Isotopes

Suitable for UK KS5 or ages 17-18

Notes for teachers

At a glance

This lesson is inspired by research at Oxford University into the climate during the Cretaceous period, 140 million years ago. As minerals formed in rocks, they used oxygen from rain, preserving it and the isotopes it was made of. Oxygen-16 is lighter than oxygen-18, and evaporates more readily in the tropics near the equator. Similarly, as clouds move north and south towards the poles, heavier oxygen-18 drops out preferentially in rainfall, leaving heavier isotopes of oxygen-18 behind closer to the equator, and lighter isotopes of oxygen-16 closer to the poles.

In this lesson, students will take an in-depth dive into the techniques used by researchers to make new discoveries and learn about how isotopes can tell us about the history of our planet's climate. They will complete data processing challenges and make new calculations or readings from real graphical data provided by the scientists. Students will have to dig into their toolkit of experimental techniques to design, plan, conduct and critically evaluate laboratory investigations, including recording observations and risk assessing their method.

Learning Outcomes

- Consolidate understanding of isotopes, the structure of the atom, and half-lives.
- Practice balancing chemical equations and performing chemical calculations.
- Link mass spectrometry to ongoing current research and consolidate theoretical knowledge.
- Support independent decision-making creative problem solving.
- Develop good laboratory and scientific skills, including accurate observation, detailed data recording, team work, planning, and risk assessment.
- Encourage critical thinking and evaluation.
- Understand how chemistry, maths, geology and physics are linked in research.

These activities are suitable for AS students in their first year of A level studies.

Each student will need

- A copy of the student worksheet
- Some blank slips of paper
- PPE
- A calculator

Each group will need

- ~ 2 g marble chips
- 2 weighing boats
- 2 spatulas
- A 2 dp technical balance.
- Hydrochloric acid (suggestion: 2 mol dm^{-3})
- 2 x 250 cm^3 conical flasks
- 1 bored bung, to fit 1 conical flask
- Flexible tubing to fit bored bung and syringe, if available

Either

- A 500 cm^3 measuring cylinder
- A cold water bath
- A retort stand and clamp

And/or

- 500 cm^3 syringe

Lesson Activities

1. Starter activity – Fictionary

- Break the class into groups of four or five, and ask them to play Fictionary using the key words on the worksheet. It is often assumed that by Key Stage 5, students have a strong understanding of words such as molecule, but unfortunately this is not always true. This exercise consolidates their foundation knowledge of the subject.

  Printable definitions are in Appendix 1.

  > *How to play: Choose a word from the list below. All players write a definition on a slip of paper and fold it up. Players take it in turns to add the teacher's definition and read out all the answers. Each player votes on which definition they think is correct.*
  >
  > *1 point if you correctly guess the true definition*
  > *1 point if your definition gets picked by someone else as true*
  > *1 point if your definition is the same as the true definition*

- A few rounds is sufficient to warm up the class. The class do not need to get through all the definitions, as this may take up too much of the class time. Correct definitions may be printed from the appendix and handed out after the activity.
- Watch the Oxford Sparks video 'Using your science to reveal how much rain fell on the dinosaurs' (see web links).

2. Main activity: Experiment

- Ask the class to read the experiment instructions and liaise with their group to make a plan.
- During the experiment, each group will perform two experiments: a reaction between marble chips and hydrochloric acid to produce CO_2, measuring the amount made (a) via gas collection, and (b) via change in mass.
  See Appendix 2 for experimental set ups.
- Before they begin, ensure each student has produced a complete method, diagram of the intended set up, and table for results.
- Discuss as a class the appropriate health and safety measures that need to be considered for the laboratory to take place, and write precautions up on the board.
- Probe the class for best practice experimental techniques. They should consider
  - whether they are going to repeat the experiments and, if so, how many times;
  - how they are going to use team members to experiment efficiently;
  - what results they are expecting to find;
  - the precision and sizes of the equipment they have chosen to use;
  - whether key details are included in the method that would allow another person to replicate their results exactly.
- Once they have completed the experiment, ask the students to critically evaluate the two laboratory investigations, drawing comparisons, making mathematical conversions between mass and volume, and considering sources of error in the methods.

3. Main activity: Mass spectrometry

- Ask the class to read through the remaining sections on the provided worksheet, and answer the questions.
- Share answers from the class, ensuring that all students are able to express $^{18}O/^{16}O$ in terms of voltage and resistance before allowing them to move on to calculate $^{18}O/^{16}O$ ratio from the data provided.
  Answers are provided in Appendix 2.

4. Plenary

- Ask the students to interpret what they have learnt in the context of the video, and discuss the challenges and nature of current scientific research.

5. Optional Homework: Lab report

- Ask the class to write up a lab report on the experiment they performed. A good quality lab report should be written in the past tense and passive voice, and include:
  - An introduction, explaining what they wanted to find out and contexts for professional scientists performing a lab such as this beyond the classroom.
  - A method, outlining the steps they performed.
  - A diagram of the apparatus and set up.

- A risk assessment, including precautions taken.
- Results, presented clearly in tables and/or graphs.
- A discussion and conclusions.
- An evaluation, identifying sources of error, ways to improve the experiment, and/or ways to extend the experiment.

Web links

Oxford Sparks video 'Using your science to reveal how much rain fell on the dinosaurs':
https://www.oxfordsparks.ox.ac.uk/content/using-your-science-reveal-how-much-rain-fell-dinosaurs

Useful sources of information:
https://www.britannica.com/science/Cretaceous-Period
https://earthobservatory.nasa.gov/features/Paleoclimatology_OxygenBalance
http://www-naweb.iaea.org/napc/ih/documents/global_cycle/vol%20II/cht_ii_04.pdf

Image source (permissions granted): *Thermo Fisher Scientific*
http://www.ebd.csic.es/lie/PDF/DELTA_V_AdvantagePDF_26513.pdf

Safety disclaimer: The practical work suggestions given here have not been tested by us for safety. While the suggested practical work is based on existing laboratory experiments, you should always carry out your own risk assessment, especially before using or making a hazardous procedure, chemical or material. All practical work should be supervised by a qualified science teacher with suitable knowledge of the equipment used and carried out in a properly equipped and maintained laboratory. For more information, refer to www.cleapss.org.uk/.

Appendix 1. Fictionary definitions

Molecules – more than one atom bonded together with covalent bonds to make a discrete chemical unit.

Compounds – made up of more than one kind of atom.

Elements – made up of one kind of atom.

Isotopes – atoms of the same element which have the same numbers of protons but different numbers of neutrons

Relative molecular mass – the weighted average mass of a molecule given the relative abundances of its elements, and compared to 1/12 of 12-carbon.

Nucleon – a particle in the nucleus of an atom.

Relative isotopic mass – the weighted average mass of one nuclide compared to 1/12 of 12-carbon.

Relative atomic mass – the weighted average mass of an atom of an element given its relative abundances, and compared to 1/12 of 12-carbon.

Appendix 2. Answers to questions

Experiment

A sensible acid is hydrochloric acid. Acids that contain oxygen should be avoided, as these would contaminate the sample with other isotopes.

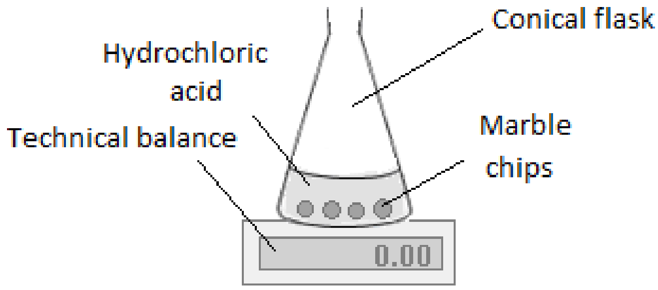
$$CaCO_{3\,(s)} + 2HCl_{\,(aq)} \rightarrow CO_{2\,(g)} + CaCl_{2\,(aq)} + H_2O_{\,(l)}$$

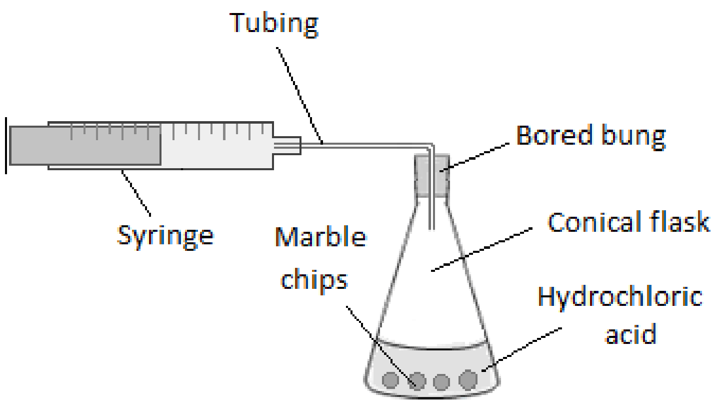
Assuming 100% of the mass of the marble chip is $CaCO_3$ and that the acid is in excess, 1.00 g produces:

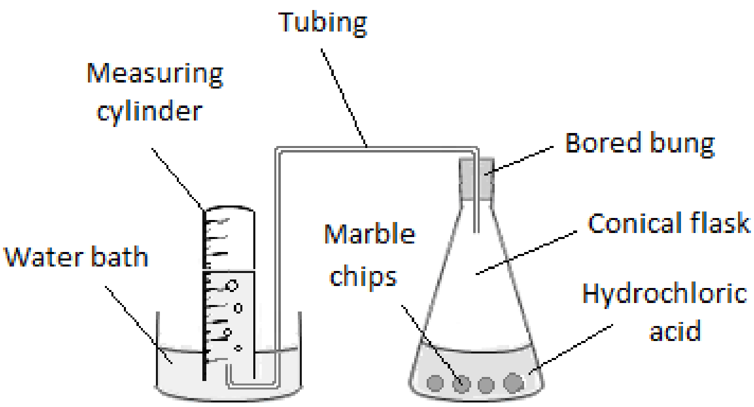
moles = mass/Mr = $1.00/(40.08 + 12.01 + 16.00 \times 3) = 9.99 \times 10^{-3}$ 1:1 $CaCO_3$:CO_2
Volume = moles x 24,000 = 240 cm^3
Mass = moles x Mr = $9.99 \times 10^{-3} \times (12.01 + 16.00 \times 2) = 0.44$ g

SiO_2 will not react with HCl.

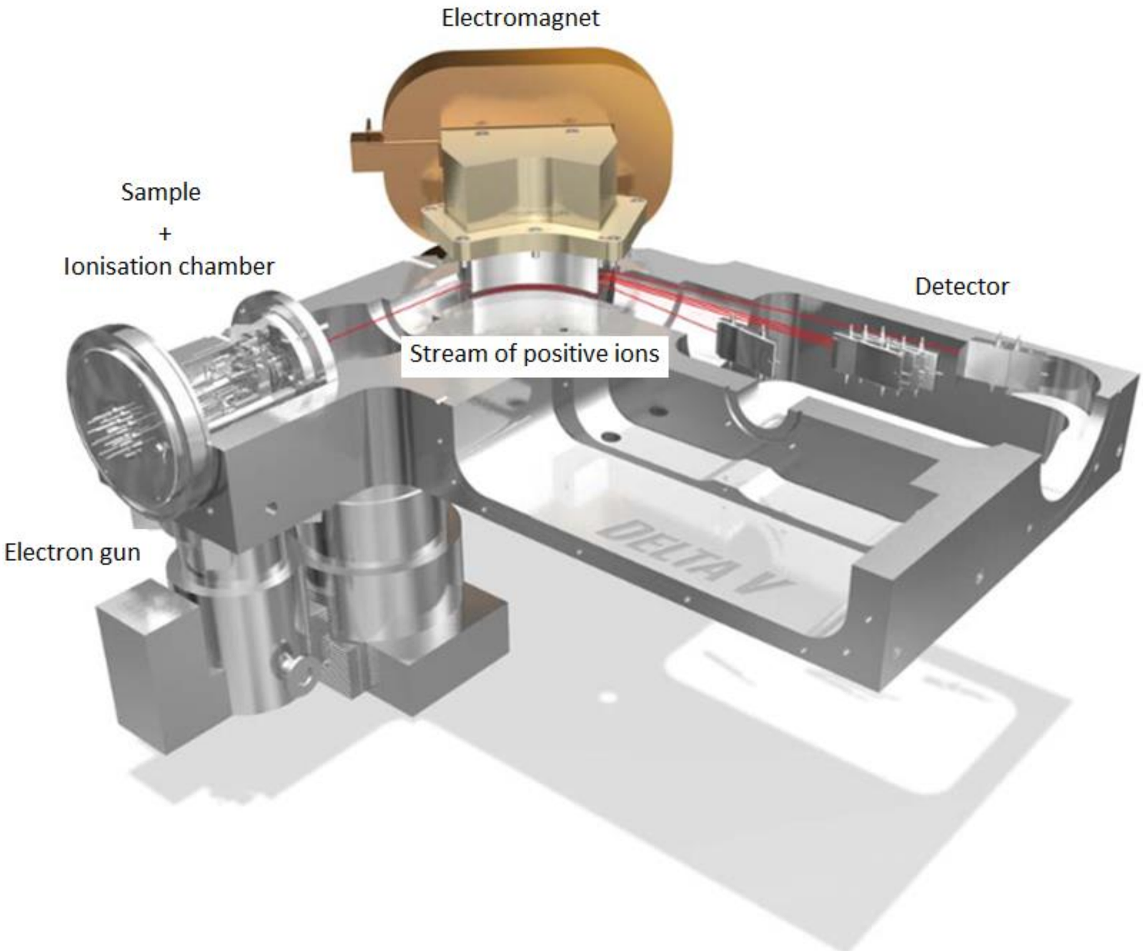
Suitable experimental set ups:







Mass spectrometry



Thermo Fisher Scientific

What happens at the detector?

It is difficult to use a traditional mass spectrum because… : the relative heights are so different that the resolution of the graph is not suitable for reading both isotopes.

$^{18}O/^{16}O = (V_{18}/R_{18}) / (V_{16}/R_{16})$ or $^{18}O/^{16}O = V_{18}R_{16} / V_{16}R_{18}$

$^{18}O/^{16}O$:

$R_{18} = 1337\ \Omega$ $V_{18} = 6$
$R_{16} = 2.000\ \Omega$ $V_{16} = 4.5$

$V_{18}R_{16} / V_{16}R_{18} = 6 \times 2.000 / 4.5 \times 1337 = 0.001995$
$0.001995/0.002005 = 0.9950$
$(0.9950 – 1) \times 1000 = - 4.99$ ‰ or – 5.0‰

δ notation

Normalisation is important because no two mass spectrometers are identical (e.g. different electronics, lab conditions, efficiency).

Natural variations in $^{18}O/^{16}O$ ratios are very small. Expressing these changes in parts per thousand makes it easier to see the small differences between samples.

Estimating rainfall

What are the limits of using today's data to make estimates about the past?

This means working outside existing data range, where we can't assume everything progressed steadily - there could have been big perturbations we haven't taken into account.

Small errors can be magnified over long periods of time.

We can't test the data to be sure - everything is based on assumptions.

The mean annual precipitation estimated should (approximately) be between 1590 mm/year and 2280 mm/year (based on temperatures of 30 and 25˚C).

Including units should be reinforced.

Altitude and latitude

Increasing altitude – as an air mass rises, it gets cooler and will rain out the heavy isotope-bearing water first during its ascent. This will lead to rainfall with lower $\delta\, ^{18}O$ ‰ values at higher altitudes.

Extension

The short half-life of carbon-14 means we can tell how long ago a living thing or material such as wood died, as the isotope decays away. This allows carbon dating of historical artefacts.

The long half-life of uranium isotopes means we can perform radiometric dating of rocks. Geological timescales are significantly longer than human timescales, and carbon-14 decays away too quickly to be useful.

The stable nature of oxygen-18 means that Ricky can investigate how much rain fell in the Cretaceous period without having to account for how age has depleted the isotopic abundance of heavy oxygen.