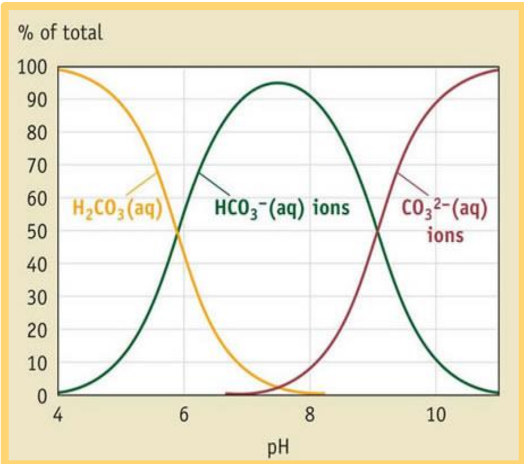
This extra carbon dioxide reacts with the water molecules, forming more carbonic acid (Equation 2). Because this compound is acidic, it dissociates and releases H^+ ions, increasing the ocean's acidity (Equation 3). This process is called ocean acidification.

However, it is important to note that pH is a logarithmic scale. Since pH = -log [acid concentration], an increase in H^+ concentration would result in a lower pH. For example, a drop in pH from 8.1 to 7.9 represents a 58% increase in acidity!

- Finally, and most importantly, the bicarbonate splits once more, resulting in carbonate and hydrogen ions.

$HCO3^- \rightleftharpoons H^+ + CO3^{\ 2-}$ - Equation 4

As shells contain predominantly calcium carbonate, this reaction is vital to their formation. Graph 2 demonstrates that at a pH of 8.1 (the current pH of the ocean), the equilibrium position is such that just below 90% is in the bicarbonate form, leaving around 10% as carbonate. Sea organisms, such as the cockle shell, have adapted and can build and maintain their shells in this environment.



From: https://explainingclimatechange.com/lesson8/8_4_3.html

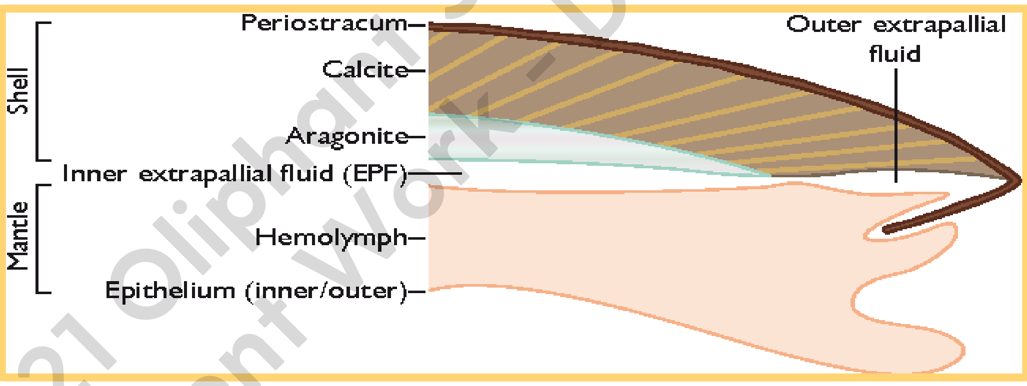
This experiment was carried out to test the hypothesis 'a greater concentration of dissolved carbon dioxide in seawater will result in the faster dissolution of cockle shells.' Carbonated water was used to alter the pH levels of the seawater, testing if the cockle shells could survive in more acidic waters.

- In the presence of acid (H^+), the insoluble calcium carbonate reacts to form soluble bicarbonate.

$CaCO_3 + 2H^+ \rightleftharpoons 2HCO3^- + Ca^{2+}$ - Equation 5

While none of the shells (other than control) remained completely intact, the experimental results in graph 1 clearly show that an increased acidity was associated with increased rates of mass loss. These ranged from 0.005 g/week in shell 1 (pH 7.5) to 0.07 g/week in shell 4 (pH 6.0). This can be explained by the collision theory, which states that a higher concentration (H^+) will result in an increased probability of successful collisions, and therefore reaction (dissolution of shells).

An interesting finding was that a lower pH resulted in an earlier observable mass loss. This is because cockle (bivalve) shells are coated in a thin, uncalcified layer of protein called the periostracum. The more acidic the water was, the quicker the inside (containing calcium carbonate) was exposed.

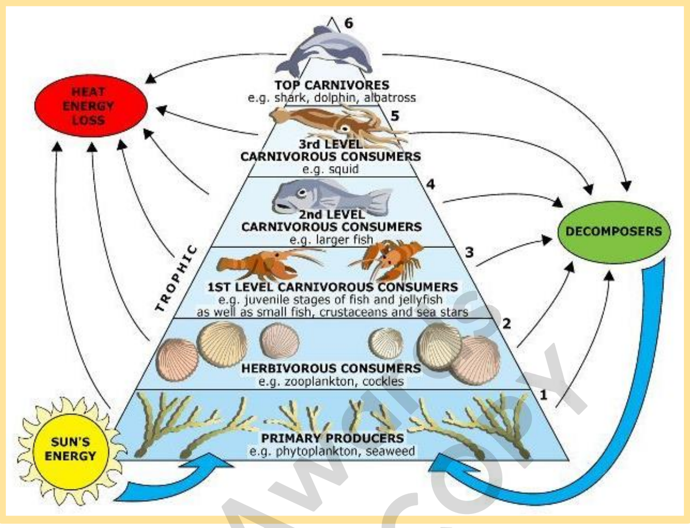


From: Laser ablation analysis of bivalve shells – Archives of environmental information:

However, once the periostracum was broken down, the rate of mass loss (equation 5) was relatively linear. Since the jars were refilled with carbonated water each week, there was a constant supply of acids (H^+). These acids had access to only the outer layer of carbonates at any given time, which when consumed by reaction, would expose a new layer underneath. This steady supply of acid and carbonates kept the reaction rate constant.

○ The impact on shells, sea life and the ecosystem:

Le Chatelier's principle states that by changing the conditions of a dynamic equilibrium, their positions will shift to re-establish a new equilibrium. Hence, increasing the acidity (H^+) of the ocean would shift equation 4 to the left, encouraging the carbonate to transform back into bicarbonate (graph 2) and reducing the concentration of carbonates in the ocean.



From: https://www.sciencelearn.org.nz/resources/367-toxins-and-food-webs

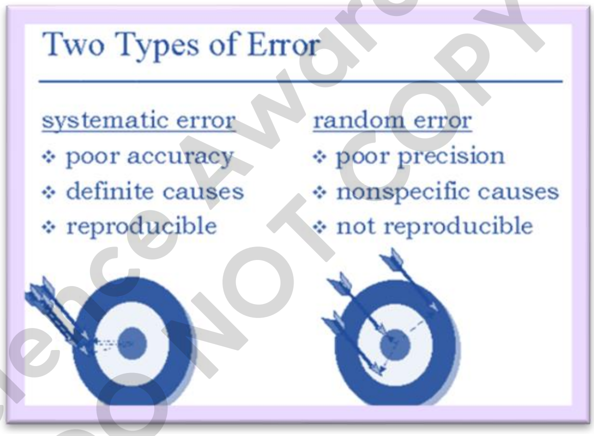
Unfortunately, this means that the organisms would need to work harder to draw the carbonates into their system, compromising their ability to build and maintain their shells. This would be terribly damaging to the ecosystem, as shells provide protection for organisms and habitats for sea life. Their absence would cripple the food chain and unbalance the delicate structure of the ocean. On land, human societies would be impacted as well. By 2100, the global loss of molluscs (such as oysters and mussels) due to ocean acidification will cost the food industry over $130 billion. Additionally, losing the Great Barrier Reef to ocean acidification would not only be a loss of heritage and beauty, but a huge $5.4 billion blow to Australia's tourism economy.

Evaluation

○ Potential Errors

The two types of errors that may occur in experiments are systematic and random errors.

Systematic errors are repetitive and affect the measurements by the same amount each time. Shell sanding to equalize mass is an example. Since some of the shells were sanded more than others, their periostracum was weakened and so they may have dissolved faster. This made the experiment unfair as it created more than one independent variable. In hindsight, more cockle shells should have been collected to ensure 5 of them had the same mass.



From: https://www.facts-about-india.com/errors-in-measurement.php

Another systematic error may have occurred when measuring the acidity of the seawater. Since the pH meter was not calibrated each week before use, the readings may have been skewed. The reason why the pH meter was only calibrated on Day 0 was because of the high costs and inaccessibility of buffering solutions. This may have resulted in inaccurate data.

Random errors are harder to avoid as they can occur at any given time. For example, different amounts of air pockets between the lids and water in each jar may have affected the results. Variable air pockets allowed some of the dissolved carbon dioxide to escape from the seawater and raised its pH. A solution would be mixing excess sea water and carbonated water in a separate container and then filling the jars to the brim, ensuring each jar contained an equal (zero) amount of air.

Another random error may have occurred when measuring the acidity of the sea water. Since the pH meter used was only accurate to one decimal digit, a solution measured as '7.5' could have actually ranged from 7.45 to 7.55. As the pH scale is logarithmic, a small difference such as this would change the acidity of the seawater by a lot, resulting in inaccurate data. To solve this, a pH meter with more than one decimal digit should have been used. Or, at a lower cost, the experiment should have been repeated multiple times, and the result averaged.

○ Improvements

A key improvement for this experiment would have been to study the impact of sea water with an acidity between 7.5 and 8 (pH increments 0.1). Although this experiment would've needed to be run over a longer period (100 days) to observe changes, it would be more relevant to the expected changes in oceanic acidity, and therefore more useful information.

○ Further Investigations

Further investigation on this subject, would include testing the impacts of acidic seawater on other sea organisms such as coral. Depending on the chemical structure of their shells, their rate of dissolution may be faster or slower than cockle shells. By observing these trends, new information can be gathered and used to quantify the impacts of ocean acidification.

○ Conclusion

This experiment proves the hypothesis, 'a greater concentration of dissolved carbon dioxide in seawater will result in the faster dissolution of cockle shells.' It suggests that rising atmospheric carbon dioxide levels threatens both the ecosystem of the ocean and our economy. If humans continue to release large amounts of carbon dioxide into the atmosphere, the Great Barrier Reef will succumb to extinction - the natural wonder becoming a thing of the past. Hopefully, increased scientific knowledge will encourage humanity to reduce their carbon footprint, to save shelled organisms, the ocean, and our planet.

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○ Acknowledgements:

My Dad helped me understand the chemical theory behind my experiment and supervised me during the most dangerous parts.

- **Logbook is enclosed as a separate document**
- **Risk assessment for Scientific Inquiry enclosed as a separate document**
- **Word Count (*not including tables or headings*): 2179**

Priyanka Thavarajah

Oliphant Science Awards

- Science Inquiry Logbook -

16/04/21 - Great Barrier Reef Foundation says that 'Climate change is the single greatest threat facing the reef'

Climate Change
- impacts on reef -

Rising sea temperatures
- Heat stress = mass coral bleaching
- loss of habitats
- Costal ~~erosion~~ erosion
- land indundation

Severe weather events
- Increased frequency of cyclones etc.
- Destroy reef structures

Ocean Acidification
- Oceans absorb CO_2 (30%)
- Decrease pH of ocean
- Weakens structure of coral and shells through dissolution
- Prevents reproduction

Key questions

- How does CO_2 decrease the pH of the Ocean?
- Why does an increased acidity weaken the structure of coral & shells?
- Does the ~~speed~~ rate of dissolution depend on the acidity of the water?

* Disscusion

18/04/21 - How does CO_2 decrease the pH of the ocean?

- ↓ pH = ↑ H^+ (acid) in solution ← * chemistry elmhurst *

↳ * ~~logarmithic~~ logarmithic *

$$pH = -\log[H^+]$$
$$-pH = \log[H^+]$$
$$10^{-pH} = [H^+]$$
$$\therefore \frac{1}{10^{pH}} = [H^+]$$

each step on pH scale is 10x more acidic than the previous one.

- $CO_{2(aq)} + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$ ← ocean buffering system

1. $CO_{2(g)} \rightleftharpoons CO_{2(aq)}$

Carbon dioxide in air dissolves in ocean

2. $CO_{2(aq)} + H_2O \rightleftharpoons H_2CO_{3(aq)}$

Carbon dioxide reacts with water becoming carbonic acid.

3. $H_2CO_{3(aq)} \rightleftharpoons H^+ + HCO_3^-$ (increase acidity)

Carbonic acid splits into hydrogen & bicarbonate.

more CO_2 in water = more H^+ = lower pH
(from equation 3)

Disscussion

19/04/21 - Why does a lower pH weaken the structure of coral and shells?

- Coral & shells are mostly made of calcium carbonate.
  $CaCO_3^{2-}$

- ~~HCO3~~ $HCO_3^- \rightleftharpoons H^+ + CO_3^{2-}$

The bicarbonate splits into hydrogen and carbonate

While there is currently enough carbonate in the ocean for shells & coral to maintain their exoskeletons, as the pH drops the equation shifts to the left (Le Chateliers) in order to keep an equilibrium.
∴ more H^+ = more bicarbonates and less carbonates.

Less carbonates in ocean = more energy needed to grow & maintain shells = less energy for things like reproduction

- $CaCO_3 + 2H^+ \rightleftharpoons 2HCO_3^- + Ca^{2+}$

When in contact with acid (H^+), calcium carbonate reacts to form bicarbonate. This damages the structure of shells and since there is not enough carbonates to regrow, they begin to dissolve.

* Chemistry Libretexts*
* explainingclimatechange.com*

21/04/21 - Does the rate of dissolution depend ~~on~~ on the acidity of the water?

EXPERIMENT idea

Components:	How I will do it:
• Measure pH of seawater	• Use electronic pH meter
• Make sea water more acidic ~~wit~~ using CO_2	~~Soda stream~~? ← too expensive • Add carbonated water to sea water in different amounts
• ~~Meaus~~ Measure difference between shells	• Weigh shells ~~after~~ each week for 4 weeks?
• Find shells with same starting mass	• Find shells with similar mass then sand them so that they weigh exactly the same.

Make sure it is a Fair Test:

Independent Variable - pH of the seawater

Dependent Variable - The rate that the shells dissolve

Control Variables
- Type, size, brand of jars
- Type & weight of shell
- Drying time & time in jars
- type of carbonated water
- weighing scale (electronic)
- pH meter
- temperature of water

29/04/21 - Test #1

Question : Does ~~lowering the pH of~~ increasing the concentration of CO_2 in seawater cause sea shells to dissolve at a quicker rate?

Hypothesis : The greater the concentration of CO_2, the quicker the cockle shells will dissolve.

Outline : 5 cockle shells (sanded so that they are the same weight) are put in 5 jars with different concentrations of carbonated water, and therefore different pHs - ~~8.00~~ 8.0 (control), 7.5, 7.0, 6.5, 6.0. Over a course of 4 weeks, the shells will be weighed each week and their masses will be recorded into this log book.

~~Equim~~

Equipment : ~~5 jars~~

- jar x 5
- cockle shell x 5
- pH meter
- electronic weighing scale
- sandpaper
- 2.5L of seawater
- Pipet
- 500ml carbonated water
- Paper towel
- Logbook & pen
- Stirring rod
- Measuring cylinder
- Permanent marker

24/04 → 5/06 - Results

experiment extended to 7 weeks because only 2 shells had lost mass

acidity ↓ | time span ↓

	Day 0	Day 7	Day 14	Day 21	Day 28	Day 35	Day 42	Day 49	
pH 8.0	6	6	6	6	6	6	6	6	0
pH 7.5	6	6	6	6	6	6	5.99	5.99	0.01
pH 7.0	6	6	6	6	6	5.98	5.96	5.95	0.05
pH 6.5	6	6	6	5.96	5.92	5.87	5.87	5.8	0.2
pH 6.0	6	5.95	5.89	5.84	5.77	5.69	5.62	5.51	0.49

mass of shell (g)

mass loss after 7 weeks

Notes for evaluation:

Potential errors: systematic → sanding shells - zeoring?
→ pH callibration

random → air pockets

Notes for result section:

- → control lost no mass
- → ↓ pH = ↑ mass loss
- → ↓ pH = faster rate of mass loss
- → ↓ pH = ↓ time taken to make an observable change in mass