4.1 The wave equation

ADDITIONAL

Knowledge and understanding

N Numeracy   CCT Critical and creative thinking

The speed, wavelength and frequency of any wave depend upon each other and are linked by a formula called the wave equation:

$$v = f\lambda$$

where

v = speed of wave (m/s)

f = frequency of wave (Hz)

λ = wavelength of wave (m)

The equation can be rearranged to calculate frequency as: $f = v/\lambda$

and wavelength as: $\lambda = v/f$

Worked example

Su plays a note on her violin of frequency 4100 Hz. Given that the speed of sound in air is 330 m/s, calculate the wavelength of this sound wave.

$\lambda = v/f = 330/4100 = 0.08$ m

This means that the sound wave has a wavelength of approximately 8 cm.

1 Use the speed of sound in air as 330 m/s to answer the following questions. Round your answers to two decimal places.

(a) Carla plays middle C on a piano, which has a frequency of 256 Hz. **Calculate** the wavelength of the sound wave producing this note.

(b) Sebastian is annoyed by a mosquito buzzing near his ear. The buzzing sound is made by the wings of the mosquito, which beat about 600 times per second. **Calculate** the wavelength of the sound wave produced.

(c) An elephant makes a very low sound of 20 Hz as it communicates to its herd. **Calculate** the wavelength of this sound.

(d) A mobile phone makes sound of frequency 16 000 Hz when an SMS is received. **Calculate** the wavelength of this sound.

2 Use the speed of electromagnetic radiation as 300 000 000 m/s to answer the following questions. Round your answers to two decimal places and express them using scientific notation. For example 300 000 000 m/s = 3×10^8. Be sure to use standard units of m, m/s and Hz in your calculations.

(a) Microwave radiation used to cook food in a particular oven has a wavelength of 3 cm. **Calculate** the frequency of this radiation.

(b) Microwaves of wavelength 30 cm are used to transmit signals in a mobile phone network. **Calculate** the frequency of this radiation.

(c) A UHF TV signal uses a radio wave of 80 cm. **Calculate** the frequency of this radiation.

(d) A 500 kHz radio wave is used to transmit an AM radio signal. **Calculate** the wavelength of these radio waves.

(e) A truck driver uses a 20 MHz (20 000 000 Hz) shortwave radio for communications. **Calculate** the wavelength of the radio waves being used.

Butterflies and mobiles

Knowledge and understanding

L Literacy CCT Critical and creative thinking

A company called Qualcomm has developed a display for mobile phones and other devices which copies how a butterfly wing produces colour. Rather than using a battery-powered light source for the phone display, it uses light from the room or sunlight as its source. This means that the phone's battery life is longer between charging. The phone has tiny reflective units in it that cause light waves entering it to overlap, or interfere with other light waves. Some light waves cancel each other out and some add to each other. This produces different colours in the same way that the wings of a Morpho butterfly cause light to interfere and create colours.

The basic unit of the display that causes the interference of incoming light is a tiny square of glass and metal (called an IMOD element). This unit has two layers of reflective surfaces with an air gap between them (Figure 4.2.1). The air gap can be closed or opened by applying a small voltage across it. When it opens, light waves can reflect off the bottom reflecting membrane and the top reflecting surface (the 'thin film stack'). If the gap is the right size, the two reflected waves of light add to each other and appear a certain colour, such as blue. When the air gap closes, no light reflects off the surfaces and they appear black.

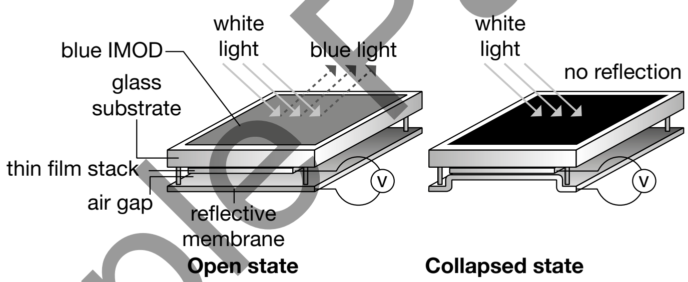


Figure 4.2.1

To make an IMOD element produce light of a particular colour, the air gap is manufactured in three different sizes. Red is the largest gap and blue is the smallest. Green is a medium-sized gap. You can see some sets of the basic units in Figure 4.2.2.

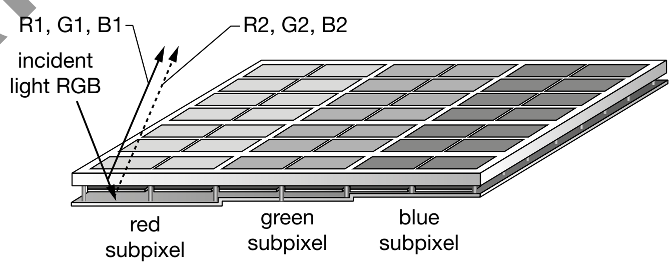
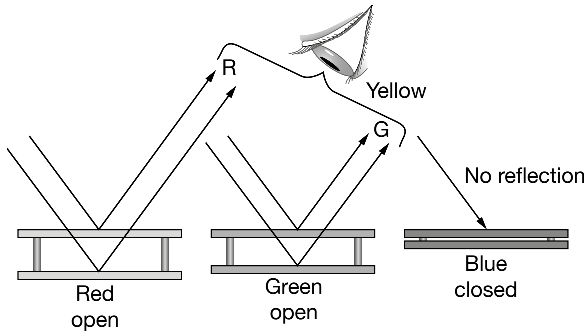


Figure 4.2.2

When the screen needs to produce particular colours, the three different colours of IMOD elements are opened or closed in sets of three to create a colour effect. You can see an example in Figure 4.2.3 on the following page. To produce a yellow colour, you would need to allow red and green light to mix, but not let any blue light through. So the blue IMOD element is turned off, and red and green light reflect out of the two nearby elements. Your eye detects this reflected light as yellow. By turning different combinations of elements off or on, the screen can produce all the colours of the spectrum.

Figure 4.2.3



1 **State** the main advantage of a mobile phone display that uses outside light.

2 **Name** the animal that was the inspiration for this idea.

3 **Name** the basic unit of the display.

4 **Describe** the structure of the basic unit.

5 **Explain** how the structure of an element affects the colour of light it produces.

6 **Explain** how a red, a green and a blue element next to each other can produce yellow light.

7 **Propose** what would have to happen to the three IMOD elements to produce:

(a) red light

(b) blue light.

EXTENSION

Knowledge and understanding

L Literacy CCT Critical and creative thinking

Scientists reveal how snakes 'see' at night

by Marlowe Hood

15 March, 2010

Scientists revealed Sunday for the first time how some snakes can detect the faint body heat exuded by a mouse a metre (three feet) away with enough precision and speed to hunt in the dark.

It has been known for decades that rattlesnakes, boas and pythons have so-called pit organs between the eye and the nostril that can sense even tiny amounts of infrared radiation—heat—in their surroundings.

Among pit vipers, the western diamondback rattlesnake, native to northern Mexico and southwestern United States, is in a class of its own, its heat-seeking ability up to 10 times keener than any of its cousins.

Even with tiny patches covering its eyes, the snake has shown the ability to track and kill prey blindfolded.

But exactly how these reptiles detect and convert infrared signals into nerve impulses has remained a mystery, and the subject of sharp debate.

One candidate was the photochemical process underlying vision, whereby the eye sees electromagnetic radiation—visible light for humans—in the form of photons that activate receptor cells, which in turn convert the energy into a biochemical signal to the brain.

Some fish, for example, can see into the infrared wavelength of the electromagnetic spectrum.

But David Julius, a molecular biologist at the University of California in San Francisco, demonstrated in laboratory experiments that a different neurological pathway was at work for the serpentine 'sixth sense'.

'In this case, the infrared radiation is actually detected inside the pit organ as heat,' Julius said in a phone interview. 'We found the molecule responsible.'

A very thin membrane inside the pit organ—essentially a hollow, bony cavity—warms up as the radiation enters through an opening in the skin, he explained.

Because the membrane is in a hollow space, it is exquisitely sensitive to changes in temperature.

'The heated tissue then imparts a signal to nerve fibres to activate the receptors we have identified,' known as TRPA1 channels.

The neurochemical pathway involved suggests that snakes feel heat rather than see it.

'The molecule we found belongs to a family of receptors related to pain pathways in mammals,' Julius said.

In humans, the equivalent mechanism is called the 'wasabi receptor' because it allows our sensory nervous system to detect irritants—such as the Japanese condiment—that belong to the mustard family.

It is not, however, activated by heat.

The discovery, published in *Nature*, may also shed light on how snakes, which have been slithering across the planet for more than 100 million years, evolved.

'Studying change in sensory molecules is an interesting way to look at evolution because as animals inhabit different niches, smell and taste different things, hunt different animals, their sensory systems have to adapt,' Julius said.

The findings also suggest that the forces of natural selection yielded the same remarkable heat-seeking mechanism in reptiles on separate occasions.

4.3 EXTENSION

Unlike boas and pythons, which also have pit organs, vipers—including rattlesnakes—are relatively recent arrivals, in evolutionary terms, and thus must have developed the same capacity independently.

'It is amazing to think that random mutation could have come up with the same kind of solution more than once,' Julius said.

1 List three types of snakes that can detect infrared radiation.

____

2 Describe the structure of the pit organ of a snake.

____

____

3 Identify stages in the detection of infrared radiation in the pit organ of a snake by completing the following.

______ ______ enters the pit organ →	This warms up a very thin ______ which →	transmits a signal to ______ ______ →	This activates receptors called ______ channels.

4 Explain how a snake would use this sixth sense to its advantage.

____

____

5 Describe what TRPA1 channels allow a human to detect.

____

6 Identify why scientists believe that vipers developed their heat-seeking ability independently of that of boas and pythons.

____

____

7 Discuss three ways in which your life would be different if you had a heat-sensing pit organ between your nostrils and your eyes.

____

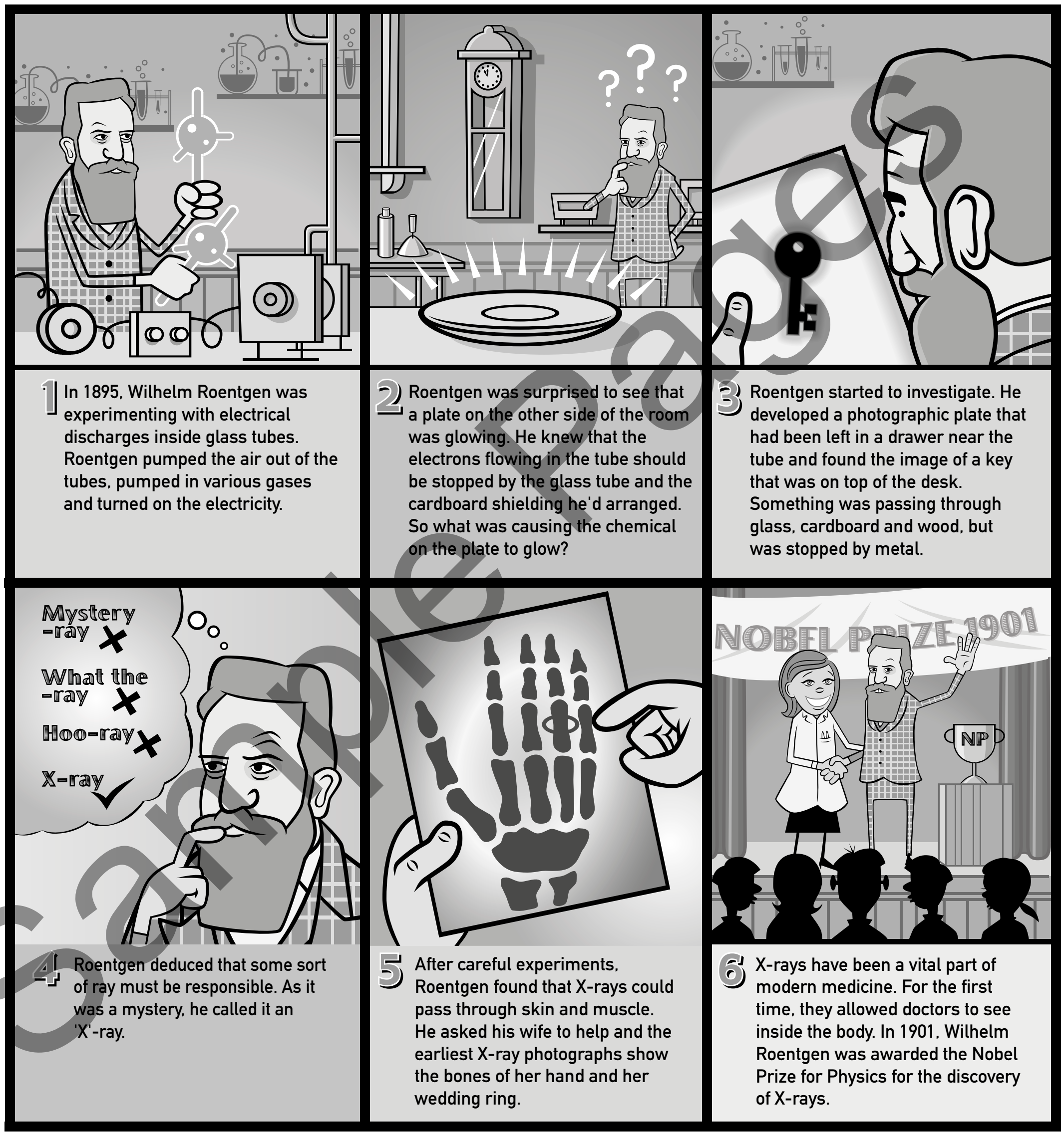
____

4.4 The discovery of X-rays

Working scientifically

L Literacy **CCT Critical and creative thinking** **WE Work and enterprise**

At times something happens in an experiment that was not expected. Some of the most remarkable scientific discoveries have been made by accident. To make a breakthrough a scientist needs to make careful observations and to think 'outside the square'. Wilhelm Roentgen did just that when he discovered X-rays.



1 **Recall** which year Wilhelm Roentgen discovered X-rays.

____

2 **Describe** what Roentgen was initially investigating with gas tubes.

____

____

3 Roentgen covered the glass discharge tube with cardboard. **Describe** what he saw happening on the other side of the room that made him curious.

4 **Propose** how Roentgen realised that something was able to pass through glass, cardboard and wood but was stopped by metal in the room in which he was working.

5 If the radiation Roentgen produced had been able to pass through metal in addition to glass, cardboard and wood, **predict** how the photographic plate would have appeared.

6 **Explain** why Roentgen called the radiation *X-rays*.

7 Looking at the diagram of Roentgen's wife's hand, **propose** what properties of X-rays make them a very useful tool in medical diagnosis.

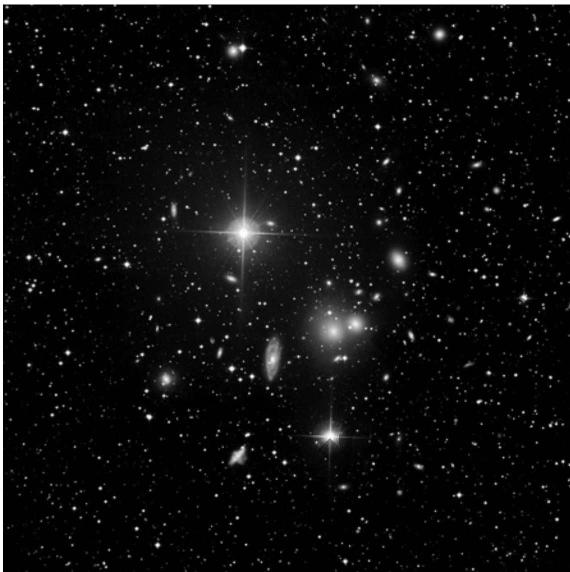
8 **Recall** which official recognition Roentgen received for his discovery.

4.5 Creating a false-colour X-ray image

Working scientifically

N Numeracy **CCT Critical and creative thinking** **WE Work and enterprise**

When you take a photo of a friend, you are capturing an image produced by visible light. Images can also be created by observing wavelengths of electromagnetic radiation that are invisible to the human eye, such as radio waves, microwaves or X-rays. These images are said to be 'false colour', because different colours correspond to a specific range of intensities of radiation. The galaxy cluster, Hydra A, is located 840 million light years from Earth. It is held together by gravity, and consists of hundreds of galaxies and huge clouds of extremely hot gas. Matter in Hydra A is at temperatures up to 100 million degrees Celsius. X-rays are produced at these extreme temperatures. The image below shows what Hydra A looks like in visible light. Observatories such as the Chandra X-ray Observatory can detect the presence of high-energy X-rays in this cluster.



0	0	1	1	1	1	2	2	2	2	2	2	1	1	0
0	0	1	1	2	3	2	2	2	2	2	2	2	2	1
0	1	1	1	2	3	3	3	3	2	3	2	2	1	1
1	1	1	2	3	3	3	4	3	3	3	3	3	2	1
1	1	2	2	3	4	4	5	4	3	3	3	3	2	1
1	1	2	3	3	4	5	5	5	4	5	3	2	2	2
1	1	2	3	3	4	6	6	5	5	5	3	2	2	1
1	1	2	3	4	5	5	6	5	4	4	3	2	2	1
1	1	2	3	4	5	5	4	4	4	3	3	3	2	1
1	1	2	3	3	4	4	4	4	4	4	3	2	2	1
1	1	2	2	3	3	4	4	3	3	3	3	2	2	1
1	1	2	2	2	3	3	3	3	2	2	2	2	2	1
1	1	2	2	2	3	3	3	3	2	2	2	2	2	1
0	1	1	1	2	2	2	2	2	2	2	1	2	2	1
0	1	1	1	1	1	2	2	2	1	1	1	1	1	0

1 Using the grid above, **create** your own false-colour image that shows the intensities of the X-ray emissions found in the cluster. The numbers shown represent very intense X-ray emission (6) to no X-ray emissions (0). To display these variations, use the colour code: 6 = white, 5 = yellow, 4 = orange, 3 = pink, 2 = purple, 1 = blue, 0 = black.

2 **Explain** why it is useful to view a region of space or a target on Earth using forms of radiation other than visible light.

4.6 Radiation dose

Knowledge and understanding

L Literacy **PSC Personal and social capability** **WE Work and enterprise**

X-rays are used in diagnostic procedures to give information about a person's body. When an X-ray or CT (computed tomography) image is taken, the patient is exposed to X-ray radiation. The high energy of such radiation can damage cells in the body, and large doses of radiation absorption may be harmful. The level of radiation a patient experiences when undergoing diagnostic imaging has a low risk. However, it is important for people working with such radiation to monitor their absorption using a personal radiation monitoring device (PMD).

Every year, your body absorbs a certain amount of radiation from the background sources around you. Radiation occurs naturally on Earth in soil, food, water, the atmosphere and in vegetation. Cosmic rays from space that reach the atmosphere also contribute to background radiation. There are greater numbers of these rays at increased altitude. Some forms of radiation are more damaging than others. A quantity called the *dose equivalent* is a measure of the relative effect of the radiation that is absorbed. It is measured in a unit called the sievert (Sv). The average annual background radiation dose that is absorbed per person in Australia is about 2.5 mSv.

The Background Equivalent Radiation Time unit (the BERT) is a useful way for people to compare the radiation dose from a medical procedure to how many hours, days or weeks it would take them to absorb a similar amount of background radiation. For example, one flight from Europe to Australia exposes a person to an effective radiation dose of around 0.11 mSv. This is similar to absorbing about 15 days of natural background radiation. Table 4.6.1 compares BERT values for some medical procedures. These are included as a guide; actual measurements vary with differences between patients.

Table 4.6.1 BERT values for some medical procedures

Procedure	Approximate effective radiation dose (mSv)	Natural background radiation this is equivalent to (BERT)
Chest X-ray	0.025	3 days
Dental X-ray	0.06	1 week
X-ray: lumbar spine	0.47	10 weeks
X-ray: abdomen or pelvis	0.35	7 weeks
CT: head	1.6	8 months
CT: chest	3.8	1.5 years
CT: abdomen/pelvis	10.0	3 years
Bone scan	4.2	1.8 years
Mammogram	0.44	9 weeks

CT: computed tomography
Mammogram: breast scan

1 **Recall** how people working in medical imaging monitor their absorption so they are not exposed to dangerous levels of radiation.

2 **List** three examples of background radiation that originate from Earth.

3 **State** the source of background radiation from space.

4 **Explain** why aircraft crew must monitor their exposure to cosmic radiation.

5 (a) **State** the unit of the dose equivalent. ______

(b) **Recall** the average amount of background radiation that is absorbed by a person living in Australia per year. ______

6 (a) **State** what BERT stands for.

(b) **Explain** why the BERT is used.

7 Use Table 4.6.1 to answer the following.

(a) **State** how long would it take to absorb the amount of background radiation that is absorbed in a dental X-ray. ______

(b) **Calculate** how many times larger the natural background radiation of a CT scan of the pelvis is compared to a head CT.

(c) **Compare** the effective radiation dose of a mammogram with that of a head CT.

4.7 Literacy review

Knowledge and understanding

L Literacy

1 Recall electromagnetic radiation by completing the following words.

Clue	Word
The entire range of frequencies of electromagnetic radiation is called the electromagnetic ________	s __ __ __ t __ __ __
These rays are the highest-energy form of electromagnetic radiation	__ a __ __ __
This type of radiation is felt by your skin as heat	__ n __ r __ __ __ __
This type of electromagnetic wave is commonly used in cooking and in mobile phone transmission	m __ __ r __ __ __ __ __ __
This band of electromagnetic waves are longest in wavelength	__ a __ __ __ w __ __ __ __
Your eyes detect this electromagnetic radiation as ________ light	v __ __ __ __ __ __
You need to protect your skin and eyes from ________ light	__ l __ __ a __ __ __ __ __ __
This high-energy radiation has been used for over a century to produce images of inside the body	__-r __ __ __
A narrow tube made from glass or plastic that is used to transmit pulses of light	o __ __ __ __ __ __ __ i __ __ __
A transparent material that allows light of a particular colour to pass through	f __ __ t __ __
The splitting of white light into its component colours	__ __ __ p __ __ s __ __ __

2 Identify each of the words from question 1 in the wordfind below.

T	W	D	A	A	G	M	U	R	T	C	E	P	S	E
H	J	C	O	W	M	I	C	R	O	W	A	V	E	I
P	S	W	T	B	J	F	E	L	B	I	S	I	V	N
W	H	Q	Y	I	O	A	U	B	O	T	U	V	A	F
I	T	E	L	O	I	V	A	R	T	L	U	M	W	R
E	R	B	I	F	L	A	C	I	T	P	O	L	O	A
G	N	I	S	N	E	S	E	T	O	M	E	R	I	R
H	W	G	L	N	O	I	S	R	E	P	S	I	D	E
S	O	N	W	E	F	U	Q	H	G	A	M	M	A	D
S	Y	A	R	X	Y	N	C	F	I	L	T	E	R	E