X-RAYS AND DNA – TEACHER NOTES AND HANDY HINTS

This resource is designed to provide an insight into X-ray crystallography, the technique used by Maurice Wilkins and Rosalind Franklin to study DNA. James Watson and Francis Crick discovered the structure of DNA using data obtained from X-ray images of DNA. The activity combines individual tasks and group discussion and will take approximately two hours to complete, but may be extended or reduced depending on the amount of time and resources available and the nature of the students. The activity could also be entirely non-practical, with the teacher leading a discussion and encouraging participation from the students. It is assumed that the students are aware of the discovery of the structure of DNA, and it is recommended that a brief review of the story is given as an introduction to this resource.

Activity 1 is based on experiments described in Hammond, C. (1992) *Introduction to crystallography* (revised edition), Royal Microscopy Society **Microscopy Handbooks 19**, p80-83, Oxford University Press, Oxford, UK.

Activity 2 is based on an experiment described in Marshall, R. and Nott, M. (2004) An optical analogue demonstration of X-ray diffraction of DNA using a DIY diffraction grating, *School Science Review*, **85** (312), 18-19.

Activity sheet – aims and benefits

The aim of this activity is to provide an insight into X-ray crystallography, the technique used by Maurice Wilkins and Rosalind Franklin to study DNA. The results of their work provided key clues about the size and shape of DNA, which were used by James Watson and Francis Crick to discover the structure of DNA at the Cavendish Laboratory in Cambridge in 1953. The resource can be used to introduce key information such as the electromagnetic spectrum, or to extend study to diffraction and X-ray crystallography. The activity encourages students to:

a) make careful observations.
b) investigate independent variables.
c) present and discuss their results.
d) consider careful set up of experimental apparatus.
e) consider practical applications of abstract ideas.

Throughout the activity the teacher should emphasise that the discovery of the structure of DNA was based on manual model building as well as the interpretation of X-ray images. It should also be made clear that careful measurements and calculations were necessary to make the discovery possible. In his first attempt to explain Rosalind Franklin's interpretation of the X-ray images to Francis Crick, James Watson got the amount of water in DNA wrong by a factor of ten. This basic mistake led James Watson and Francis Crick to make a highly inaccurate model. It was embarrassing for both them and the head of the Cavendish Laboratory, William Lawrence Bragg, when Rosalind Franklin and Maurice Wilkins pointed out their mistakes!

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Hints

1. You will need to provide the students with a diagram of the electromagnetic spectrum. The electromagnetic spectrum and applications of different wavelengths may be introduced in a separate lesson. To simplify the introduction of the electromagnetic spectrum use a diagram that illustrates common applications of different wavelengths. You could also give an example for the first entry in the table, e.g. microwave, used for cooking.
2. Nylon net curtain material is an effective fabric to use as a grating in activity 1 because the nylon threads that make up each of the strands are tightly twisted giving sharply defined transparent/opaque boundaries and clear spaces between the strands that are similar in width to the strands. Extend the activity by repeating the experiment with a different grating (e.g. a piece of a different fabric with an open weave).
3. Extend the activity by asking the students to measure and record the dimensions of the experimental apparatus, and any changes they make (e.g. the angle of rotation of the grating and the degree of shearing of the grating). This information may then be used for a quantitative analysis of the results and as a basis for the group discussion (activity 3).
4. The group discussion of the results from activity 1 may form a separate lesson, or the basis of a single independent non-practical lesson. Differences in results may be caused by:
    - the use of different gratings (e.g. different fabrics or fabric patterns)
    - different interpretations of a 'point source' of light
    - differences in the angle of rotation of the grating
    - differences in the amount of shearing of the grating
5. The angle between the two sides of the "X"-shaped diffraction pattern produced in activity 2 is the pitch angle of the bolt threads, and is analogous with the twist repeat of DNA. Different bolt threads will give different angles between the two sides of the "X"-shape.
6. The "X"-shape can also be produced by illuminating the edge of a single bolt, resulting from edge diffraction of a zigzag, rather than diffraction by a zigzag slit as described in the activity sheets.
7. Extend the activity by discussing why crystals diffract X-rays but do not diffract other wavelengths. Ask the students to suggest suitable gratings for the diffraction of electromagnetic radiation of different wavelengths, and design experiments to test their ideas. Then ask the students to try and reproduce an "X"-shaped diffraction pattern with their newly designed experimental apparatus, and remind them of the analogy with the DNA double helix.

X-RAYS AND DNA – STUDENT NOTES

Maurice Wilkins and Rosalind Franklin used X-ray crystallography to study DNA, and their work provided key clues to the size and shape of the DNA molecule. The results of their work were used by James Watson and Francis Crick to construct an accurate model of the structure of DNA at the Cavendish Laboratory in Cambridge in 1953.

What are X-rays?

X-rays, like visible light, are a form of electromagnetic radiation. All electromagnetic radiation can be thought of as waves. There is a whole range of different kinds of electromagnetic radiation that have different wavelengths and correspondingly different energies, which forms the electromagnetic spectrum. Electromagnetic radiation with shorter wavelengths has higher energy, and that with longer wavelengths has lower energy.

Question 1: Look at the diagram of the electromagnetic spectrum provided by your teacher. List two types of electromagnetic radiation and ways in which they are used in everyday life.

Types of electromagnetic radiation	**Everyday uses of electromagnetic radiation**
1.	1.
2.	2.

What is X-ray crystallography?

X-ray crystallography is the use of X-rays to study crystalline materials. X-ray crystallography was invented by William Lawrence Bragg when he was a research student at the Cavendish Laboratory. He realized that it was possible to figure out where the atoms are in a crystal from the way X-rays are diffracted by the crystal. He suggested that the angle of diffraction is dependent on the separation between sheets of atoms known as ‘Bragg planes’. He tested his idea by doing experiments using X-rays on lots of different crystals with his father, William Henry Bragg. William Lawrence Bragg used the results of these experiments to define Bragg’s law. William Lawrence Bragg and William Henry Bragg shared the Nobel Prize in Physics in 1915 for this work.

What is diffraction?

Electromagnetic radiation is diffracted when it interacts with a regular structure that has a repeat distance that is about the same as the wavelength of the electromagnetic radiation. This phenomenon is common in the natural world, and occurs across the full range of wavelengths. For example, visible light can be diffracted by a ‘grating’ that has lines spaced about a few thousand angstroms ($\sim 10^{-6}$ m) apart, such as a net curtain.

X-rays have wavelengths of about a few angstroms ($\sim 10^{-9}$ m), which is the same as typical distances between atoms in crystalline solids. This means that X-rays can be diffracted from crystals which have regularly repeating atomic structures.

X-RAYS AND DNA – ACTIVITY SHEET

In these activities you will investigate the diffraction of visible light through a grating to produce diffraction patterns. This activity is similar to the X-ray crystallography techniques used by Rosalind Franklin and Maurice Wilkins to study DNA. Their work using the X-ray diffraction technique provided key clues about the size and shape of DNA, which were used by James Watson and Francis Crick when they discovered the structure of DNA at the Cavendish Laboratory in Cambridge in 1953.

Activity 1: Introduction to diffraction

This activity is based on experiments described in Hammond, C. (1992) *Introduction to crystallography* (revised edition), Royal Microscopy Society **Microscopy Handbooks 19**, p80-83, Oxford University Press, Oxford, UK.

Apparatus

Grating (e.g. piece of net curtain, $20cm^2$)
Lamp
Card screen with pinhole
Display screen or wall

Procedure

1. Place the lamp about 5m from the display screen or wall.
2. Switch on the lamp.
3. Place the card screen with pinhole in between the lamp and the display screen or wall (about 10cm away from the lamp) to create a point source of light.
4. Place the grating (e.g. piece of net curtain) in between the point source of light and the display screen or wall, parallel to the card screen with pinhole.

The point source of light is diffracted by the grating. The image of the point source on the display screen or wall is repeated to form a grid of diffraction spots.

Question 1: What can you see on the display screen or wall?..

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Question 2: Draw a diagram of the pattern you can see on the display screen or wall in box A.

5. Move the grating further away from the point source of light.

The diffraction pattern is not changed by moving the grating closer to or further away from the point source of light. The size of the pattern is independent of the position of the grating.

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Question 3: What can you now see on the display screen or wall? Has the pattern changed? ………………………………………………………………………………………………

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Question 4: Draw a diagram of the pattern you can now see on the display screen or wall in box B.

6. Rotate the grating about a vertical axis so that it is no longer parallel to the card screen with pinhole (by about 30 degrees).

Rotating the grating about a vertical axis makes the effective spacing between the lines in the grating smaller. This finer spacing of the diffraction grating lines will make the diffraction spots more widely spaced out.

Question 5: What can you now see on the display screen or wall? Has the pattern changed? ………………………………………………………………………………………………

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Question 6: Draw a diagram of the pattern you can see on the display screen or wall in box C.

7. Return the grating to its previous position (parallel to the card screen with pinhole). Shear the grating by moving one side of it upwards by about 2cm and the other side downwards by about 2cm.

Before the grating is sheared, the angle between the vertical and horizontal grating lines is 90 degrees. After shearing, the angles between the two sets of grating lines are no longer 90 degrees. The rows of diffraction spots are rotated so that they are in directions perpendicular to the lines of the grating.

Question 7: What can you now see on the display screen or wall? Has the pattern changed? ……………………………………………………………………………………………

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Question 8: Draw a diagram of the pattern you can see on the display screen or wall in box D.

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Activity 2: Advanced diffraction

This activity is based on an experiment described in Marshall, R. and Nott, M. (2004) An optical analogue demonstration of X-ray diffraction of DNA using a DIY diffraction grating, *School Science Review*, **85** (312), 18-19.

Apparatus

Grating (e.g. two 24BA bolts)
LASER light
Display screen or wall

Procedure

1. Fix the two bolts to a surface so that the two threads are "in step", with a small gap between them, producing a "zigzag" slit that will act as a grating.

2. Shine the LASER light through the grating (zigzag slit) so that a diffraction pattern appears on the display screen or wall.

A standard diffraction grating with its slits vertical will give a horizontal diffraction pattern. A standard diffraction grating with its slits horizontal will give a vertical diffraction pattern. Shining the LASER light through the zigzag grating produces an "X"-shaped diffraction pattern. In this case, the "X"-shape is produced because the "zigs" give one side of the "X" and the "zags" give the other side of the "X". The angle between the two sides of the "X" is the pitch angle of the bolt threads. The "X"-shape produced by the diffraction of the LASER light by the zigzag grating is similar to the "X"-shape produced by the diffraction of X-rays by the DNA double helix.

Question 9: What can you see on the display screen or wall? ………………………………

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Question 10: Draw a diagram of the pattern you can see on the display screen or wall in box E.

Activity 3: Group discussion

Question 11: Compare your results from activity 1 with those of other people in your class. Did you get the same results? Explain your answer. ....

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X-RAYS AND DNA – ACTIVITY SHEET

Box A	Box B
Box C	Box D
Box E	Notes