Isotopes

Suitable for UK KS5 or ages 17-18

Student worksheet

Starter activity – Fictionary

Break into groups of four or five. Choose a word from the list below and have everybody write a definition on a piece of paper and put it into a pile. The true definition should be provided by the teacher. Shuffle the pile. One person reads out the definitions whilst the rest guess the correct definition.

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

Relative isotopic mass **Elements** **Isotopes**

Molecules **Compounds** **Relative molecular mass**

Relative atomic mass **Nucleon**

Experiment

In this experiment, break your team in two. You'll be using acid to dissolve rock samples, and measure how many moles react. Not all acids would make sensible choices to dissolve your rock samples (e.g., given that you want to analyse the oxygen isotopes in the carbon dioxide produced). Choose a sensible acid and justify your choice.

Acid: ______________________________

Justification: ____

You will be using hydrochloric acid. You have been supplied with marble chips (mostly $CaCO_3$). Write a balanced chemical equation (including state symbols) for the reaction between marble chips and hydrochloric acid.

Start with about 1g of marble. Weigh out the amount you are using, and record the exact mass here: _________ g

Using your equation and the mass of marble you weighed out, calculate the mass and volume (remember standard gas volumes) of CO_2 you would expect to release under standard conditions.

Mass: _________ g

Volume: _________ cm^3

Another type of rock is sandstone, which is 94% SiO_2. Predict the chemical reaction when hydrochloric acid is added to sandstone (*hint*: HCl is stored in glass bottles).

One team will use a balance to measure the change in mass, whilst the other will use gas collection. Allocate a method to each team, and write out a method for your experiment, including a fully labelled diagram and equipment list.

Method:

Diagram:

Draw a suitable table for your results.

Table:

Now perform your experiment. Fill in your table of results and record your observations carefully.

Observations: ____

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Compare your results with the other team, and your estimated mass and volumes of CO_2. Do they differ? If so, why?

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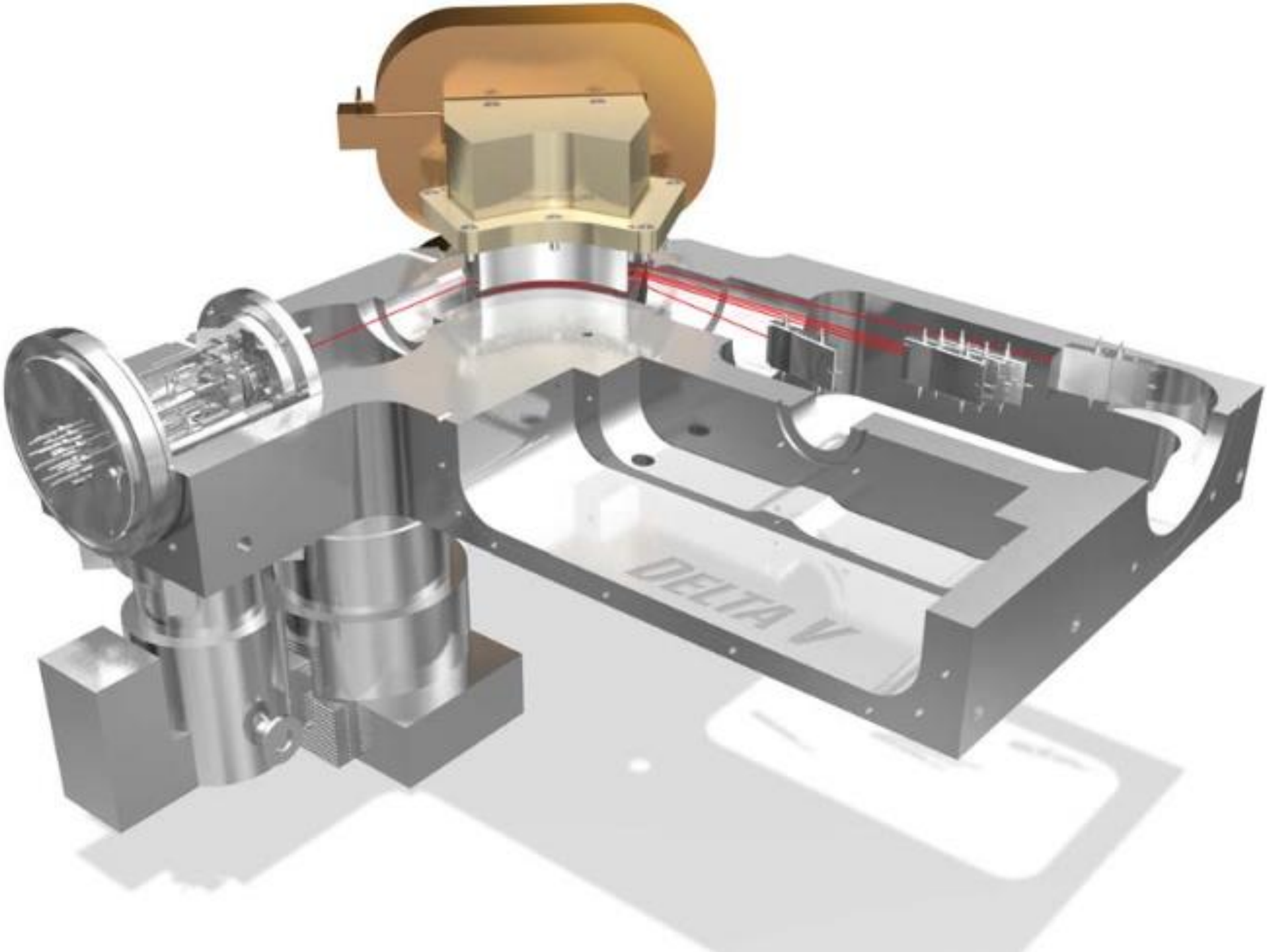
Mass spectrometry

In your groups, discuss what you already know about mass spectrometry and how a mass spectrometer works. Below is a diagram of a Thermo Fisher Scientific mass spectrometer – the same kind that Ricky was using. Can you label the different parts to show what happens to a sample as it travels to the detector? The following labels might help: electromagnet; detector; ionisation chamber; stream of ions.



What happens at the detector?

Scientists often need mass spectrometers to measure isotopes with very different abundances and so they can be designed in ways to make the measured signals more similar and easier to compare.

At the detector, charged ions induce an electric current across insulating Faraday cups. A **voltage change** is measured. The number of ions (n) in a beam is proportional to the current.

$$n \propto i$$

where $i = V/R$

i = current (A), V = voltage (V) and R = resistance (Ω)

In Ricky's mass spectrometer, two Faraday cups are used to measure the ratio of ^{18}O to ^{16}O. One measures gas ions containing ^{16}O, whilst the other measures gas ions containing ^{18}O. The ratio of $^{18}O/^{16}O$ is the ratio of the currents:

$$^{18}O/^{16}O = i_{18} / i_{16}$$

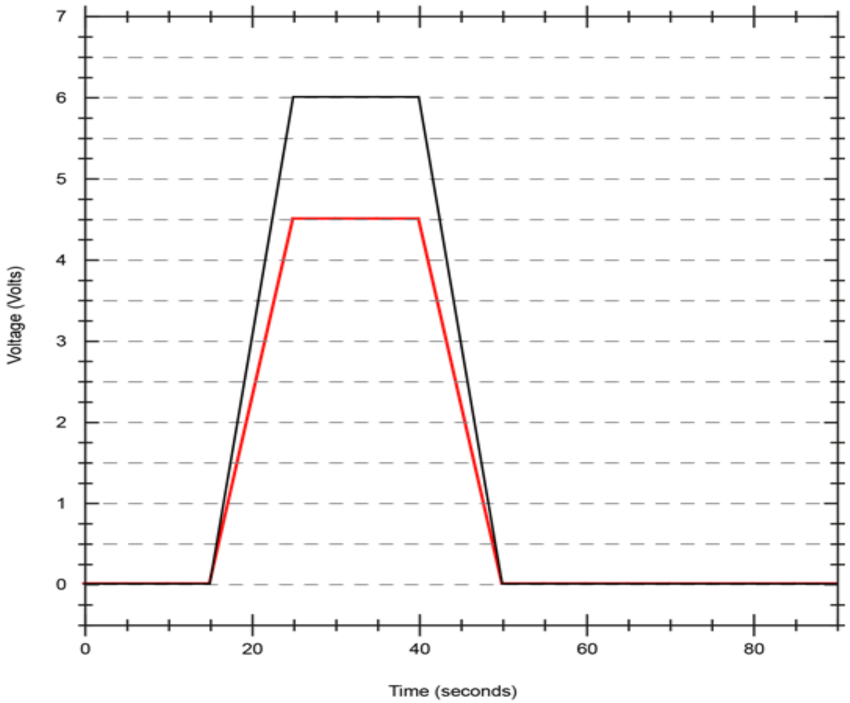
Using the equation $i = V/R$, express $^{18}O/^{16}O$ in terms of voltage and resistance (V_{18} and R_{18} for the voltage and resistance across the Faraday cup measuring ^{18}O and V_{16} and R_{16} for that measuring ^{16}O..

The graph below shows the output for one of Ricky's siderite samples. Using graph and

$R_{18} = 1337\ \Omega$

$R_{16} = 2.000\ \Omega$

…can you calculate the $^{18}O/^{16}O$ ratio of the sample (to 4sf)?



Graph showing voltage measured on two Faraday cups in a mass spectrometer for one of Ricky's samples. Sample gas is allowed to enter the ionisation chamber at t = 15 seconds. ^{18}O = black, ^{16}O = red.

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

δ notation

Scientists use "δ" notation to express the variation of an isotopic ratio of an element in a sample (in parts per thousand or "per mil", ‰) compared to the isotopic ratio of a standard. The standard δ ^{18}O ‰ value is set to zero using the equation below.

$$\delta\ ^{18}O\ ‰ = \left(\frac{\left(\frac{^{18}O}{^{16}O}\right)_{sample}}{\left(\frac{^{18}O}{^{16}O}\right)_{standard}} - 1 \right) x\ 1000\ ‰$$

Why do scientists normalise the ratios measured on the mass spectrometer to a standard?

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The standard, measured on Ricky's mass spectrometer, has a $^{18}O/^{16}O$ ratio 0.002005. Use this value for the standard, the ratio you calculated for Ricky's sample from the graph above and the equation to calculate δ ^{18}O ‰ of Ricky's siderite sample.

δ ^{18}O ‰:

Why are δ ^{18}O values expressed as parts per thousand?

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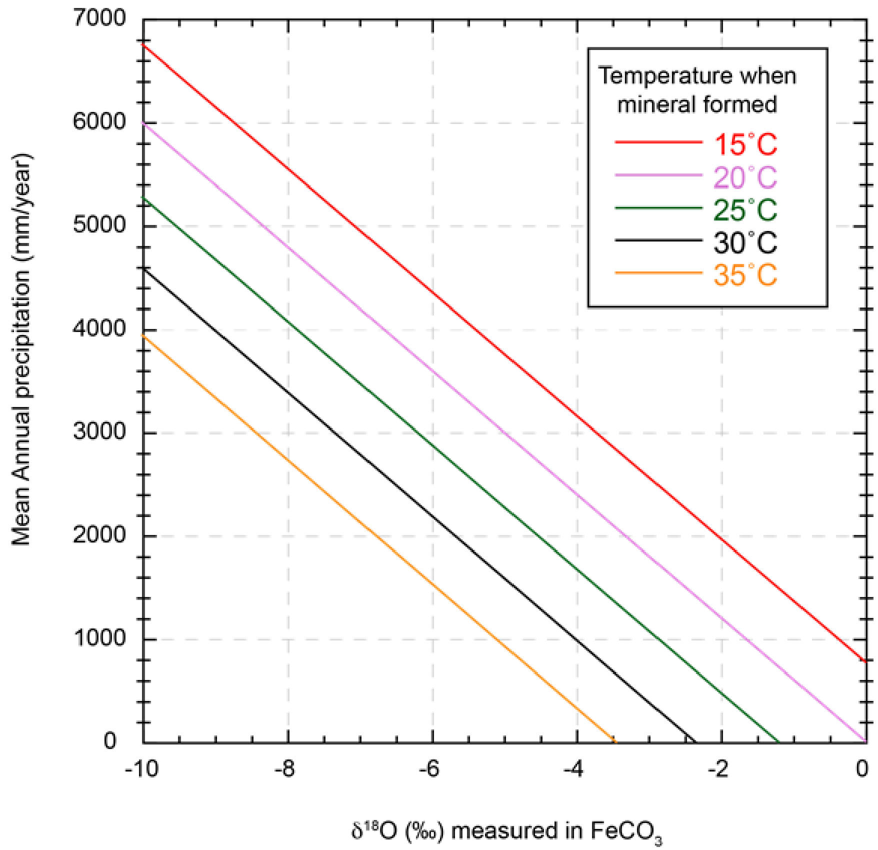
Estimating rainfall

The δ ^{18}O ‰ depends on both the temperature and how much ^{18}O was in the water from which the minerals formed.

Ricky's sample of siderite grew during the Early Cretaceous period, 140 million years ago, in waterlogged soil in what is now southern England. The water came from rainfall. Scientists use graphs of rainfall data collected **today** to make estimates about the rainfall 140 million years ago, like the graph below.



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

Limits: ____

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On the basis of other chemical measurements and fossils, we think temperatures in southern England 140 million years ago were between 25 ˚C and 30˚C.

Use the graph to estimate mean annual precipitation in southern England during the Early Cretaceous.

Mean precipitation: __________________________________

Altitude and latitude

Latitude and altitude can also influence $\delta\ ^{18}O$ ‰.

The graph assumes that Ricky's sample was originally formed at a latitude of ~30˚N of the equator and at an altitude close to sea-level.

What affect does increasing altitude have on $\delta\ ^{18}O$ ‰ of rainfall and why?

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Extension

The half-life of an isotope describes how long it takes for half of it to decay away.

- ^{14}C has a half-life of 5,730 ± 40 years and is used for dating historic artefacts.
- ^{238}U has a half-life of 4.47 billion years and ^{235}U has a half-life of 0.70 billion years. These isotopes are used to estimate the age of rocks.
- ^{18}O is considered stable.

Use these data to comment on why each of these isotopes is chosen for its use.

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