This guide accompanies the video “Satellites, Seas and CO₂” presented by Dr Jamie Shutler, Plymouth Marine Laboratory, and produced by the ESA OceanFlux Greenhouse Gas project.

It is intended to provide background information to the film and to enable students to perform the experiment shown in the film.
Satellites, Seas and CO\textsubscript{2}

A guide for students

The oceans cover two thirds of the surface of the earth and influence our atmosphere and our climate. The gas carbon dioxide (CO\textsubscript{2}) is of particular importance as it contributes to global warming by absorbing radiation, causing the atmosphere to heat up and re-radiate heat back down to the ground. It is this insulating property of CO\textsubscript{2}, rather like the glass in a greenhouse, that causes it to be known as a greenhouse gas.

The oceans can act as a sink for CO\textsubscript{2}. If these natural stores did not exist the earth would be warming at much greater rate that what we observe today. However, when CO\textsubscript{2} enters the oceans it alters the chemistry of the water and makes it more acidic (see box on CO\textsubscript{2} and the oceans) which can have devastating effects on marine organisms.

Breaking waves

As a wave breaks, whitecapping appears - which is where the seawater captures a pocket of air. This air then goes into the sea as a bubble, and as the bubble disperses the gases dissolve into the ocean. These bubbles of air contain CO\textsubscript{2}, and thus waves can influence the amount of CO\textsubscript{2} that goes into the ocean.

The effect of increasing acidity on development of mussel shells.
The bottle experiment

Introduction
The oceans absorb one third of the carbon dioxide emitted each year, and this changes the chemistry of the water, which can have an impact on marine life. The amount of CO₂ which can dissolve in the seawater is mostly dependent on the temperature of the water and this can be illustrated with the following experiment using bottles of carbonated drinks. Carbonated drinks contain CO₂ which is dissolved in the liquid under high pressure (see box).

Equipment
- 2 bottles of carbonated drink
- 2 aspirin tablets
- Thermometer
- Stopwatch (optional)

Method
1. Take two identical bottles of carbonated drink and place one in the refrigerator overnight and keep the other at room temperature (or even better leave it in the sun!).
2. Carefully open both bottles and take the temperature of each drink.
3. Place an aspirin in each bottle at the same time to release the contained CO₂.
4. Observe what happens to the drink in each bottle, you may want to use a stopwatch so that you can note the times when things happen.

Questions/discussion
1. Which bottle produced the most bubbles?
2. Which bottle overflowed first?
3. Use the graph above to determine the solubility of CO₂ for each of your bottles - how does this help to explain what happened in your experiment?

Outcomes
At the end of this experiment students should be able to:
- explain the differences in solubility of CO₂ at different temperatures;
- observe the effect of temperature on the rate of a reaction; and
- have a basic understanding of the concept of ocean acidification.

For further experiments we recommend looking at The other CO₂ problem - ocean acidification.

Carbon dioxide in the oceans

Atmospheric CO₂ absorbed by the oceans not only makes the water more acidic but also causes changes to the chemistry of the water, such as reducing the number of carbonate ions available. This can have a devastating effect upon marine life, particularly calcifying animals such as mussels and corals, which rely upon the supply of carbonate ions as the building blocks to form their shells and skeletons.

When CO₂ dissolves in seawater it can either:
- Remain as a dissolved gas, which can freely exchange between the ocean and atmosphere and can be taken up by marine plants and phytoplankton. The oceans have a limited capacity to hold dissolved CO₂.
- Combine with molecules of water to form a weak acid called carbonic acid (H₂CO₃), the same acid that is found in carbonated drinks (see bottle experiment). This reaction can be shown as:

\[ \text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \]

Then the carbonic acid dissolves in water and breaks apart into its constituent ions, a hydrogen ion and a bicarbonate ion (the same as in baking soda):

\[ \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^- \]

Most of these hydrogen ions will then combine with carbonate ions in the seawater to form addition bicarbonate ions, although some will stay as hydrogen ions and reduce the pH of the seawater.

\[ \text{H}^+ + \text{CO}_3^{2-} \rightleftharpoons \text{HCO}_3^- \]

This means that when CO₂ dissolves in seawater there will be an increase in dissolved CO₂, hydrogen ions, and bicarbonate ions and a decrease in the number of carbonate ions and the pH of the seawater, contributing to the phenomenon of ocean acidification.

This same reaction occurs in carbonated drinks when CO₂ is dissolved in the liquid. When aspirin is added to the carbonated drink it reacts with the bicarbonate ion to produce water and carbon dioxide gas which we can see bubbling out of the bottles in the experiment.
Satellites, Seas and CO₂

Further resources

Videos

Satellites, Seas and CO₂ video
Dr Jamie Shutler of Plymouth Marine Laboratory explains the OceanFlux Greenhouse Gases project, which is a two year project funded by the European Space Agency. The aim of the project is to improve the quantification of air-sea exchanges of greenhouse gases.
https://www.youtube.com/watch?v=4uak0vVggGY

The other CO₂ problem animation
A short, powerful and entertaining animation about the issue of ocean acidification, produced by Ridgeway School (Plymouth, UK) and Plymouth Marine Laboratory.
https://www.youtube.com/watch?v=F5w_FgpZkVY

Ocean acidification: connecting science, industry, policy and public
A short film about ocean acidification which brings together a wide range of stakeholders including, HSH Prince Albert II of Monaco, school children, a Plymouth fishmonger, a UK government Chief Scientific Adviser, representatives from industry and policy making departments, as well as a group of internationally recognised expert scientists.
https://www.youtube.com/watch?v=kCp8cetvtL8

Publications

Frequently asked questions about ocean acidification
Concise, understandable summaries of current knowledge of ocean acidification. Produced by the US Ocean Carbon and Biogeochemistry Program and the UK Ocean Acidification Research Programme.
https://darchive.mblwholibrary.org/handle/1912/5373?show=full

The other CO₂ problem - ocean acidification
Eight experiments to help young people understand the basics of ocean acidification. Teachers will find information on the preparation and running of the experiments as well as answers to any questions.

Hot, sour and breathless - ocean under stress
A guide to the triple stresses facing the ocean - rising temperatures, ocean acidification and ocean deoxygenation. Written in clear, easy to understand language it explains how these three interacting factors will cause substantial changes in marine physics, chemistry and biology.

Websites

PML | Plymouth Marine Laboratory
An independent, impartial provider of scientific research and contract services relating to the marine environment. http://www.pml.ac.uk

National Centre for Earth Observation
This is a PML contribution to the UK National Centre for Earth Observation http://www.nceo.ac.uk

Oceanflux Greenhouse Gases project
The Oceanflux Greenhouse Gases project is a two year project funded by the European Space Agency, the objective is to improve the quantification of air-sea exchanges of greenhouse gases. The project aims to develop and validate new and innovative products combining field data, satellite observation, and models. http://www.oceanflux-ghg.org/

NERC UK Ocean Acidification Research Programme
A £12m, 5 year research programme seeking to understand ocean acidification in order to provide data and advice to develop mitigation and adaptation strategies. Contains a section with links to many further resources. http://www.oceanacidification.org.uk/