



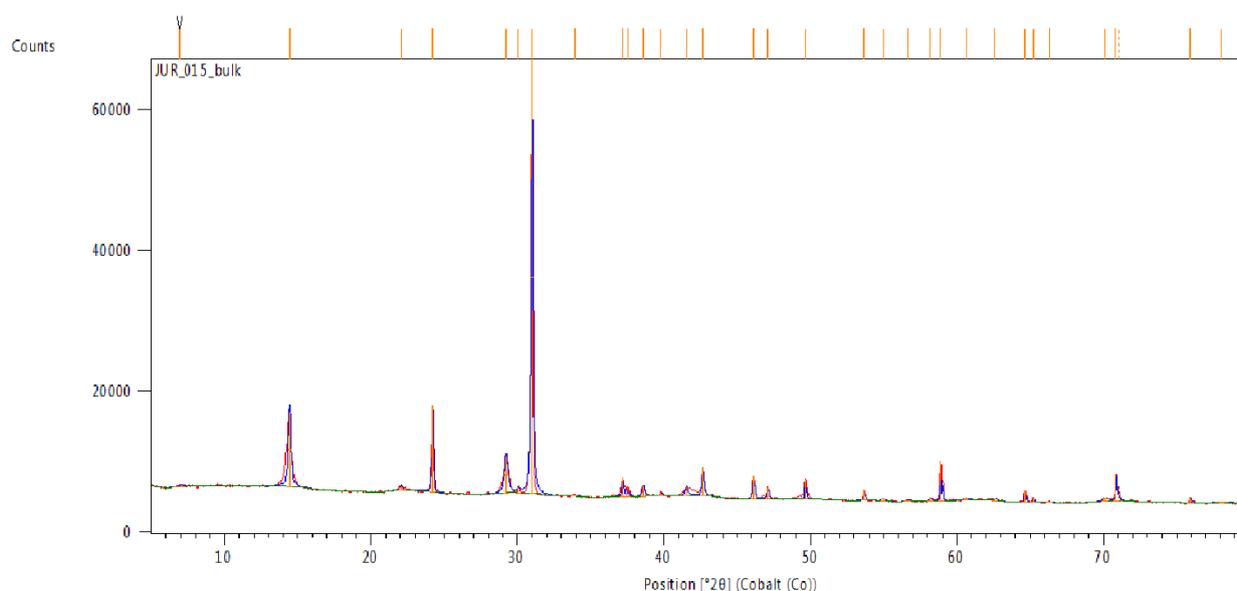
Key Stage 5 – Fingerprinting First Life

Notes for teachers

At a glance

This lesson is inspired by research at Oxford University into Australian mudstone fifteen times older than the dinosaurs. Traces of oxygen, nutrients, and early life in the mudstone have helped entirely reshape our picture of evolution and how the Earth developed. One of the most chemically, biologically and tectonically interesting eras in Earth history is the Neoproterozoic era. Fossils from this time show the first multicellular life forms, and mineral morphologies suggest that microbes existed that respired and deposited iron and other inorganic materials.

In this lesson, students will be exploring x-ray diffraction, the analytical technique used by scientists to explore the underlying atomic structures of minerals, isotopic dating, and using microscopes to image microstructure.



Learning Outcomes

- Students will link structure and bonding covered in the chemistry specifications to the physical shapes of crystal structures, and enhance microscope skills.
- Students will learn about the inverse relationship between the structural arrangements of atoms in space and the diffraction pattern produced by constructive and destructive interference of electromagnetic waves.
- Students will learn about radioactive isotopic decay and perform calculations.
- Students will develop an understanding of how chemistry, biology, geology and physics are linked in practical scientific investigations.



Each student will need

- A copy of the student worksheet
- Access to a microscope
- Access to a range of minerals in crystal form (suggestions: quartz, pyrite, selenite, pyroxene, micas, calcite)
- A piece of gauzy fabric, e.g. chiffon – or a range of fabrics, if possible
- Access to a monochromatic laser pen

Possible Lesson Activities

1. Starter activity

- Write the key words below up on the board and ask them to guess their meanings, write down their guesses, then research them to compare. They will need to use the internet to do research.

Key words: biogeochemistry, biomineralisation, geochronology, chemostratigraphy

- Challenge the class to research and match the eras on the **era matching sheet** to what was happening on Earth at that time, and place the eras in the correct chronological order (answers in [appendix 1](#)). They will need to use the internet to do research.

2. Main activity: Through the Lens

- Ask the class to read through **Structures and Bonding** on the provided worksheet.
- Hand out minerals, and ask the class to use a microscope or magnifying lens to examine the structures of at least three and complete the **Through the Lens** activity.

3. Main activity: Interference

- Ask the class to read through **X-ray Supermicroscope** on the provided worksheet and complete the **Interference** activity.
- Provide the class with laser pens and safety briefing (see [appendix 2](#)). Allow them to explore the **Diffraction Patterns** activity by shining the light through a piece of gauzy fabric. If available, offer wider and narrower weave fabrics for them to experiment with (examples in [appendix 3](#)).

When the weave is very wide compared to the wavelength of the light (or so big that it's just a whole), the class will see just one laser beam, and no diffraction pattern, whilst a very narrow weave fabric will give a more spaced out pattern. They can also see this effect by changing the wavelength of light (using different coloured laser pens) and recalling the electromagnetic spectrum.

- Check that the class have understood that an inverse relationship exists between the spacing of the atoms and the spacing of the diffraction pattern – this is how the diffraction pattern can act as a structural fingerprint.

4. Main activity: X-ray Fingerprinting

- Ask the class to read through **Fingerprinting Early Life** on the provided worksheet.
- Provide the class with the reference spectra and sample spectra from the Neoproterozoic era, and explain that these are one-dimensional diffraction patterns.
- Provide the class with the reference spectra and sample spectra from the Mars Rover and challenge them to identify evidence of early life. They may wish to work in groups.



The reference spectra show the patterns you would expect to see if that mineral is present.

The real spectra show a mixture of minerals in Neoproterozoic mudstone samples.

*By comparing where the peaks are in the Neoproterozoic spectra and sample spectra, the students can decide which they think may be present. The intensities of peaks can vary because of **moisture** and the amounts of some minerals present may be **higher** than others. There may also be non-crystalline (amorphous) things present, which do not give peaks but can raise the baseline of the spectra. If the students think hydroxyapatite mineral is present, this could indicate evidence of early life. A good way to see whether the patterns overlay is to hold up a Neoproterozoic spectrum overlaid with a reference spectrum against the window to let the light shine through.*

- Show the animation. 'Ancient Mysteries in Marvellous Mud' (see weblinks).
- Extension: ask the class to read **Radioactive Isotopic Dating** and attempt the calculation (answers in **appendix 4**).

5. Plenary

- Return the class' attention to the key words on the board.
- Ask them to discuss why living things might make minerals in certain morphologies. You can leave them with this thought to take away from the lesson.

Web links

Oxford Sparks 'Ancient Mysteries in Marvellous Mud' animation:

<https://www.oxfordsparks.ox.ac.uk/content/ancient-mysteries-marvellous-mud>

Iron-respiring bacteria:

<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC123774/> (open source)

<https://pubs.acs.org/doi/abs/10.1021/es990021x> (not open source)

Laser pens (see **appendix 2** for safety guidelines):

Here is a trusted site: <http://skylineselect.co.uk/>

And here are some others that are <1 mW and a little cheaper

[https://www.aliexpress.com/item/Powerful-Red-Purple-Light-Laser-Pointer-Pen-5mW-650NM-Burning-Match-Visible-](https://www.aliexpress.com/item/Powerful-Red-Purple-Light-Laser-Pointer-Pen-5mW-650NM-Burning-Match-Visible-Beam/32853138519.html?ws_ab_test=searchweb0_0,searchweb201602_5_10152_10065_5722813_10151_10344_10068_10130_10324_10342_5722613_10547_10325_10343_5722913_10340_10548_10341_10696_10192_10190_10084_10083_5722713_10618_10307_10820_10301_10821_10303_10059_100031_10103_10624_10623_10622_10621_10620_5722513,searchweb201603_25,ppcSwitch_5&algo_expid=650d75ca-22b1-461f-bec9-3a3f55fffc2-11&algo_pvid=650d75ca-22b1-461f-bec9-3a3f55fffc2&transAbTest=ae803_2&priceBeautifyAB=0)

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and

[https://www.aliexpress.com/item/Powerful-SD-Laser303-Adjustable-Focus-532nm-Green-Laser-Pointer-Light-Output-power-less-than-1mw-](https://www.aliexpress.com/item/Powerful-SD-Laser303-Adjustable-Focus-532nm-Green-Laser-Pointer-Light-Output-power-less-than-1mw-no/32828030238.html?ws_ab_test=searchweb0_0,searchweb201602_5_10152_10065_5722813_10151_10344_10068_10130_10324_10342_5722613_10547_10325_10343_5722913_10340_10548_10341_10696_10192_10190_10084_10083_5722713_10618_10307_10820_10301_10821_10303_10059_100031_10103_10624_10623_10622_10621_10620_5722513,searchweb201603_25,ppcSwitch_5&algo_expid=650d75ca-22b1-461f-bec9-3a3f55fffc2-11&algo_pvid=650d75ca-22b1-461f-bec9-3a3f55fffc2&transAbTest=ae803_2&priceBeautifyAB=0)

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<https://www.oxfordsparks.ox.ac.uk/content/ancient-mysteries-marvellous-mud>



[a-22b1-461f-bec9-3a3f55fffc2-20&algo_pvid=650d75ca-22b1-461f-bec9-3a3f55fffc2&transAbTest=ae803_2&priceBeautifyAB=0](https://www.oxfordsparks.ox.ac.uk/content/ancient-mysteries-marvellous-mud)

Appendix 1. Answers to era-matching

Cenozoic 66 million years ago-now

- Himalyas form
- Large mammals evolve
- South America attaches to North America

Mesozoic 252-66 million years ago

- Pangaea breaks up
- Dinosaur populations boom, then big dinosaurs become extinct
- Temperatures are high and sea levels low

Paeleozoic 541-252 million years ago

- Cambrian explosion – the evolution of fish, amphibians and land animals
- Coal beds are formed
- Supercontinent Pangaea forms

Neoproterozoic 1000-541 million years ago

- Earliest fossils of multicellular life
- Rodinia breaks up
- In a “snowball Earth” ice sheets reach the equator

Mesoproterozoic 1600-1000 million years ago

- Supercontinent Rodinia forms
- Sexual reproduction evolves
- Nuna supercontinent breaks up

Paeleoproterozoic 2500-1600 million years ago

- Nuna supercontinent forms
- Great Oxygenation event occurs – increasing the Earth’s oxygen
- Eukaryotic life evolves

Neoarchean 2800-2500 million years ago

- Photosynthesis evolves
- Supercontinent Kenorland forms and breaks up
- Earth begins to cool

Mesoarchean 3200-2800 million years ago

- Supercontinent Vaalbara starts to break up
- Earliest reefs form
- Atmospheric carbon dioxide reaches pre-industrial levels

Paeleoarchean 3600-3200 million years ago

- Supercontinent Vaalbara forms
- A large asteroid collides with Africa
- Earliest fossilised bacteria

Eoarchean 4000-3600 million years ago

- Believed to be the era in which the first life evolved
- High pressure no-oxygen atmosphere
- Earth’s crust develops



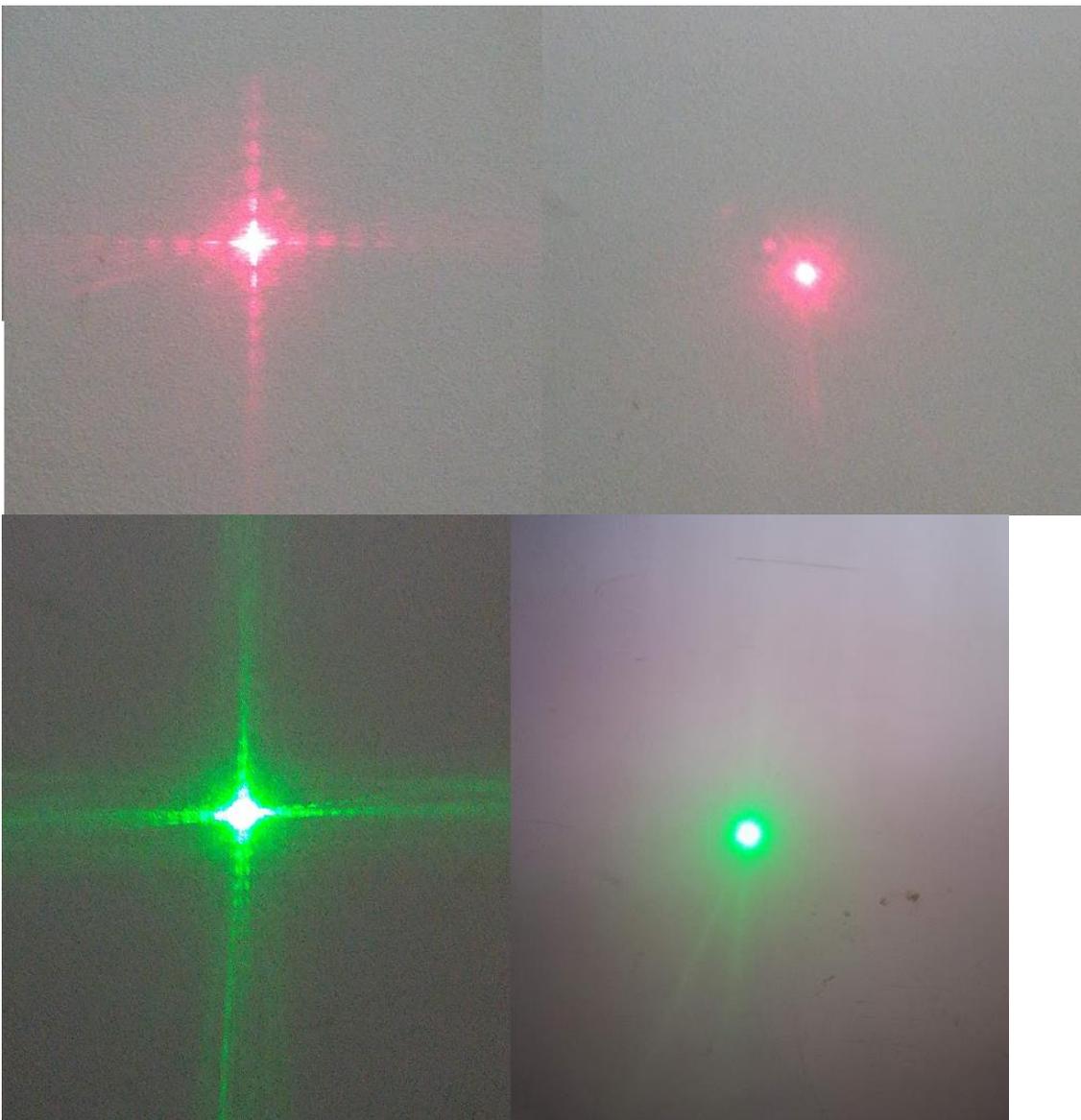
Appendix 2. Laser pen safety

Laser Pen Health and Safety – according to Public Health England (PHE) guidelines

- Laser pointers in the UK have special requirements to be legal under Health and Safety legislation , for a General public presentation use type laser, the requirements are Class 2 , less than one Milliwatt (1 mW) in Power and must have a "momentary switch". The laser classification scheme was introduced over 40 years ago to provide guidance to users of lasers. The laser classification scheme in this document is taken from BS EN 60825-1.
- Buy laser pens from the UK and with a maximum power output of 1 miliwatt (mW). In the UK, the threshold for toy laser pointers is lower, at 0.39 mW.
- Educate children about the dangers of lasers and consequences if they misuse them: in particular, holding them against skin or pointing them at eyes.

Public Health England, publichealth@rospa.com

Appendix 3. Laser pen diffraction patterns





Appendix 4. Answers to isotopic dating

1. $T_{1/2} = 4.16 \times 10^{10}$ years.
2. $t = 785$ million years.
3. None would remain

Appendix 5. Answers to Fingerprinting Early Life

Sample 1 contains no apatite, **Sample 3** contains 1% apatite, and **Sample 2** contains 10% apatite (10% is at the high end of the spectrum of natural samples containing this mineral).