Heavy Water

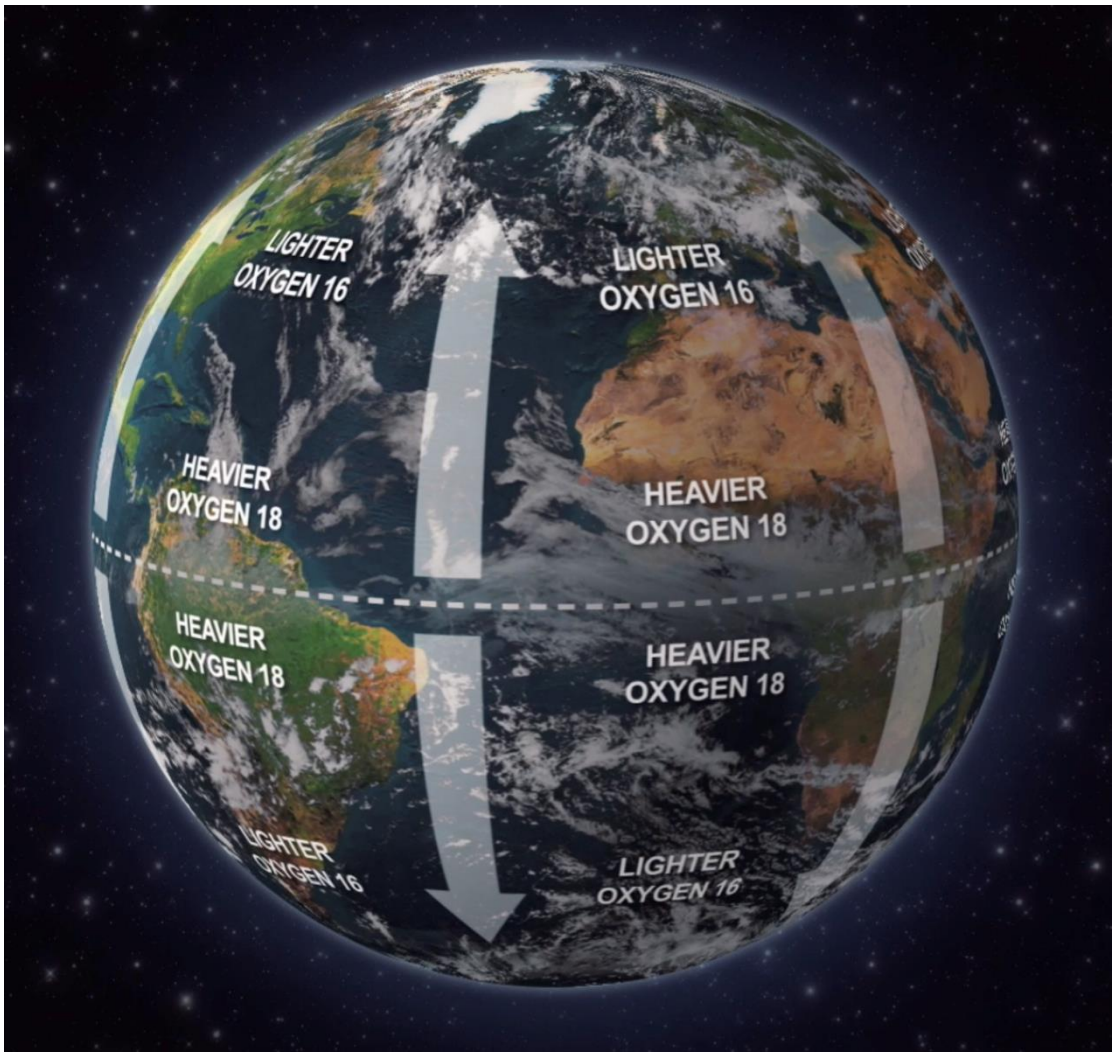
Suitable for UK KS3 or ages 11-14

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, back when dinosaurs roamed the earth. As rocks formed, they used oxygen from rain, preserving it and the isotopes it was made of. Water molecules containing oxygen-18 are heavier than those containing oxygen-16, and fall from the clouds more readily when it rains, leaving heavier isotopes of oxygen behind closer to the equator, and lighter isotopes closer to the poles.

In this lesson, students will learn about isotopes, subatomic particles and the structure of the atom, linking it to concepts of weight and density. They will calculate relative atomic mass, make comparisons between molecules, and build on their knowledge of the composition of the atmosphere, using it as an example of a mixture and comparing it to pure carbon dioxide. They will prepare carbon dioxide by mixing vinegar and bicarbonate of soda.



Learning Outcomes

Knowledge

- Learn about the structure of the atom and its subatomic particles.
- Consolidate knowledge of the composition of the atmosphere, and link it to the idea of mixtures and pure substances.
- Understand more about the differences between weight and density.
- Understand more about evaporation and condensation (collision theory and energy exchange).

Laboratory skills

- Develop an understanding of the scientific method through designing an experiment, repeating experiments.
- Evaluate risks.
- Ask questions, make predictions, and record observations and measurements.

Each student will need

- A copy of the student worksheet
- A calculator
- A balloon
- PPE, including goggles

Each pair will need

- 1 test tube
- 1 ruler
- 1 spoon
- Bicarbonate of soda
- Vinegar
- A balloon

A periodic table and access to a sink will be required for the class.

Lesson Activities

1. **Starter activity**
    - Watch the Oxford Sparks video, 'Using your science to reveal how much rain fell on the dinosaurs' (see web links).
    - On the worksheet, students match up the subatomic particles with their masses and charges.

2 **Worksheet activities: Isotopes**
    - Ask the class to read through the section headed **'Isotopes**, **Looking carefully**, **Heavy water'** and **'Our atmosphere'** on the provided worksheet, and answer the questions.
    - Each student will need a balloon for the last activity.

Answers are provided in the appendix

2. Main activity: Experiment

- The experiment is broken into 3 steps.
  In step 1, the class (working in pairs) experiment with bicarbonate of soda and vinegar to work out what mixing ratio is needed to create enough froth to fill their test tube but not bubble over.
  In step 2, they repeat this experiment, placing the bicarbonate of soda in a balloon and sealing the balloon over the top of the test tube so that it fills with almost pure carbon dioxide (and a little displaced air).
- The class will need the other practical equipment.
- At the start, invite the class to discuss their ideas and link their predictions to the work they have been covering in class, and the video.
- Ask the students to think carefully and critically about how to make the experiment safe.
- Invite the class to share their discoveries and talk about the experiments.
- To complete this activity, ensure the students have filled in their worksheets and read the final passages.

3. Plenary

- Ask 'why do things evaporate?'. Discuss the students' experiences of evaporation occurring at a faster rate at higher temperatures – why is this?

  *Introduce the concept of **average energy**, and that as molecules bump they **exchange energy**, so some have more than others at any given time. A molecule with enough energy can "escape" or evaporate.*

To demo this, ask the class to move around and "bump" – giving OR receiving a small item such as a rubber or post-it note when they meet another student. At the end, most students will have as many rubbers as they started with, some will have more and some will have fewer. To escape the surface of the ocean (that is to say evaporate) a molecule needs to have a speed (related to its individual energy) above a certain value. Below water's boiling point only some of the molecules will attain this speed.

Optional extension relating this to kinetic energy: Given the idea that individual water molecules in a beaker (or an ocean) have a range of energies, get the students to think about what sort of energy this is and the appropriate equation:

Answer: kinetic energy = 0.5 x mass x (speed)^2

Discuss how the speeds of oxygen-16 containing versus an oxygen-18 containing water molecules would compare for the same kinetic energy. Hence discuss which water molecules are more likely to evaporate.

- Ask the students to review what they have learnt and consider how rain falls in different amounts and different types across the world. Look at the diagram of the world from the video. You may wish to provide them with a blank map and ask them to shade in the gradient of heavy oxygen rainfall away from the equator.

4. Extension

- Ask the class to read the extension activity and discuss how the half-life of isotopes affects its usefulness.
    - *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.*

5. Optional Homework: Lab report

- Ask the class to write up a lab report on the oil experiment they performed. A good quality lab report should include:
    - An introduction, explaining what they wanted to find out and making a prediction.
    - 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

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/.

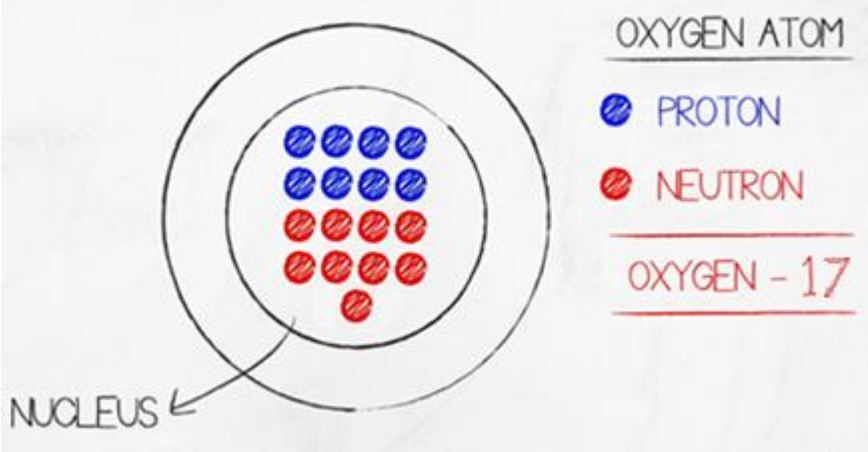
Appendix. Answers to questions

Starter activity

Particle	*Charge*	*Mass*
Proton	*+1*	*1 g per mole*
Neutron	*0*	*1 g per mole*
Electron	*-1*	*tiny*

Worksheet activities: Isotopes

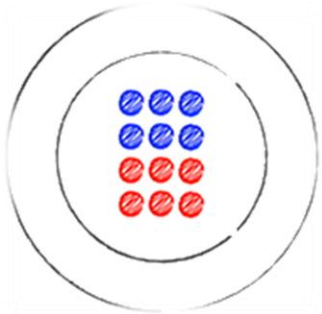
Draw and name the isotope:



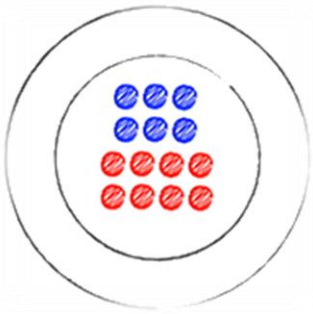
How many atoms in every 10,000 oxygen atoms are oxygen-16? 10,000 - 20 - 4= 9976

Average atomic mass of a randomly selected oxygen atom: 16.0044

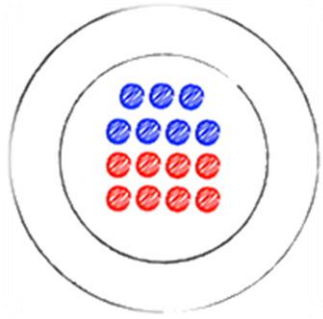
Worksheet activities: Looking carefully



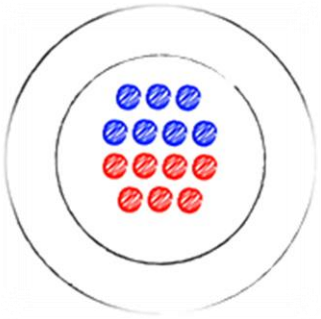
carbon-12



carbon-14

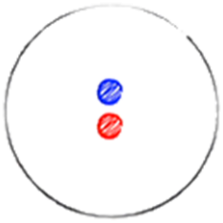


nitrogen-15



nitrogen-14

hydrogen-1



hydrogen-2 (or deuterium)

Worksheet activities: Heavy water

True or false? True

Density calculation. Density = mass/volume

Molecule	***Atoms***	***Mass***
Carbon dioxide	*3*	*44*
Nitrogen	*2*	*28*
Oxygen	*2*	*32*
Water	*3*	*18*

Worksheet activities: Our atmosphere

Gas	Inhaled air	Exhaled air
Nitrogen	78.1%	78.1%
Oxygen	**20.9%**	16%
Water vapour	0-3%	> inhaled air
Carbon dioxide	0.03%	**4.0%**
Noble gases	**0.94%**	0.94%

Heavier or lighter? Heavier