

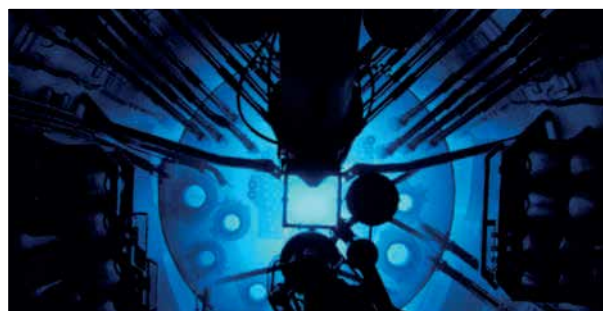


# Discoveries with light

A teacher resource on the Australian Synchrotron

Years 9–12  
Physics and  
Chemistry

**A super-size guide**  
on the science behind  
Australia's largest particle  
accelerator and the  
applications of  
Synchrotron science  
to society.



# INTRODUCTION TO THE GUIDE

The Australian Synchrotron Educational Resource, *Discoveries with Light*, targets Years 11–12 Physics and Chemistry, and Year 9–10 Physical Science and Chemical Sciences.



This guide covers concepts such as interaction of light and energy, nuclear physics, and radioactivity through the workings and applications of the Australian Synchrotron.

The Australian Synchrotron, located at the heart of Melbourne's south-east innovation precinct, is one of the southern hemisphere's most significant pieces of scientific infrastructure. A world-class research facility, it produces a powerful source of light – X-rays and infrared radiation – a million times brighter than the sun.

This light is harnessed and channelled down 'beamlines', where the light is focused onto samples, empowering researchers from across academia and industry to understand the fundamental structure, composition and behaviour of materials on scales ranging from the atomic to the macroscopic.

The Australian Synchrotron provides clients with a level of detail and accuracy not possible using conventional laboratory-based equipment.

The Australian Synchrotron, which is owned and operated by the Australian Nuclear Science Technology Organisation (ANSTO), has more than 5000 researchers registered as users. In 2014-15 the Australian Synchrotron supported more than 4300 researcher visits and close to 1000 experiments. As of June 2015, the Australian Synchrotron had hosted more than 26,000 researcher visits since opening its doors in 2007.

## How to use the guide

The notes in this study guide offer both variety and flexibility of use for the differentiated classroom. You and your students can choose to use all or any of the five sections – although it is recommended to use them in sequence, along with all or a few of the activities within each section.

## THE 'FIVE Es' MODEL

This resource employs the 'Five Es' instructional model designed by Biological Sciences Curriculum Study, an educational research group in Colorado. It has been found to be extremely effective in engaging students in learning science and technology. It follows a constructivist or inquiry-based approach to learning, in which students build new ideas on top of the information they have acquired through previous experience.

Its components are:

### ENGAGE

Students are asked to make connections between past and present learning experiences and become fully engaged in the topic to be learned.

### EXPLORE

Students actively explore the concept or topic being taught. It is an informal process where the students should have fun manipulating ideas or equipment and discovering things about the topic.

### EXPLAIN

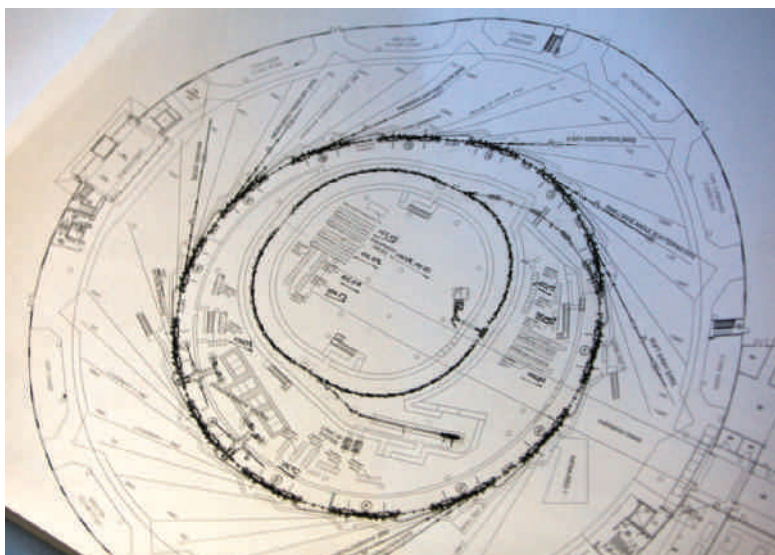
This is a more formal phase where the theory behind the concept is taught. Terms are defined and explanations are given about the models and theories.

### ELABORATE

Students have the opportunity to develop a deeper understanding of sections of the topic.

### EVALUATE

Both the teacher and the students evaluate what they have learned in each section.



A blueprint for the Australian Synchrotron, which opened in July 2007

Sections	Pages
<b>Background</b> A bright light Synchrotron development across the centuries	4 7
<b>Profiles</b> Beamline scientist Dr Danielle Martin	9
<b>Engage</b> What is a Synchrotron and what can it do?	10
<b>Explore</b> Teacher information Stations One to Ten	12 14–23
<b>Explain</b> Teacher's instructions Getting started Article One – The Australian Synchrotron: An illuminating tool Article Two – Beams and machines Article Three – Amazing discoveries Questioning Toolkit	24 25 26 32 38 42
<b>Elaborate</b> Learning Matrix Linked Activity One Linked Activity Two	43 46 49
<b>Evaluate</b> Crossword Creating your own Synchrotron quiz Individual unit review	52 54 55

**PUBLISHER**  
Karen Taylor

**HEAD OF CONTENT**  
Heather Catchpole

**PRODUCTION MANAGER**  
Heather Curry

**WRITERS**  
Sally Parker  
Phil Dooley  
Ewen Dobbin

**SUB-EDITOR**  
Bob Guntrip

**DESIGNERS**  
Alison Eaton, Suzanne Elworthy



This Australian Synchrotron Learning Resource is produced by Refraction Media for Australian Synchrotron.

© 2016 Australian Synchrotron, all rights reserved. No part of this publication may be reproduced in any manner or form for commercial purposes or outside of an educational setting. This guide was first published September 2016.

# A BRIGHT LIGHT

The Australian Synchrotron is one of Australia's largest science facilities, and it's all driven by electrons herded into tiny bunches and accelerated through intense magnetic fields to nearly the speed of light.



The Australian Synchrotron is situated Clayton, a suburb of Melbourne, Victoria

**T**he Australian Synchrotron generates a wide variety of light wavelengths. At its most intense, it can produce X-rays 10 trillion times brighter than a hospital X-ray. And by using this extraordinary array of light, scientists can peer into the heart of matter and unravel the atomic structure of complex molecules such as proteins, drugs, and a range of advanced materials. The Australian Synchrotron taps into many areas of science.

## ELECTRICITY AND MAGNETISM

Electrons are accelerated to extraordinary energy in the Synchrotron simply by generating a positive voltage, which attracts the negatively charged electrons according to the equation  $E = qV$ , where  $q$  is the charge (a constant) and  $V$  is the voltage applied.

But once the electrons begin circulating, supplying a fixed voltage is not enough. A high-frequency alternating voltage is used, synchronised with the circulating bunches of electrons. The electrons surf on the positive part of the voltage cycle, with the negative part of the cycle occurring between these bunches.

### ● Circular motion

Keeping the electrons on the circular path of the Synchrotron's storage ring is the task of strong magnetic fields. As the electrons pass through these fields, they experience a force at right angles to both their direction of travel and the magnetic field lines. (The magnitude of the force is  $F = qvB$ , where  $B$  is the magnitude of the magnetic field – its direction can be worked out with the right-hand push rule or Fleming's left-hand rule). Remember electrons are negatively charged!



A wide range of people utilise the facilities at the Australian Synchrotron from many different fields of research.

The force on the electrons generated by the magnetic fields changes their direction of travel – it does not slow them down or speed them up.

The continual change of direction guides the electrons along a circular path. The force at right angles to the path provides the centripetal force required for constant circular motion ( $F = mv^2/r$ , where  $m$  is the mass being acted upon,  $v$  is its velocity and  $r$  is the radius of the ring). Equating this with the magnetic force equation above gives a link between the speed of the electrons, the radius of the ring and the magnetic field.

### ● Relativity

By the time the electrons have been sped up to 3 billion electronvolts (3 GeV), they are travelling at well over 99.9999% of the speed of light. At such speeds special relativity comes into play. The main way this manifests is that the electron mass increases. As the electrons are given more energy, they do not get much faster, they instead become heavier.

Relativity is also responsible for the tight beam of radiation emitted from the Synchrotron. At low speeds radiation would spread widely, but a relativistic aberration, sometimes known as the headlight effect, means the radiation is mostly emitted in the forward direction of travel.

### ● Energy conservation

Conservation of energy means that as the electrons emit radiation, they slow down. This means that the bunches start to spread, and need to be refocused and sped up as well. The energy to speed them up is supplied through radio frequency radiation.

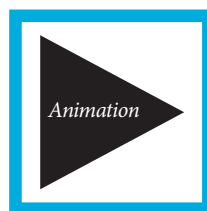
### ● Properties of light

The radiation (e.g. X-rays or infrared) travels in a straight line, as it is a form of light. To guide and focus it onto a target (e.g. a sample to be analysed) requires optical components such as mirrors and lenses. Like all light, it can be reflected, refracted and diffracted. But different parts of the spectrum interact with materials very differently. The glass optics used with visible light are useless in some other parts of the spectrum. For X-rays and infrared, different materials, such as ceramics, and special coatings, such as metals, are needed.

### ● Wave properties

Some beamlines can be used to analyse samples using X-ray diffraction – a basic property of all waves. In this technique, the sample is exposed to X-rays that are spread – diffracted – after contact with atoms in the sample.

What makes this powerful is the constructive and destructive interference between the waves diffracted by the different atoms. At certain diffraction angles the X-rays will be in phase, so a spot will appear. At other angles, the X-rays diffracted by different atoms will be out of phase and no spot will appear. A simple form of this is the double slit experiment, or the diffraction pattern created by laser light hitting a grating.



## ● Atomic structure

In contrast to the wave nature of diffraction, a number of the beamlines rely on the particle nature of X-ray light to do spectroscopy.

In spectroscopic beamlines X-ray photons interact with the electron shells of the atoms in the sample. A useful approximation of how the electron shells behave can be seen in the Bohr model of the atom.

The Bohr model suggests that the atom consists of a central nucleus which contains protons and neutrons, while the electrons orbit around the nucleus in what are known as shells, each with a specific amount of energy.

If the energy of an X-ray photon matches the energy difference between two shells it will be absorbed and make an electron jump into a higher energy shell. If the energy is too high, you knock an electron out of the atom altogether. This then leads to the fluorescence spectroscopy mentioned below. If the X-ray photon's energy is too high or too low, then it will pass through the atom without being absorbed. Scientists can then deduce which atoms are in the sample from the different energy photons that are absorbed – this is called absorption spectroscopy.

X-ray spectroscopy is unique because the photons have enough energy to interact with inner shell electrons in large atoms that are very tightly bound.

Absorption spectroscopy in the visible and ultraviolet interacts with outer electrons, because of their smaller differences between energy level. But when atoms form molecules, the outer electrons do the bonding, which changes the energy levels and makes it hard to tell what the atoms are. On the other hand, inner-shell electrons are not involved in bonding, so X-ray photons can tell you which atoms are in your complicated molecule.

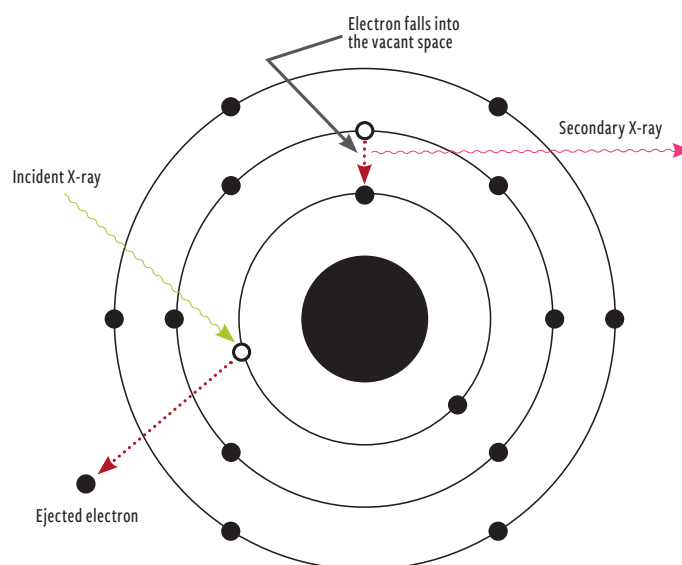
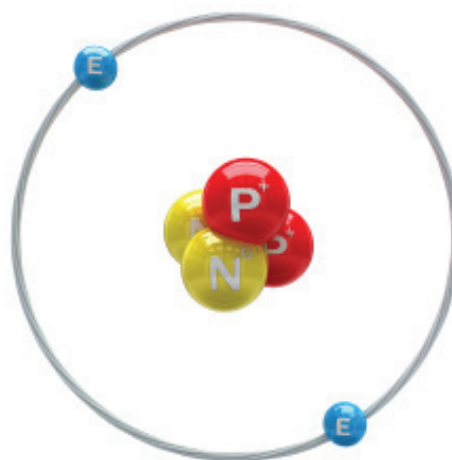
As elements increase in size according to the periodic table, they have more positively charged protons in their nucleus, and a matching number of electrons in an increasing number of shells around that nucleus. The large positive charge of the nucleus of a big atom, such as lead, holds the innermost shells very tightly. Knocking an electron out of an inner shell therefore needs high-energy X-rays.

When an X-ray does knock out such an electron, another electron from an outer shell will drop into the newly created gap, emitting energy as it falls. But that electron has also left a gap, so there can be a cascade of electron transitions, each one emitting a photon. The spectrum of this radiation, called X-ray fluorescence, gives away which atoms are in the sample.

Absorption spectroscopy is also used at the other end of the Synchrotron spectrum, with

infrared radiation. The energy of infrared photons is so low that it can't bump electrons to different energy shells. Instead it sets molecules vibrating and rotating.

As with electron energy, the rotational and vibrational energy occurs in specific levels – this “quantisation” is a consequence of quantum mechanics. Infrared photons that match the energy difference between two levels are absorbed, while those that don't match pass straight through.



Top | The Bohr model of an atom: electrons orbit protons and neutrons  
Bottom | High-energy X-rays knock an electron out of an inner shell

## SYNCHROTRON DEVELOPMENT ACROSS THE CENTURIES

**1838**

Michael Faraday notices a glow between two electrodes in an evacuated glass tube, unaware he is watching electrons being accelerated by an electrical current. Faraday's observation inspires physicists such as Heinrich Geissler, William Crookes, Nikola Tesla and Johann Hittorf to study the puzzle of the glow – which became known as the cathode ray – though it would not be solved for another 60 years.

**1895**

Wilhelm Röntgen discovers X-rays with a cathode ray in a vacuum tube. X-rays are generated when electrons (which were unidentified at that time) in the cathode ray hit the glass of the tube.

**1897**

Physicist Joseph Larmor calculates that light is emitted by charged particles spiralling in a magnetic field – these days called Synchrotron radiation.

**1929**

Robert Van de Graaff invents the Van de Graaff generator, which can generate 5 million volts with which to accelerate electrons.

**1944**

Russian Vladimir Veksler comes up with the idea of using varying magnetic fields to compensate for the effects of relativity: the Synchrotron is born.

**1873**

Frederick Guthrie discovers hot metals emit a negative charge (i.e. electrons, which had not yet been identified), an effect now called thermionic emission, which lies at the heart of Synchrotrons. In 1880 Edison rediscovers the effect while investigating filament breakage in light bulbs.

**1897**

JJ Thomson discovers cathode rays are composed of electrons – the first identification of a sub-atomic particle.

**1909**

Ernest Rutherford sees inside the atom for the first time and finds it is mostly empty space. In a forerunner to today's Synchrotron X-ray diffraction experiments, he bombards a target of gold foil with subatomic particles – alpha particles from a radioactive source. He is surprised to find most alpha particles pass straight through while a few are scattered very strongly.

**1932**

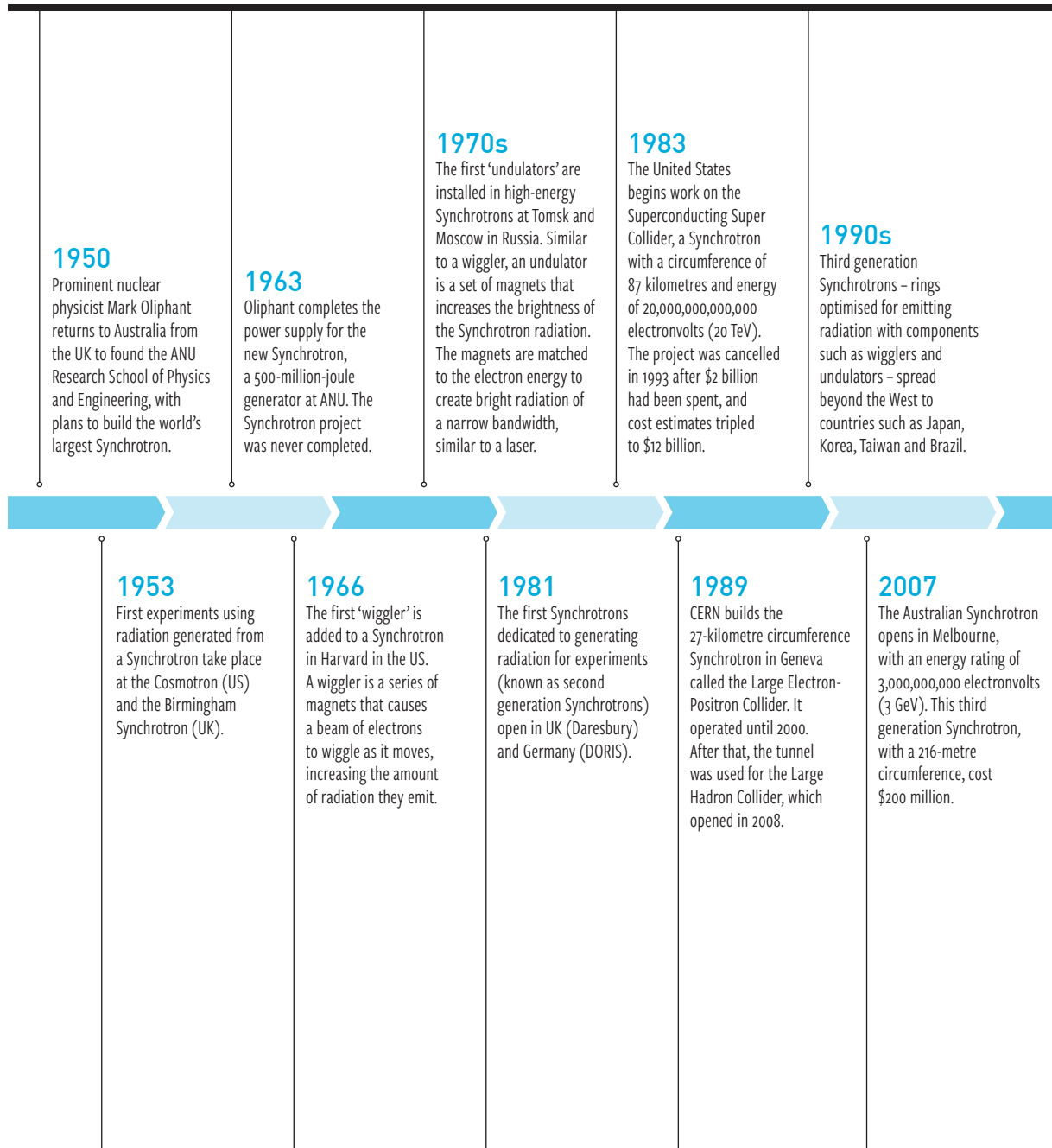
Two landmark accelerators are completed: John Cockcroft and Ernest Walton develop a particle accelerator at Cambridge University and use it to split the atom, splitting lithium into helium. Their linear accelerator (linac) is a 2.4-metre-tall tube that accelerates protons with a field of 400,000 volts, and proves Einstein's theory that  $E = mc^2$ .

In California, Ernest Lawrence develops the cyclotron, which uses an AC current to accelerate electrons as they orbit at high speed within a magnetic field. The 69-centimetre radius experiment accelerates electrons to 4.8 million electronvolts. Larger experiments are limited by electrons reaching a significant fraction of the speed of light – so fast that the Einstein's Theory of Relativity comes into play and the mass of the electrons begins to increase, requiring more and more energy for every little increase in speed.

**1945**

Ernest Lawrence's colleague Edwin McMillan independently comes up with the Synchrotron idea, and successfully tests it in California. Later he and Veksler find out about each other's research and become friends.

SYNCHROTRON DEVELOPMENT ACROSS THE CENTURIES continued





# BEAMLINE SCIENTIST DR DANIELLE MARTIN

Australian Synchrotron beamline scientist  
Dr Danielle Martin leads world-class  
collaborative research

**H**elping researchers study coral health, stem-cell therapy and car paints is all in a day's work for Australian Synchrotron scientist Danielle Martin.

"We get so many different people come through with all kinds of projects," she says. "There's a real enthusiasm for collaboration and finding new ways to make their research accessible across the board."

Danielle works at the Infrared Microspectroscopy (IRM) beamline, which is used to help researchers answer a wide range of questions relating to biology, materials, environmental and medical fields.

Currently, she is working with a marine science group from James Cook University, Queensland to find out how to keep coral reefs healthy. At the other end of the scale, Danielle is also helping a forensics group from Western Australia examine car paints to improve car identification methods. This is all while she is using the IR beamline to look at the stomach ulcer causing bacteria *Helicobacter pylori* in collaboration with Monash University and the Hudson Institute of Medical Research.

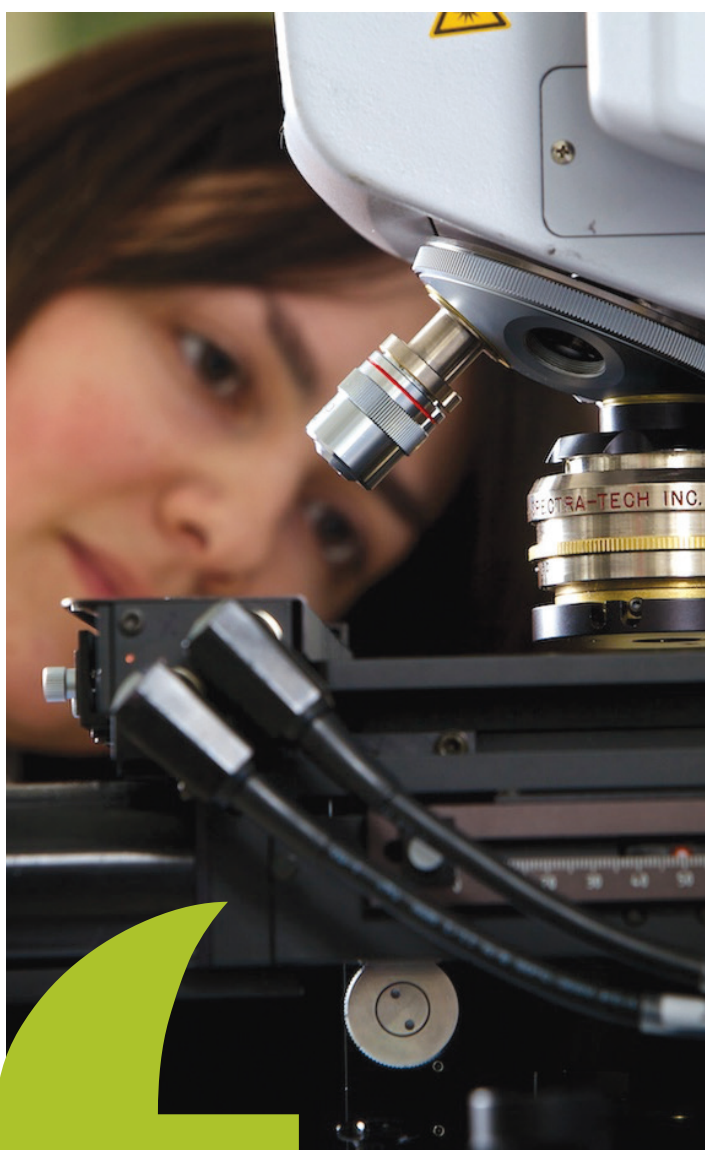
"The research is so diverse and it's amazing how the techniques we develop on one project can then be applied to something entirely different."

To keep things running at optimal efficiency for all these projects, each of the Australian Synchrotron's 10 different beamlines requires its own on-site technical and mechanical support.

"The most challenging thing is making sure that it is on par with other beamlines around the world," says Danielle. "We are always figuring out ways to keep up to date with the latest technology."

While Danielle's undergraduate studies at Monash University focused on the biomedical and forensic sciences, she moved towards UV spectroscopy for her PhD.

"This ended up giving me a broad background," she says. "The Australian Synchrotron saw my solid foundation in different areas as a strength."

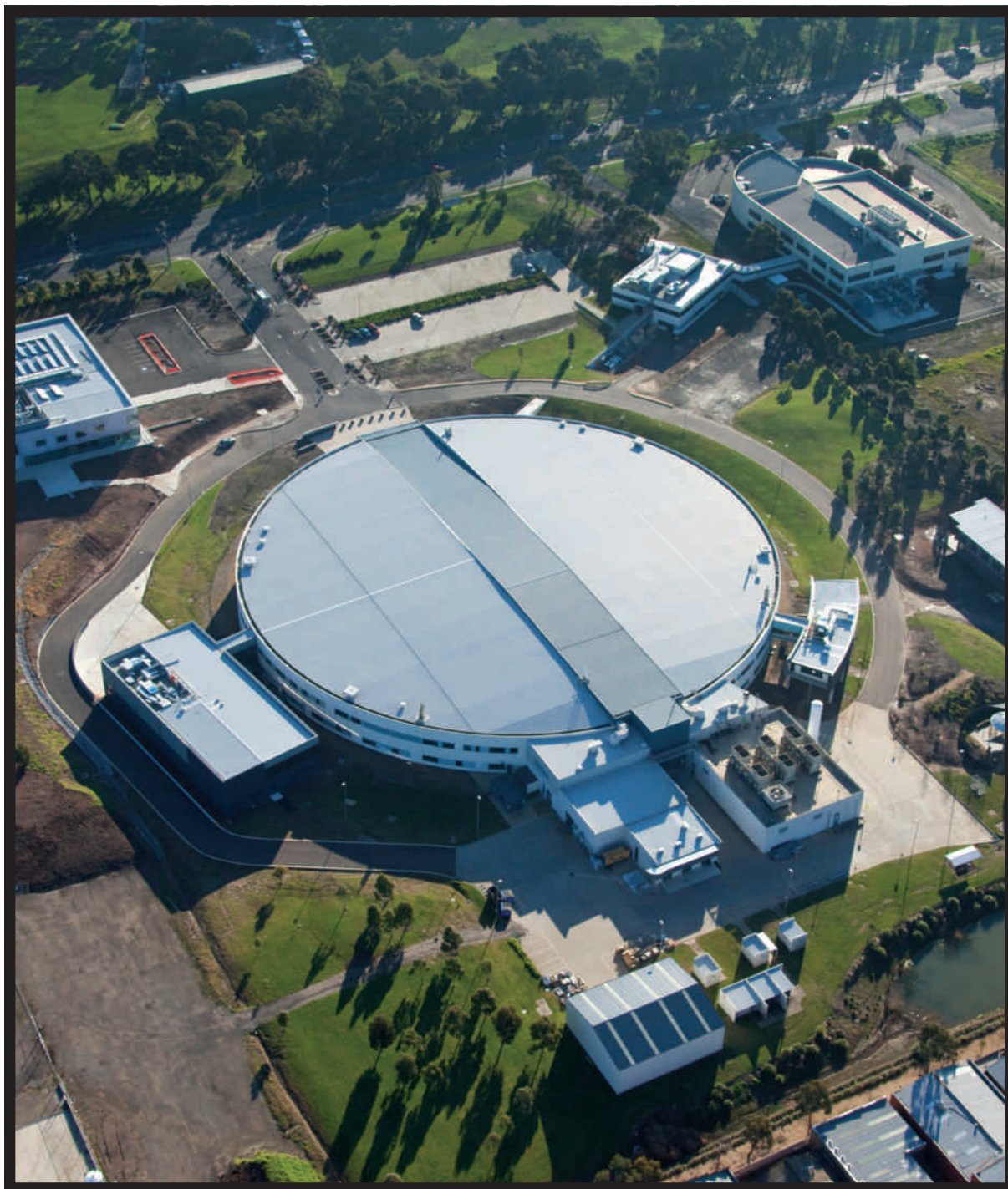


WE GET SO  
MANY PEOPLE  
COME THROUGH  
WITH ALL KINDS  
OF PROJECTS

# WHAT IS A SYNCHROTRON AND WHAT CAN IT DO?

Look at the following image of the Australian Synchrotron. Share anything you know about it.

What do you think it does? How do you think it works? What do we use a Synchrotron for?



**TRUE OR FALSE?**

The Australian Synchrotron can....

1 Help us make chocolate healthier.

2 Check the metal in bridges to see if they are still safe.



3 Provide criminal evidence about whether a person used a particular explosive or not.

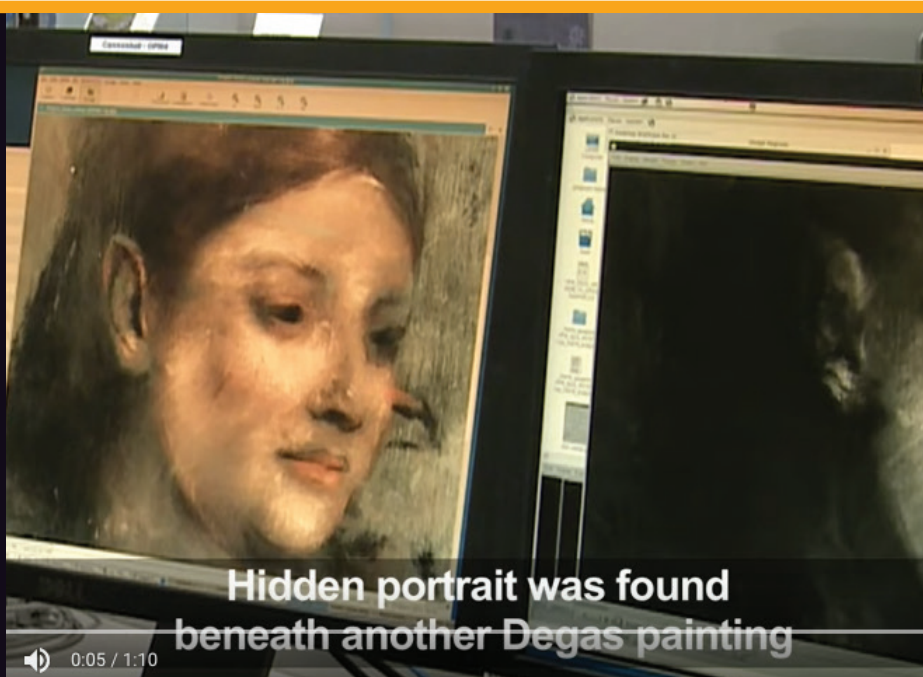
4 Help develop new drugs to fight disease.



5 Improve the amount of important micronutrients found in plants grown for food.

WATCH THE FOLLOWING VIDEO of the Australian Synchrotron

Share your ideas with the rest of the class on the types of research at the Synchrotron that you think would be useful.



# TEACHER INFORMATION

The aim of the *Explore* section is for students to investigate some of the scientific theory behind how the Synchrotron works and what it can do. It is intended that students make their own discoveries as they work around the stations in the room; they should be encouraged to record their questions as they ask them. When they learn the theory in the *Explain* section about how the Synchrotron works, they can refer back to these activities.

The table below lists the equipment and preparation required for each of the workstations. Stations can be completed in any order.

Station	Equipment
<p>1. Teacher demonstration: Deflecting an electron with fine beam tube and magnets (both permanent and coils).</p>	<p>Fine beam tube in a stand, 0-24 V variable power supply, HT 0-250 V power supply with special shrouded connecting leads, 6.3 V AC power supply, 2x Magnadur magnets, connecting leads</p> <p><b>STUDENTS SHOULD OBSERVE THIS DEMONSTRATION FROM A SAFE DISTANCE DUE TO ITS USE OF HIGH CURRENT.</b></p> <p>Alternately use a cathode ray tube and put a magnet near it to observe the deflection of the beam.</p>
<p>2. Teacher demonstration: spark produced by strong electric field (model of electron gun)</p>	<p>Set up HT (High Voltage) power supply with two electrodes clamped to retort stands (croc clips will do).</p> <p>During the demonstration, decrease the distance between tips of electrodes till a spark is observed, OR place electrodes close together to begin with, then gradually increase potential difference between electrodes, up to 5 kV. Observe that a spark occurs when the potential difference is high enough.</p> <p>Placing candle flame between electrode gap increases length of spark gap.</p> <p>This illustrates fundamental principles of electron gun – large potential difference produces a strong electric field, which accelerates electrons.</p>
<p>3. Online simulation to control fast-moving electrons in a magnetic field</p>	<p>Computer and access to the link <a href="http://www.kcvs.ca/site/projects/physics">www.kcvs.ca/site/projects/physics</a></p>
<p>4. Magnet race track – use magnets to 'push' a piece of metal along a track.</p>	<p>1 set = 2x magnets, paperclips, pen and paper</p>
<p>5. Magnetic field around a fixed magnet using a plotting compass</p>	<p>1 set = sheet of blank A4 paper, bar magnet, pencil, small compass</p> <p>This YouTube video shows the activity and results <a href="https://www.youtube.com/watch?v=DM0373nDp8M">www.youtube.com/watch?v=DM0373nDp8M</a></p>
<p>6. Magnetic field around a solenoid</p>	<p>Solenoid set up with a power pack ready for students to turn on; several compasses.</p>

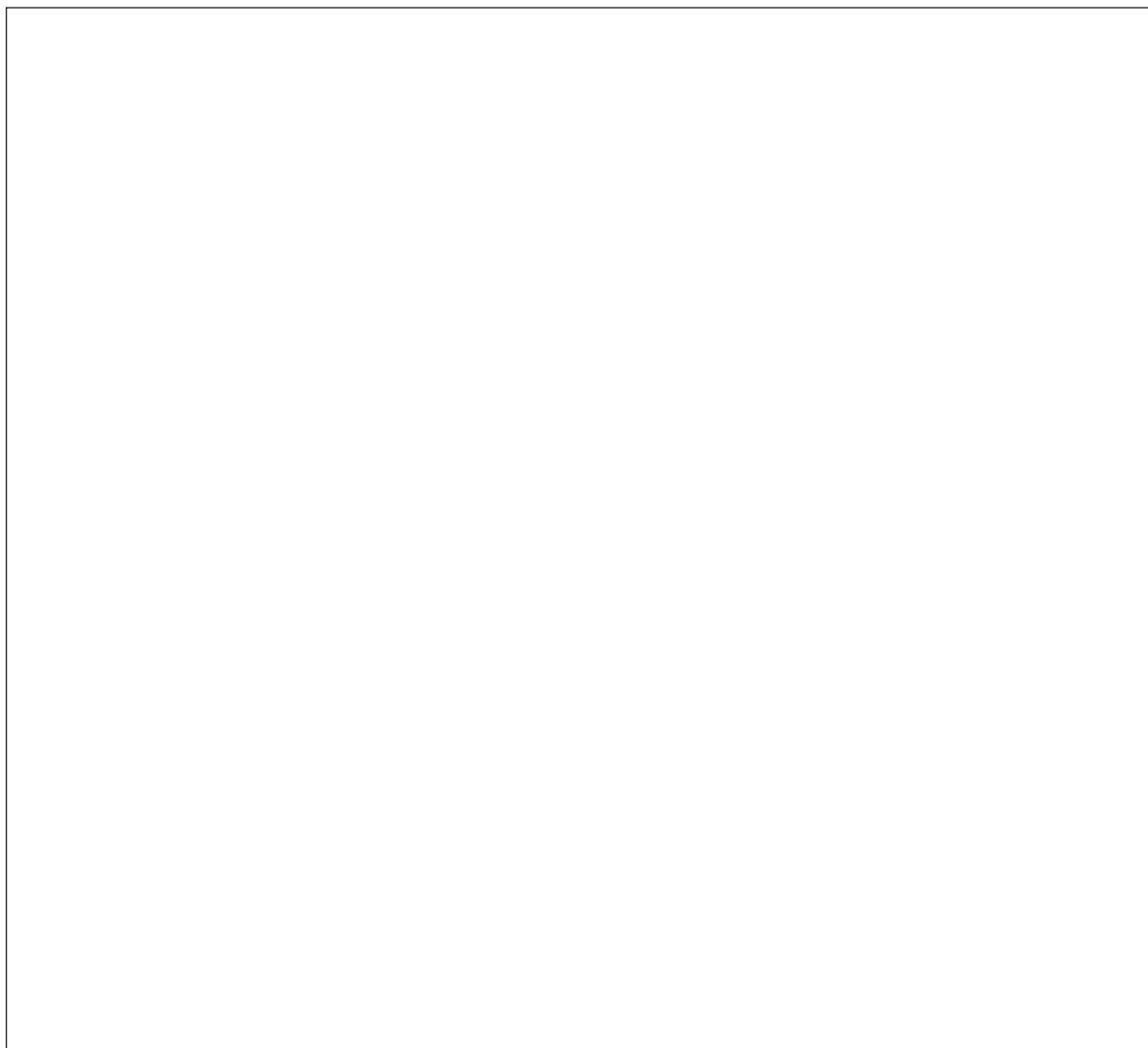
Station	Equipment
7. 3D field around magnet using fluid-filled container with iron filings	Fluid-filled clear container with suspended iron filings; bar magnet  This video demonstrates the effect <a href="http://www.youtube.com/watch?v=8llkHQta0lg">www.youtube.com/watch?v=8llkHQta0lg</a>
8. Centripetal force using rubber stopper, string, masses and tube	1 set = glass tube, nylon thread, mass with hook, paperclip, rubber bung set up as shown in diagram
9. Diffraction of human hair using a laser beam	Laser beam is aimed at a long human hair (held vertically in a retort stand and clamp) so that the laser beam diffracts onto a flat white surface (such as a wall or a box with a white piece of paper attached). The teacher will have to set this up beforehand so that the distance between the laser, the hair and the flat white surface yields a focused image. The laser is turned off to begin with so students can predict how the pattern will appear on the white sheet before turning it on to see the actual diffraction pattern.
10. Photo 51: DNA and its diffraction pattern	Image of Rosalind Franklin's Photo 51 and a model of DNA

# STATION ONE

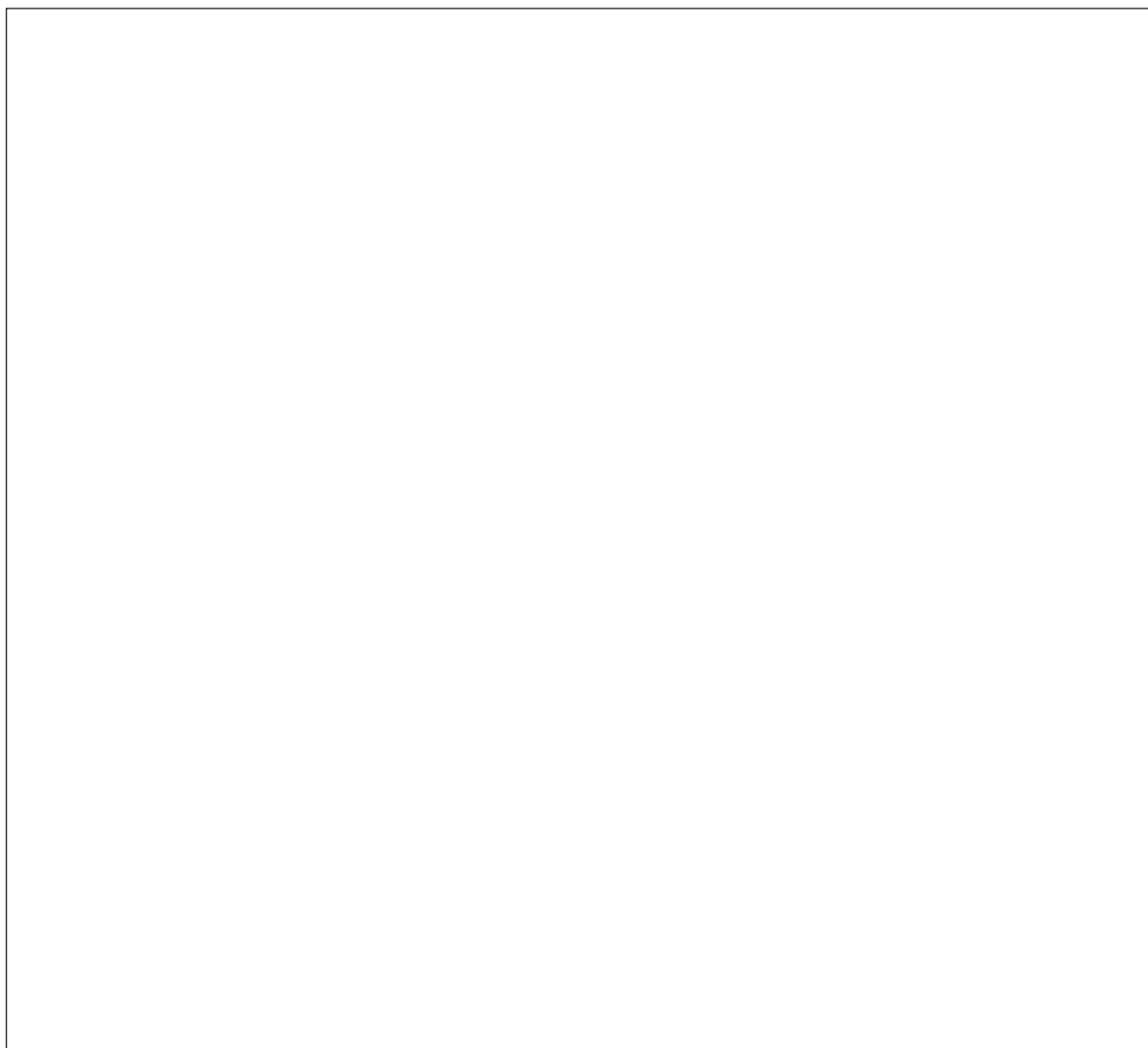
## **TEACHER DEMONSTRATION: DEFLECTING AN ELECTRON WITH FINE BEAM TUBE AND MAGNETS**

**NOTE:** Students should stand back from this demonstration for safety reasons.

1. Your teacher will set up the fine beam tube according to the manufacturer's instructions.
2. Turn off the lights and draw any blinds so the room is dark.
3. Your teacher will turn on the heater. When the filament is glowing they will slowly increase the voltage until a fine beam can be seen.
4. Draw and label a 2D scientific drawing of the beam inside the fine beam tube.



- Carefully place a magnet near the tube and note the effect the magnetic field has on the beam inside the tube.
- Draw and label a 2D scientific drawing of the deflected beam inside the tube to show the effect of the magnetic field.



- Is it possible to control the direction of the beam with the magnet? Or is the movement of the beam random when the magnet comes near it? Explain your responses using your observations.

---

---

---

---

---

---

---

- Use your knowledge of the charge of electrons to identify the positive and negative terminals on your 2D scientific drawing in Question 6.

# STATION TWO

## TEACHER DEMONSTRATION: SPARK PRODUCED BY STRONG ELECTRIC FIELD

**NOTE:** Students should stand well back from this demonstration due to high voltage used.

1. Your teacher will set up a high-voltage power supply connected to two electrodes. There will be a small air gap between the electrodes.

2. Observe the gap between the electrodes. What happens when the potential difference (voltage) between them is increased?

---

---

---

---

---

3. Observe the gap between the electrodes. What happens when the distance between them is reduced?

---

---

---

---

---

4. Your teacher will place a candle flame in the electrode gap. Observe what happens.

---

---

---

---

---

5. Why do you think this is happening?

---

---

---

---

---



# STATION THREE

## SIMULATION TO CONTROL FAST-MOVING ELECTRONS IN A MAGNETIC FIELD

1. Using your computer go to the following link [www.kcvs.ca/site/projects/physics](http://www.kcvs.ca/site/projects/physics)
2. Click on 'Particle in a Magnetic Field (2D)' and use the applet to discover:
  - a. how a change in velocity affects the radius of the particle path
  - b. how a change in the magnetic field affects the radius of the particle path
3. Now you need to keep the radius constant, just like that of a Synchrotron.
  - a. Increase the initial velocity of the particle. What happens to the radius of orbit?
  - b. Adjust the magnetic field to bring the orbit radius back to the initial value.
  - c. What must be done to the strength of the magnetic field in order to maintain a constant orbital radius of an accelerating particle?

# STATION FOUR

## MAGNET RACETRACK

1. Use the pen to draw a zigzag or winding path from one end of the paper to the other.
2. Draw on a start line and a finish line at either end of your zigzag line.
3. Use the magnets to repel a paperclip and 'push' or guide it along the path from the start to finish. If the magnet touches the paperclip in any way, you are disqualified.
4. What was your fastest time?

# STATION FIVE

## MAGNETIC FIELD AROUND A FIXED MAGNET USING A PLOTTING COMPASS

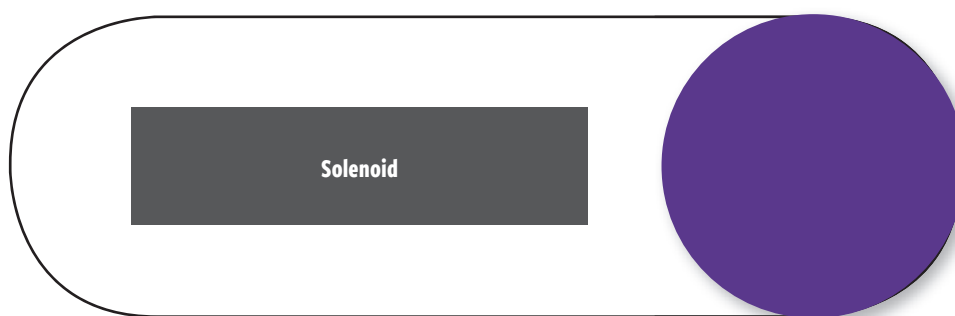
1. Place the magnet in the middle of a blank sheet of paper and draw a line around it to mark its position.
2. Choose a point at the edge of the magnet and mark it on the paper with a cross.
3. Line up one of the needles of the compass so it points directly to the centre of the cross you have just made. (See reference video: [www.youtube.com/watch?v=LIIiPh4sqa0](http://www.youtube.com/watch?v=LIIiPh4sqa0))
4. Make a second cross on the other side of the magnet where the other arrow points to.
5. Move the compass so that the needle now points to the second cross you have made and make a third cross on the other side of the magnet.
6. Continue in this fashion until you have made a line of crosses than run to the edge of the page or back to the magnet.
7. Join the crosses from the magnet outwards. This is your first magnetic field line.
8. Repeat steps 1 to 7 by choosing 7 or 8 more points at intervals around the edge of the magnet.
9. When you have finished you should have several magnetic field lines arcing out from the magnet.
10. Draw arrows on your magnetic field lines to show that the lines point from north to south.



# STATION SIX

## MAGNETIC FIELD AROUND A SOLENOID

1. Make sure the power is turned off.
2. Place the compasses randomly in a circle around the solenoid. Note the direction of the needles in the compasses.
3. Turn on the power. What happens to the compass needles?
4. Move one of the compasses in a path around the solenoid – does the needle move at all?
5. Make a sketch of the direction of the magnetic field lines around the solenoid using the direction of the compass needles as a guide.



# STATION SEVEN

## 3D FIELD AROUND MAGNET USING FLUID-FILLED CONTAINER CONTAINING IRON FILINGS

1. With the magnet well away from the centre of the clear container, shake to disperse the suspended iron filings.
2. Insert the bar magnet into the space in the middle of the container.
3. Predict how the iron filings will move around the magnet.
4. Observe the movement of the iron filings. Describe their pattern. How is this different to a 2D magnetic field?

---

---

---

---

---



# STATION EIGHT

## CENTRIPETAL FORCE USING RUBBER STOPPER, STRING, MASSES AND TUBE

1. Hold the glass tube with the thread inside it, as shown in the diagram below. Gently swing the rubber bung round in a circle.
2. Slowly increase the velocity of the circular motion of the bung.
3. What happens to the distance between the rubber bung and the top of the glass rod (the radius)?

---



---



---

4. Why do you think this happens?

---



---



---

5. As the radius of a Synchrotron is fixed, what variable needs to be manipulated so that the radius of the motion of the particles inside it is fixed?

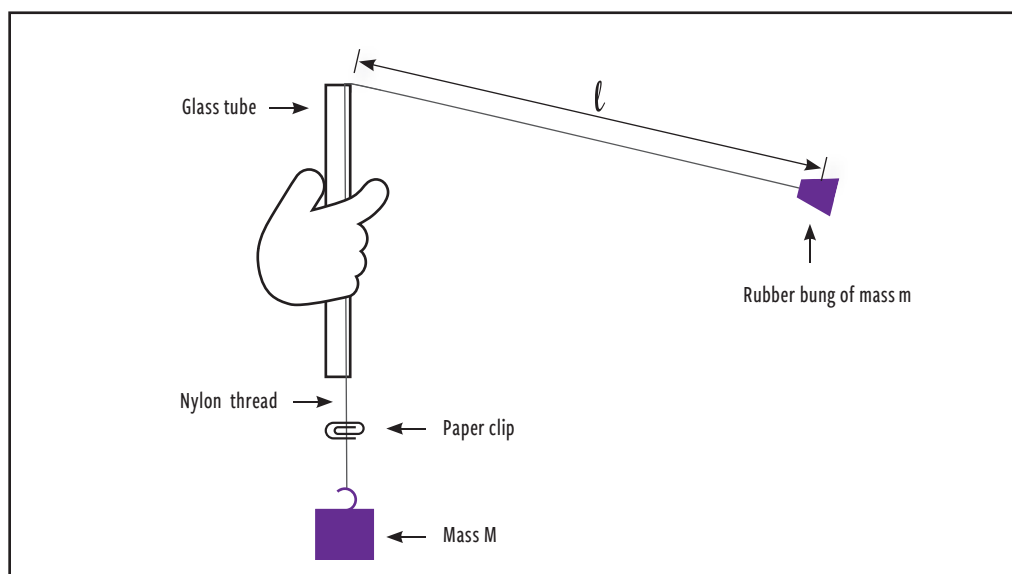
---



---



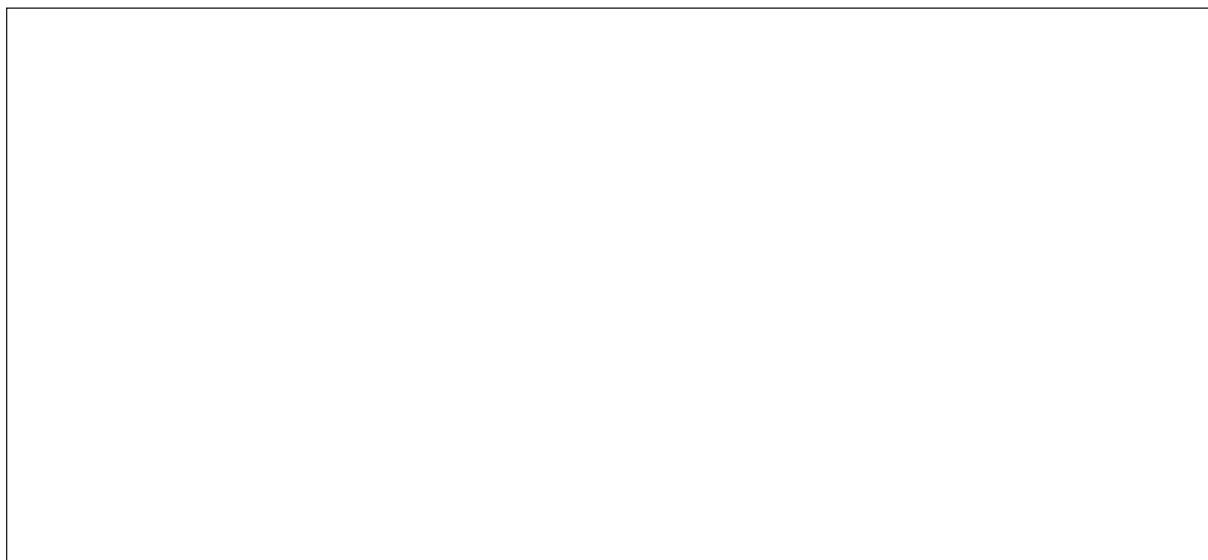
---



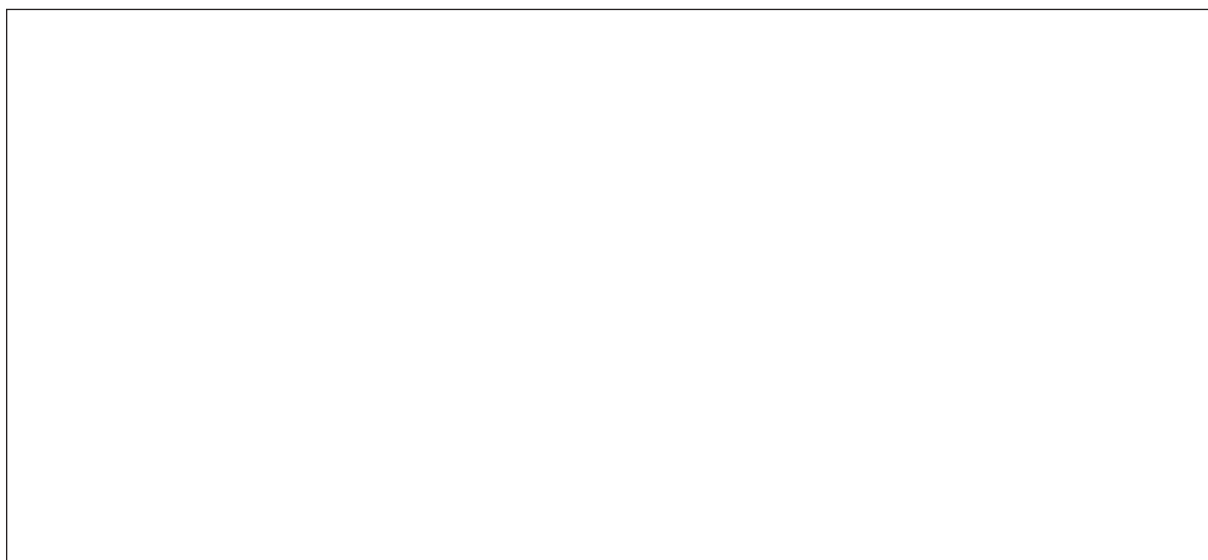
# STATION NINE

## DIFFRACTION OF HUMAN HAIR USING A LASER BEAM

1. Before turning on the laser, predict and draw the pattern the hair will leave on the white background when the laser is shone onto it:



2. Turn on the laser being careful not to touch the position of the laser, hair or the white background.
3. What pattern is left on the white background? Draw it here:



4. How do you think it made this pattern? Record your ideas here.

---

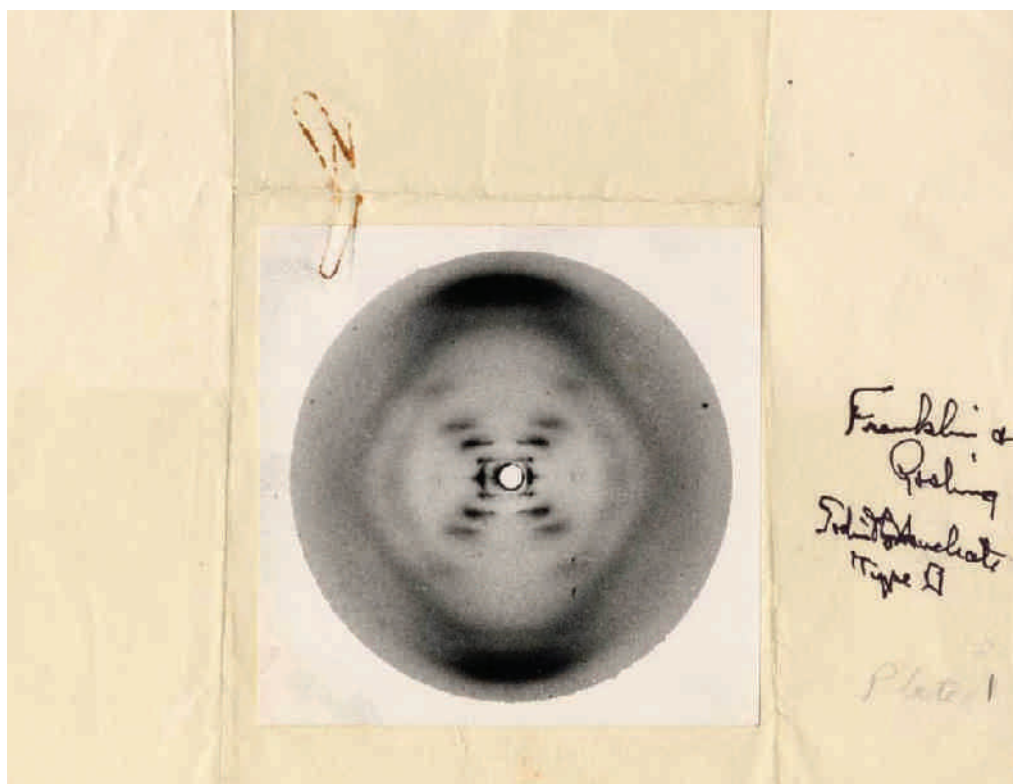
---

---

# STATION TEN

## PHOTO 51: DNA AND ITS DIFFRACTION PATTERN

1. What is the model of?
2. Examine Photo 51 – a famous photo in biology as it helped scientists understand the structure of DNA.
3. Compare the model and the photo – how are they related?



# TEACHER’S INSTRUCTIONS

**In this section, we explain the science of how the Synchrotron works and what it can do.**

We do this by getting students to read informative articles on the subject.

Before putting students to work, however, it’s useful to discover what they already know in a broad sense about particle accelerators such as the Australian Synchrotron, and discuss what they would like to find out.

For each of the three articles related to the Australian Synchrotron there are linked literacy activities. These are:

- Glossary
- Comprehension and summary
- Questioning toolkit

## ARTICLES

### 1. The Australian Synchrotron: An illuminating tool (page 26)

Here we look at the different parts that make up the Synchrotron, and what they do. We discover how the Synchrotron generates and accelerates radiation, and consider the characteristics of radiation that make it such a useful tool in scientific research.

### 2. Beams and machines (page 32)

Here we look at how the beamlines in the Synchrotron work. The specialist function of each of the 10 beamlines is described, providing a broad overview of the technical and medical applications of the Synchrotron.

### 3. Amazing discoveries (page 38)

Three fascinating case studies are outlined, looking at:

- Detecting space dust in the Pilbara
- Analysing the ochre pigment used in Aboriginal art
- Helping to connect a bionic eye to a patient’s brain



# SYNCHROTRON FACT OR FICTION?

## ACTIVITY 1

Read the following statements about the Synchrotron and decide if they are fact (true) or fiction (not true).

	Statement	True or False?
1	The Synchrotron makes the electric beam travel around its circumference millions of times per second	
2	Channelling the Sun's radiation down to the Earth creates the intensity of the radiation in the Synchrotron	
3	The electron beam that travels inside the circular beams of the Synchrotron naturally curves by itself (that is, it bends as it moves and does not travel in a straight line like other forms of energy)	
4	Scientists can only carry out one experiment at a time at the Australian Synchrotron	
5	Different types of radiation used in the Synchrotron have different characteristics for different applications	

**Answers:**  
 1. True - The electron beam travels at almost the speed of light.  
 2. False - The Synchrotron makes its own radiation, which is more intense than the radiation of the Sun.  
 3. False - Energy is needed to guide the electron beam on a circular path.  
 4. False - There are 10 beamlines for scientists to use, and room for more to be set up later.  
 5. True - There are different beamlines for different uses used in the Synchrotron.

## ACTIVITY 2

Use your own ideas as well as those from class discussions to put together a series of questions about the Australian Synchrotron that would help you to learn more.

# THE AUSTRALIAN SYNCHROTRON

## AN ILLUMINATING TOOL

The Australian Synchrotron is a machine that produces extremely bright light beams that are used to explore the structure of materials in great detail.

### THE ENGINE OF THE SYNCHROTRON

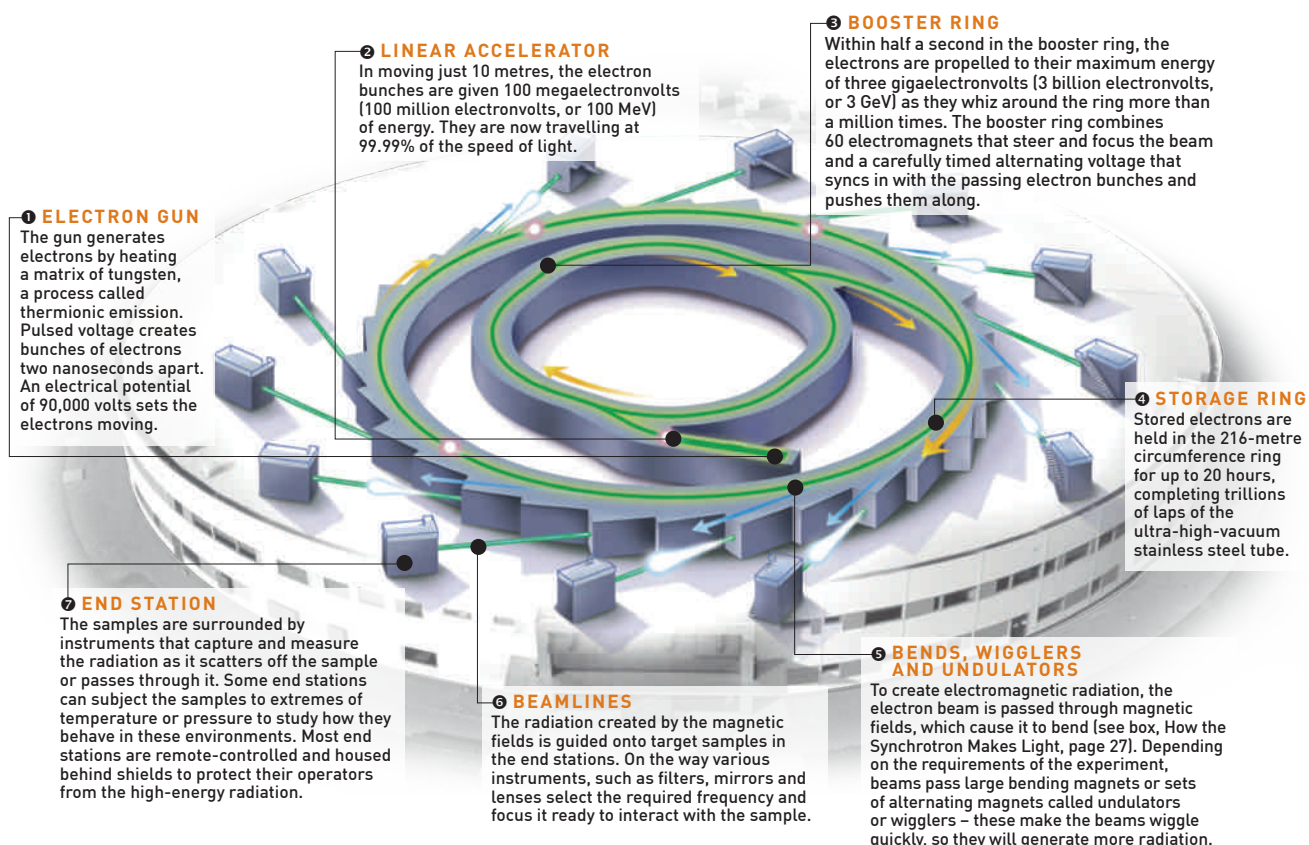
is a beam of electrons circulating in a ring 216 metres in circumference at close to the speed of light. At various places along the ring, the beam passes through magnetic fields, which cause it to bend, in the process giving off energy in the form of electromagnetic radiation. The frequency of the radiation ranges from low-frequency infrared radiation up to high-energy X-rays.

The radiation created by the Synchrotron is incredibly bright and allows researchers to study the finest structure of complex molecules and tiny crystals. The radiation can be channelled into different beams, called beamlines, allowing different experiments

to be run concurrently. Currently there are 10 such beamlines in use at the Australian Synchrotron. Each uses different lenses and filters to prepare the beam before it shines on the sample, and different detectors to collect data.

There is room for expansion around the storage ring, with capacity for more than 30+ beamlines to be operating at the same time.

The Synchrotron beamlines are effectively huge, powerful microscopes. The remarkable uses to which they have been put includes finding traces of explosives in forensic examinations, analysing ochre paint in Aboriginal art and designing new drugs to treat Alzheimer's disease.



## HOW THE SYNCHROTRON MAKES LIGHT

One of the strangest things about electromagnetism is that it sometimes exerts forces sideways. Gravity moves masses towards each other; with electricity, like charges repel. But when moving charges, such as electrons, pass through a magnetic field they are neither attracted nor repelled but turn sideways. If the area of magnetic field is large enough, the charged particle will just keep turning and turning, and end up going around and around in a circle.

This change of direction is the source of Synchrotron radiation. Electromagnetic radiation is created when charged particles are accelerated: the magnetic force is accelerating the charges and so radiation is generated.



Dr Bernt Johannessen working with the Australian Synchrotron X-ray Absorption Spectroscopy Beamline

### SYNCHROTRON RADIATION

The amount of radiation generated by an electron going through a magnetic field depends on its charge (which is constant) and its acceleration – in other words the tightness of the corner. So to make the light as bright as possible, the electrons need to be travelling as fast as possible, and the magnets need to be as strong as possible.

Both of these conditions are met in the Synchrotron. The energy of the electrons is 3 GeV, the equivalent of connecting about 250 million car batteries together, and the magnets are up to 4 tesla – 100,000 times stronger than the Earth's magnetic field. The result: X-rays 10 trillion times brighter than a hospital X-ray.

Another great advantage of Synchrotron radiation is that it covers a broad spectrum of energies and is highly tunable. No other

laboratory-based source is able to produce the broad range of energies that the Synchrotron can produce, and the high tunability of the beam allows scientists to select the precise wavelength they want for their experiment, from low-energy infrared right up to hard X-rays.

Three other characteristics make Synchrotron radiation especially useful. First, the light is polarised, because the electron beam travels in a flat plane – this adds to the Synchrotron's versatility, making it possible to view materials in different types of light. Second, the light is emitted in a 'collimated' beam – that is, like a laser, its rays run parallel to one another – so it is easy to harness into a beamline. Finally, because the electrons generating the light circulate in bunches, the light is generated in pulses, allowing for specialised time-based experiments at the beamlines.

**ACTIVITY 1 - GLOSSARY**

Using the table provided, define some of the terms used in the article.

Term	Definition
Synchrotron	
Speed of light	
Magnetic field	
Electromagnetic radiation	
Infrared radiation	
X-ray	
Beamline	
Port	
Synchrotron storage ring	
Electron gun	

ACTIVITY 1 – GLOSSARY *continued*

Term	Definition
Linear accelerator	
Booster ring	
Storage ring	
Undulators (wigglers)	
End station	
GeV	
Tesla	
Polarised	
Collimated beam	

**ACTIVITY 2 – COMPREHENSION AND SUMMARY**

Answer the following questions about the article.

1. Write a tweet (140 characters) to someone who knows nothing about the Synchrotron describing it and what it does.

---

---

---

2. Describe how radiation is generated in the Synchrotron.

---

---

---

3. Once generated, how is the electron beam:

a. Stored?

---

---

---

b. Accelerated?

---

---

---

c. Made to bend around the inside of the stainless steel tube?

---

---

---

4. Why does the storage ring have to be an ultra-high vacuum?

---

---

---

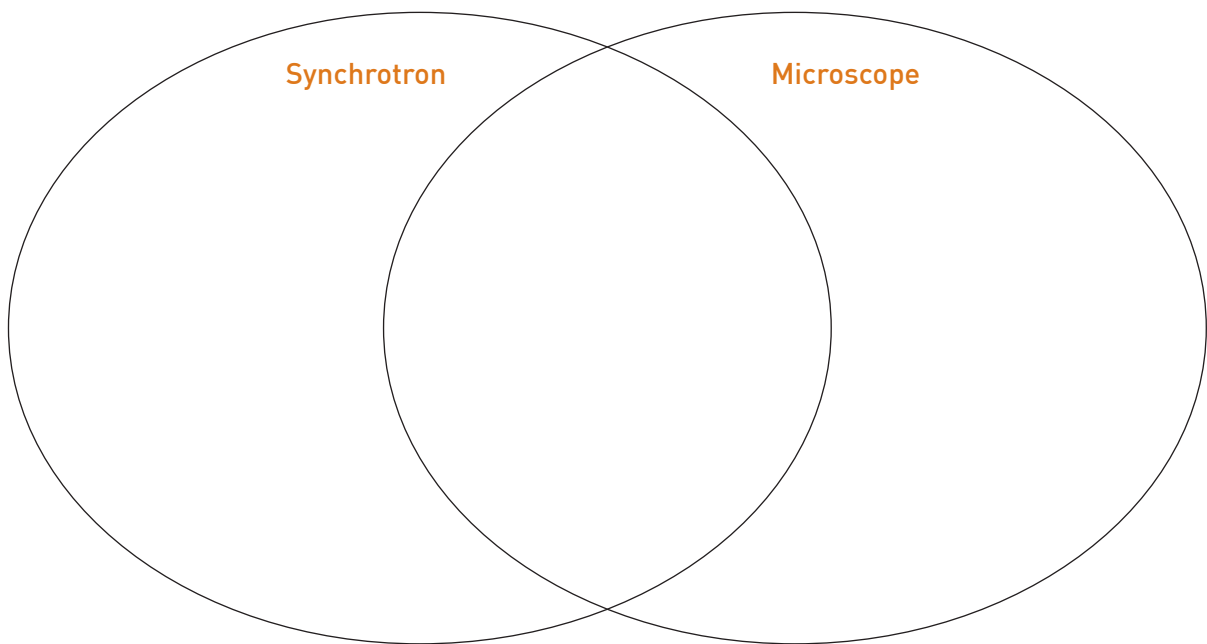
5. Outline as many different characteristics of the Synchrotron radiation as you can that make it useful as a research tool.

---

---

---

6. In the article, the Synchrotron beamlines are compared to 'extremely huge, powerful microscopes'. Complete the Venn diagram below to compare and contrast the structure and application of the Synchrotron beamlines and typical microscopes like those in your classroom.



7. The article says the electrons in the Synchrotron can travel at 99.99% the speed of light. How fast can they travel in one second?

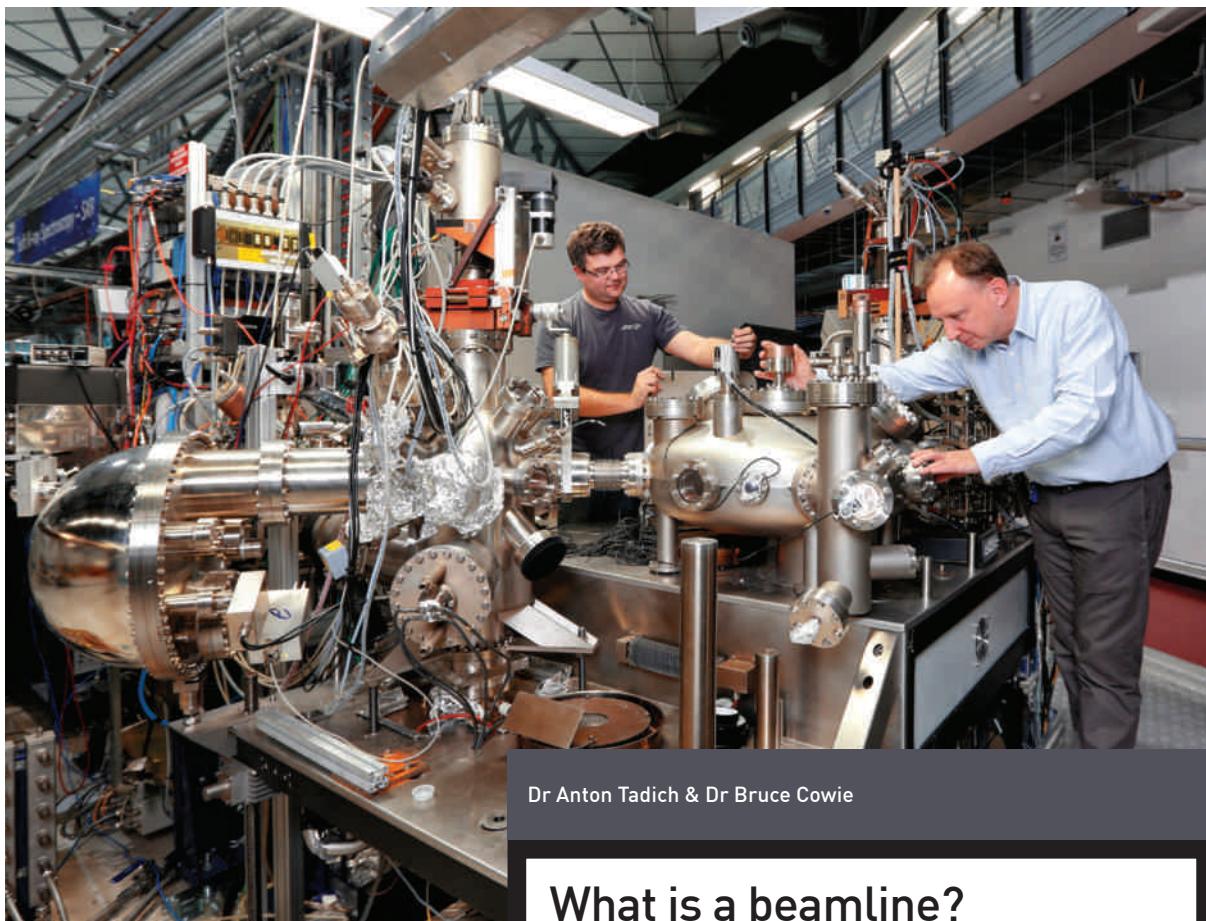
---

---

---

# BEAMS AND MACHINES

Powerful light generated by the Australian Synchrotron's high-energy ring of electrons travel along different 'beamlines' to be used in different sets of experiments.



Dr Anton Tadich & Dr Bruce Cowie

## What is a beamline?

X-ray and infrared beams from the Australian Synchrotron travel through equipment that prepares the beam and guides it to the materials being tested, and records the interaction between the materials and the beams – the whole process is known as a 'beamline'. There are 10 operational beamlines at the Australian Synchrotron.

**IF YOU BREAK YOUR ARM**, the doctor will send you for an X-ray, which shows the bones inside your body.

The Australian Synchrotron produces X-rays as well, but they are far stronger and more versatile than those produced by a medical X-ray machine and give scientists much more detailed images.

Unlike the shadowy images of a broken arm, the images created by the bright X-rays at the Australian Synchrotron can create high-contrast images, and can do it so quickly that they can even make X-ray videos.

The brightness of the Synchrotron beamlines also enables other techniques for studying the structure of things without cutting them open. Radiation is siphoned off the circulating beam of electrons into 10 separate arms, or beams. Each

one has a different speciality in working out the precise details of how the atoms and molecules are arranged in even the tiniest sample.

### EXPERIMENTAL TECHNIQUES

There are three families of experiments. One beamline uses the simplest process, which is similar to conventional X-ray images or CT scans – the image is much like a shadow of the



material being studied. However, the remarkable qualities of Synchrotron radiation means they are far sharper and provide more information than medical X-rays.

The second family of experiments, utilised by six of the beamlines, uses spectroscopy. This technique measures the way that materials absorb and emit radiation at specific energies in order to study which atoms make up the sample and in what proportions.

The third and most complex scan type uses diffraction – the patterns produced when X-rays bounce off materials that contain regular patterns of atoms. With some complex unravelling, the diffraction patterns can reveal the way atoms are arranged in a material.

### IMAGING AND MEDICAL THERAPY BEAMLINE

The Imaging and Medical Therapy beamline is the longest beamline at the Australian Synchrotron. X-rays created by the Synchrotron travel 136 metres to a separate building where they are used to create high-contrast X-ray images and to treat diseases such as cancer.

Over the length of the beamline, the X-ray beam expands to a size large enough to image small animals. It is so bright that it can image soft tissue as well as bones and can take quick snapshots and reveal processes such as lung function and asthma as they happen. It can also make use of the changes in refractive index to bring out subtle details of samples, a technique known as phase contrast imaging.

As well as medical processes, this beamline can scan materials to reveal dynamic processes such as minerals precipitating and alloys solidifying.

### INFRARED MICROSCOPY AND TERAHERTZ/FAR INFRARED BEAMLINES

Two more beamlines use infrared radiation for spectroscopy – the Infrared Microscopy and the Terahertz/Far Infrared beamlines. This region of the electromagnetic spectrum tells scientists about how molecules are bonded together and has been used to examine everything from the forensic analysis of car paints to planetary gases. It is an absorption technique where different infrared energies are absorbed by the molecules of different components in a sample, giving information about the chemistry of a sample.

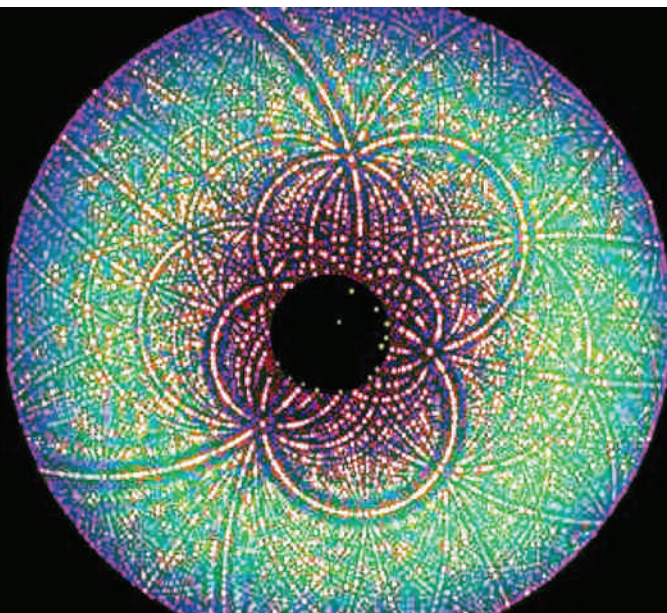
Each beamline operates with different energies of infrared light – the Terahertz/Far IR beamline uses very long infrared wavelengths, almost microwave light, while the Infrared Microscopy beamline uses shorter infrared wavelengths – and each beamline specialises in the types of samples they examine and the types of information they provide.

The Terahertz/Far Infrared beamline is ideal for examining gases and is used a lot for environmental and atmospheric studies. It can also be used to examine solid samples, such as for research improving battery technology.

The Infrared Microscopy beamline is ideal for examining solid samples rather than gases. It is used a lot for the study of medical samples to examine the progression and treatment of disease. Other studies include examining volcanic rock to help understand volcanic eruptions, and to study the pigments used in art works, for example to examine the breakdown of pigments in important historical paintings to help conservators improve museum storage conditions.

## Diffraction

Diffraction patterns are created when Synchrotron light bounces off a crystalline sample. When an X-ray strikes an atom, its energy is scattered out like ripples on a pool. The ripples from all the different atoms interact and, depending on the wavelength and the atoms' spacing, are amplified and cancelled out as they interact. Scientists can analyse these interference patterns to trace back the original atomic structure of the material.



### X-RAY ABSORPTION SPECTROSCOPY BEAMLINE

Spectroscopy is also used in the X-ray Absorption Spectroscopy beamline. This technique allows scientists to study how the inner electrons of atoms absorb X-rays at very specific energies. Scientists use both absorption spectroscopy – the study of exactly which energy X-rays are absorbed – and photoelectron spectroscopy, in which the inner electrons are kicked right out of the atom by the X-ray. Instruments capture these escaping electrons and by measuring how fast they are travelling, can work out how strongly they were originally bound to the atomic nucleus.

These medium- to high-energy X-rays can probe into large atoms and have been used to look at the role of metal atoms in Alzheimer's disease and also to study how metal ore deposits form.

### SOFT X-RAY BEAMLINE

The Soft X-ray beamline works in a similar way, but for smaller elements such as carbon and nitrogen, whose inner electrons are not bound so tightly to the atomic nucleus. It uses the lowest energies of the X-ray beamlines.

This is especially useful for studying the surface of nanomaterials, such as graphene, which are set to play a big role in the development of nanotechnologies such as quantum computers. It is also useful for analysing minerals, which helps in the development of more efficient methods to extract ore from rocks, producing less waste than current techniques.

### MICROSPECTROSCOPY (X-RAY FLUORESCENCE SPECTROSCOPY) BEAMLINE

The Microspectroscopy (X-ray Fluorescence Spectroscopy) beamline also relies on knocking out electrons from the inner atomic shells of elements. It is used to analyse the new X-rays that this process creates, when electrons from outer shells fall into the newly-created gap left by the departing inner electron. Each element has a unique fluorescence pattern of different energies, which allows scientists to detect which elements are found in the sample.

This beamline has the smallest beam size – a tiny 100-nanometre diameter or about a thousandth of a human hair – which gives it the power to pick out extremely fine detail.

It has been used to help design drugs for medical use, to analyse air pollution and in a forensic investigation of the death of the racehorse Phar Lap.

### MX1 AND MX2

The MX1 and MX2 (Macromolecular Crystallography and Micro-crystallography) beamlines are designed to analyse the diffraction pattern (see box, Diffraction, page 32) created when X-rays are scattered off crystals. It uses medium- to high-energy X-rays, whose short wavelengths are necessary for analysing the spacings of atoms within crystals and molecules.

MX1 is designed to analyse lots of samples quickly, when 'large crystals' (0.2mm) can be grown of materials such as proteins. While MX2 is a finer beam that can achieve diffraction from the tiniest of crystals (0.001 - 0.01mm). Growing small crystals is often a problem with complex molecules such as viruses or drugs bound to proteins. These beamlines have been used to study carnivorous mushrooms, a potential new flu drug and new-generation solar cells.

### SMALL ANGLE AND WIDE-ANGLE X-RAY SCATTERING BEAMLINE

Another diffraction-scattering beamline is the Small Angle and Wide-Angle X-ray Scattering beamline. One reason that diffraction is powerful is that the beam is scattered further by smaller structures. This beamline can detect X-rays that are scattered to wide angles by tiny atomic structures, at the same time as the small scattering that comes from larger-scale molecular patterns.

This combined information has been used to study how milk is digested, to watch heart muscles beating and work out how to turn gold into nano-rods.

### POWDER DIFFRACTION BEAMLINE

When a sample is not a single crystal, but a powder – like salt, made up of lots of crystals – or even a mixture of different materials, the Powder Diffraction beamline can help unravel the atomic structure of the sample. Crystals of the same material have identical structure but are in lots of different orientations, and different materials will have different crystal structures altogether. Clever software can take the combined diffraction pattern created by these crystals and work backwards to calculate the molecular structures for each material in the powder.

The Powder Diffraction beamline can also heat or cool samples, or put them under high pressure. It has a range of special holders for many different kinds of samples, such as ceramics to hold nuclear waste, and porous materials to trap carbon dioxide from the atmosphere. It's used a lot in battery development and has also been used to simulate the high-pressure environment in the interior of Jupiter's moons.

**ACTIVITY 1 - GLOSSARY**

Using the table provided, define some of the terms used in the article.

Term	Definition
<b>Diffraction</b>	
<b>Diffraction patterns</b>	
<b>Crystalline sample</b>	
<b>Spectroscopy</b>	
<b>Absorption spectroscopy</b>	
<b>Photoelectron spectroscopy</b>	
<b>Nanomaterial</b>	
<b>Graphene</b>	
<b>Microspectroscopy</b>	
<b>Powder diffraction</b>	

**ACTIVITY 2 – COMPREHENSION AND SUMMARY**

Answer the following questions about the article.

1. How do the diffraction patterns made as particles come off from a particular molecule allow us to understand the molecule’s structure? When considering your answer, look at information on the Bragg equation online such as this video: <http://bit.ly/2cdzeQ0>, and the research by William and Lawrence Bragg, Australian scientists whose work led to the Nobel Prize for Physics in 1915.

---



---



---



---

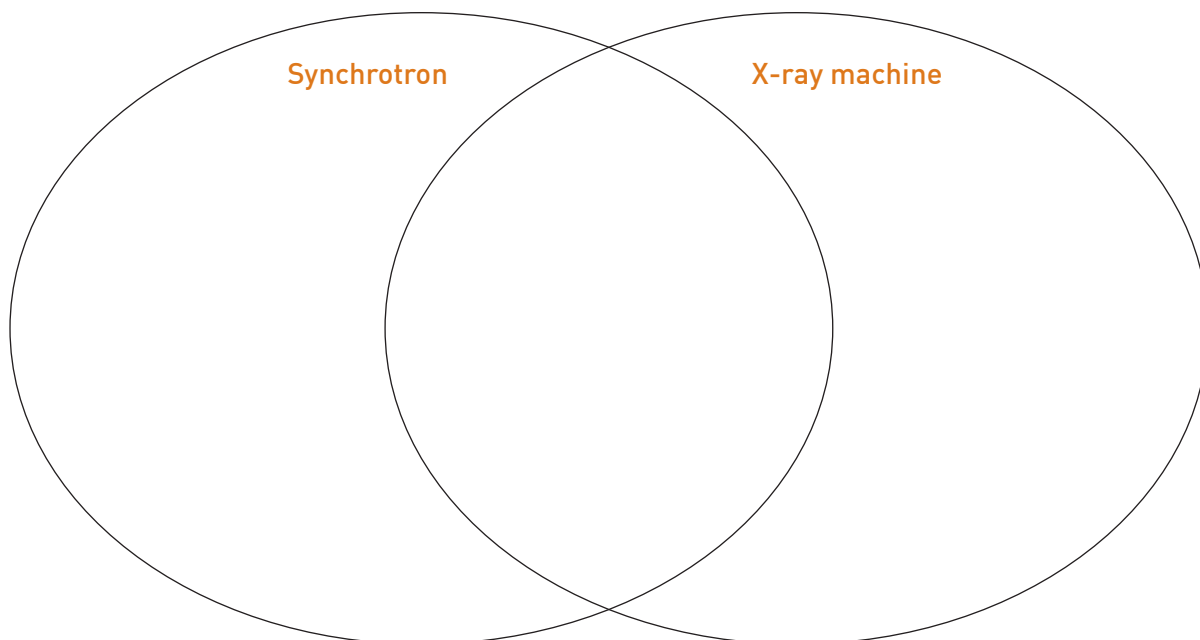


---

2. List the three general beam types in the table below. Then describe the families of experiments carried out by each – how they work and their uses.

General beam type	How it works	Uses

3. In the article, the Synchrotron beamlines are compared to a 'medical X-ray machine'. Complete the Venn diagram below to compare and contrast the structure and application of the Synchrotron beamlines and a typical X-ray machine like those used in medicine to make images of your bones.



4. Which beamlines could be used for the following purposes?

	Purpose	Beamline
1	To find out which elements a molecule is made up of	
2	To look at the role of metal atoms in disease, or the formation of metal ores	
3	To look at how molecules are bound together, such as in pigments	
4	To find out what happens when you heat a molecule or put it under pressure	
5	To treat cancer	

# AMAZING DISCOVERIES

From detecting space dust to studying Aboriginal art, the uses of the Australian Synchrotron are as boundless as human ingenuity.



Top: The Synchrotron could help to develop brain implants for a bionic eye  
Bottom: Micrometeorites are some of the samples which the Synchrotron has analysed

**USES OF THE AUSTRALIAN Synchrotron** have included exploring the ancient history of Earth’s atmosphere, studying Aboriginal art and developing brain implants for the bionic eye.

## SPACE DUST FOSSILS CLUES TO ANCIENT ATMOSPHERE

When Monash scientists Dr Andrew Tomkins and Dr Sasha Wilson wanted to analyse ancient space dust dug up from the Pilbara in Western Australia, they brought their samples to the Synchrotron.

The team extracted space dust 2.7 billion years old – the oldest fossil micrometeorites ever found – from ancient limestone and found it gave surprising clues to the Earth’s atmosphere at the time, Dr Tomkins explains:

“We found that most of the micrometeorites had once been particles of metallic iron – common in meteorites – that had been turned into iron oxide minerals in the upper atmosphere, indicating higher concentrations of oxygen than we expected.

“This was an exciting result because it is the first time anyone has found a way to

sample the chemistry of the ancient Earth’s upper atmosphere.”

The find leaves scientists with a puzzle. They had thought the Earth’s atmosphere at that time had very little oxygen, because the plants that today make oxygen from carbon dioxide had not yet developed.

The team now think there may have been a layer of oxygen in the upper atmosphere after all, created by ultraviolet light from the Sun breaking down carbon dioxide.



The Australian Synchrotron is uncovering details of Aboriginal history through the study of artifacts such as cave paintings, leaving the objects undamaged following its analysis

### X-RAYING ABORIGINAL HISTORY

For tens of thousands of years Aborigines across Australia have painted their weapons, their art, their caves and even themselves with ochre.

Now the Synchrotron is revealing details of that history as its X-ray fluorescence beam is used to study a boomerang and a bark painting.

Lead researcher Dr Rachel Popelka-Filcoff from Flinders University says the sensitive analysis will help researchers better understand Indigenous art and artefacts.

“Relatively little is understood about the procurement, composition, and mixing of the natural mineral pigments that have been used in Aboriginal objects.

“This new method provides an alternative to traditional destructive testing, allowing the return of the object undamaged to the museum collection.”

Ochre is a reddish brown pigment. Its colour comes from haematite, a mineral containing iron oxide. But if the iron oxide contains water, the ochre changes colour, to brown or even a gold colour. And if the haematite grains are larger, red ochre can even look purple.

Add to that variations in how the layers of ochre are applied and the Synchrotron’s powers can reveal a new realm of information

about when and where artefacts were made.

“The findings from across Australia will help to reconstruct ancient exchange routes, build on the existing provenance of Aboriginal art and objects, and help conservation and authentication studies,” Dr Popelka-Filcoff says.

### THE RACE TO RESTORE SIGHT

The Australian Synchrotron is helping researchers work out how to connect a bionic eye into the brain of a patient.

The group of researchers from Monash University and the company Minifab are exploring implanting electrodes just a twentieth the diameter of a human hair into the brain.

The researchers use the microbeam crystallography facility to find out if the body’s immune system attacks the platinum-iridium electrodes while they are implanted.

Only a 50-micron section of the electrode contacts with the vision neurons, so researchers need to check that the rest of the electrode, which has an insulating coating, does not get damaged and short-circuit to the wrong neurons.

“People are going to have these electrodes in their brains forever, hopefully, and we need to make certain that they will be able to survive in this fluid environment,” said researcher Associate Professor Ramesh Rajan.

**ACTIVITY 1 – GLOSSARY**

Using the table provided, define some of the terms used in the article.

Term	Definition
Ochre	
X-ray fluorescence	
Haematite	
Electrodes	



**ACTIVITY 2 - COMPREHENSION AND SUMMARY**

Answer the following questions related to the article.

1. How might our knowledge of the Earth's ancient atmosphere be changed by the research done by Dr Tomkins and Dr Wilson from Monash University?

---

---

---

---

---

---

---

---

2. How can knowledge of pigments in Aboriginal artefacts studied by Dr Rachel Popelka-Filcoff from Flinders University help us understand how tribes lived and interacted in the past?

---

---

---

---

---

---

---

---

3. Why is the Australian Synchrotron research with the bionic eye so important?

---

---

---

---

---

---

---

---

# BRINGING IT ALL TOGETHER

Write your ideas and opinions relating to each of the different types of questions.

[Inspired by Jamie McKenzie’s Questioning Toolkit. Further reading on questioning toolkits: McKenzie, Jamie (2000) *Beyond Technology*, FNO Press, Bellingham, Washington, USA. [www.fno.org/nov97/toolkit.html](http://www.fno.org/nov97/toolkit.html)]

Type of question	Your ideas and opinions
<p><b>Essential questions</b> These are the most important and central questions. They probe the deepest issues that confront us and can be difficult to answer.</p> <p><b>Questions</b> What is the Synchrotron’s greatest value? How will the Synchrotron expand our scientific knowledge in the future?</p>	
<p><b>Subsidiary questions</b> These questions help us to manage our information by finding the most relevant details.</p> <p><b>Questions</b> What university courses would scientists need to take in order to work at the Australian Synchrotron? For scientists using beamlines at the Synchrotron, what knowledge and skills are needed? What are some of the safety rules that visitors to the Synchrotron need to follow?</p>	
<p><b>Hypothetical questions</b> Questions designed to explore the possibilities, the ‘what ifs’. They are useful when we want to test our hunches.</p> <p><b>Questions</b> If you were able to design your own experiment, what would you use the Synchrotron for? Which beamline would you need to use?</p>	
<p><b>Provocative questions</b> Questions to challenge convention.</p> <p><b>Questions</b> Does it matter if the general public doesn’t understand how the Synchrotron works? Who decides which experiments will be carried out at the Synchrotron, and when and where they will take place? Should some experiments take priority over others? Are there experiments that shouldn’t be allowed to take place, that is, certain knowledge we shouldn’t pursue?</p>	

# ABOUT THE LEARNING MATRIX

## WHAT IS THE SYNCHROTRON LEARNING MATRIX?

A Learning Matrix is a flexible classroom tool designed to meet the needs of a variety of different learning styles for students of different capabilities. Students learn in many different ways: some are suited to hands-on activities, others are strong visual learners; some enjoy intellectually challenging and independent hands-off activities, while others need more guidance. Our Matrix provides a range of science learning activities from which teachers and/or students can choose.

## CAN I USE THE MATRIX FOR 1 OR 2 LESSONS, OR FOR A WHOLE UNIT OF STUDY?

Either! The Matrix is designed to be time flexible as well educationally flexible. Choose to complete one activity, or as many as you like.

## IS THERE ROOM FOR STUDENT NEGOTIATION?

Yes! Students can be given a copy of the Matrix and choose their own activities, or design their own activities in consultation with their teacher.

## WHAT DO THE COLUMN HEADINGS MEAN?

### Developing

This is designed to enhance student comprehension of information by including research (other people's knowledge and ideas) in their activities.

### Extending

Gives the student the opportunity to apply or transfer their learning into a new format where they have to create using their own skills or evaluate using their own criteria.

## WHAT DO THE ROW HEADINGS MEAN?

### First-hand investigations

These are hands-on activities that follow the scientific method. It includes experiments and surveys and is great for kinaesthetic and logical learners, as well as budding scientists.

### Maker space activities

This is about hands-on building, troubleshooting and reviewing the students' own designs.

### Ethical thinking

Here, students learn to recognise and explore ethical concepts. They examine the reasons behind ethical decisions, consider their consequences and reflect on ethical actions. Students examine values, rights, responsibilities and points of view.

### Information and Communications Technology (ICT)

In ICT students use searches to locate, access and generate digital data and information. Students generate ideas, plans and processes, and communicate these via ICT. They select and use software, manage data, understand social and ethical protocols, and understand the impacts of ICT.

### Personal and social capabilities

Here, students recognise emotions, personal qualities and achievements in themselves and diverse perspectives and relationships with and between others. They learn self-management through working independently and so learn how to express emotions appropriately. Students work collaboratively to make decisions, negotiate, resolve conflicts and develop leadership skills.

### Creative and critical thinking

This models the inquiry process. Students question, identify, clarify, organise and process information. They generate ideas, possibilities and actions, connect ideas, consider alternatives and seek solutions. Students also reflect on thinking (metacognition) and processes, apply logic and reasoning, draw conclusions and evaluate procedures. Knowledge is transferred into new contexts.

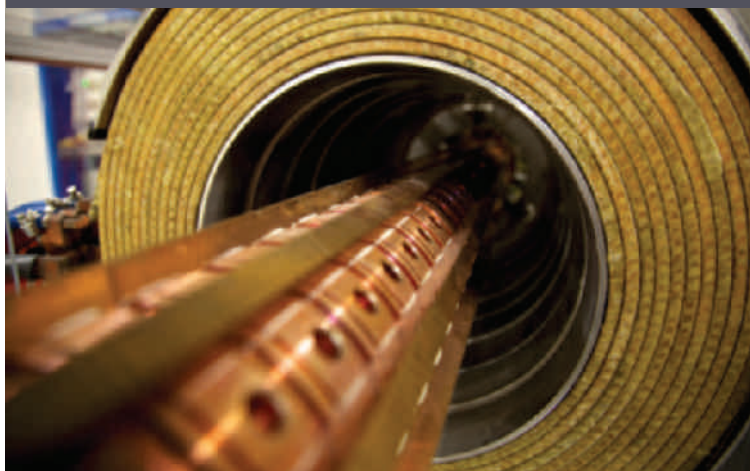
### Time travel

Here, students consider scientific and technological development as a linear process by travelling back in time or speculating on possible future developments.

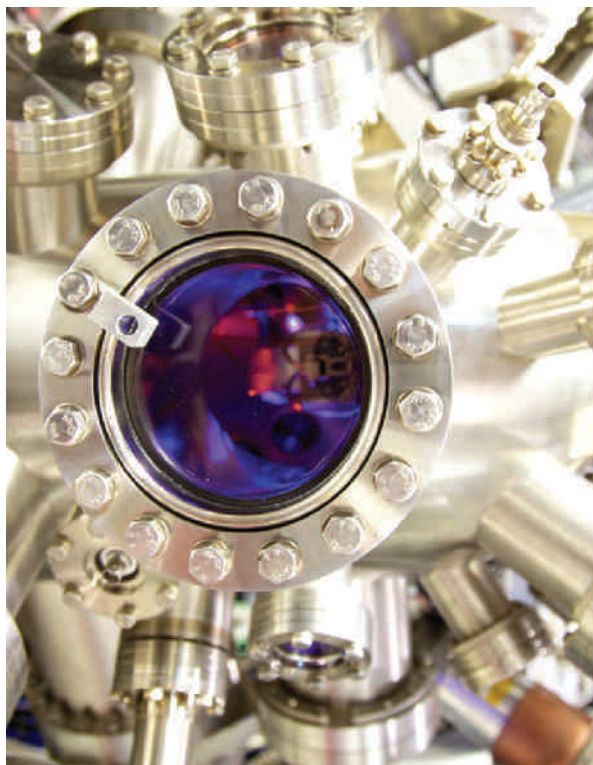
# SYNCHROTRON LEARNING MATRIX



Left | Australian Synchrotron's Imaging and Medical Beamline Tunnel  
Below | The Synchrotron's linear accelerator



	Developing	Extending
First-hand investigations	<p>Estimation of the speed of light using a microwave and marshmallows. <b>See Linked Activity 1.</b></p>	<p>Using diffraction to measure the wavelength of a laser. <b>See Linked Activity 2.</b></p>
Maker space activities	<p>Build an electromagnet using everyday laboratory materials, such as an iron nail and copper wire. Test the electromagnet by wiring it up to a power supply and seeing how many paperclips it can lift. What is the relationship between the number of times the copper is wrapped around the nail and the number of paperclips the electromagnet can lift?</p>	<p>Build a tabletop linear accelerator using neodymium magnets and ball bearings to model a Synchrotron. Watch this <i>Make Magazine</i> video (<a href="http://www.youtube.com/watch?v=RkBaOhyZMKk">www.youtube.com/watch?v=RkBaOhyZMKk</a>) to learn how. Prepare a risk assessment before starting and include precautions such as pointing the accelerator at the wall rather than into the room, and having a container to catch the last ball bearing in. What makes this a chain reaction?</p>
Ethical thinking	<p>Research three projects carried out using the Australian Synchrotron and describe their aims, outcomes and social applications.</p> <p>Imagine you are the science minister and have \$1 million for funding one of these projects. Which project will you fund and why?</p>	<p>Should school students, science students and/or the everyday person know more about the benefits that research at particle accelerators brings to society? If they did, what might be the consequence? Write a list of '10 things you should know about particle accelerators' that you think we all would benefit from knowing..</p>
ICT	<p>Use a computer simulation related to particle accelerators to collect data to plot on a graph. For an example, see <a href="http://www.kcvs.ca/site/projects/physics">www.kcvs.ca/site/projects/physics</a> and scroll down to the second to last applet demonstrating Rutherford's scattering experiment. Using the impact parameter as your independent variable, plot it against the angle of scattering (using the protractor to measure the angle) as your dependent variable. What is the relationship between the two variables?</p>	<p>Find an interactive applet or game on the internet that simulates how particle accelerators work. Design a student worksheet or a set of instructions for young students who have no prior knowledge of particle accelerators so the game makes sense to them and they can learn something new as they play.</p>



Left | Soft X-ray Spectroscopy beamline equipment  
Below | Dr Susan Cumberland working in X-ray absorption spectroscopy



	Developing	Extending
<b>Personal and social capabilities</b>	<p>Watch the following video about research applications of the Australian Synchrotron. <a href="http://www.youtube.com/watch?v=74n8L5X2YSI">www.youtube.com/watch?v=74n8L5X2YSI</a></p> <p>Choose one research project that interests you and prepare a case study to promote the benefit of this type of research to the general public. You can create a poster, pamphlet or advertisement.</p>	<p>Design your own novel investigation for the Synchrotron. Model a proposal for beamline time by stating the following:</p> <ul style="list-style-type: none"> <li>• Name of project</li> <li>• What you want to discover</li> <li>• Which beamline you would like to use and why</li> <li>• How much time you will need on the beamline</li> <li>• What you will do with the data/information once you have collected it</li> <li>• What the purpose of the research is [e.g. How it is going to make the world a better place?]</li> </ul>
<b>Creative and critical thinking</b>	<p>Watch the following video <a href="http://www.youtube.com/watch?v=9cfD0uf4lw8">www.youtube.com/watch?v=9cfD0uf4lw8</a> (35 minutes) of British science communicator Suzie Sheehy talking about and demonstrating particle accelerators (and what not to do with them). As you watch the video design some criteria you can use to 'judge' the video. Apply these criteria and use it to write a review for your science magazine.</p>	<p>Write a script, design a new logo, create a sculpture or write a song to promote, respond to or educate us about the Australian Synchrotron and what it does. Carry out research, make planning notes and annotate your end product to describe its purpose.</p>
<b>Time travel</b>	<p>Choose one of the particle accelerators mentioned in the <i>Timeline</i> (or any other such as the SPEAR collider) and create a profile in order to compare it to the Synchrotron. How is the technology the same/different? How are the applications the same/different?</p>	<p>Imagine it is the year 2080. What products or medical treatments are available due to research using the Synchrotron that are not available today? Choose one or more current applications and extrapolate the idea or process into the future to imagine a better or new application not currently available, and then describe it.</p>

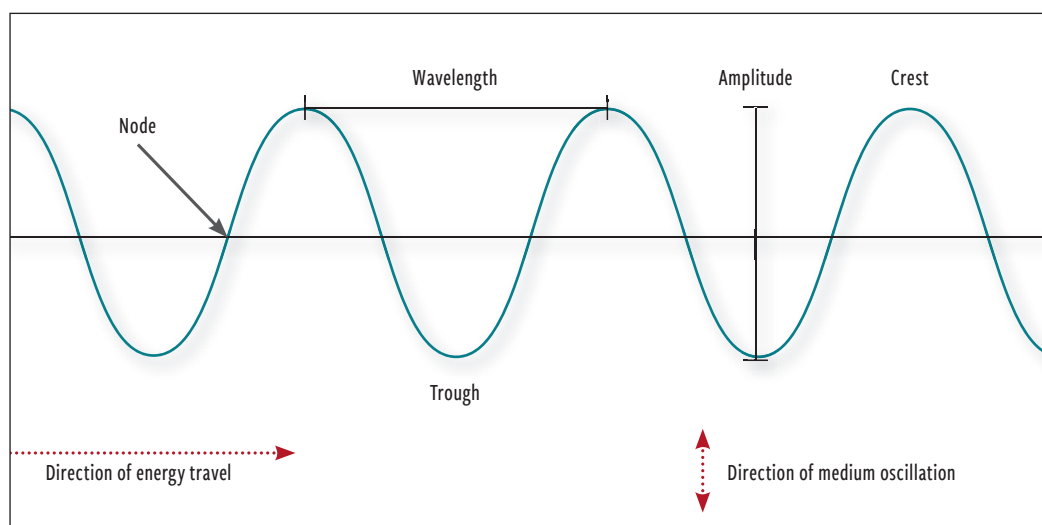
### LINKED ACTIVITY 1 – ESTIMATING THE SPEED OF LIGHT WITH A MICROWAVE

You don't need special scientific equipment to measure the speed of light – you can do it with a microwave, a ruler and some marshmallows!

#### ● Introduction

The speed of light ( $C$ ) is equal to the wavelength ( $\lambda$ ) of an electromagnetic wave (such as light waves and microwaves), multiplied by the frequency ( $f$ ) of that wave using the equation  $C = f\lambda$ .

Using a microwave oven without its turntable generates a 'standing wave' that is formed by the waves from the electrical circuits inside the microwave and the waves that reflect off its interior walls. The energy is the greatest at the peaks and troughs, or antinodes, of the standing wave, which are revealed by the points at which the marshmallows first melt.



#### ● Aim

To measure the wavelength of microwaves inside a microwave oven to estimate the speed of light.

#### Materials

1. One microwave minus the turntable
2. 2 packets of mini marshmallows
3. Large paper plate
4. Ruler

#### ● Risk Analysis

Create a risk assessment before you complete this experiment. Include any hazards related to using the microwave, such as overheating, and food samples that may be contaminated by contact with laboratory equipment.

#### ● Method

1. Remove the turntable from the microwave.
2. Scatter mini marshmallows over the paper plate. Spread them out so they cover the whole of the plate but are not quite touching.
3. Place the plate in the microwave and close the door.
4. Microwave the marshmallows on high power for a few seconds, or until the marshmallows start to melt.
5. Carefully remove the plate of marshmallows from the microwave so that you do not move or touch the hot marshmallows.
6. Locate the centre of any two melted circles of marshmallow.
7. Measure the distance between the two centre points and record the measurement in the results table below.
8. If you only have one circle of melted marshmallow in Step 5, identify any partial circles around the edge of the plate and estimate where its centre would be. Measure the distance between the two centre points of the circles and record it in the data table.

● **Results**

**STEP 1 – Calculate the variables ready to use in the calculation.**

<b>1</b>	Distance between the hot spots , which is half a wavelength (A)	_____ cm
<b>2</b>	Wavelength (A x 2 = B)	_____ cm
<b>3</b>	Wavelength converted to metres (B ÷ 100)	_____ m
<b>4</b>	Frequency of the microwave (should in the information listed in a label on the microwave) in hertz	_____ Hz

**Step 2 – Apply the variables to the calculation**

$$C = f\lambda$$

C= (Item 4 in your table above x item 3 in your table above) m/s

**Step 3 – Compare to the speed of light**

What is the speed of light? \_\_\_\_\_

What is your estimated speed of light? \_\_\_\_\_

● **Discussion**

1. What is the difference between the actual speed of light and your calculated speed of light?

---



---



---



---



---

2. Suggest places where errors might be introduced into this investigation.

---



---



---



---



---

3. Suggest ways to improve the accuracy of any measurements in this experiment in order to improve the estimation of the speed of light.

---



---



---



---



---

4. What do you think are some advantages and disadvantages of making estimates?

---



---



---



---



---

5. How accurate do you think the scientists at the Australian Synchrotron need to be when measuring the speed of the particles in the different beamlines, and what might be the effect of their not being highly accurate?

---



---



---



---



---

● **Conclusion**

Write a conclusion that corresponds to your aim and summarises your results.

---



---



---



---



---



## LINKED ACTIVITY 2 – DIFFRACTION GRATING MEASURING THE WAVELENGTH OF A LASER

### ● Background Information

The following information is helpful when completing this investigation:

- Waves diffract (bend around) objects
- Small slits, of the same order of magnitude as wavelength of the light, cause large degrees of diffraction
- A diffraction grating consists of lots of slits that are very closely spaced together
- Diffraction gratings cause visible interference patterns on a screen in a series of dark and light fringes
- Laser light produces a series of spots on a screen. The angle between these spots is linked to the wavelength of the laser light.
- The equation needed to calculate the wavelength is  $n \lambda = d \sin \theta$

### ● Aim

To estimate the wavelength of laser light using diffraction and interference.

### ● Hypothesis:

### ● Materials

1. Laser
2. Diffraction grating
3. White screen (Large piece of paper will suffice)
4. Tape measure
5. Calculator

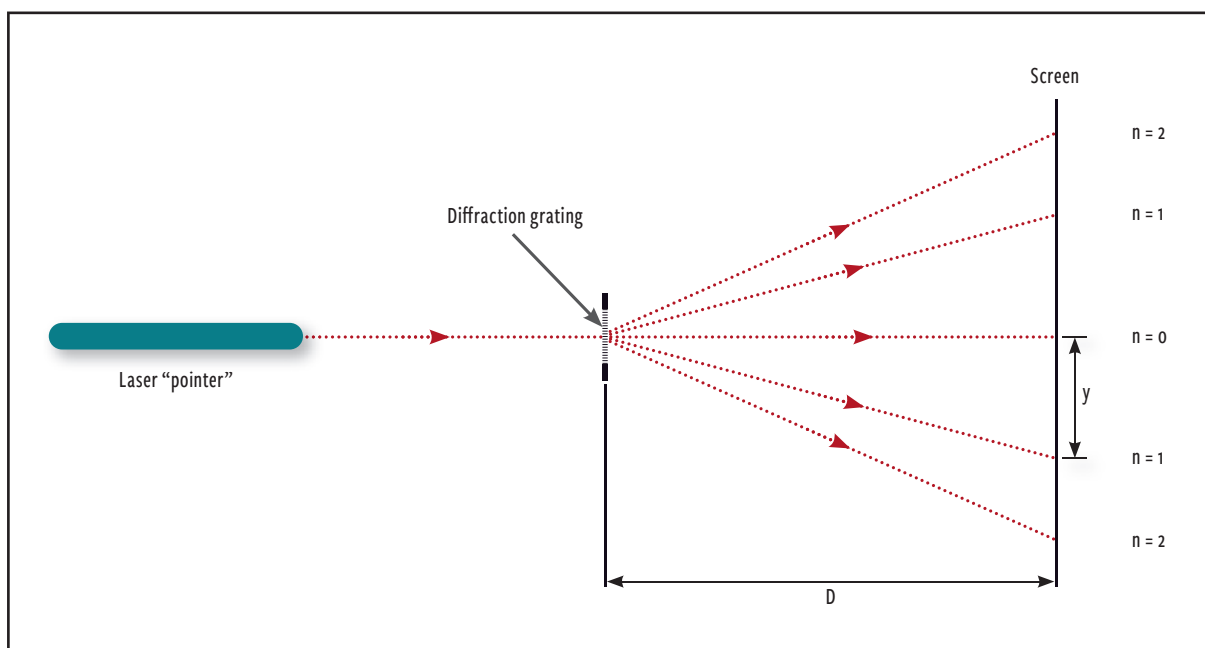
### ● Risk assessment

Create a risk assessment before you complete this experiment. Include any hazards related to using the laser.

Risk	Precaution	Consequence

● Method

1. Turn on the laser and shine its light through the grating.
2. Vary the distance to the screen in order to produce several bright spots on the white screen. Identify and mark the central spot ( $n = 0$ )
3. Pick one of the outer spots and note how far it is (in spots) from the central spot. This is 'n' in the equation. Record n in the Data Table.
4. Measure distance on the white screen from the central spot to the spot you have chosen. This distance is 'y' in the Date Table.
5. Measure the distance from grating to screen. This is D in the Data Table.
6. Calculate the angle  $\Theta$  using the formula  $\tan \Theta = y/D$ . Record in table.
7. The space between the slits of the grating (d in the equation) will be marked on the grating. Record this in the Data Table.
8. Use the formula  $n\lambda = d\sin \Theta$  to find the wavelength of the laser light.  
(Rearrange the equation to give  $\lambda = d\sin \Theta/n$ )



**NOTE:** The idea is to shine the laser light through a grating – an array of many slits, not just two. To get the laser beam to go through many slits it has to be broadened. That is what the lenses in the diagram are for.

● Results

Data Table

Number of spots from the centre (n)	Distance 'y' (m)	Distance D (m)	$\Theta$ ( $\Theta = y/D$ )	d (m)	$\lambda = d\sin \Theta/n$ (m)

**● Discussion**

1. Diffraction works best when the size of the gap or object is about the same as the wavelength of the light. What wavelength of light would be required to examine the atomic structure of a substance?

---

---

---

---

---

2. Referring to question 1, what is this type of electromagnetic radiation called?

---

---

---

---

---

3. This experiment shows diffraction of visible light. The simple pattern on the screen tells us something about the minute gaps between the grating slits. What would be the advantages of using shorter-wavelength light?

---

---

---

---

---

**● Conclusion**

Write a conclusion that corresponds to your aim and summarises your results.

---

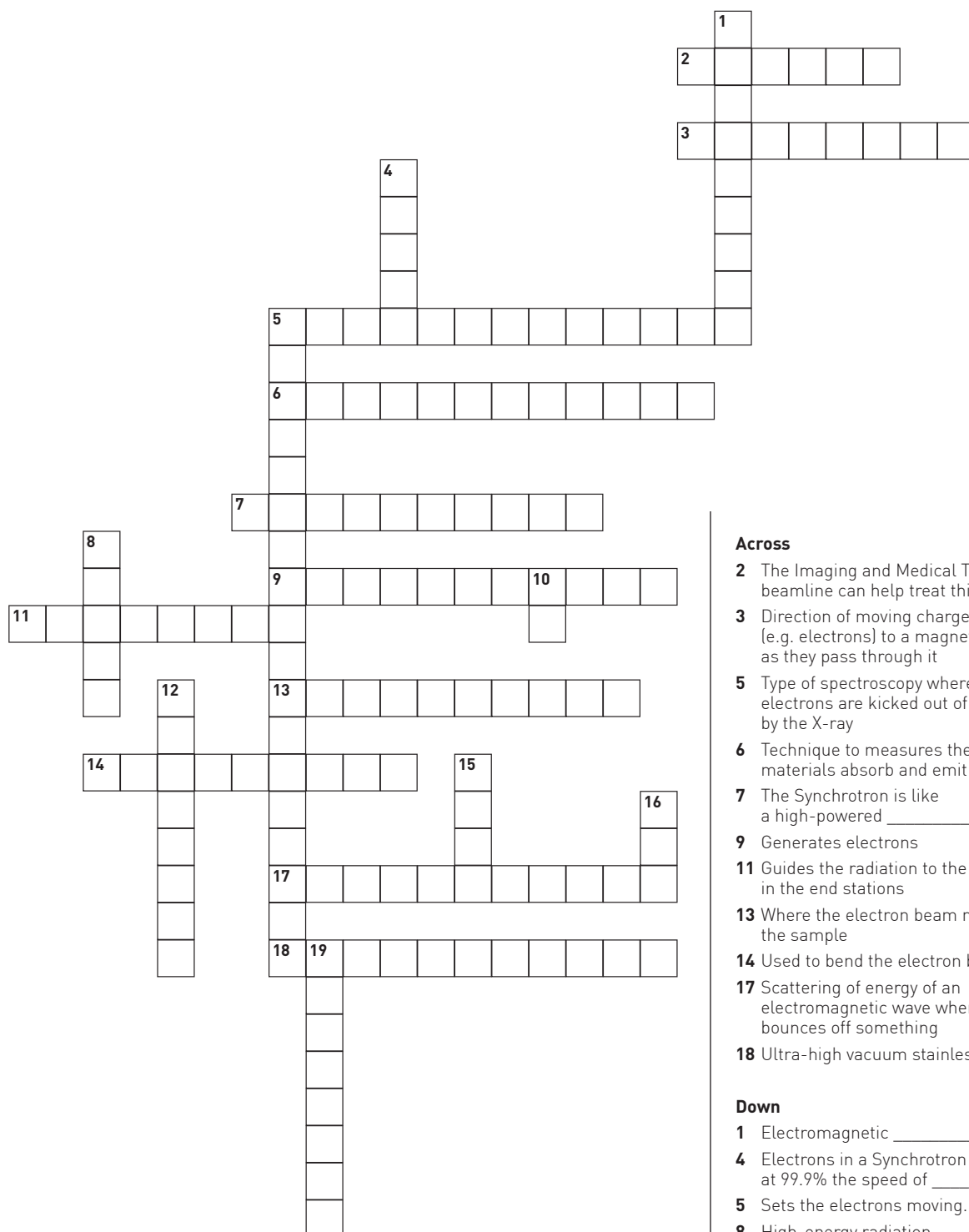
---

---

---

---

# CROSSWORD



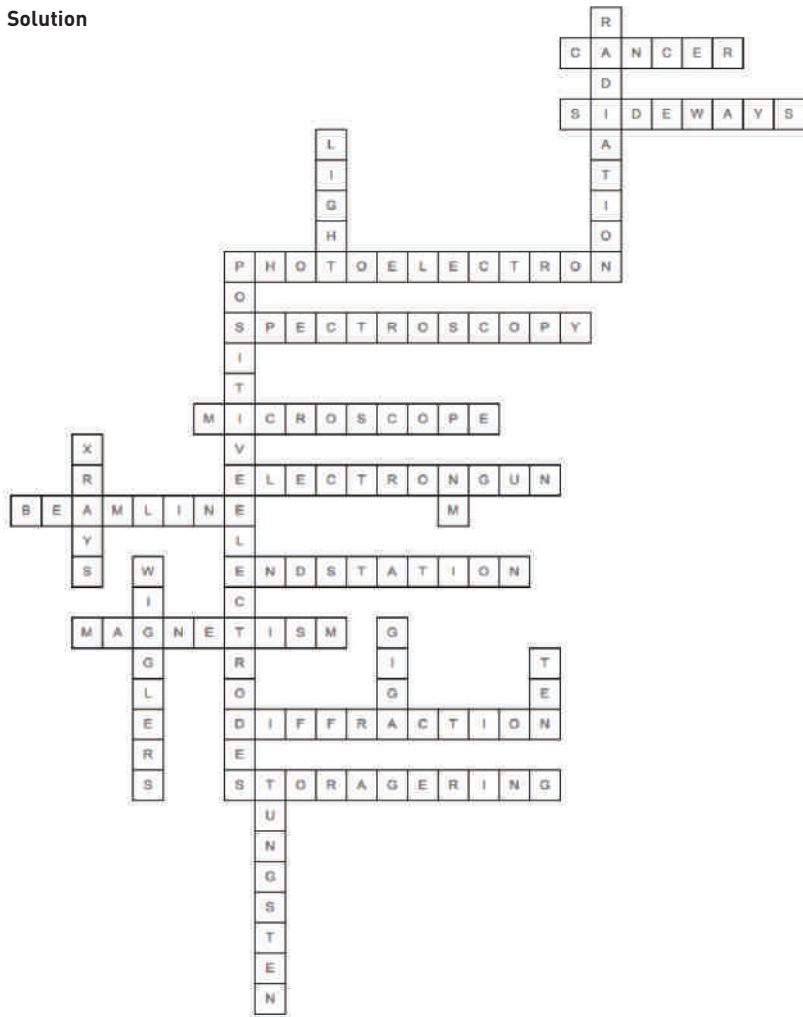
## Across

- 2 The Imaging and Medical Therapy beamline can help treat this disease
- 3 Direction of moving charges (e.g. electrons) to a magnetic field as they pass through it
- 5 Type of spectroscopy where the inner electrons are kicked out of the atom by the X-ray
- 6 Technique to measure the way that materials absorb and emit radiation
- 7 The Synchrotron is like a high-powered \_\_\_\_\_
- 9 Generates electrons
- 11 Guides the radiation to the samples in the end stations
- 13 Where the electron beam meets the sample
- 14 Used to bend the electron beams
- 17 Scattering of energy of an electromagnetic wave when it bounces off something
- 18 Ultra-high vacuum stainless steel tube

## Down

- 1 Electromagnetic \_\_\_\_\_
- 4 Electrons in a Synchrotron can travel at 99.9% the speed of \_\_\_\_\_
- 5 Sets the electrons moving.
- 8 High-energy radiation
- 10 Nanometre
- 12 Sets of undulating magnets
- 15 A billion electronvolts
- 16 The Synchrotron's number of beamlines
- 19 The metal that is heated when electrons are generated

Solution



# CREATING YOUR OWN **SYNCHROTRON QUIZ**

- a) Ask each student to call out a word related to the activities you have carried out in this unit of work about the Synchrotron. Record these words on the board.
- b) Each student must pick six words from the board and write a definition for each.
- c) Students then pick four more words from the board and write a paragraph describing them. They should highlight their chosen words in the paragraph.
- d) Students create a concept map showing all they have learnt about how a Synchrotron works and what it does using at least half the words from the board. They should show links between words and write along lines connecting words to show how the terms are related.

# SYNCHROTRON

## INDIVIDUAL UNIT REVIEW

What about you?	Drawing
<p>Describe your favourite activity during this unit of study.</p>	<p>Create an image that summarised for you this unit of work.</p>
Learning summary	Your philosophy
<p>Write two dot points to outline what you have learnt about how the Synchrotron works and two dot points about what the Synchrotron can do.</p>	<p>Describe your overall thoughts about Synchrotron science after completing this unit. What is its value to science in Australia? What are its capabilities for the future? Where will it take our knowledge and understanding of the world around us?</p>
More questions?	Metacognition
<p>Write three questions that you still have about how the Synchrotron works or what it does, or anything else related to this unit of study.</p>	<p>Which activities did you find helped you learn the easiest? Why?</p>

# CURRICULUM LINKS

Australian Curriculum Link	Background and Profiles	Engage	Explore	Explain	Elaborate (Linked Activity 1)	Elaborate (Linked Activity 2)	Elaborate (Matrix)	Evaluate
Year 9								
Science Understanding								
<b>Chemical sciences</b> All matter is made of atoms that are composed of protons, neutrons and electrons; natural radioactivity arises from the decay of nuclei in atoms [ACSSU177]								
<b>Physical sciences</b> Energy transfer through different mediums can be explained using wave and particle models [ACSSU182]								
Year 10								
Science Understanding								
<b>Chemical sciences</b> The atomic structure and properties of elements are used to organise them in the Periodic Table [ACSSU186]								
<b>Physical sciences</b> Energy conservation in a system can be explained by describing energy transfers and transformations [ACSSU190]								
<b>Physics</b> The motion of objects can be described and predicted using the laws of physics [ACSSU229]								
<b>Biological sciences</b> Transmission of heritable characteristics from one generation to the next involves DNA and genes [ACSSU184]								



# CURRICULUM LINKS

Australian Curriculum Link	Background and Profiles	Engage	Explore	Explain	Elaborate (Linked Activity 1)	Elaborate (Linked Activity 2)	Elaborate (Matrix)	Evaluate
Years 9–10								
Science as a Human Endeavour								
Nature and development of science								
Scientific understanding, including models and theories, is contestable and is refined over time through a process of review by the scientific community (ACSHE157)								
Advances in scientific understanding often rely on developments in technology and technological advances are often linked to scientific discoveries (ACSHE158)								
Use and influence of science								
People use scientific knowledge to evaluate whether they accept claims, explanations or predictions, and advances in science can affect people's lives, including generating new career opportunities (ACSHE160)								
Values and needs of contemporary society can influence the focus of scientific research (ACSHE228)								
Years 9–10								
Science Inquiry Skills								
Questioning and predicting								
Formulate questions or hypotheses that can be investigated scientifically (ACSIS164)								
Planning and conducting								
Plan, select and use appropriate investigation types, including field work and laboratory experimentation, to collect reliable data; assess risk and address ethical issues associated with these methods (ACSIS165)								

## CURRICULUM LINKS

Australian Curriculum Link	Background and Profiles	Engage	Explore	Explain	Elaborate (Linked Activity 1)	Elaborate (Linked Activity 2)	Elaborate (Matrix)	Evaluate
Select and use appropriate equipment, including digital technologies, to collect and record data systematically and accurately (AC SIS166)								
Processing and analysing data and information								
Analyse patterns and trends in data, including describing relationships between variables and identifying inconsistencies (AC SIS169)								
Use knowledge of scientific concepts to draw conclusions that are consistent with evidence (AC SIS170)								
Evaluating								
Evaluate conclusions, including identifying sources of uncertainty and possible alternative explanations, and describe specific ways to improve the quality of the data (AC SIS171)								
Critically analyse the validity of information in primary and secondary sources and evaluate the approaches used to solve problems (AC SIS172)								
Communicating								
Communicate scientific ideas and information for a particular purpose, including constructing evidence-based arguments and using appropriate scientific language, conventions and representations (AC SIS174)								





Australian Government



## Locations

Lucas Heights | Camperdown | Clayton