

5. MODELLING X-RAY DIFFRACTION

This material has been developed as part of the Australia School Innovation in Science, Technology and Mathematics Project funded by the Australian Government Department of Education, Science and Training as part of the Boosting Innovation in Science, Technology and Mathematics Teaching (BISTMT) Programme.

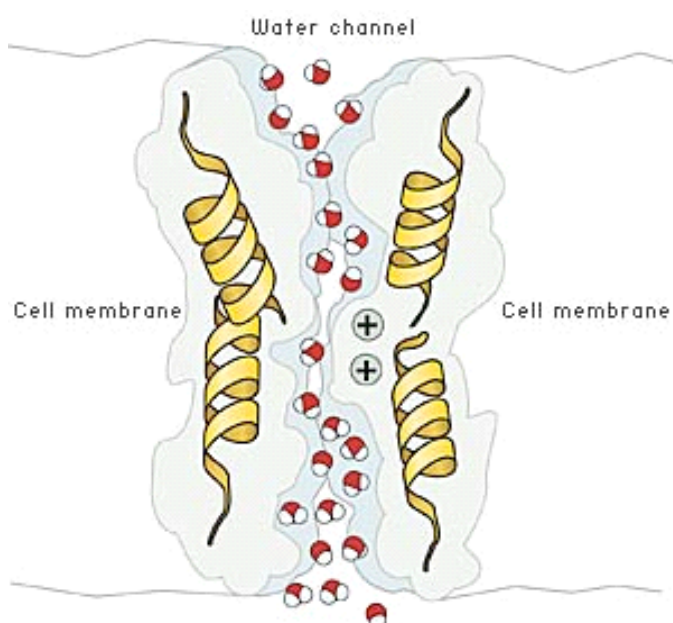
Synchrotron Investigations

5.1 Modelling X-ray diffraction in the classroom

Background

Waves such as water waves, sound waves or electromagnetic waves often bend or pass around objects; this bending is known as diffraction. The degree of diffraction depends on the size of the object, and the wavelength of the wave. When an object is very small, such as an atom or a molecule, very small wavelength waves, such as X-rays, are required to observe diffraction effects. X-ray diffraction 'patterns' can be used to determine the arrangement of atoms and molecules in a material.

One of the most useful features of a synchrotron is that it produces very bright X-rays that have well defined wavelengths. These X-rays are useful for examining the diffraction patterns from various materials.



The 2003 Nobel Prize in chemistry was awarded to Peter Agre and Roderick MacKinnon who used the X-rays from a synchrotron to help determine the structure of 'water channels' in cells. These channels allow water to flow through cell membranes.

Structure of a water channel in a cell membrane

Image courtesy: Australian Synchrotron, State of Victoria

Biophysicists from the University of Western Australia, use X-rays from a synchrotron to determine the amount of iron deposited in living cells that are affected by a condition known as 'iron overload' disease or haemochromatosis.

In this experiment your students will use laser light (instead of X-rays) to determine the structure of a very fine mesh (Experiment 1) and then the width of a fine hair (or wire, or gap in Experiment 2). The principles used are very similar to the methods employed in cutting-edge research at synchrotron facilities around the world.

There is a video available demonstrating a similar experiment as that outlined in this section.

Teachers, please note, for information on the maths relating to this please see section 7.2.

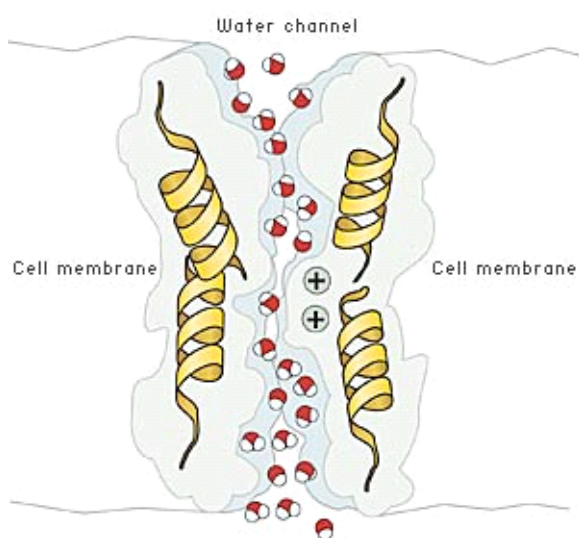
Synchrotron Investigations

5.2 Modelling X-ray diffraction in the classroom

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Experiment 1 – determining the structure of fine mesh

Safety precautions

NEVER look directly at a laser light.

NEVER shine a laser light in another person's eye.

Ensure that laser reflections do not enter anyone's eye.

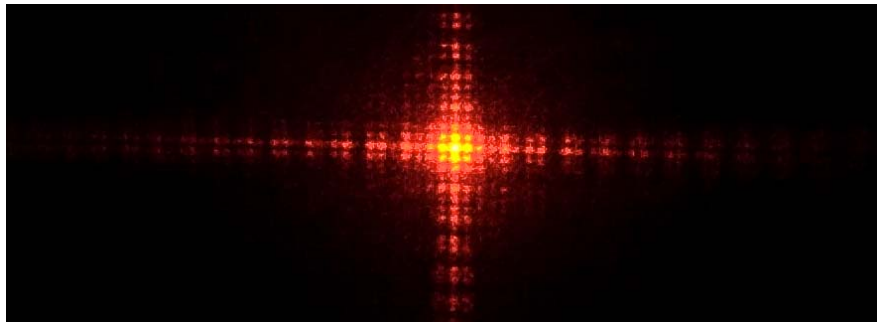
Ensure that you only use 'Class 1' or 'Class 2' lasers (this should be written on the laser).

Materials

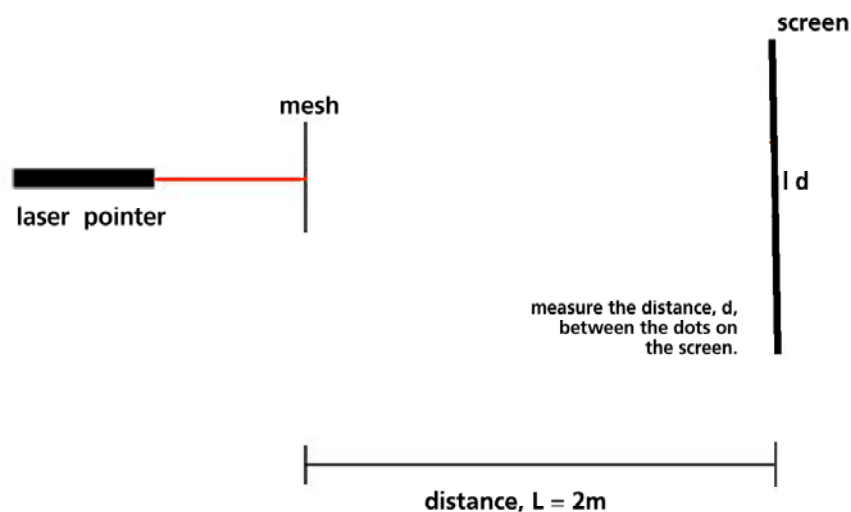
- a laser pointer
- two different samples of fine wire mesh. Ensure grid spaces are different. Preferable grid spacing for both the fine mesh and coarse mesh should be less than 0.5 mm (stockings work well)
- a ruler
- a screen, wall or whiteboard

Aim

To determine the grid spacing of very fine mesh with the aid of a diffraction pattern, similar to the one shown below.



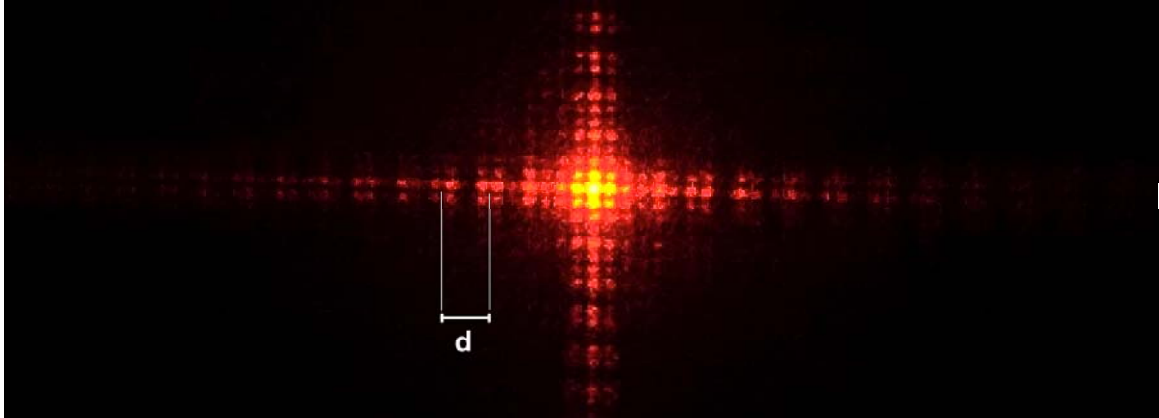
Method



1. Set up the equipment as shown in the diagram using the coarse mesh (that is the mesh that has the largest grid spacing). The distance L between the mesh and the screen should be around 2 m.

2. Measure the distance between the dots on the screen (see white line on diagram below). Call this distance d_1 .

$d_1 =$ _____ (for coarse mesh)

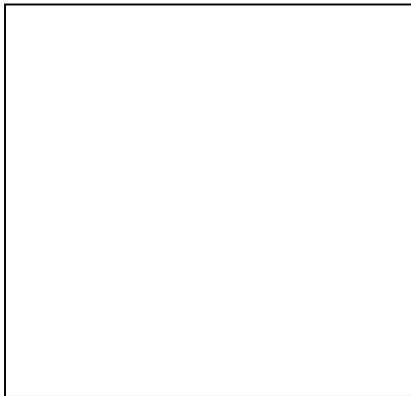


3. Repeat the process using fine mesh (The smallest grid spacing) and measure the distance between the dots on the screen. This distance is d_2

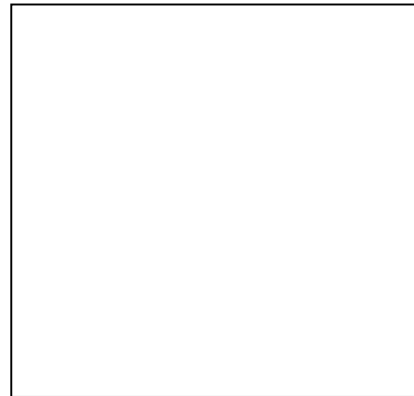
$d_2 =$ _____ (for fine mesh)

4. Draw a scaled diagram of the diffraction pattern you observe on the screen in each case (1 cm = 1 cm).

Coarse mesh



Fine mesh



Analysing the results

5. Which mesh (fine or coarse) produced the diffraction pattern with the largest spacing between the dots?

6. The equation that relates the distance between the dots (d) the wavelength of the laser light (λ), the length (L) and the grid spacing of the mesh (w) is: $w = \frac{\lambda L}{d}$. For a red laser the wavelength (λ) is approximately 6.5×10^{-7} m
 - a) Using your answer from *Question 2*, calculate the grid spacing between the wires in the coarse mesh using the above equation.

 - b) Using your answer from *Question 3*, calculate the grid spacing between the wires in the fine mesh using the above equation.

Checking your results

Now you will attempt to measure the spacing of the grids in the fine and coarse mesh using a ruler.

Coarse mesh results

7. Using your ruler count the number of grid spacings in the coarse mesh within a distance of 1 cm.

8. Using your answer in *Question 7*, calculate the distance for one grid space of the coarse mesh and express your answer in metres.

9. How do your answers in **6a)** and **8** compare?

Fine mesh results

10. Using your ruler count the number of grid spacings in the fine mesh within a distance of 1 cm.

c) Using your answer in **10**, calculate the distance for one grid space of the fine mesh and express your answer in metres.

d) How do your answers in **6b)** and **10a)** compare?

11. What would you expect to happen to the distance between the dots in the diffraction pattern if a finer mesh with a smaller grid spacing (d) was used? Explain the reason for your answer.

Did you know?

Similar diffraction techniques can be used with the very short wavelength X-rays from a synchrotron to determine the size and structure of atoms and molecules.

The discovery of the double helix structure of DNA molecules used X-ray diffraction techniques.

Experiment 2 – determining the width of a hair using diffraction

Safety precautions

NEVER look directly at a laser light.

NEVER shine a laser light in another person's eye.

Ensure that laser reflections do not enter anyone's eye.

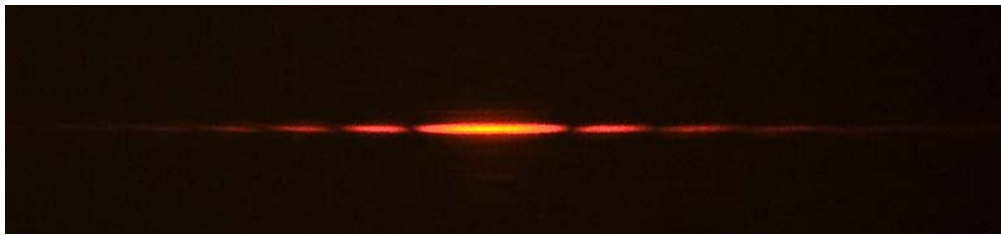
Ensure that you only use 'Class 1' or 'Class 2' lasers.

Materials

- a laser pointer
- a fine hair, or wire, or narrow slit (eg a single slit diffraction aperture)
- a ruler
- a screen, wall or whiteboard

Aim

To determine the width of a fine hair using the diffraction of laser light, similar to the one shown below.



Method

1. Set up the equipment as shown in the diagram and shine the laser light onto the fine hair. (arrows indicate dark areas from a single slit)

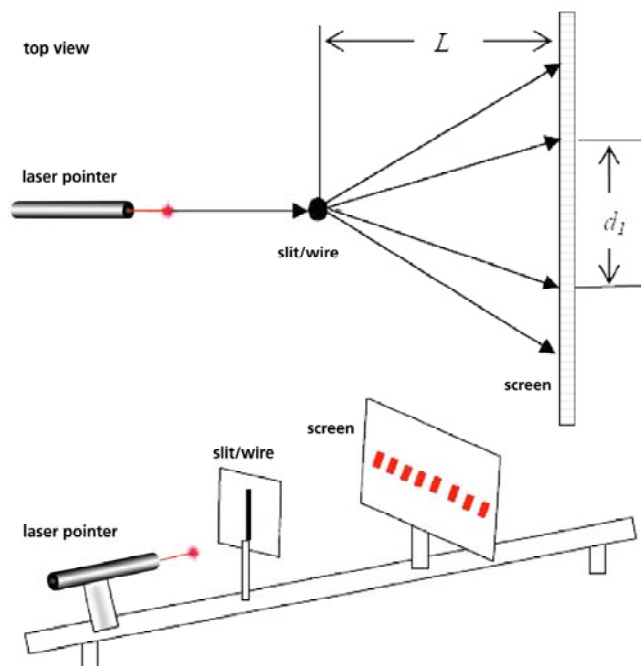


Image courtesy: DUIT Multimedia

2. Draw a scale image of what you see on the screen.

3. Note the central bright spot. Measure the distance (d_1) between the middle of the two dark regions on either side of the bright spot.

$$d_1 = \text{_____} \text{ m}$$

4. Calculate the width (w) of the hair (or slit if you have used a slit) using the equation

$$\text{Where: } w = \frac{2\lambda L}{d_1}$$

λ = wavelength = 6.5×10^{-7} m for red laser light

L = distance between hair and screen

d_1 = distance between dark spots on either side of the central bright spot (measure from the centre of the dark spots)

$$w = \text{_____} \text{ m}$$

5. Can you use the above equation to describe what would happen to the distance (d_1) between the dark spots if you used a thicker hair? Can you confirm your prediction by repeating the experiment using a thicker hair?

